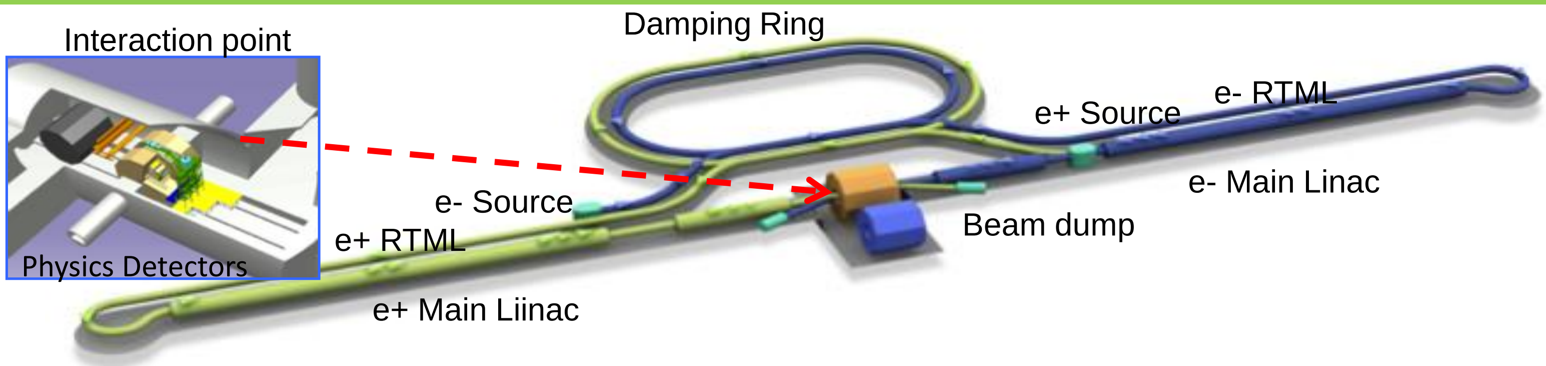
ILC Project Update

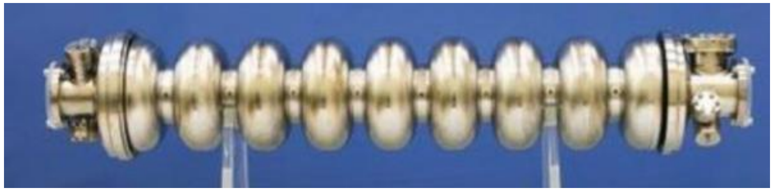
Shin MICHIZONO
KEK/Linear Collider Collaboration (LCC)

- *ILC area systems*
  - *Electron source*
  - *Positron source*
  - *Damping ring*
  - *RTML (bunch compressor)*
  - *Superconducting RF*
  - *Final focus*
  - *Beam dump*
  - *CFS*
- *ILC preparation (US, Japan, Europe)*
- *Technical preparation in "Recommendations on ILC Project"*
  - *MEXT and SCJ's comments*
  - *Superconducting RF*
  - *Positron source*
  - *Damping ring*
  - *Final focus*
  - *Beam dump*
- *Summary*

Technology of the ILC



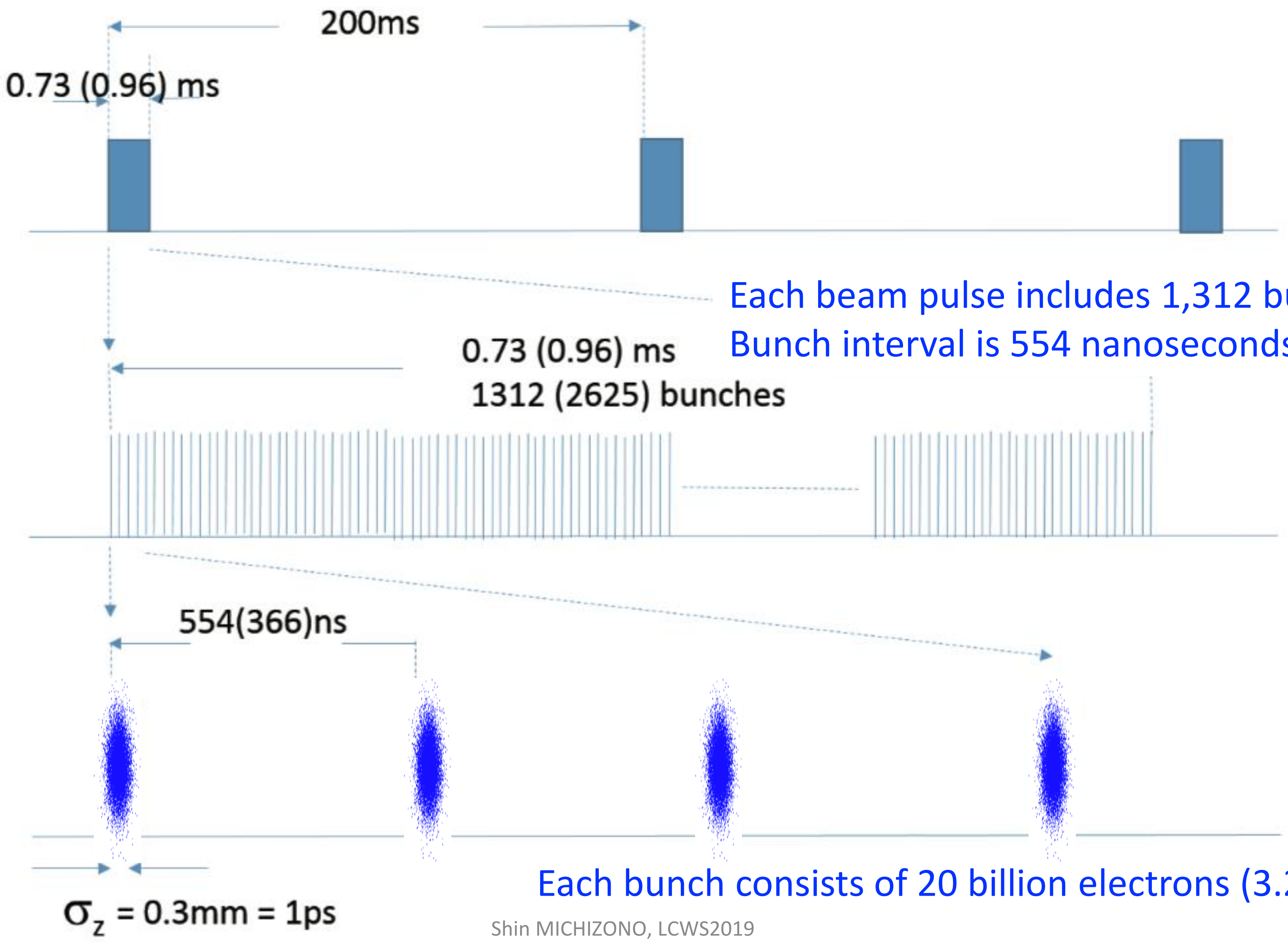
- Creating particles ***Sources***
  - polarized elections/positrons
- High quality beams ***Damping ring***
  - Low emittance beams
    - Small beam size (small beam spread)
    - Parallel beam (small momentum spread)
- Beam transport ***RTML (bunch compressor)***
- Acceleration ***Main linac***
  - superconducting radio frequency (SRF)



- Getting them collided ***Final focus***
  - nano-meter beams
- Go to ***Beam dump***

ILC beam structure

The ILC is operated at a repetition rate of 5 Hz.
A beam pulse comes every 200 milliseconds.。



Each beam pulse includes 1,312 bunches.
Bunch interval is 554 nanoseconds.

Each bunch consists of 20 billion electrons (3.2 nC).

ILC Project Update

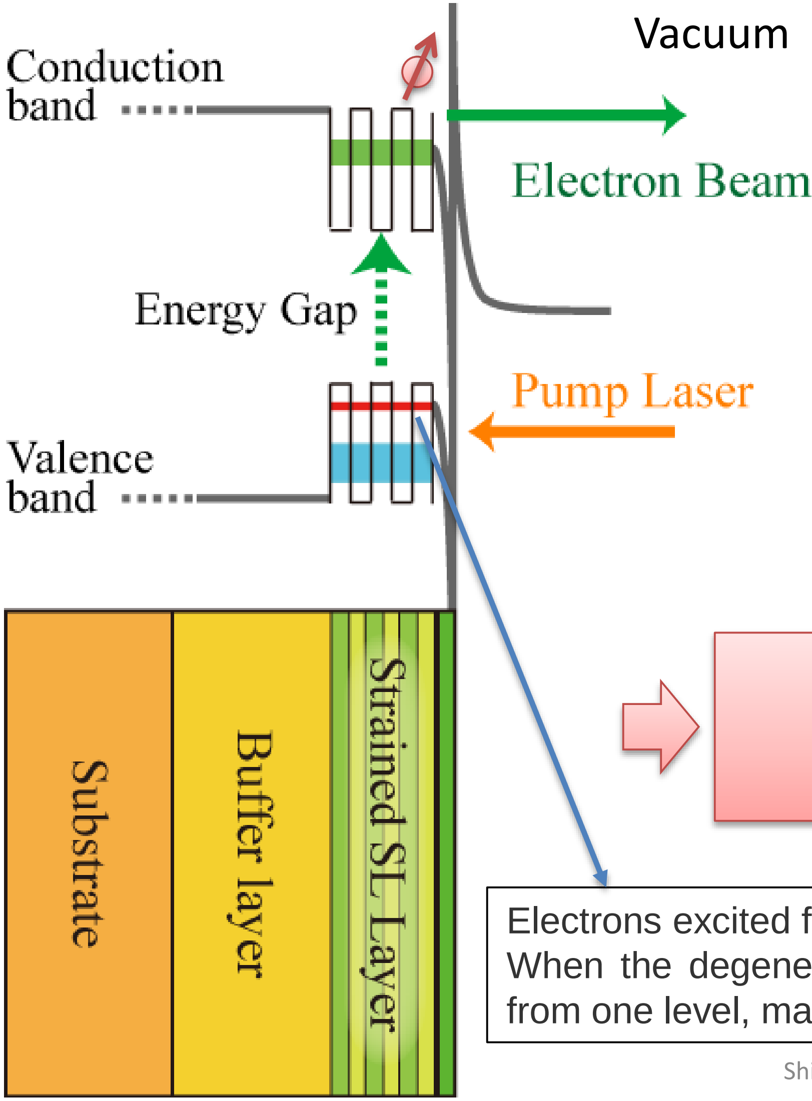
Shin MICHIZONO
KEK/Linear Collider Collaboration (LCC)

- *ILC area systems*
  - *Electron source*
  - *Positron source*
  - *Damping ring*
  - *RTML (bunch compressor)*
  - *Superconducting RF*
  - *Final focus*
  - *Beam dump*
  - *CFS*
- *ILC preparation (US, Japan, Europe)*
- *Technical preparation in "Recommendations on ILC Project"*
  - *MEXT and SCJ's comments*
  - *Superconducting RF*
  - *Positron source*
  - *Damping ring*
  - *Final focus*
  - *Beam dump*
- *Summary*

Generation of polarized electron

3 step model for electron emission

N.Yamamoto, LCWS2014



1. At the Super-lattice (SL) layers, electrons are pumped by ***Circularly polarized laser*** from the highest valence band to conduction band.
2. Excited electrons are diffused to surface .
3. Electrons are emitted through the ***NEA (Negative Electron Affinity) surface***.

These processes contribute parameters such as ***Polarization, Quantum Efficiency (QE)***.
Energy Gap (structure design) corresponds to λ.

Electrons excited from the heavy hole and from the light hole have different spins. When the degeneracy of these two levels is solved and electrons are excited from one level, max. 100% spin polarization can be obtained.

Results at Nagoya Univ.

N.Yamamoto, LCWS2014

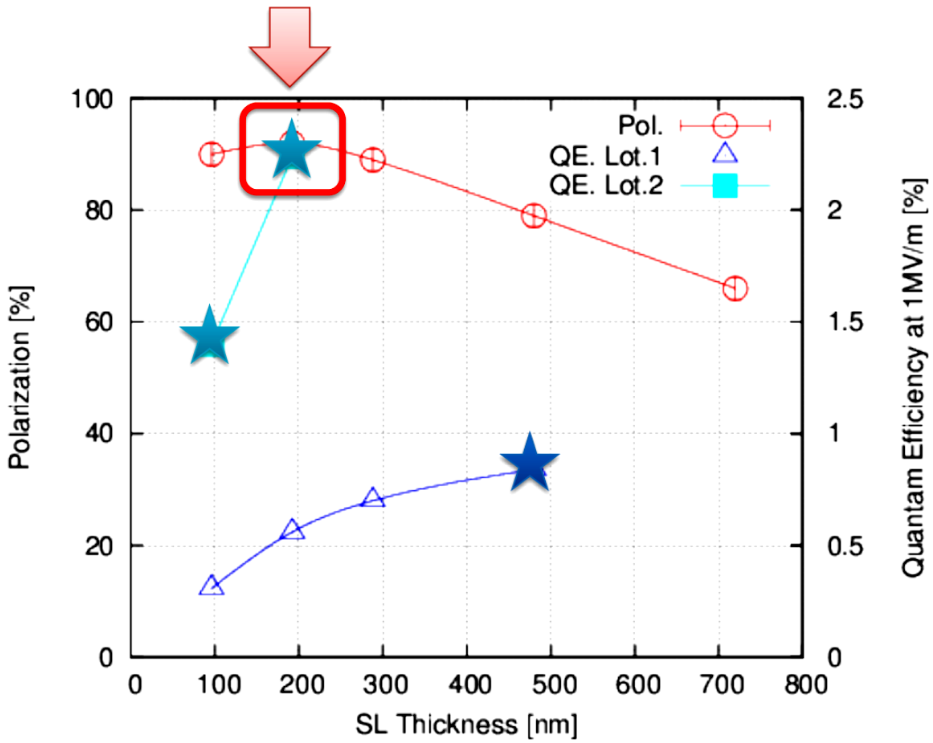
- Strain-Compensated Superlattice
  - Higher crystal quality
  - Thicker superlattice

GaAs-GaAsP Strain–Compensated .

Max. Pol. (~ 92%)
QE(~ 2.2 %) were achieved

- Obtained
  - Pol. ~92%
  - With QE 2.2%
- ~90% looks realistic

$$P \equiv \frac{N_L - N_R}{N_L + N_R}$$



Demonstrated ILC parameters (e- source)

Parameter	Requirement	Design	Achieved	Unit	Facility
Bunch Charge	3.2	4.8	8.0	nC	SLAC -SLC
Average Beam current	21	42	1000	μA	JLAB
Beam current in pulse	5.8	11.6	60	mA	Cornell U.
Polarization	80	80	90	%	Nagoya, SLAC, KEK
Quantum Efficiency	0.5	0.5	2.2	%	Nagoya
Drive Laser (in pulse)	1.8	10	>10	W	Commercially available

ILC Project Update

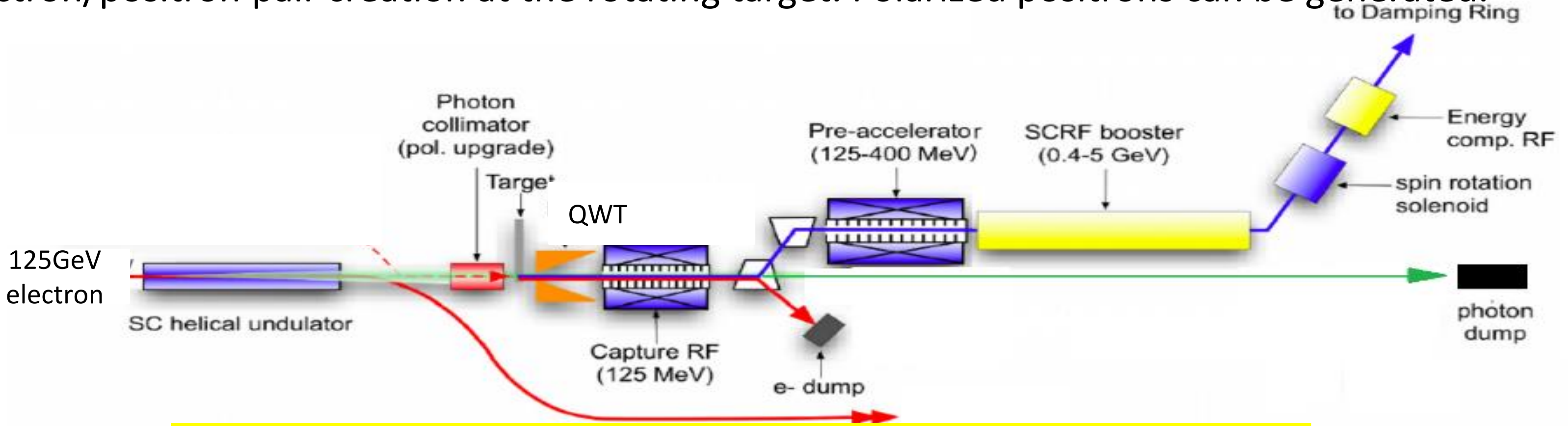
Shin MICHIZONO

KEK/Linear Collider Collaboration (LCC)

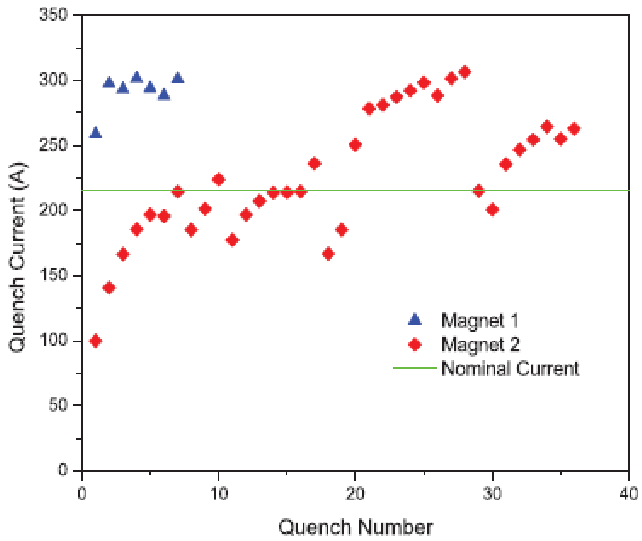
- *ILC area systems*
  - *Electron source*
  - *Positron source*
  - *Damping ring*
  - *RTML (bunch compressor)*
  - *Superconducting RF*
  - *Final focus*
  - *Beam dump*
  - *CFS*
- *ILC preparation (US, Japan, Europe)*
- *Technical preparation in "Recommendations on ILC Project"*
  - *MEXT and SCJ's comments*
  - *Superconducting RF*
  - *Positron source*
  - *Damping ring*
  - *Final focus*
  - *Beam dump*
- *Summary*

Positron Source (Undulator)

125 GeV electrons are injected to the helical undulator. The photons produced at the undulator is used for the electron/positron pair creation at the rotating target. Polarized positrons can be generated.



Positron source will be reported at Tuesday Accelerator Plenary
K.Yokoya "Progress of the Accelerator Design"



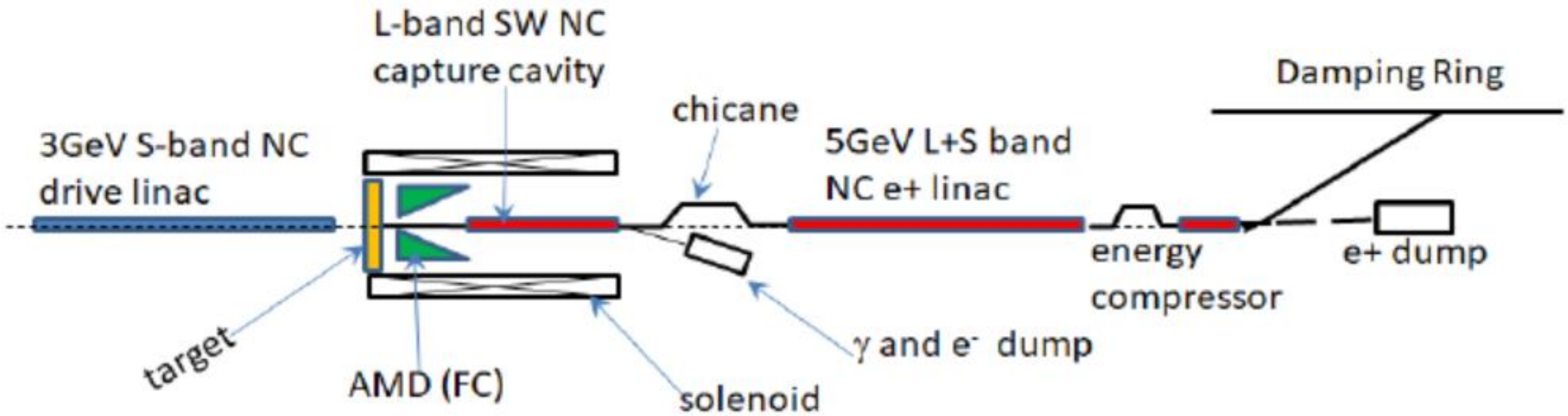
test at Daresbury

PHYSICAL REVIEW LETTERS **107** (2011) 174803

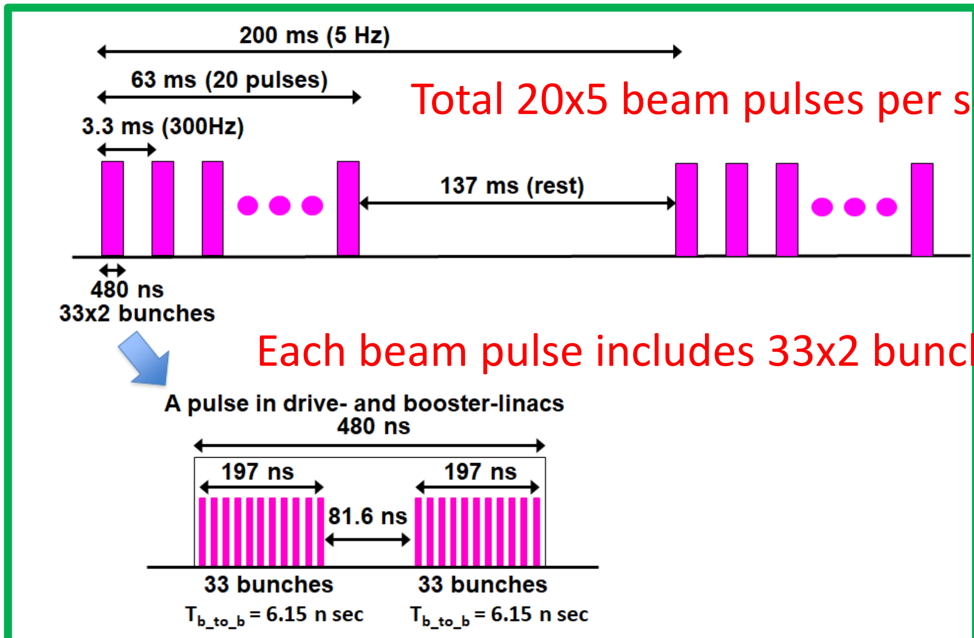
Two undulators in one cryomodule were tested. Both achieved nominal magnetic fields.

Positron Source (e-Driven)

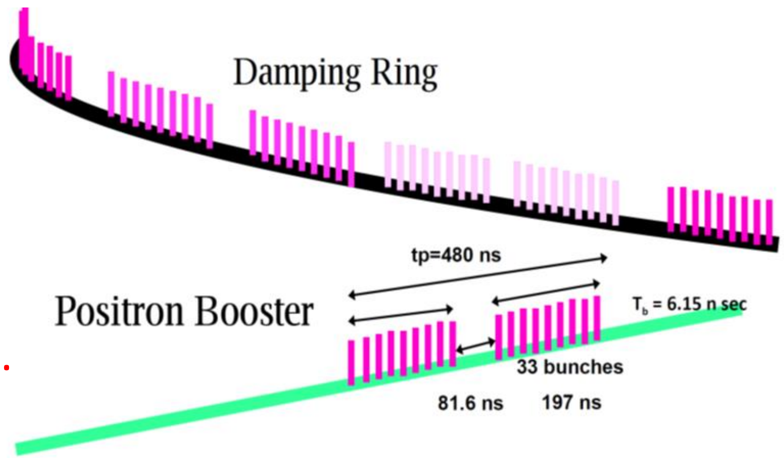
Extra 3GeV linac is used for the positron generation. High energy electrons are not necessary. (Electron independent commissioning is possible. However, polarization is not available.)



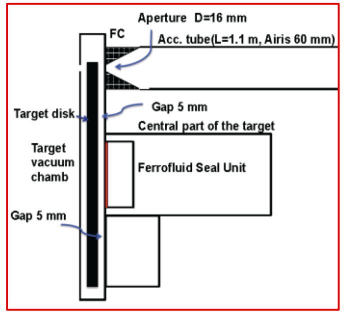
Total 20x5 beam pulses per sec.

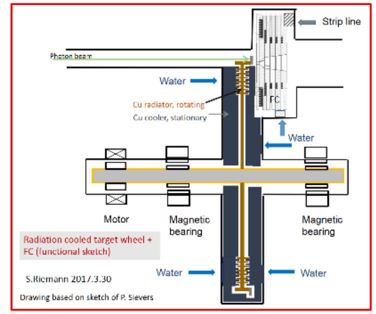


Each beam pulse includes 33x2 bunches.



Positron rotating target





	E-Driven	undulator	Existing X-ray generator
Cooling/Seal	water/magnetic fluid	Radiation/ magnetic levitation	water/magnetic fluid
radius（mm）	250	500	160
weight（kg）	65*	50*	17
Tangential velocity（m/s）	5	100	160
rotation (rpm)	200	2,000	10,000
Beam heat load(kW)	20	2	90
Vacuum pressure（Pa）	10^{-6}	10^{-6}	10^{-4}

*The weight depends on the design of the disk part and the material

- Reliable rotating target
- Replacement of rotating target

Demonstrated ILC parameters (e+ source)

Parameter	Requirement	Design	Achieved	Unit	Facility
Bunch Charge	3.2	4.8	8.0	nC	SLAC SLC (E-Driven)
Undulator pitch	11.5	11.5	2.5	mm	SLAC E166
Positron Polarization (optional)	30	30	80	%	SLAC E166
W-Re Target Heat Load (PEDD* for E-Driven)		34	70	J/g	SLAC SLC (E-Driven)
Ti alloy Target Heat Load (PEDD for Undulator)		61	160	J/g	Estimated from physics constant table
Flux Concentrator Peak field (E-Driven)	**5.0**	**5.0**	10	T	BINP
QWT peak field (Undulator)	1.0	1.0	2.3	T	KEK

PEDD: peak energy deposition density

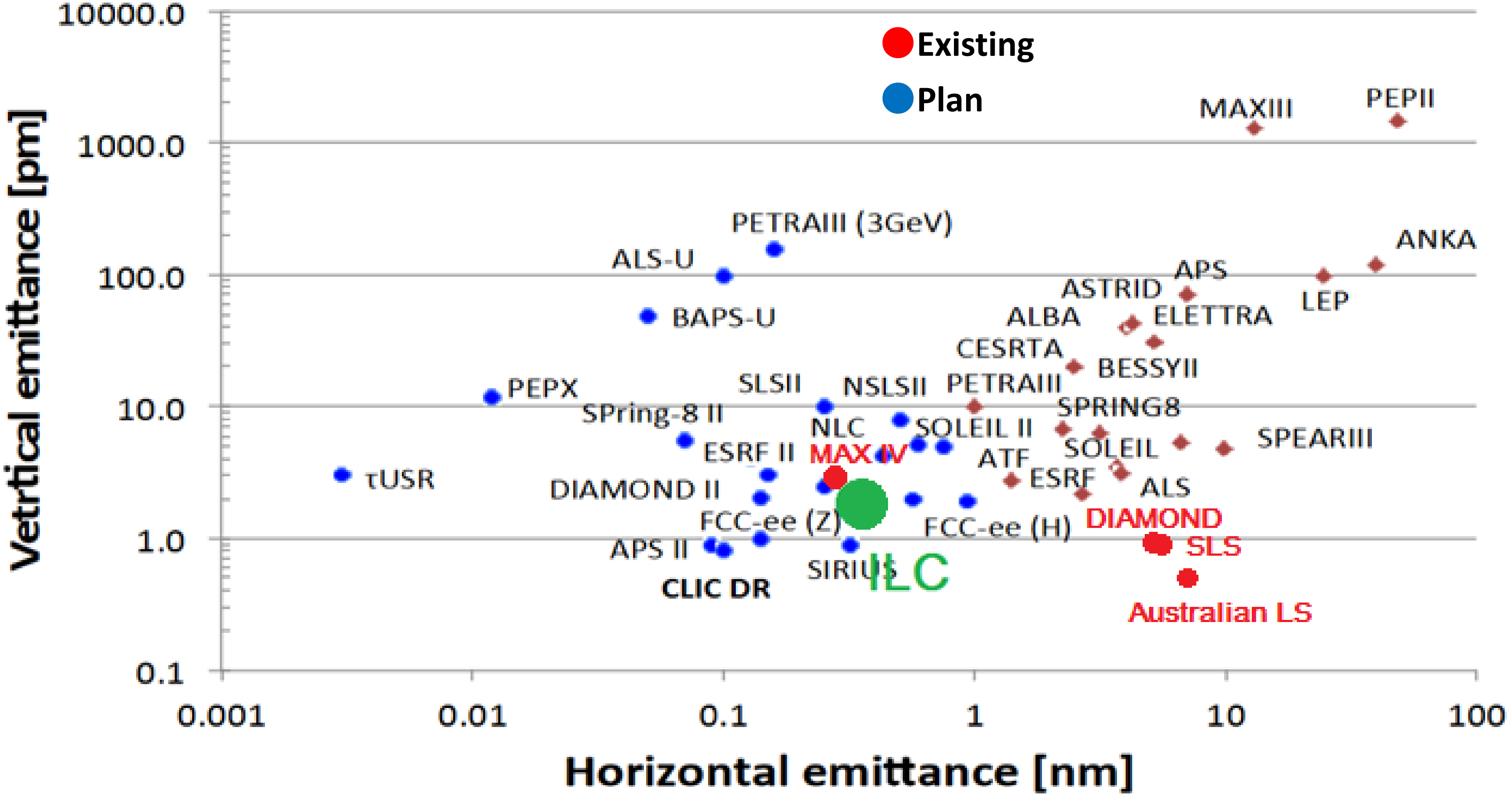
ILC Project Update

Shin MICHIZONO
KEK/Linear Collider Collaboration (LCC)

- *ILC area systems*
  - *Electron source*
  - *Positron source*
  - *Damping ring*
  - *RTML (bunch compressor)*
  - *Superconducting RF*
  - *Final focus*
  - *Beam dump*
  - *CFS*
- *ILC preparation (US, Japan, Europe)*
- *Technical preparation in "Recommendations on ILC Project"*
  - *MEXT and SCJ's comments*
  - *Superconducting RF*
  - *Positron source*
  - *Damping ring*
  - *Final focus*
  - *Beam dump*
- *Summary*

Damping ring

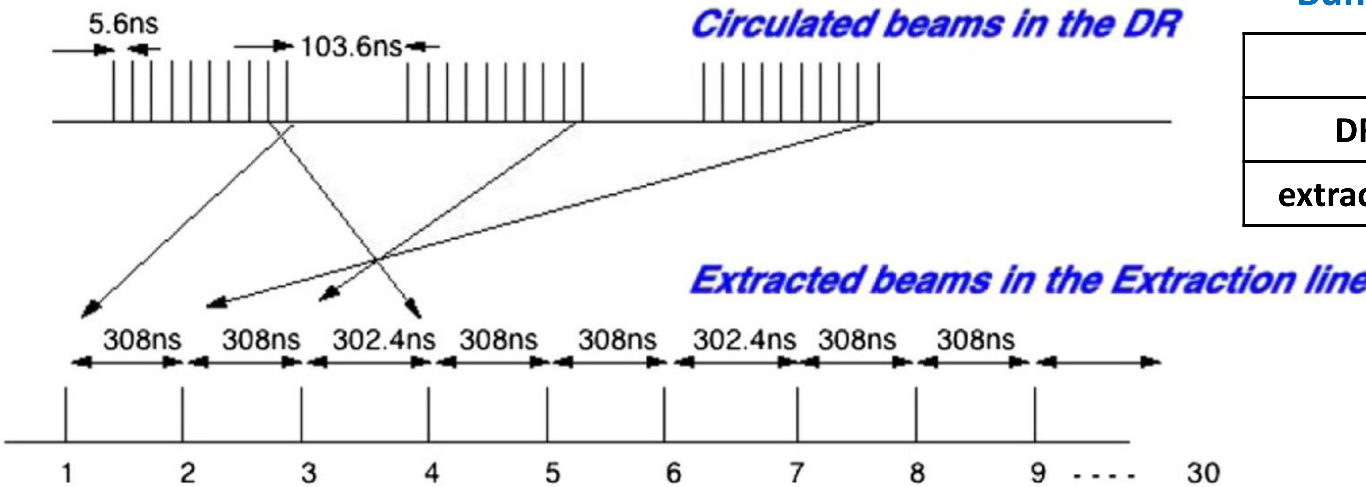
Worldwide light sources' emittance



Horizontal emittance is smaller at MAX IV.
Vertical emittance is smaller at Australian LS, SLS, DIAMOND.

Beam extraction by fast kicker

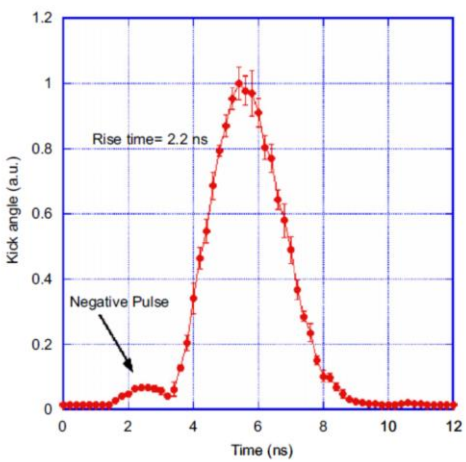
Bunch extraction test at ATF



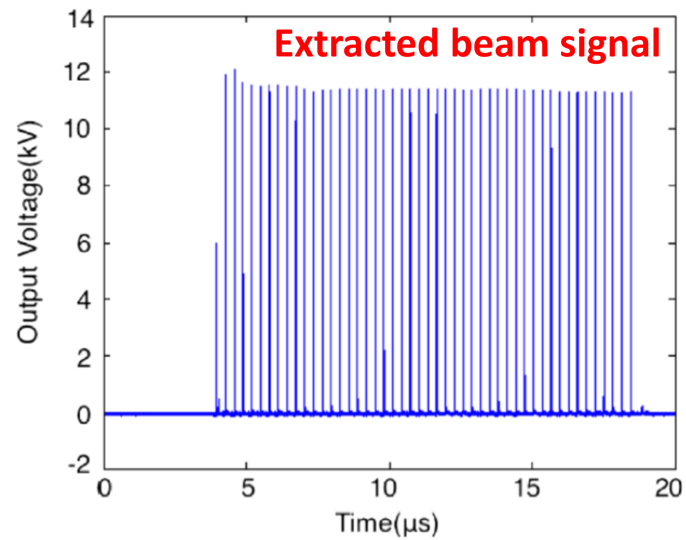
Bunch-space at ATF exp. and ILC

	ATF exp.	ILC
DR	5.60 ns	6.15 ns
extraction	302-308ns	554 ns

Fast Kicker waveform



T.Naito *et al.*, NIM **A 571** (2007) 599.



T.Naito *et al.*, PR ST-AB **14** (2011) 051002

Demonstrated ILC parameters (Damping Ring)

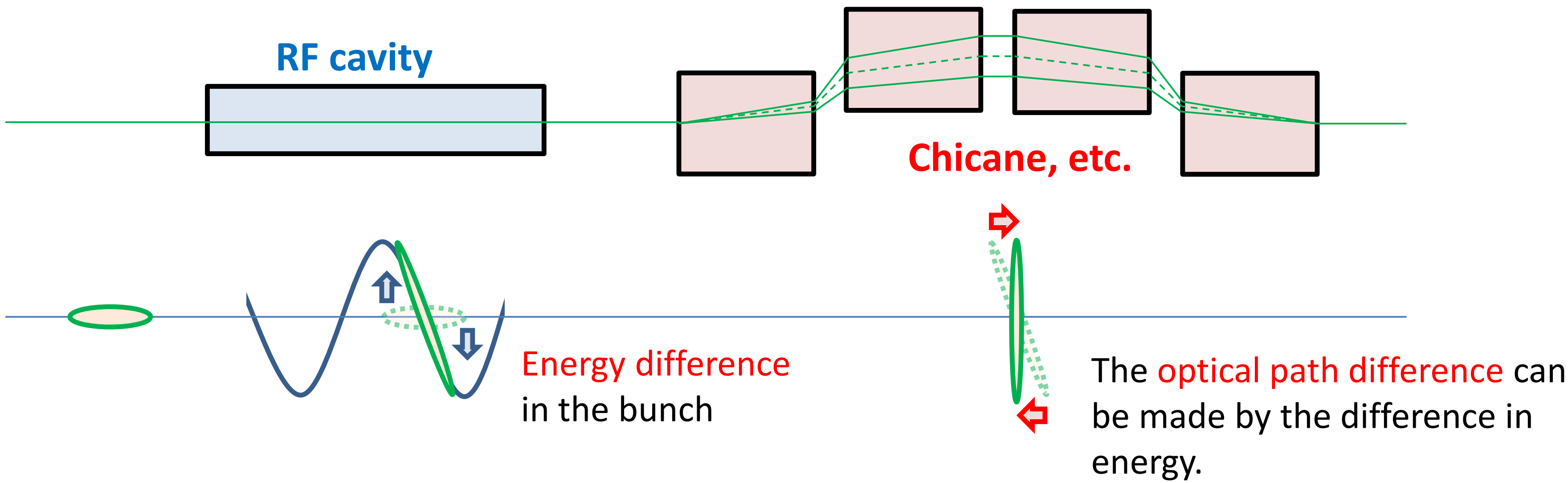
Parameter	Requirement	Design	Achieved	Facility	Comment
Horizontal Emittance(ε_x)	0.4nm	0.4nm	0.34nm	MAX-IV	Pedro F. Tavares, 2017 Phangs Workshop
Vertical Emittance (ε_y)	2pm	2pm	< 2pm	SLS, Australian LS, Diamond LS	TDR
Normalized Emittance ($\gamma\varepsilon_x/\gamma\varepsilon_y$)	4.0μm/20nm	4.0μm/20nm	4.0μm/15nm	ATF	Y. Honda *et al.*, PRL **92** (2004) 054802.
Fast Ion instability				SuperKEKB	On going
Electron Cloud Instability				SuperKEKB/CesrTA	On going
Kicker Rise Time	< 6.15ns	< 3.07ns	2.2ns	ATF	T. Naito *et al.*, NIM **A 571** (2007) 599.
Kicker Voltage	$\pm$10kV	$\pm$10kV	$\pm$10kV	ATF	T. Naito *et al.*, PR ST-AB **14** (2011) 051002.
Kicker Voltage stability	0.07%	0.07%	0.035%	ATF	
Kicker Frequency	1.8MHz	2.7MHz	3.25MHz	ATF	
Fast Kicker extraction test				ATF	

ILC Project Update

Shin MICHIZONO
KEK/Linear Collider Collaboration (LCC)

- ILC area systems
  - Electron source
  - Positron source
  - Damping ring
  - RTML (bunch compressor)
  - Superconducting RF
  - Final focus
  - Beam dump
  - CFS
- ILC preparation (US, Japan, Europe)
- Technical preparation in "Recommendations on ILC Project"
  - MEXT and SCJ's comments
  - Superconducting RF
  - Positron source
  - Damping ring
  - Final focus
  - Beam dump
- Summary

RTML　(Bunch compressor)



"Bunch compressor" compresses the bunch from 6 mm to 0.3 mm before entering the main linac (15GeV).
This final bunch length is one or more orders of magnitude longer than FEL etc., so it is not difficult (eg SACLA; FWHM 3 "µm").

If the phase of the RF cavity is jittered, jitter occurs in the arrival time of the beam at the collision point. Therefore, the phase jitter of the RF cavity of the ILC bunch compressor must be kept within 0.24° (0.15 mm). (but not difficult compared with the XFEL requirements of ~0.01°)

Demonstrated ILC parameters (RTML)

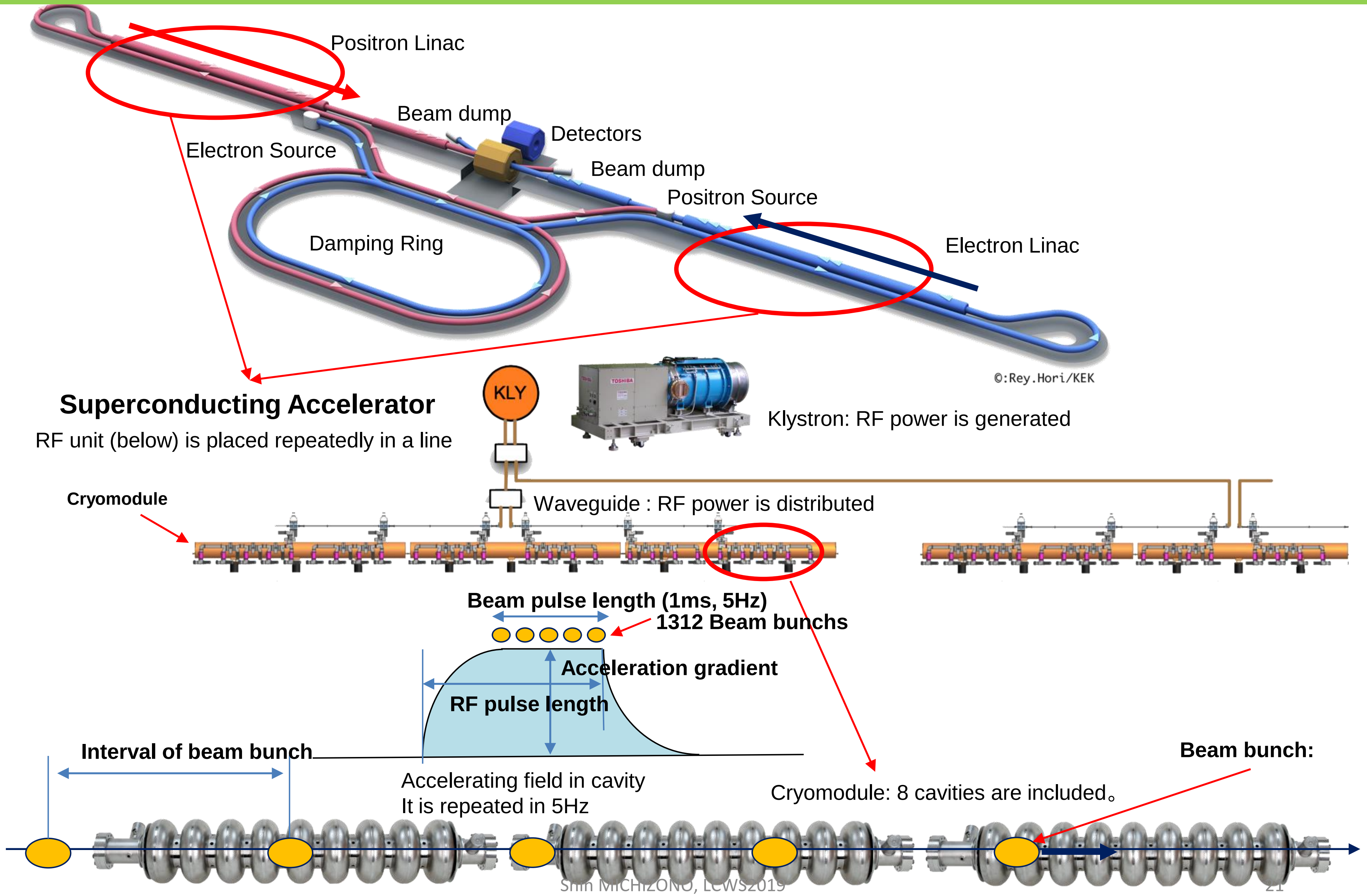
Parameter	Requirement	Design	Achieved	Facility	Comment
BC phase error	0.24°		0.042°	KEK-STF	M.Omet, Ph.D thesis (2014)
BC amplitude error	0.5%		0.041%	KEK-STF	
Horizontal emittance increase ($\gamma\varepsilon_x$)	$1\mu\mathrm{m}$	RTML ($0.47\mu\mathrm{m}$) , BC ($0.43\mu\mathrm{m}$), ML ($0.00\mu\mathrm{m}$), total ($0.90\mu\mathrm{m}$)		In simulation	TDR
Vertical emittance increase ($\gamma\varepsilon_y$)	15 nm	RTML (6.4nm) , ML (4.5nm), total (10.9nm)		In simulation	TDR

ILC Project Update

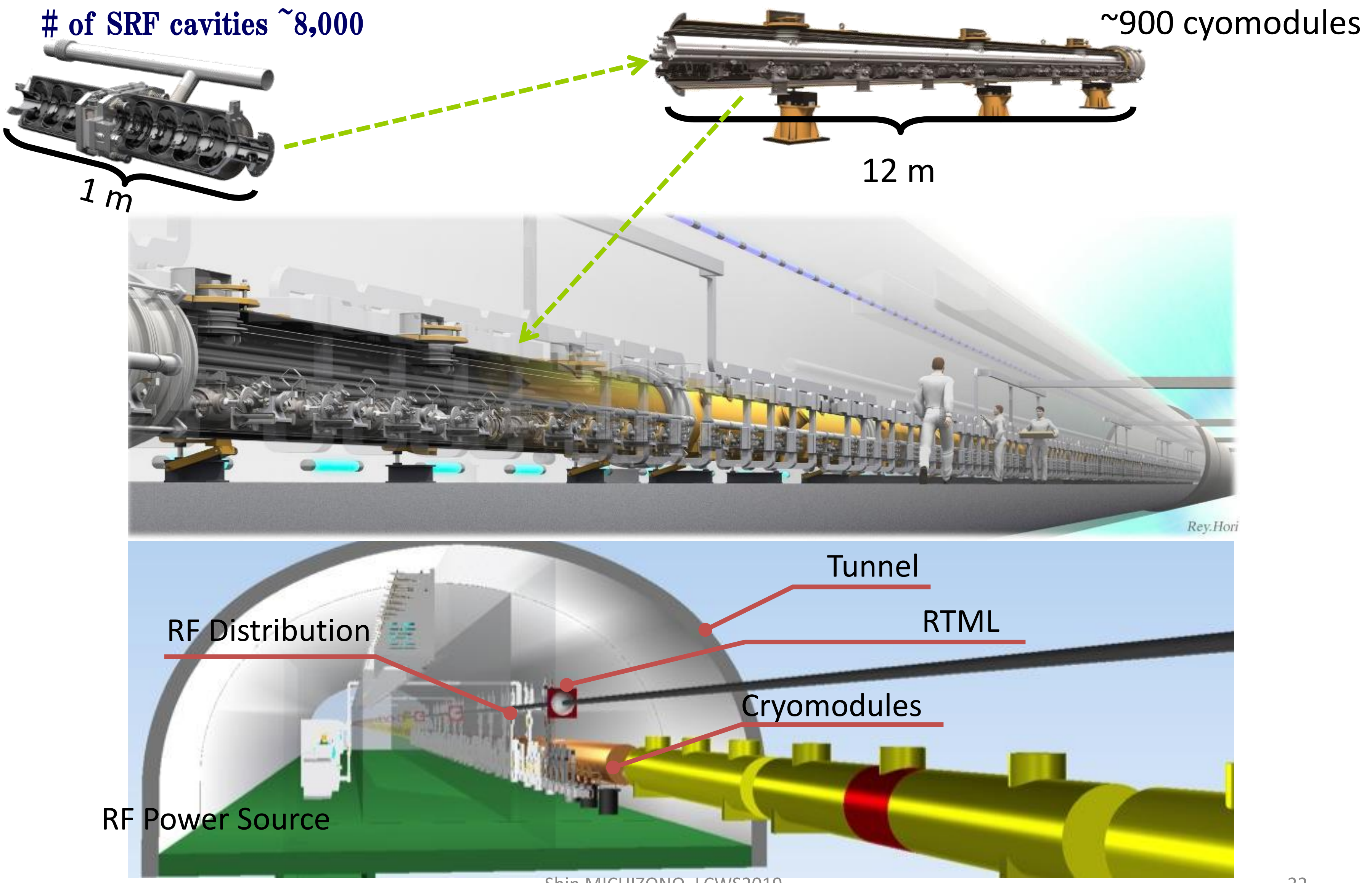
Shin MICHIZONO
KEK/Linear Collider Collaboration (LCC)

- *ILC area systems*
  - *Electron source*
  - *Positron source*
  - *Damping ring*
  - *RTML (bunch compressor)*
  - *Superconducting RF*
  - *Final focus*
  - *Beam dump*
  - *CFS*
- *ILC preparation (US, Japan, Europe)*
- *Technical preparation in "Recommendations on ILC Project"*
  - *MEXT and SCJ's comments*
  - *Superconducting RF*
  - *Positron source*
  - *Damping ring*
  - *Final focus*
  - *Beam dump*
- *Summary*

Beam Acceleration in Main Linac

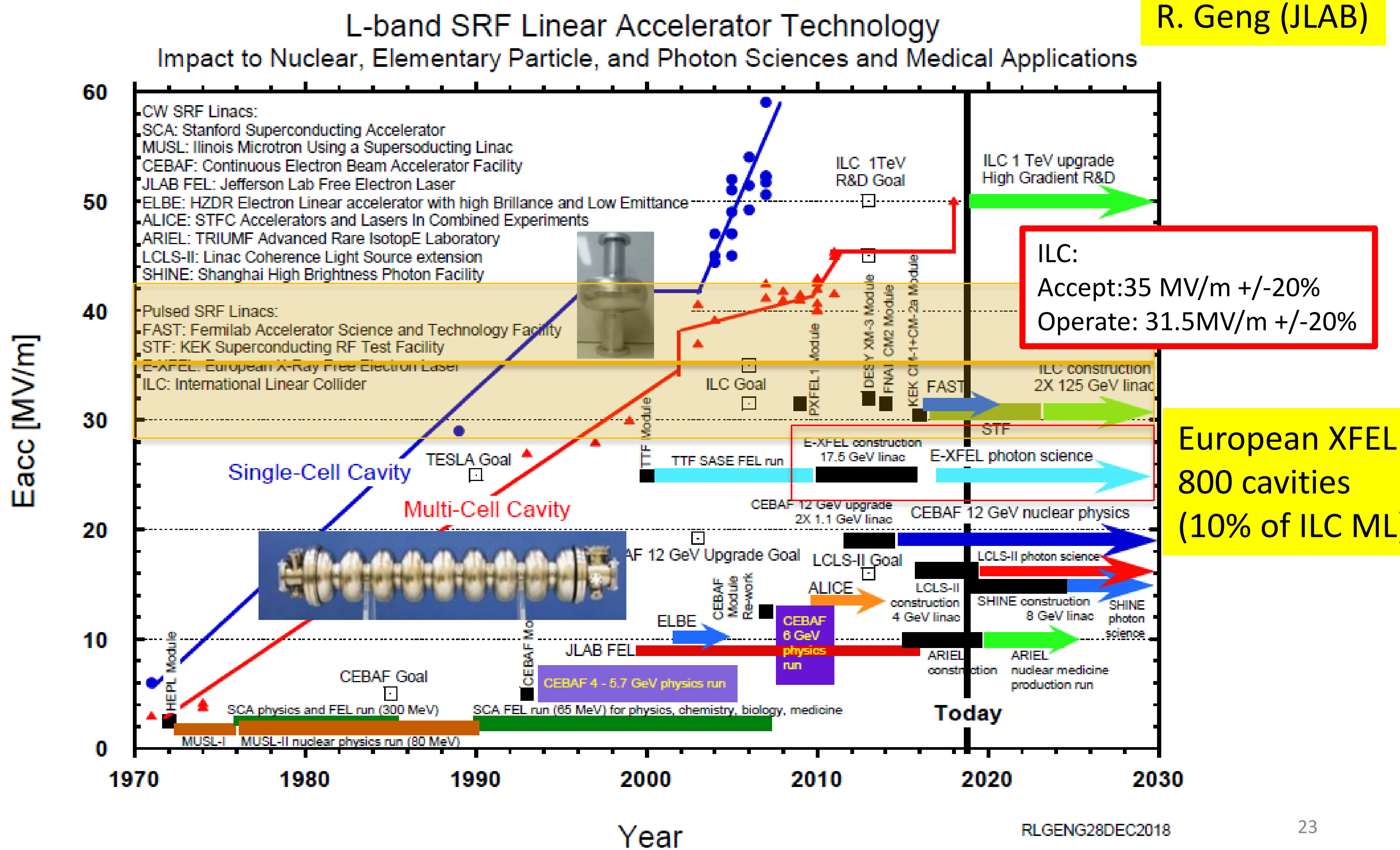


Main Linac at the ILC



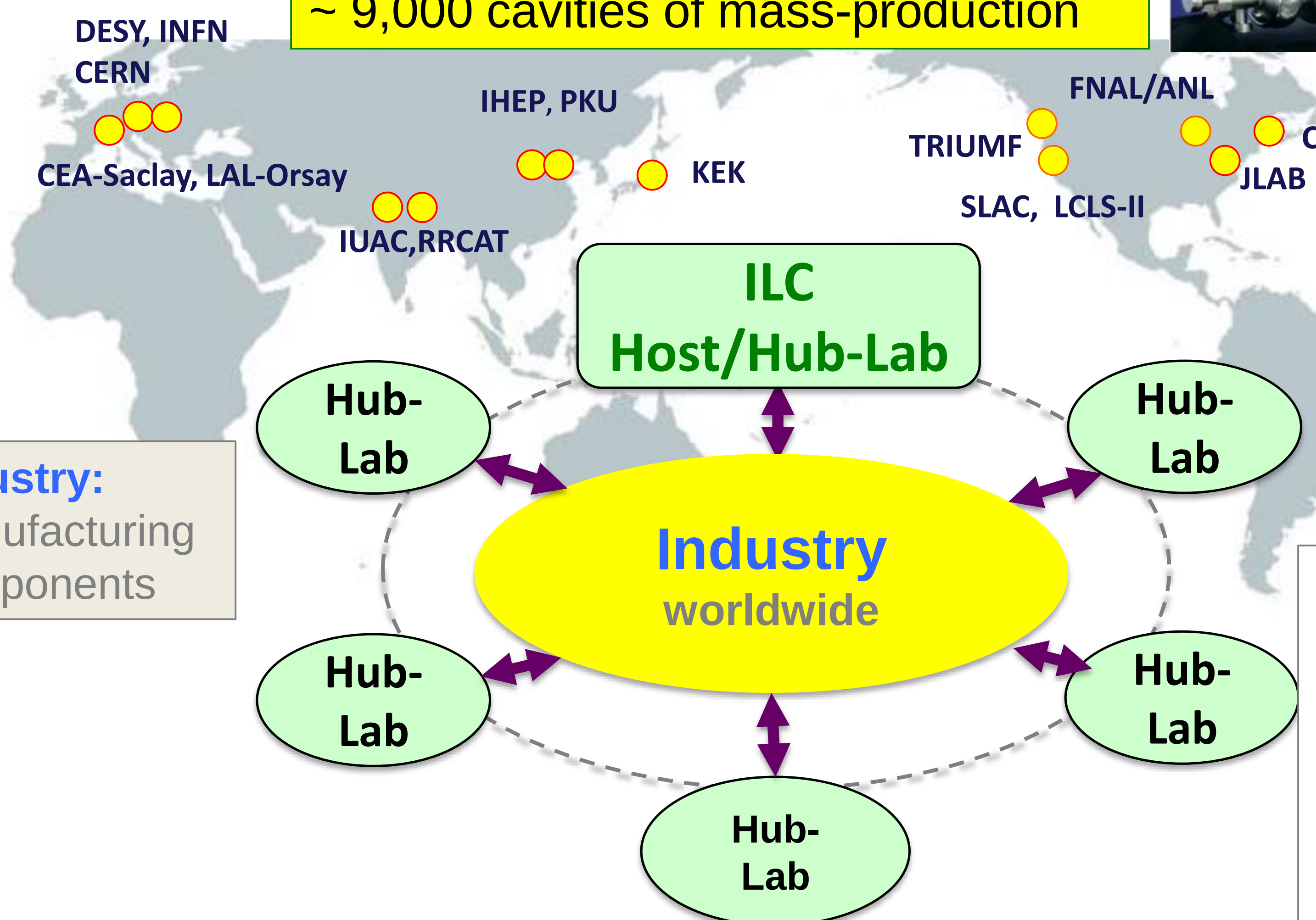
Matured SRF technologies

R. Geng (JLAB)



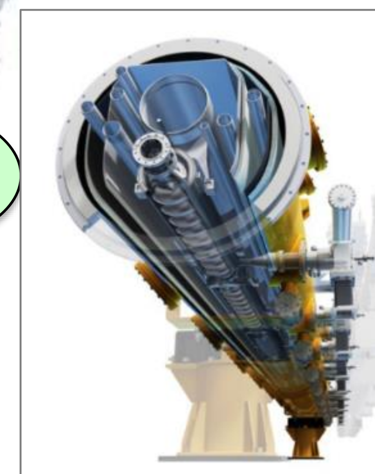
ILC SRF Global Integration Model

~8,000 x 1.1(Yield = 90%)
~ 9,000 cavities of mass-production



Industry: manufacturing components

Hub-lab: regionally hosting integration & Test



Demonstrated ILC parameters (SRF)

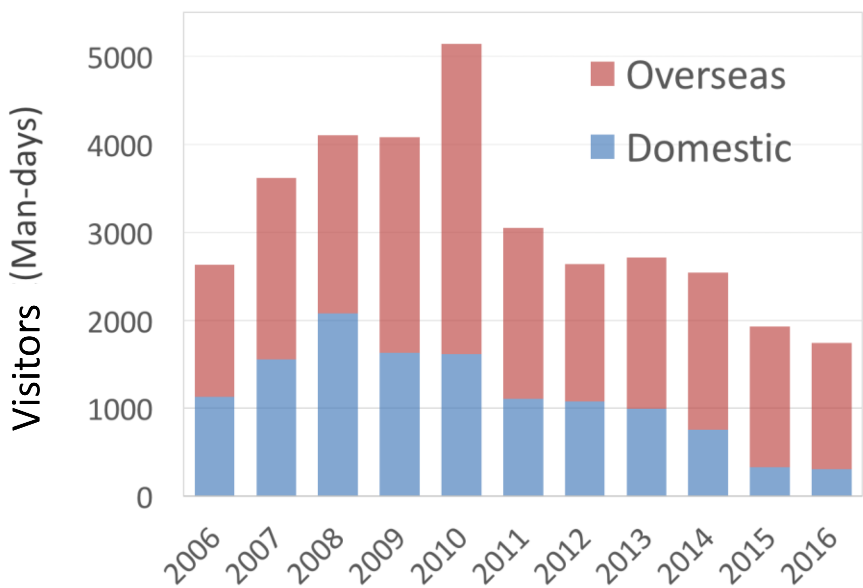
Parameter	Requirement	Achieved	Comment
Acc. Gradient in the cryomodule	31.5 MV/m	32.5MV/m (PXFEL-1, DESY) 31.5MV/m(CM-2, ASTA) 32 MV/m(CM-1&2a,STF)	DESY-Proto-XFEL (ILC-TDR V3, Part-1, p43) FNAL-ASTA (E. Harms, AWLC14 May 2014) STF(KEK news May 22,2019)
Average Q0 in cryomodule	10^{10}	-- (PXFEL-1, DESY) 0.9×10^{10}(CM-2, ASTA) 0.7×10^{10}(CM-1&2a,STF)	FNAL-ASTA (E. Harms, AWLC14 May 2014) KEK-STF report (Y. Yamamoto, STF,2016)
Acc. Gradient at vertical test	≧35(±20%) MV/m ≧90%yield	<37 MV/m> ~94%	TDR vol-3 part I, Chapter 2.3
Beam current	5.78mA	6mA (800μs beam pulse length)	
Number of bunches	1312	2400 (800μs beam pulse length)	
Bunch charge	3.2nC	3nC (600μs beam pulse length) 2nC (800μs beam pulse length)	DESY-FLASH 9mA-study, TDR vol-3 part I, p.80
Bunch space	554ns	333ns	
Bunch length	727μs	800μs	
Rf pulse width	1.65ms	>1.65ms	
RF pulse repetition	5Hz	10Hz	DESY XFEL

ILC Project Update

Shin MICHIZONO
KEK/Linear Collider Collaboration (LCC)

- *ILC area systems*
  - *Electron source*
  - *Positron source*
  - *Damping ring*
  - *RTML (bunch compressor)*
  - *Superconducting RF*
  - ➡ *Final focus*
  - *Beam dump*
  - *CFS*
- *ILC preparation (US, Japan, Europe)*
- *Technical preparation in "Recommendations on ILC Project"*
  - *MEXT and SCJ's comments*
  - *Superconducting RF*
  - *Positron source*
  - *Damping ring*
  - *Final focus*
  - *Beam dump*
- *Summary*

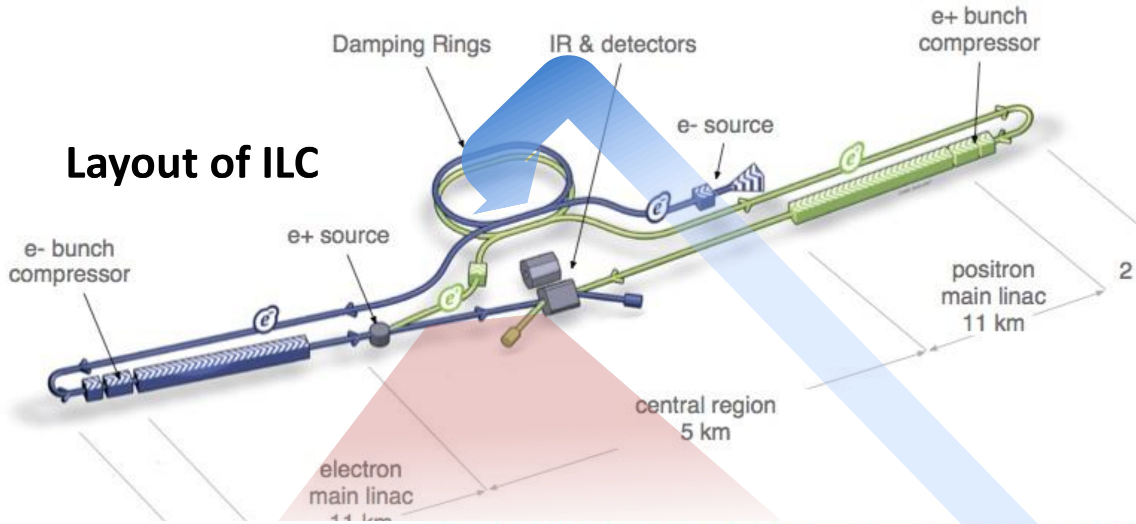
ATF International Collaboration



- ATF international collaboration established in 2005.
- During the construction phase (~2010), many researchers joined for the installation of the components of in-kind contribution.
- Since 2011, the researchers visit for mainly the beam study.
- Many researchers are working for this collaboration.

ATF/ATF2: Accelerator Test Facility

Layout of ILC



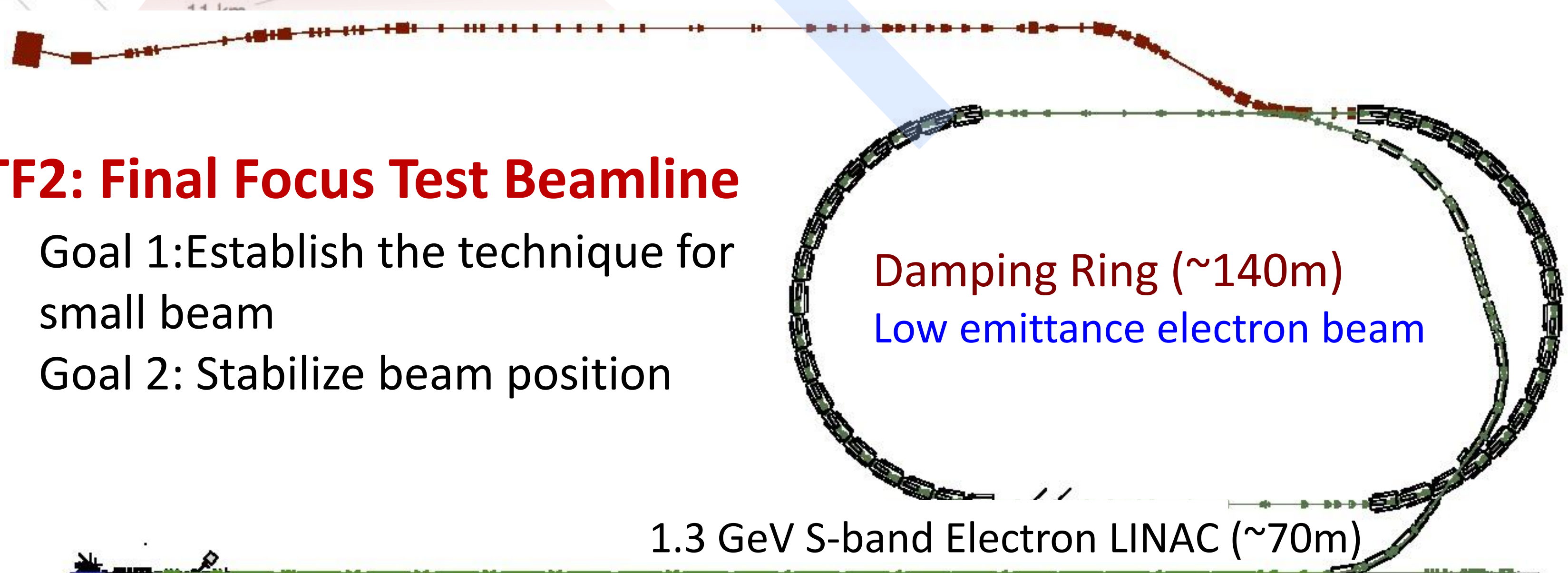
Develop the nanometer beam technologies for ILC

- Key of the luminosity maintenance
- 7.7 nm beam at IP (ILC250)

ATF2: Final Focus Test Beamline

Goal 1:Establish the technique for small beam

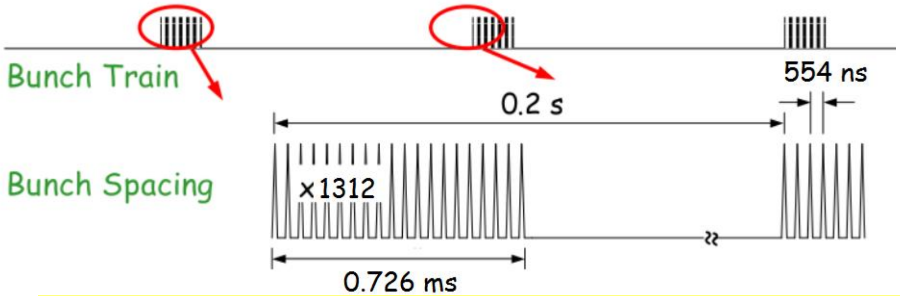
Goal 2: Stabilize beam position



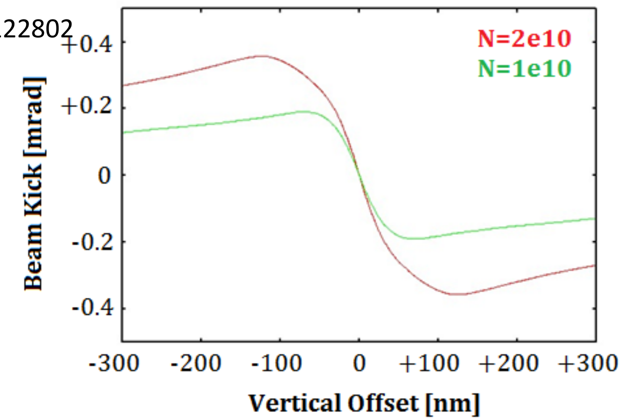
FONT* Bunch train feedback at final focus

*Feedback On Nanosecond Timescales
https://journals.aps.org/prab/abstract/10.1103/PhysRevAccelBeams.21.122802

ILC bunch structure

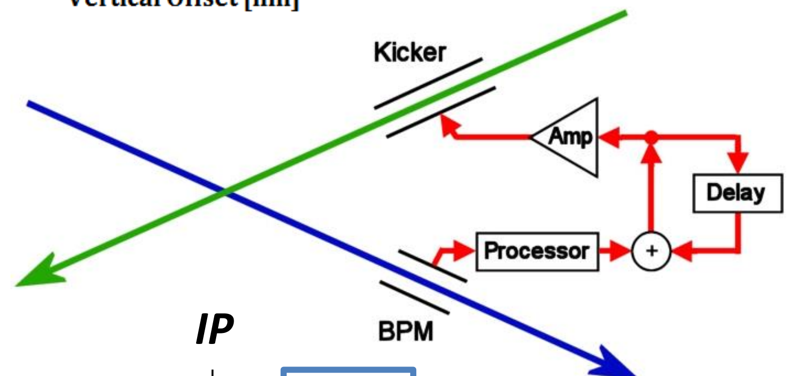


CAIN simulation

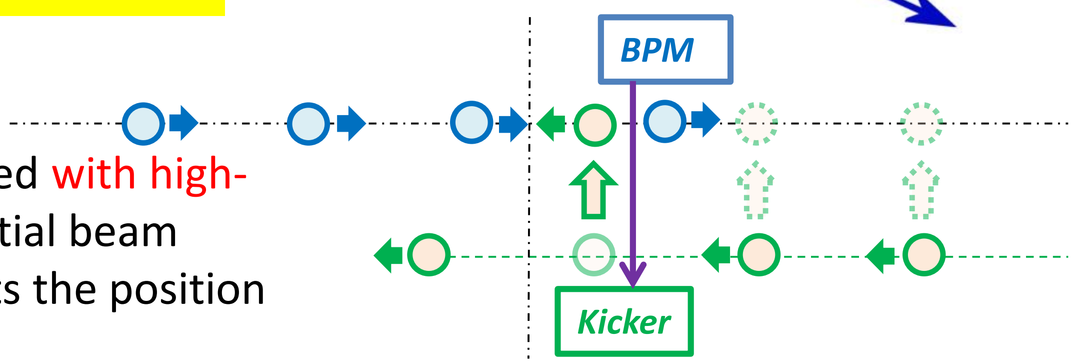


Depending on the relative position of the beam, beams are greatly scattered by the beam-beam effect.

The position of the beam between pulse trains shifts due to ground vibrations and equipment noise.
On the other hand, the position of the beam does not change significantly in the pulse train.



Efficient beam collision can be achieved with high-speed feedback that measures the initial beam position of the pulse train and corrects the position of subsequent bunches in the train.
Feedback latency should be less than bunch space.



The first bunch does not collide, but the second and subsequent bunches will collide.

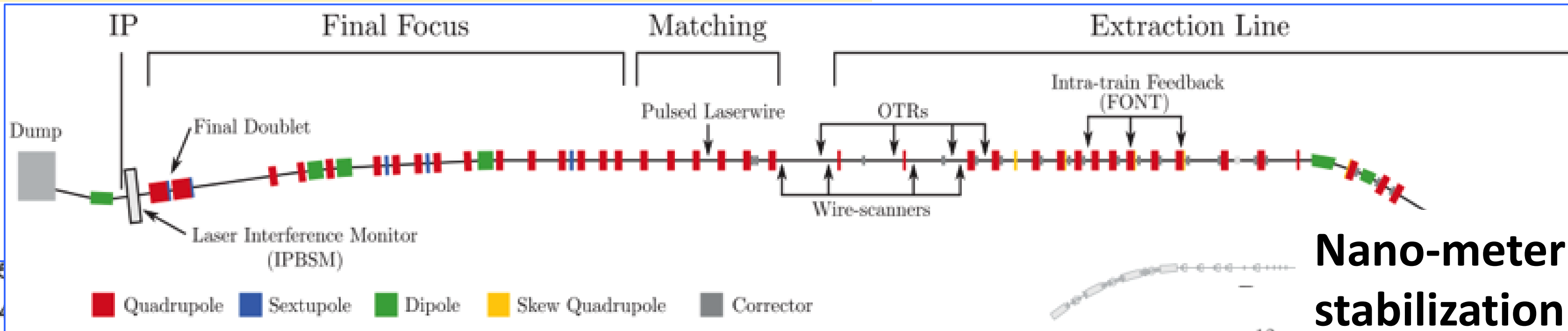
Beam Size and Stability at ATF2 for final focus at ILC

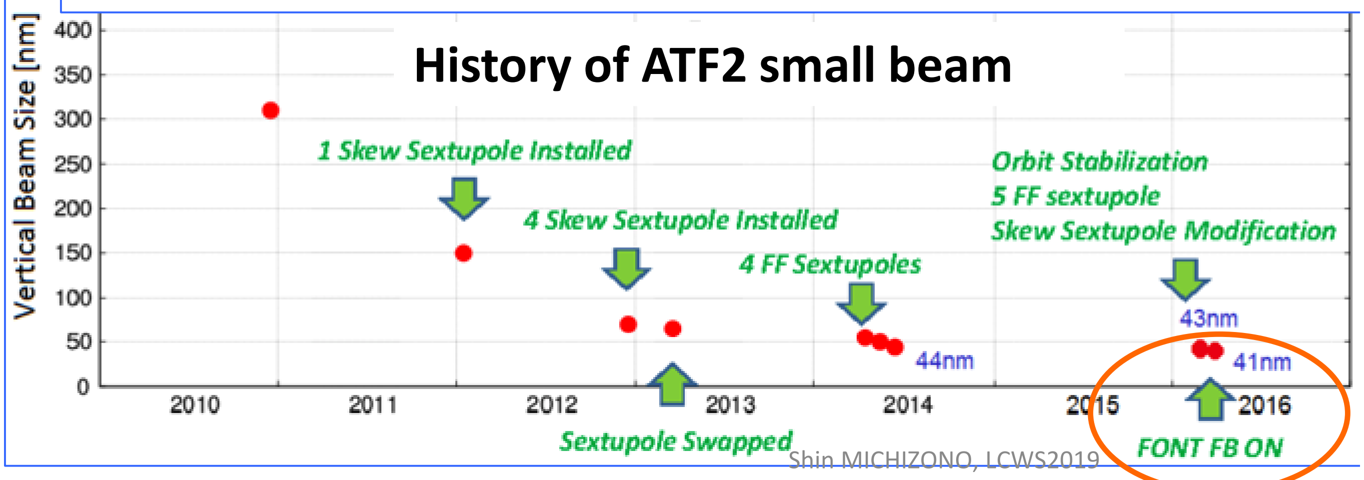
Goal 1: Establish the ILC final focus method with same optics and comparable beamline tolerances

- ATF2 Goal : **37** nm → ILC **7.7** nm (ILC250)
    - Achieved **41 nm** (2016)

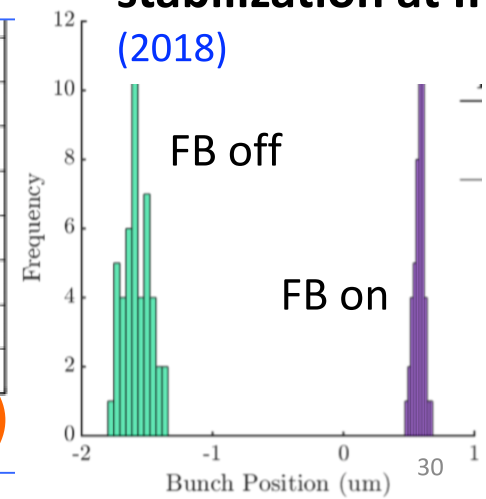
Goal 2: Develop a few nm position stabilization for the ILC collision

- **FB latency 133 nsec achieved** (target: < 366 nsec)
- **positon jitter at IP: 106 → 41 nm (2018)** (limited by the BPM resolution)





Nano-meter stabilization at IP (2018)



Demonstrated ILC parameters (Final focus)

Parameter	Requirement	Design	Achieved	Facility	Comment
ATF2 beam size (σ_y^*)	37 nm (ATF2 design)		41 nm	ATF2	T.Okugi, LINAC2016
ILC beam size	7.7 nm (ILC design)			ATF2	
Feedback position stability	12% of beam size (1nm)	10% of beam size	10% (FB OFF) ⇒ 4% (FB ON)	ATF2	P. Burrows, AWLC2018
Feedback latency	< 554 ns	< 366 ns	133 ns	ATF2	Physics Procedia 37 (2012) 2063. Phys.Rev.Accel.Beams .21.122802

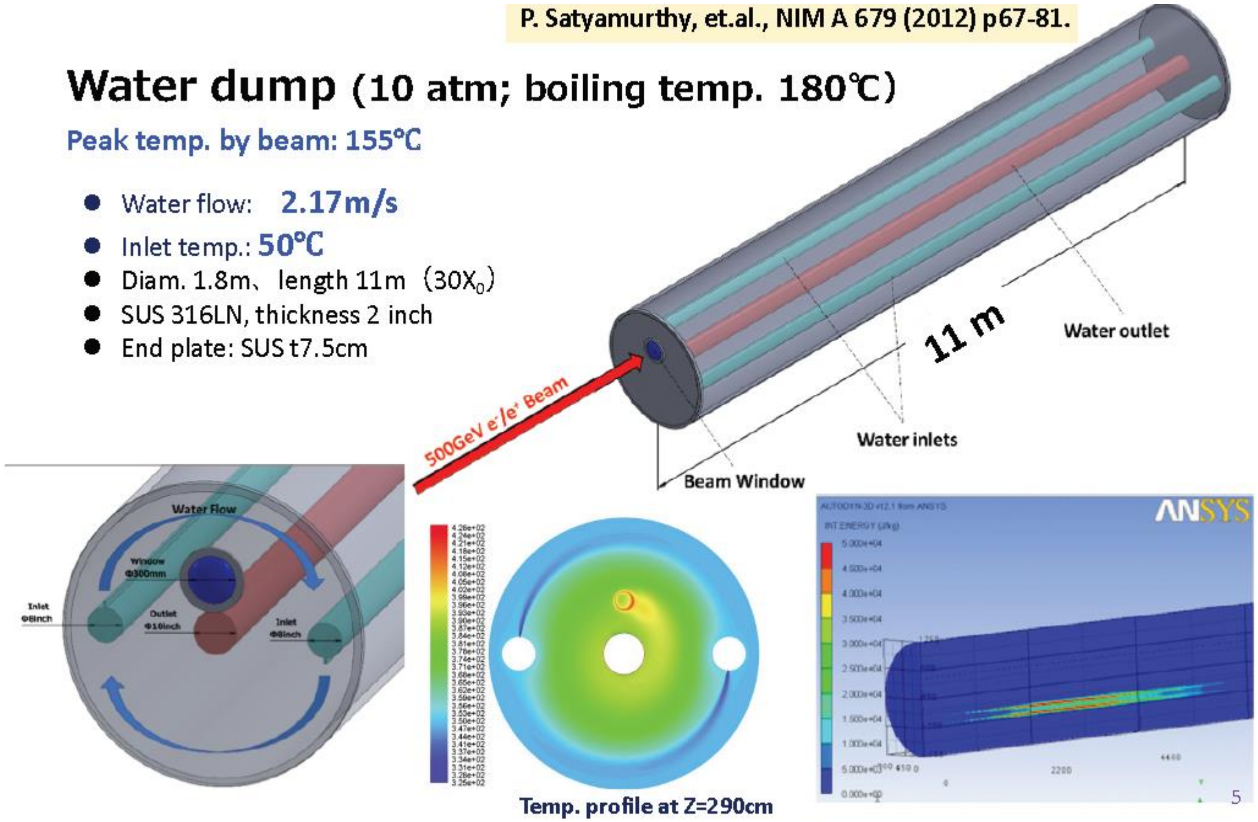
ILC Project Update

Shin MICHIZONO
KEK/Linear Collider Collaboration (LCC)

- *ILC area systems*
  - *Electron source*
  - *Positron source*
  - *Damping ring*
  - *RTML (bunch compressor)*
  - *Superconducting RF*
  - *Final focus*
  - *Beam dump*
  - *CFS*
- *ILC preparation (US, Japan, Europe)*
- *Technical preparation in "Recommendations on ILC Project"*
  - *MEXT and SCJ's comments*
  - *Superconducting RF*
  - *Positron source*
  - *Damping ring*
  - *Final focus*
  - *Beam dump*
- *Summary*

Beam dump

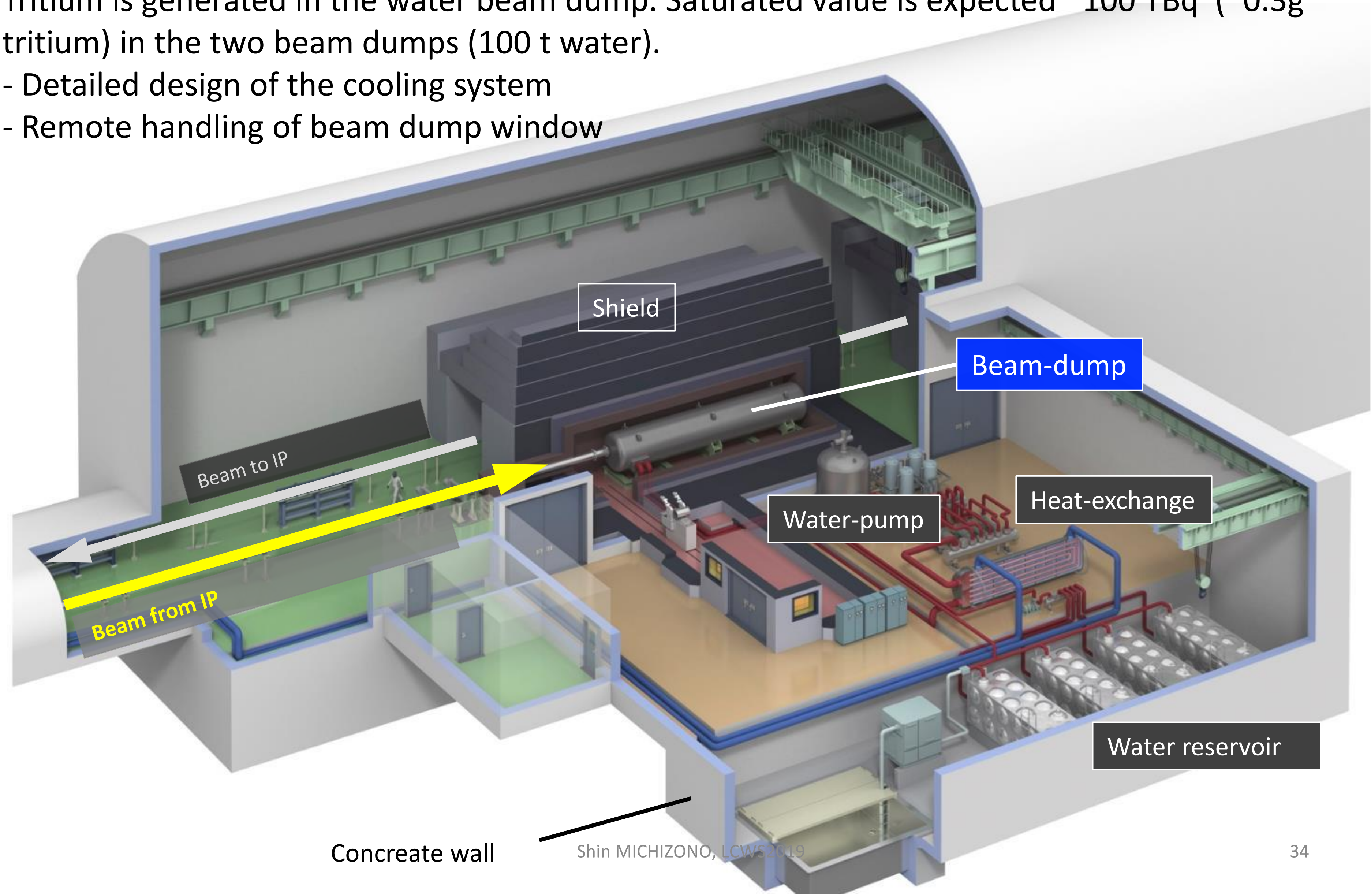
- ILC beam dump is designed for 1TeV collision energy, and ILC250 has enough margin.



Water beam dump	Req.	Des.	Achieved	unit	Comment
ILC 250GeV	**2.6**	**17**	**–**	**MW**	**Designed for 500GeV beam**
SLAC 2mile LINAC	**–**	**2.2**	**0.75**	**MW**	**ILC beam dump prototype**
CEBAF	0.9	1.0	0.73	MW	In operation at Jefferson Lab from the 90s to the present. 2 units (2 beam lines). Composite type with aluminum plates arranged in water.

Beam dump system

Tritium is generated in the water beam dump. Saturated value is expected ~100 TBq (~0.3g tritium) in the two beam dumps (100 t water).
- Detailed design of the cooling system
- Remote handling of beam dump window



ILC Project Update

Shin MICHIZONO

KEK/Linear Collider Collaboration (LCC)

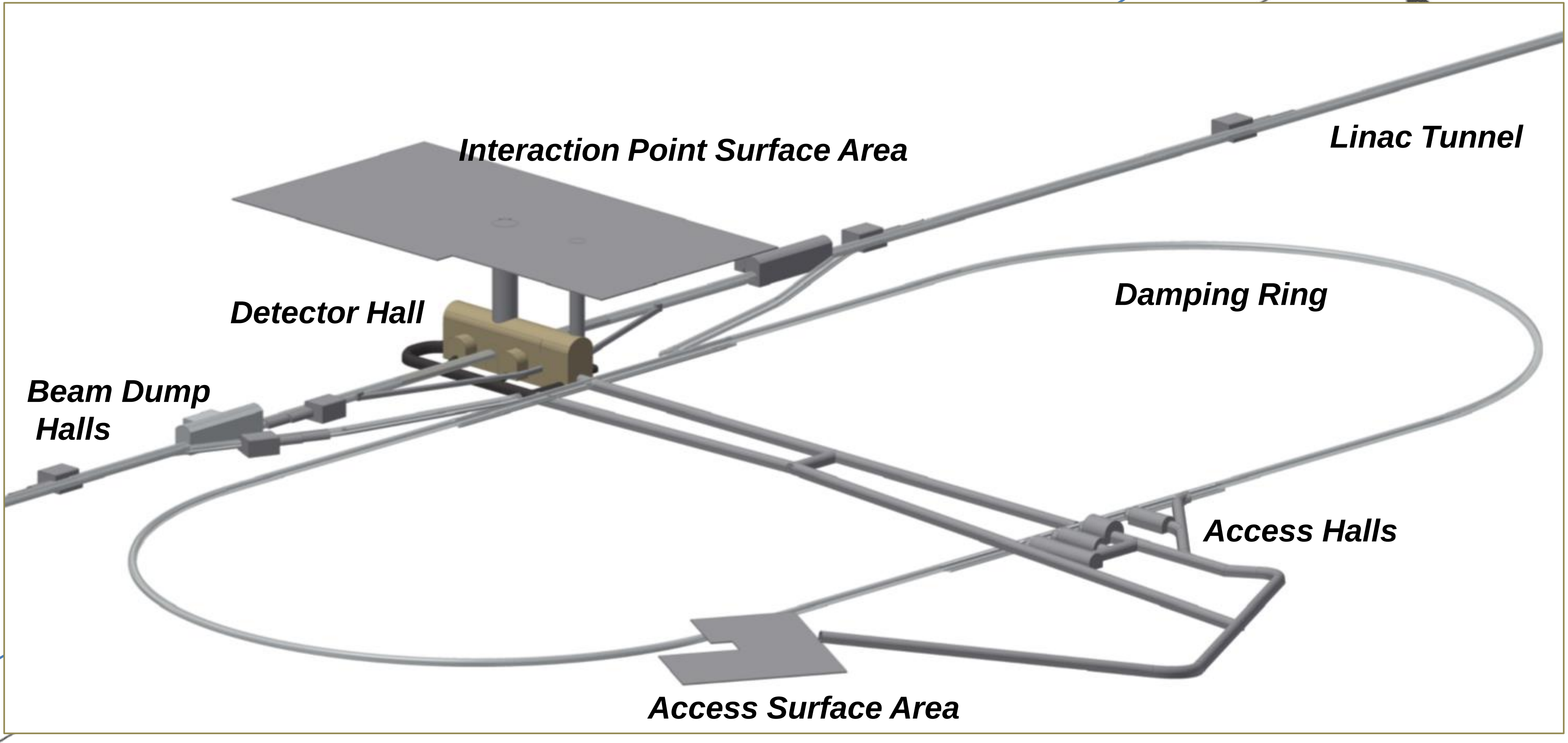
- *ILC area systems*
  - *Electron source*
  - *Positron source*
  - *Damping ring*
  - *RTML (bunch compressor)*
  - *Superconducting RF*
  - *Final focus*
  - *Beam dump*
  - *CFS*
- *ILC preparation (US, Japan, Europe)*
- *Technical preparation in "Recommendations on ILC Project"*
  - *MEXT and SCJ's comments*
  - *Superconducting RF*
  - *Positron source*
  - *Damping ring*
  - *Final focus*
  - *Beam dump*
- *Summary*

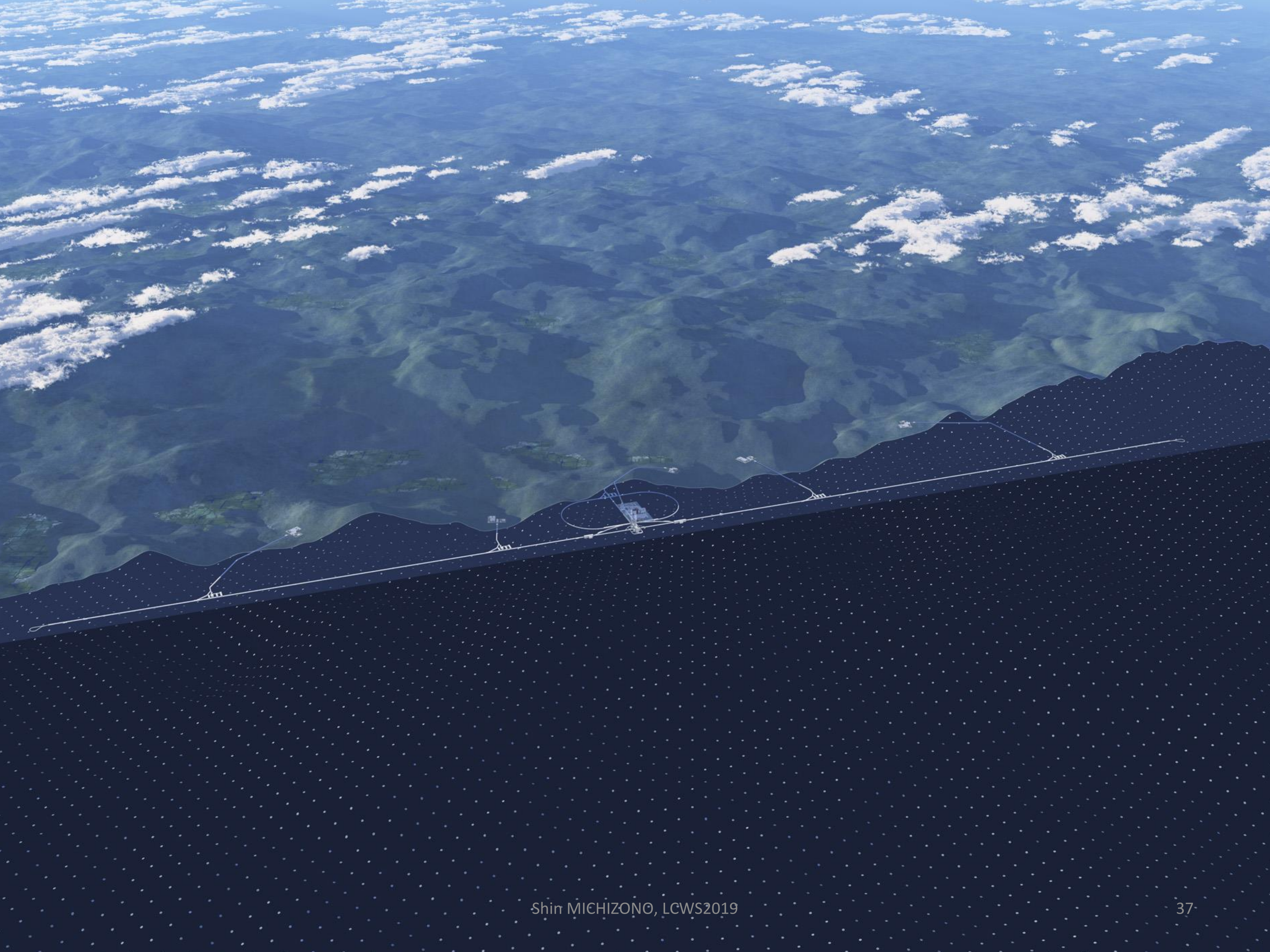
ILC Accelerator: Lattice design and tunnel design

ILC250 Lattice design was fixed, Accelerator tunnel design is on-going

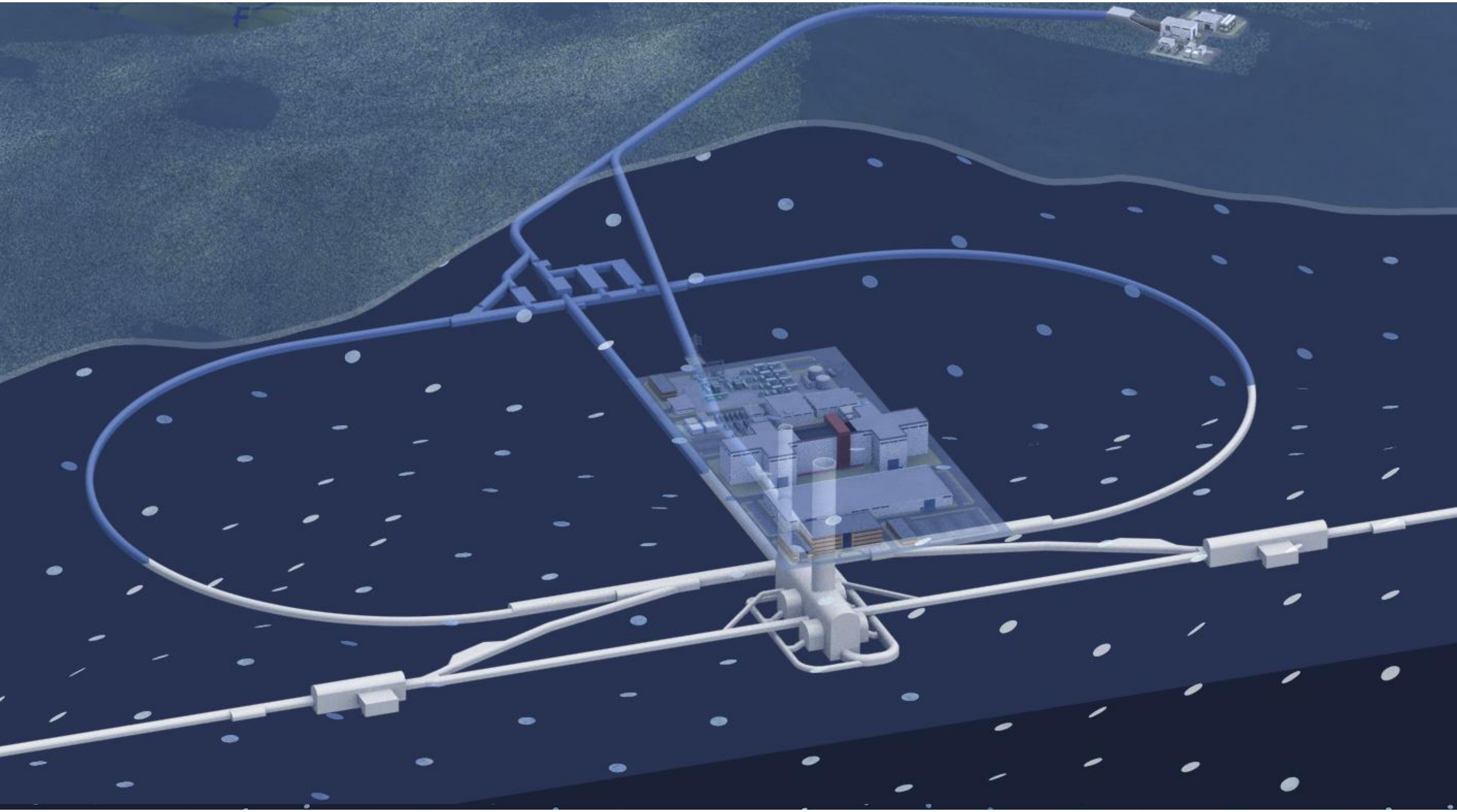
Total Accelerator tunnel length = 20,549.5m (20.5km)

Civil engineering will be reported at Tuesday Accelerator Plenary
N.Terunuma "Progress of Civil Engineering Design"



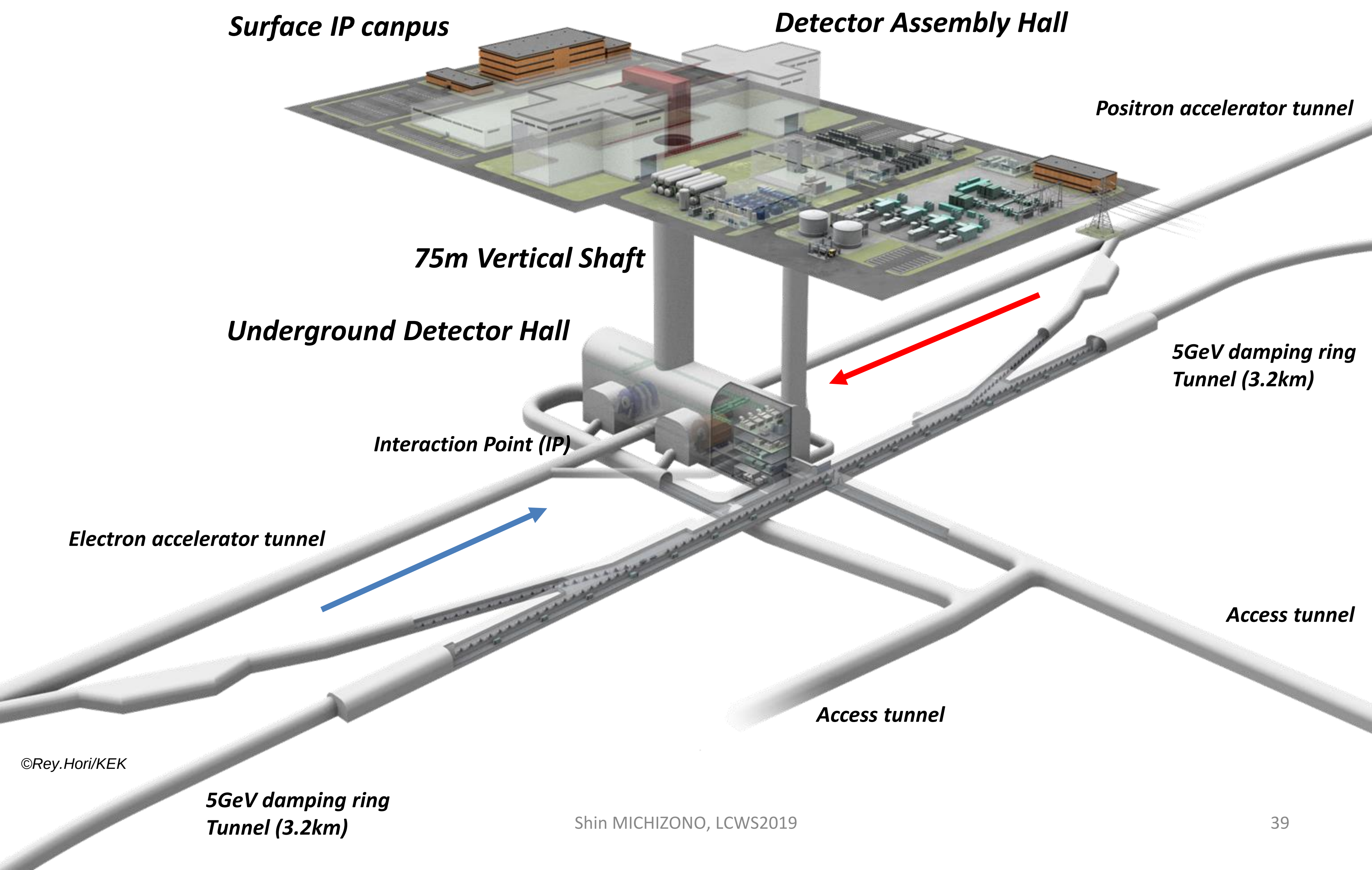


Bird's eye view of ILC in Kitakami candidate site

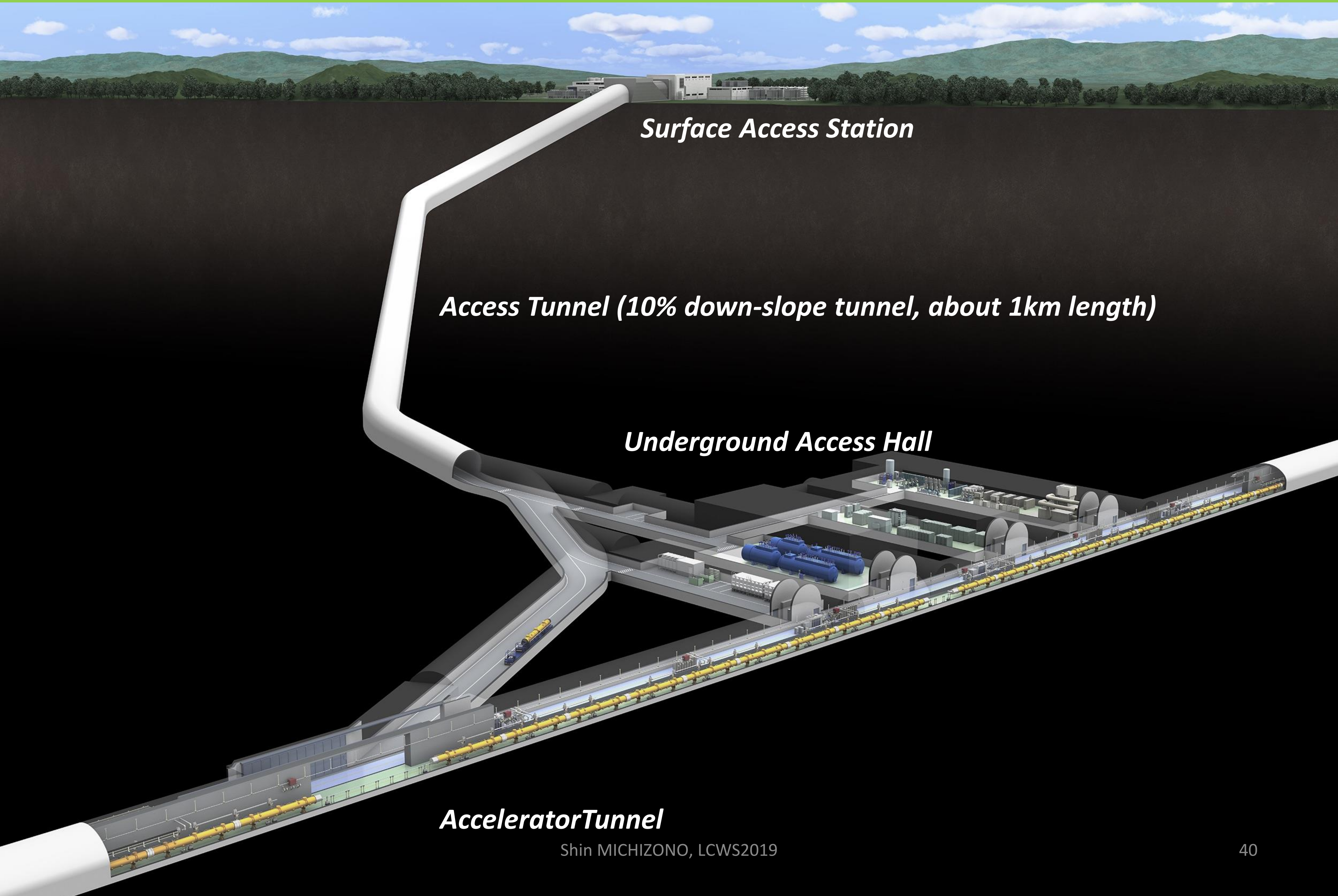


Tunnel design for Kitakami Candidate Site (ILC250GeV 20.5km)

Plan of Interaction point



Surface-to-Underground access-tunnel



ILC Project Update

Shin MICHIZONO

KEK/Linear Collider Collaboration (LCC)

- *ILC area systems*
  - *Electron source*
  - *Positron source*
  - *Damping ring*
  - *RTML (bunch compressor)*
  - *Superconducting RF*
  - *Final focus*
  - *Beam dump*
  - *CFS*

- *ILC preparation (US, Japan, Europe)*
- *Technical preparation in "Recommendations on ILC Project"*
  - *MEXT and SCJ's comments*
  - *Superconducting RF*
  - *Positron source*
  - *Damping ring*
  - *Final focus*
  - *Beam dump*
- *Summary*

ILC preparation plan/activity

European ILC preparation plan as "E-JADE" report

https://www.e-jade.eu/sites/sites_custom/site_e-jade/content/e49893/e65922/e73204/ILC-EIPP.E-JADE.v2.12.20180703.pdf

E-JADE THE EUROPEAN ILC PREPARATION PLAN (EIPP)

Date: 3/06/2018

Grant Agreement No: 645479

E-JADE

Europe-Japan Accelerator Development Exchange Programme

Horizon 2020 / Marie Skłodowska-Curie Research and Innovation Staff Exchange (RISE)

REPORT

THE EUROPEAN INTERNATIONAL LINEAR COLLIDER PREPARATION PLAN (EIPP)

The International Linear Collider
A European Perspective

Prepared by: Philip Bambade[1], Ties Behnke[2], Mikael Berggren[2], Ivanka Bozovic-Jelisavcic[3], Philip Burrows[4], Massimo Caccia[5], Paul Colas[6], Gerald Eigen[7], Lyn Evans[8], Angeles Faus-Golfe[1], Brian Foster[2,4], Juan Fuster[9], Frank Gaede[2], Christophe Grojean[2], Marek Idzik[10], Andrea Jeremie[11], Tadeusz Lesiak[12], Aharon Levy[13], Benno List[2], Jenny List[2], Joachim Mnich[2], Olivier Napoly[6], Carlo Pagani[14], Roman Poeschl[1], Francois Richard[1], Aidan Robson[15], Thomas Schoerner-Sadenius[2], Marcel Stanitzki[2], Steinar Stapnes[8], Maksym Titov[6], Marcel Vos[9], Nicholas Walker[2], Hans Weise[2], Marc Winter[16].

[1] *LAL-Orsay/CNRS*, [2] *DESY*, [3] *INN VINCA, Belgrade*, [4] *Oxford U.*, [5] *U. Insubria*, [6] *CEA/Irfu, U. Paris-Saclay*, [7] *U. Bergen*, [8] *CERN*, [9] *IFIC, U. Valencia-CSIC*, [10] *AGH, Kraków*, [11] *LAPP/CNRS*, [12] *IFJ PAN, Kraków*, [13] *Tel Aviv U.*, [14] *INFN*, [15] *U. Glasgow*, [16] *IPHC/CNRS.*

European Strategy input
The International Linear Collider
A European Prospective

USA

US-Japan Joint Research on ILC Cost Reduction
High Luminosity ILC Workshop (May 2019) @FNAL
https://indico.fnal.gov/event/20759/
https://arxiv.org/abs/1910.01276

KEK ILC action plan

https://www.kek.jp/en/newsroom/KEK-ILC_ActionPlan_Addendum-EN%20%281%29.pdf

issued on Jan. 2016.
Addendum issued on Jan.2018

Issued on 2016-1-6
Addendum issued on 2018-1-14

KEK-ILC Action Plan

KEK-ILC Action Plan Working Group

1. Introduction

The International Linear Collider (ILC) is a next-generation energy frontier electron–positron collider. It will reach a center-of-mass energy of 500 GeV in the first stage, and can be upgraded to an energy to 1 TeV in the future. It aims to precisely measure the properties of the Higgs particle and Top quark, discover new particles and phenomena, and search for new physics beyond the Standard Model of elementary particle physics.

The worldwide high-energy physics community has recognized importance of the ILC, and established the Global Design Effort (GDE) in 2005 under the supervision of the International Committee for Future Accelerators (ICFA). The GDE has advanced the design and technical development of the ILC within the international framework. In June 2013, GDE published its progress in the ILC Technical Design Report (ILC-TDR); this report included accelerator design, technology, construction costs, and the human-resource requirements necessary to realize the ILC. The ICFA established the Linear Collider Collaboration (LCC) under the supervision of the Linear Collider Board in February 2013 to oversee the detailed ILC accelerator design and engineering.

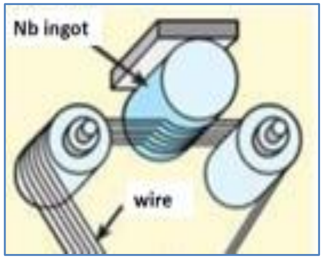
Based on discussions for its future plan, the Japan Association of High Energy Physicists proposed to host and to realize the ILC as a global project in October 2012. In May 2013, the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT) asked the Science Council of Japan (SCJ) to study the ILC project from a scientific viewpoint. In September 2013, the SCJ produced a "Report on the International Linear Collider Project". In May 2014, MEXT established the ILC Advisory Panel (ILC-AP), and has been studying issues pointed out by the SCJ. In June 2015, MEXT ILC-AP produced a report, "Summary of the International Linear Collider (ILC) Advisory Panel's Discussions to Date". Based on this report, further action has been taken to establish a new working group to verify the human resource and training plan necessary to realize the ILC.

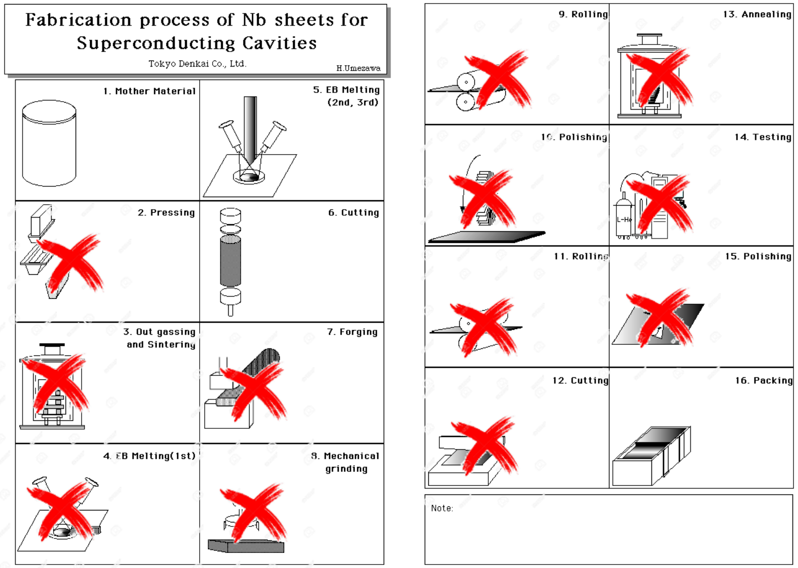
ILC Cost-Reduction R&D in US-Japan Cooperation on SRF Technology

Based on recent advances in technologies;

– Nb material/sheet preparation

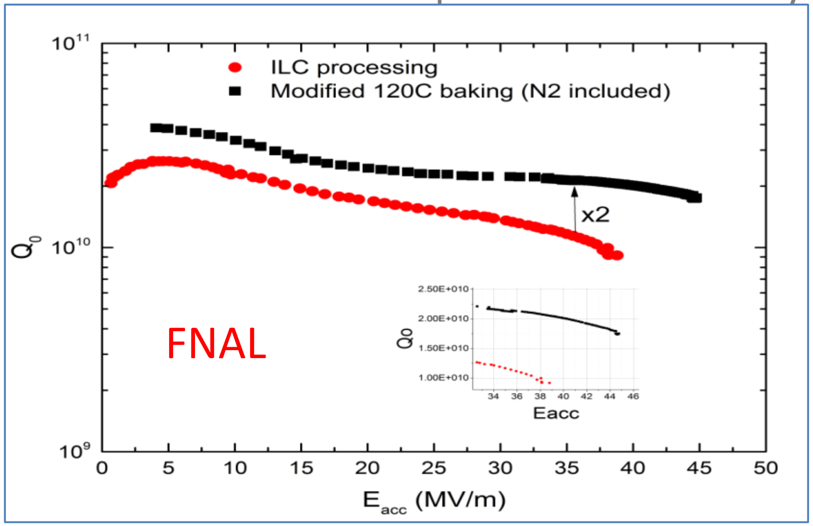
- w/ optimum Nb purity and clean surface

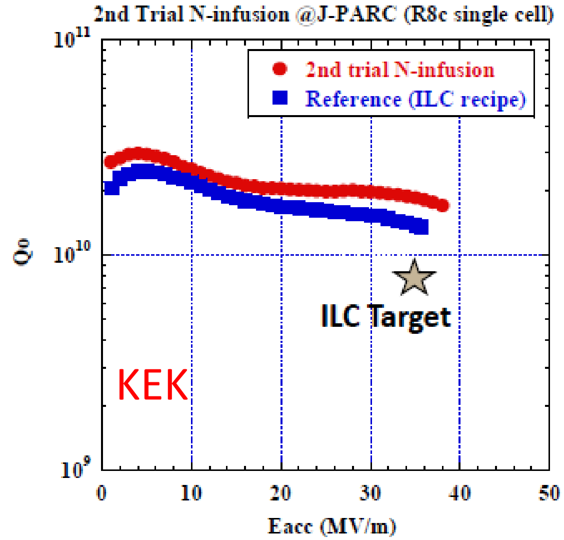




– SRF cavity fabrication for high-Q and high-G

-w/ a new "N Infusion" recipe demonstrated by **Fermilab**





Shin MICHIZC

Fermilab High Luminosity ILC Workshop (May 2019)

https://indico.fnal.gov/event/20759/

Fermilab Workshop on ILC HL-HG

Wednesday, May 8, 2019 from **08:00** to **18:00** (US/Central)
at **Fermilab (Hermitage Conference Room)**

Description Now that the Japanese decision on ILC has been delayed, the fate of ILC within the European community is likely to suffer, in particular since European enthusiasm for FCC-ee has been rising as the next Higgs Factory. Another competitor is CEPC. One of strong arguments that FCC proponents offer is the very high luminosity (6 times ILC) at 250 GeV. But the downside of FCC is of course the cost, which starts at 10B$ (from CDR) not including the tunnel (+3 B$) and detector (+2 B$). Over a longer timescale, US will hold Snowmass to discuss future options for US HEP thrusts. There will probably be many proposals, such as Muon-collider-based Higgs Factory, Neutrino Factory, PIP-III, Gamma-Gamma Higgs Factory.

The goal of this one-day workshop is to discuss the possibility for a competitive ILC Higgs Factory with high luminosity upgrade option and the 350 GeV upgrade option. Can the High Lumi ILC offer the same luminosity as FCC-ee but be significantly less expensive than FCC-ee?

We will explore paths to competitive high luminosity upgrade options for ILC, estimate the cost for the upgrade, and discuss strategies on how to increase support for ILC within the European community and later at Snowmass. We will also discuss paths to a higher energy 350 GeV top factory upgrade to correspond to the higher energy option in the FCC plans.

Material: Agenda | Beamstrahlung Photon Load on the TESLA Extraction Septum Blade | CERN-ACC-2019-0003 (FCC-ee) | CLIC 2018 Summary Report | Chapter 7 ILC Beam Delivery System | Future prospects of accelerator science for particle physics | ILC_European_Perspective_Final | ILC_Global_Project_Final long | ILC_Global_Project_Final short | The International Linear Collider Machine Staging Report 2017

Wednesday, May 8, 2019

08:30 - 08:45 Introduction to the Workshop *15'*
Speakers: Dr. Sergey Belomestnykh (Fermilab), Dr. Anna Grassellino (Fermilab)

08:45 - 09:30 High Lumi Upgrade and 350 GeV parameter options and cost impacts *45'*
Speaker: Prof. Hasan Padamsee (Cornell University)
Material: Slides

09:30 - 09:45 Discussion *15'*

09:45 - 10:15 High Q/High Gradient paths *30'*
Speaker: Dr. Anna Grassellino (Fermilab)
Material: Slides

10:15 - 10:30 Discussion *15'*

10:30 - 10:45 Coffee break

10:45 - 11:15 Detector Constraints and ILC Luminosity *30'*
Speaker: Prof. Hitoshi Yamamoto (Tohoku University)
Material: ILC table | Lum-energy-doc preliminary | Luminosity vs Log E plot | Power vs Log E plot | Slides

11:15 - 11:30 Discussion *15'*

11:30 - 13:00 Lunch

13:00 - 13:30 Impact on Positron Source *30'*
Speaker: Dr. Nikolay Solyak (FNAL)
Material: Slides

13:30 - 13:45 Discussion *15'*

13:45 - 14:15 Impact on Damping Rings and Ring-to-Main-Linac *30'*
Speaker: Prof. David Rubin (Cornell University)
Material: Slides

14:15 - 14:30 Discussion *15'*

14:30 - 14:45 Coffee break

14:45 - 15:15 Open discussion on presented options, challenges and other topics *30'*

15:15 - 15:45 Interaction Region and IP parameters *30'*
Speaker: Dr. Andrei Seryi (Jefferson Lab)
Material: Slides

15:45 - 16:15 Discussion *30'*
Material: Slides

16:15 - 16:30 Closing remarks *15'*
Speakers: Dr. Sergey Belomestnykh (Fermilab), Dr. Anna Grassellino (Fermilab), Prof. Hasan Padamsee (Cornell University)

Fermilab High Luminosity ILC Workshop (May 2019)

- Significant luminosity improvements are made possible by SRF R&D advances since TDR
- Main result is given below – by implementing technically feasible changes, ILC baseline luminosity of 1.35 x 10^{34} can be increased
  - Increased number of bunches x2
  - Increased rep rate x3
  - Increased Q_0 x 2
  - Beam and IP parameters same as ILC baseline
- Effective luminosity with polarization advantage (x 2.5) is 20 x 10^{34} $cm^{-2}s^{-1}$ (ILC) vs. 17 x 10^{34} $cm^{-2}s^{-1}$ (FCC-ee, including multiplier of 2 for multiple interaction points)
- AC power ~270 MW (ILC) vs. 282 MW (FCC-ee)

Details in https://arxiv.org/abs/1910.01276

Accelerator preparation phase R&Ds

	Pre-prep.	P1	P2	P3	P4	1	2	3	4	5	6	7	8	9	10	Phys. Exp.
Preparation .		■	■	■	■											
Construction						■	■	■	■	■	■	■	■	■		
Commissioning															■	
Physics Exp.																■

Main tasks to be done during 4-year preparation phase

KEK ILC action plan

Area	Tasks
Accelerator Design	Design parameter optimization
SCRF	Mass-production and quality control Superconducting material, cavity properties (electric field, resonance characteristics) Hub-lab functioning System performance stabilization (Stabilization of the performance and maintenance, including international transport of CM)
Nanobeam	Minimizing the beam size and demonstrating stability Beam handling (DR, RTML, BDS, BD)*
Accelerator elements - Positron source (e+) - Beam dump	e+: Undulator-driven (polarization) or an electron-driven system (backup), heat balance of the dump, cooling, safety
CFS	Basic Plan by assuming a model site, engineering design, drawings, survey, assessment
common technical support	Safety (radiation, high-pressure gas, etc.) Communication and network
Administration	General affairs, finace n , int. relations, public relations Administrative support for ILC pre-lab

European ILC preparation plan

Item/topic	Brief description	CERN	France CEA	Germany DESY	Time line
SCRF	Cavity fabrication including forming and EBW technology,	✓			2017-18
	Cavity surface process: High-Q &–G with N-infusion to be demonstrated with statics, using High-G cavities available (# > 10) and fundamental surface research		✓	✓	2017-18
	Power input-coupler: plug compatible coupler with new ceramic window requiring no-coating	✓			2017-19
	Tuner: Cost-effective tuner w/ lever-arm tuner design	✓	✓		2017-19
	Cavity-string assembly: clean robotic-work for QA/QC.		✓		2017-19
Cryogenics	Design study: optimum layout, emergency/failure mode analysis, He inventory, and cryogenics safety management.	✓			2017-18
HLRF	Klystron: high-efficiency in both RF power and solenoid using HTS	✓			2017- (longer)
CFS	Civil engineering and layout optimization, including Tunnel Optimization Tool (TOT) development, and general safety management.	✓			2017-18
Beam dump	18 MW main beam dump: design study and R&D to seek for an optimum and reliable system including robotic work	✓			2017- (longer)
Positron source	Targetry simulation through undulator driven approach			✓	2017-19
Rad. safety	Radiation safety and control reflected to the tunnel/wall design	✓			2017 – (longer)

European ILC preparation plan

European Strategy input document

The International Linear Collider
A European Perspective

Prepared by: Philip Bambade[1], Ties Behnke[2], Mikael Berggren[2], Ivanka Bozovic-Jelisavcic[3], Philip Burrows[4], Massimo Caccia[5], Paul Colas[6], Gerald Eigen[7], Lyn Evans[8], Angeles Faus-Golfe[1], Brian Foster[2,4], Juan Fuster[9], Frank Gaede[2], Christophe Grojean[2], Marek Idzik[10], Andrea Jeremie[11], Tadeusz Lesiak[12], Aharon Levy[13], Benno List[2], Jenny List[2], Joachim Mnich[2], Olivier Napoly[6], Carlo Pagani[14], Roman Poeschl[1], Francois Richard[1], Aidan Robson[15], Thomas Schoerner-Sadenius[2], Marcel Stanitzki[2], Steinar Stapnes[8], Maksym Titov[6], Marcel Vos[9], Nicholas Walker[2], Hans Weise[2], Marc Winter[16].

[1]LAL-Orsay/CNRS, [2]DESY, [3]INN VINCA, Belgrade, [4]Oxford U., [5]U. Insubria, [6]CEA/Irfu, U. Paris-Saclay, [7]U. Bergen, [8]CERN, [9]IFIC, U. Valencia-CSIC, [10]AGH, Kraków, [11]LAPP/CNRS, [12]IFJ PAN, Kraków, [13]Tel Aviv U., [14]INFN, [15]U. Glasgow, [16]IPHC/CNRS.

	SCRF	HLRF	Sources	Damping Rings	Instru-mentation	Beam Dynamics	Beam Delivery System	Cryogenics
CERN		C,O	O	G,C,O	C,G	C,G	C,G	O
France	X,E,G		G		A,G	G	C,G	
Germany	X,G	X	G	G	X	G		X,O
Italy	X,E,G			G				
Poland	X,E		O		E,O			X,E,O
Russia	X		G					
Spain	X,E				A		C,G	
Sweden	E						G	
Switzerland					X,C			
UK	E		G	G	A,C,G	C,G,A	C,G,A	

TABLE III. European expertise relevant for ILC accelerator construction, based on experience in the recent past. This is based on two major construction projects, the E-XFEL (X) and the ESS (E), several more R&D oriented efforts namely the GDE/LCC (G), ATF-2 (A), CLIC (C) and experience in other accelerator projects (O)

ILC Project Update

Shin MICHIZONO
KEK/Linear Collider Collaboration (LCC)

- *ILC area systems*
  - *Electron source*
  - *Positron source*
  - *Damping ring*
  - *RTML (bunch compressor)*
  - *Superconducting RF*
  - *Final focus*
  - *Beam dump*
  - *CFS*

- *ILC preparation (US, Japan, Europe)*
- *Technical preparation in "Recommendations on ILC Project"*
  - *MEXT and SCJ's comments*
  - *Superconducting RF*
  - *Positron source*
  - *Damping ring*
  - *Final focus*
  - *Beam dump*
- *Summary*

Recommendations on ILC Project

KEK published "Recommendations on ILC Project" based on the discussion at the international WG.

Recommendations on ILC Project Implementation

High Energy Accelerator Research Organization (KEK)

October 1, 2019

https://www.kek.jp/en/newsroom/2019/10/02/1000/
https://www2.kek.jp/ilc/en/docs/Recommendations_on_ILC_Project_Implementation.pdf

TABLE OF CONTENTS

Topics on ILC advisory panel's report

Table 4.1: Summary of the ILC Advisory Panel's Discussions to Date after Revision. The quoted page numbers refer to those of the ILC Advisory Panel's report.[21]

Page #	R&D Issues
5, 13, 32	**[Damping Ring]** There still remain issues on several subsystems, such as beam dump, positron source, electron source, beam control, and the injection/extraction of the damping ring.
32	**[Beam Dump]** The whole beam dump system should be developed in the main preparatory phase. The required technologies include durability of the window, where continuous high-power beam pass through, and its maintainability and resistance to earthquakes.
32,33	**[Positron Source]** The helical undulator scheme is adopted as the positron source. It contains some technologies under development such as the cooling of the target irradiated by the gamma rays from the undulator and the replacement method of the activated target.

Summary of the ILC Advisory Panel's Discussions to Date after Revision
http://www.mext.go.jp/component/b_menu/shingi/toushin/__icsFiles/afieldfile/2018/09/20/1409220_2_1.pdf

Topics on report of Science Council of Japan

Table 4.2: Technical issues pointed out in the report by the Science Council of Japan.[22]

R&D Issues
[**SCRF**] The design reference value for the SCRF acceleration gradient of 35 MV/m is based on the technical level that is currently achievable. It will be necessary to achieve this reliably and with a good yield including automation techniques; further performance improvement is also desired.
[**SCRF**] It is foreseen that the bulk of the SCRF cavities will be provided through in-kind contribution from the participating countries. An important issue will be the quality assurance that maintains the compatibility among them.
[**Positron Source**] In the main preparatory phase, it is planned that the prototype of the rotating target will be made and the magnetic focusing system immediately after the positron source will be developed. The technology selection is to be made by the second year of the main preparatory phase. The strategy should be clarified, taking into account the R&D cost.
[**Interaction Region**] The technology for the control and feedback system related to the beam focusing and position control needs be established. The acceptable level of microtremor in the interaction region needs to be quantified.
[**Beam Dump**] The soundness monitoring of the window material, the concrete design for a remote-controlled replacement/exchange system, and the detail of the reaction between a high energy beam and water need to be adequately studied during the main preparatory phase.

Technical preparation

4.1. Technical Preparation Plan of the Main Preparatory Phase

The technical preparation plan defines all activities necessary during the main preparatory phase to prepare for the construction phase of the ILC. It is part of the KEK-ILC Action plan, which describes the ILC project in three phases: (a) pre-preparatory phase, (b) main preparatory phase, and (c) construction phase (See Figure 3.1.). KEK released the KEK-ILC Action Plan in 2016. It was updated for ILC250[16] in 2018.[17] The KEK-ILC Action Plan includes the tasks necessary to address the specific technical issues pointed out by MEXT's ILC Advisory Panel (Table 4.1) and the SCJ report (Table 4.2). It also describes the human resources necessary in the main preparatory phase. The technical preparation plan will be conducted by the ILC Pre-Lab. The plan assumes that most of the preparatory tasks will be carried out through international collaboration.

The technical preparation plan described in the KEK-ILC Action Plan includes the following preparatory tasks and identifies the required budget:

(a) development of accelerator systems and components that addresses MEXT's ILC Advisory Panel and SCJ technical concerns (approximately 20% of budget),
(b) civil engineering (geological survey, engineering design, etc.) (approx. 30%),
(c) Hub-Lab/pilot plant in Japan (approx. 20%),
(d) detailed engineering design of accelerator components (approx. 10%),
(e) labor cost in addition to existing human resources (approx. 20%).

SRF cavity and cryomodule production

SCRF cavity and cryomodule production: SCJ and MEXTs' ILC Advisory Panel had technical concerns about maintaining cavity quality during mass production and cryomodule assembly. The plan is to demonstrate prototype manufacturing using a new cost-effective production method on the scale of 1% of the full production, corresponding to about 100 cavities in the main preparatory phase. Half of the cavities will be produced in Japan and the other half in other regions/countries. The performance of the cavities will be evaluated to test their yields, and plug-compatibility will be checked. Other components, such as couplers and tuners, are also expected to improve in terms of performance; they will also be manufactured, and their yields will be evaluated. Overall testing after assembling these parts into a cryomodule will be the final step of evaluating the performance as an accelerator component. The US and Europe have significant experience in cavity production and in formulation of countermeasures against performance degradation after cryomodule assembly. It is anticipated that Germany and the US will work on cost reduction of the cavity fabrication process and on reproducibility and high yield of cavity performance at the design gradient, while France could play a leading role in automation of cryomodule assembly.

SRF cryomodule transport

SCRF cryomodule transport: SCJ and MEXTs' ILC Advisory Panel also had technical concerns about the effect of cryomodule transport on cavity performance. Europe and the US have significant experience with land transportation of cryomodules. This experience needs to be extended to marine transport, while assuring that performance is maintained. In order to demonstrate performance preservation after transport, multiple cryomodules meeting ILC specifications will be manufactured in the main preparatory phase, and after initial performance testing, they will be delivered to another region, where their performance will be tested again. This work will be performed by international cooperation among KEK and institutes in the US and Europe by transporting cryomodules between two or more regions. It will also provide an opportunity to establish an SCRF hub laboratory in Japan.

Positron source

Positron source: SCJ and MEXT's ILC Advisory Panel had technical concerns about the rotating target, particularly its system design and the need for a plan for replacing activated targets, and about the magnetic focusing system. System designs for monitoring the reliability of the equipment and for remote handling to replace the rotating target will be performed in the main preparatory phase. Germany and the US possess experience from having studied positron sources for the ILC during the GDE process. In addition, CERN, France, and Russia possess expertise in positron sources. They could all be important partners for system design of the rotating target and the magnetic focusing devices. KEK will lead an industry-academia joint effort to develop the system design of the remote handling system for replacing the rotating target while ensuring environmental and radiation safety. In addition to these tasks pointed out by MEXT and SCJ, the KEK-ILC Action Plan recognizes that a system design of the photon dump system of the positron source is needed. CERN, Germany, and the US could become important partners in carrying out this system design of the photon dump, building upon Germany's extensive experience in system design for the undulator positron source and upon experience of CERN and the US in operating high-power beam dumps. Design of an electron-driven positron source as a backup technology will also be continued.

Damping ring

Damping Ring: MEXT's ILC Advisory Panel had technical concerns, as described in the MEXT's commissioned research/survey report [20] [NRI], about several damping ring subsystems, including stability and reliability of the injection and extraction kicker systems and necessity for a high-resolution fast feedback system. System design of the fast feedback system in the damping ring could be performed by a collaboration between Japan and Italy, and tests will be performed at SuperKEKB at KEK. SuperKEKB has a circumference close to that of the ILC damping ring and a feedback system similar to ILC250. System development of the high-resolution fast feedback system for the ILC will be performed based on experience of the system operation and upgrade development at SuperKEKB. For its injection and extraction system, fast kicker magnets and a fast-pulsed power source have been developed, and multiple kicker systems have already been operated under beam operation. The remaining task is to ensure the stability and reliability over long-term operation. A long-term stability test of the fast kicker system will be performed at the Accelerator Test Facility (ATF) at KEK. Furthermore, international collaboration is foreseen on upgrading and improving the reliability of the fast kicker system for the damping ring. CERN and Italy could be important partners for the system design of the injection and extraction system, as they have been studying fast kickers since the GDE process.

Final focus

Interaction Region: SCJ stated technical concerns about the technology of the control and feedback system and about long-term stability of beam focus and position. The beam size at the ATF2 focal point is designed to be 37 nm, which is technically equivalent to a beam size of 7 nm for ILC250. At ATF2, the achieved beam size is smaller than 41 nm, which is consistent with the design beam size. The ILC prototype feedback system has been verified to satisfy all ILC requirements. Beam focusing and position control for the ILC final focus system have been studied at ATF2 at KEK. Based on the final-focus R&D experience at ATF2 at KEK and for CLIC, a long-term stability study of beam focusing and position control for the ILC final focus system will continue through collaboration with CERN and the UK.

Beam dump

Beam Dump: SCJ and MEXT's ILC Advisory Panel stated technical concerns regarding: reliability, earthquake protection, and stability of the window of the main beam dump; reaction between the high energy beam and water; and containment of activated water. In the main preparatory phase, the scheme for monitoring the integrity of the beam dump window will be studied and the system design for items such as the containment of activated water will be performed. CERN operates beam dumps for large accelerators and high-power beam dumps, and the US operates water-circulated beam dumps. They could be important partners for the system design of the beam dump. KEK will lead the system design of the beam dump facilities, ensuring environmental and radiation safety with cooperation from the government, industry, and the scientific community.

Technical preparation with international collaboration

Table 4.3: Accelerator-related technical preparation tasks and possible partners for international collaboration as envisioned by KEK.

Component	Issue	Summary of tasks	Candidates for collaboration
SCRF Cavity	Mass production incl. automation	Performance statistics, mass production technology	France, Germany, US
	Cryomodule transport	Performance assurance after transport	France, Germany, US
Positron Source	Rotating target	Exchanging target, system design	CERN, France, Germany, US + industry-academia efforts
	Magnetic focusing system	System design	France, Germany, Russia, US
	Photon dump[23]	System design	CERN, Germany, US
Damping Ring	Fast kicker	Test of long-term stability, system design	CERN, Italy
	Feedback	Test at SuperKEKB	Italy
Interaction Region	Beam focus/position control	Test of long-term stability	CERN, UK
Beam Dump	Total system	System design	CERN, US
	Beam window, cooling water circulation	Durability, exchangeability, earthquake-resistance	CERN, US + industry-academia efforts

ILC Project Update

Shin MICHIZONO
KEK/Linear Collider Collaboration (LCC)

- *ILC area systems*
  - *Electron source*
  - *Positron source*
  - *Damping ring*
  - *RTML (bunch compressor)*
  - *Superconducting RF*
  - *Final focus*
  - *Beam dump*
  - *CFS*
- *ILC preparation (US, Japan, Europe)*
- *Technical preparation in "Recommendations on ILC Project"*
  - *MEXT and SCJ's comments*
  - *Superconducting RF*
  - *Positron source*
  - *Damping ring*
  - *Final focus*
  - *Beam dump*
- *Summary*

Summary

- *Most of the ILC accelerator parameters have been demonstrated at the various facilities.*
- *SRF Technology matured based on the success of European XFEL (10% scale of ILC Main linac).*
- *ILC preparation:*
  - *ILC cost reduction R&Ds are ongoing under US-Japan cooperation and ILC inprovement adopting these results are considered at US.*
  - *KEK issued ILC action plan.*
  - *European ILC preparation plan as "E-JADE" report was summarized.*
- *KEK published "Summary of Recommendations on ILC Project" based on the discussion at the international WG.*
- *The technical preparation plan in response to reports by ILC Advisory Panel organized by MEXT and the Science Council of Japan is presented.*
- *The plan identifies technical tasks to be carried out through international collaboration.*

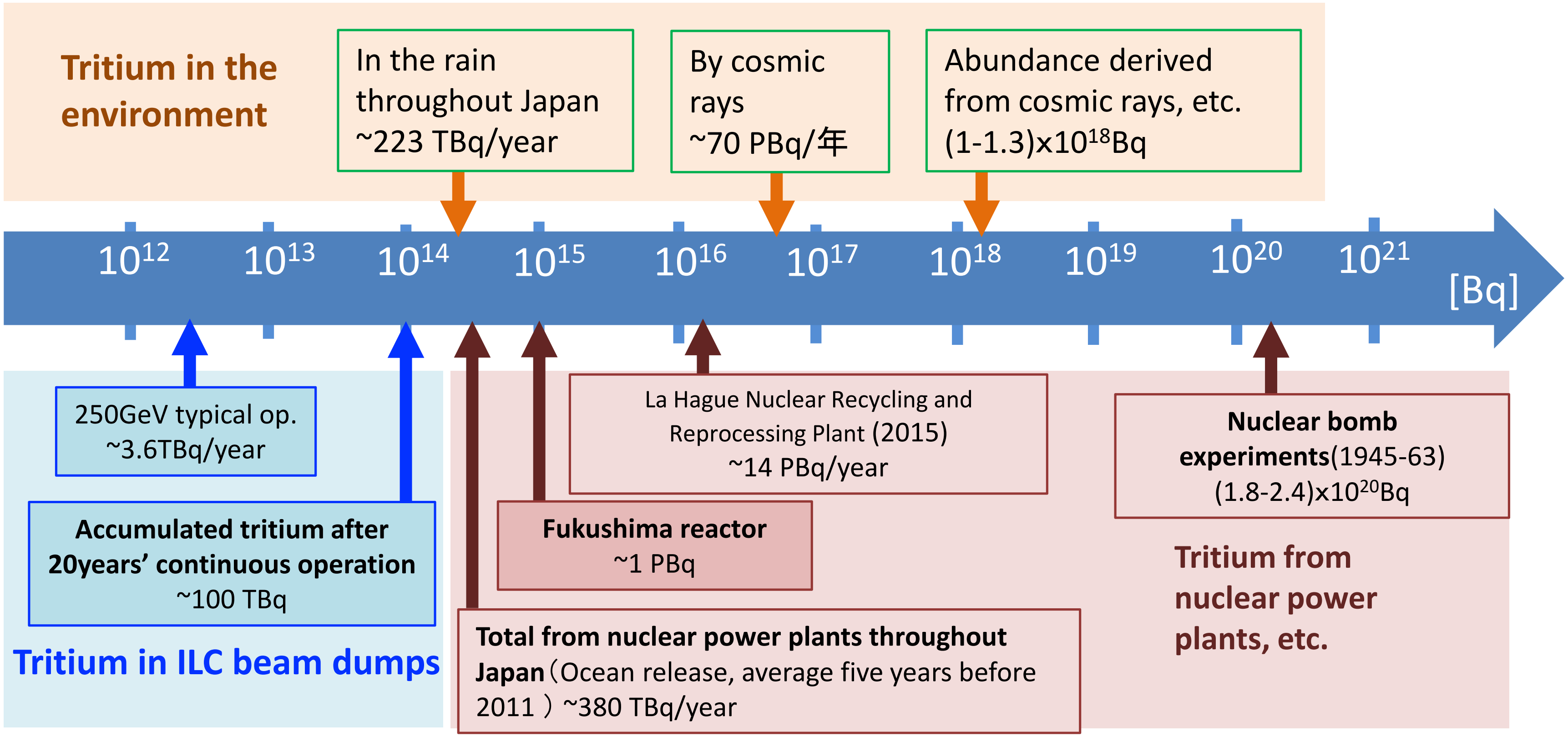
Thank you for your attention

ILC beam parameters

	ILC		
	initial	L upgr.	500 GeV
c.m. energy [GeV]	250	250	500
rep. rate [Hz]	5	5/10	5
no. bunches / pulse	1312	2625	1312/ 2625
bunch population [10^9]	20	20	20
av. beam current I_b [μA]	21	21/42	21/42
IP beta function β_x^*[mm]	13	13	11
IP beta function β_y^* [mm]	0.41	0.41	0.48
IP geometric emittance ε_x [pm]	20	20	20
IP geometric emittance ε_y [fm]	140	140	70
rms IP beam size x [nm]	516	516	474
rms IP beam size y [nm]	7.7	7.7	5.9
luminosity enhancement H_D	2.55	2.55	2.26
total luminosity L [$10^{34}/\mathrm{cm}^2\mathrm{s}^1$]	1.35	2.7/5.4	1.8/3.6
luminosity in top 1% $L_{0.01}/L$	73%	73%	58.3%
electrical site power [MW]	115	135/185	163
helium inventory [t]	43	43/85	85
site length [km]	20.5	20.5/31	31
integrated luminosity [fb^{-1}/yr]	100	300	600

Tritium

- ILC250 typical operation generates Tritium of ~3.6TBq/year.
- There are about 223 TBq annually in the rain throughout Japan.



https://www.meti.go.jp/earthquake/nuclear/osensuitaisaku/committtee/takakusyu/pdf/008_02_02.pdf (in Japanese)

ILC construction cost summary

Summary of the ILC Advisory Panel's Discussions to Date after Revision

http://www.mext.go.jp/component/b_menu/shingi/toushin/__icsFiles/afieldfile/2018/09/20/1409220_2_1.pdf

Item		500GeV ILC (original plan)	250GeV ILC (revised plan): Cost estimation presented at the TDR WG	250GeV ILC (revised plan): Option A (250GeV ILC as a Higgs factory)	250GeV ILC (revised plan): Option A' (Incorporated results from cost reduction R&D)
※The cost-estimate listed below in (1) to (7) is a summary reported by the research community. It should be necessary to pay attention to additional cost risk possibly caused by the risk factors and technical issues described in the Section 3, in this TDR-WG report.					
Construction of the ILC accelersator and detectors	(1) Accelerator (2) Detectors	1,091.2 billion-yen	735.5～803.3 billion-yen	785.3～803.3 billion-yen	735.5～753.5 billion-yen
			(3) An additional cost arising from inaccuracy and items described in the Section 3 of the report may be added		
(1)Accelerator (ref. TDR) [revised]		**990.7 billion-yen**	**635.0～702.8 billion-yen**	684.8～702.8 billion-yen	635.0～653.0 billion-yen
	Civil engineering and constru	830.9 billion-yen: **160.0 billion-yen**	515.2～583.0 billion-yen: **111.0～129.0 billion-yen**	111.0～129.0 billion-yen	111.0～129.0 billion-yen
	Acclerator construction	**670.9 billion-yen**	**404.2～454.0 billion-yen**	454.0 billion-yen	404.2 billion-yen
	Labor	**159.8 billion-yen**	**119.8 billion-yen**	119.8 billion-yen	119.8 billion-yen
(2)Detectors and related expenditures (ref. TDR) [No change]		**100.5 billion-yen**	**100.5 billion-yen**	100.5 billion-yen	100.5 billion-yen
	Detector construction	**76.6 billion-yen**	**76.6 billion-yen**	76.6 billion-yen	76.6 billion-yen
	Labor	**23.9 billion-yen**	**23.9 billion-yen**	23.9 billion-yen	23.9 billion-yen
(3)Uncertainty (ref. TDR) [No change]		**About 25% of (1)+(2)**	**About 25% of (1)+(2)**	About 25% of (1)+(2)	About 25% of (1)+(2)
	※Inaccuracy: Only the inaccuracy in the cost estimation is included. What is not included are technical risks, extension of construction period and change in market price.				
(4)Operation (ref. TDR) [revised]		**49.1 billion-yen**	**36.6～39.2 billion-yen**	39.2 billion-yen	36.6 billion-yen
	Unitilities and maintenance	**39.0 billion-yen**	**29.0～31.6 billion-yen**	31.6 billion-yen	29.0 billion-yen
	Labor	**10.1 billion-yen**	**7.6 billion-yen**	7.6 billion-yen	7.6 billion-yen
(5) Other expenditures (not in TDR)					
	Preparatory cost (Design, R&D, Environmental assessment, training, technology transfer, management and administration, including labor cost)	**Not estimated**	[New estimation] 23.3 billion-yen	23.3 billion-yen	23.3 billion-yen
	Not estimated in TDR	**Not estimated**	Not estimated	Not estimated	Not estimated
	land acquisition, living environment for oversea researchers, access road, infrastructure such as lifeline, computing center		[New estimation] Waste and spring water disposal, power transmission and substations, low votage supply		
			(6)Contingency	**About 10% of project cost (accelerator+ detectors+operation*) (ref. PIP)**	
			[New estimation] Reserve fund for unexpected expenditure.	*annual operation cost x operation years	
			(7)Decommissioning	**Equivalent to 2 years of operation.**	
			[New estimation] Accelerator components will be re-used, for which storage facilities should be prepared.		