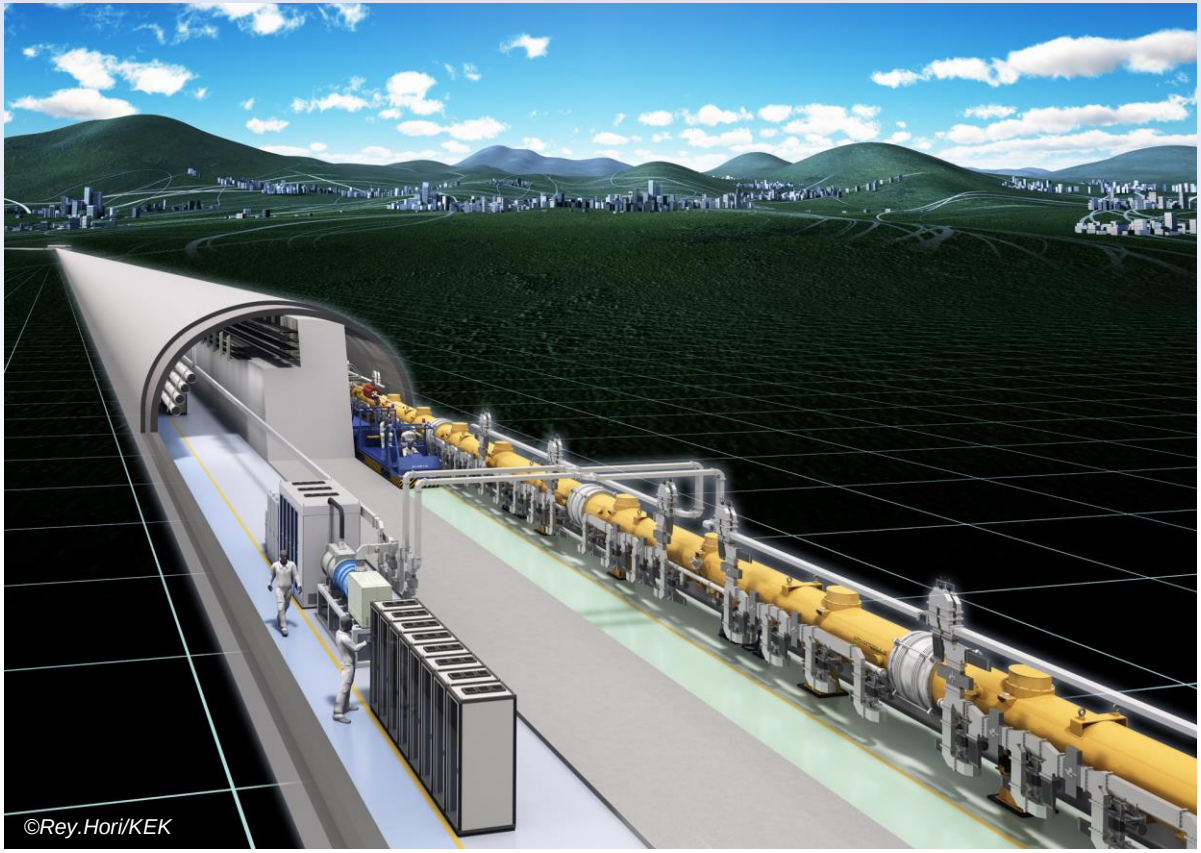


ILC Accelerator Introduction

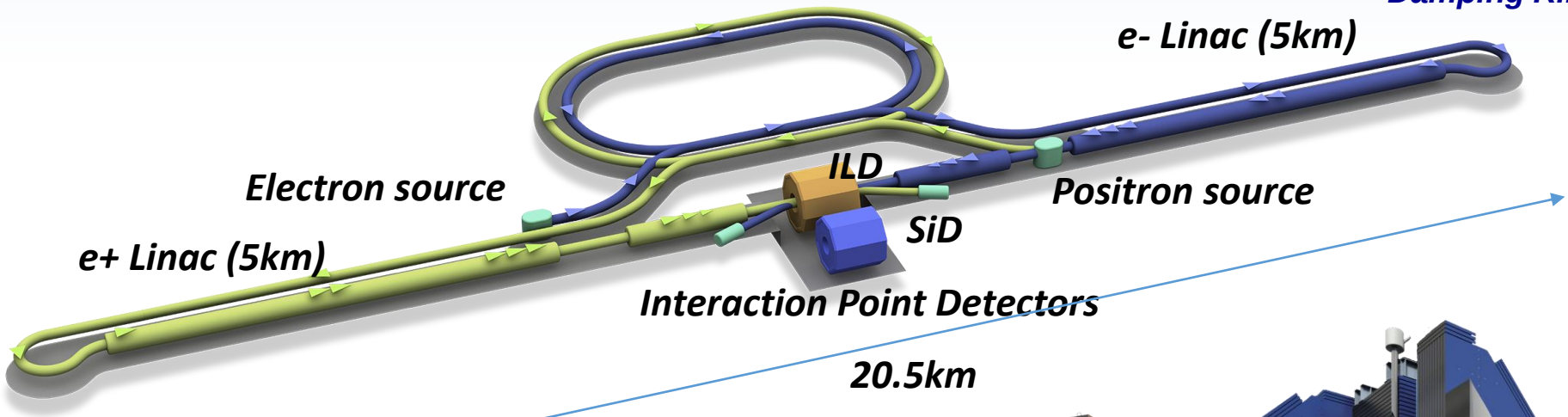
Hitoshi Hayano, KEK 05232019

Configuration of ILC Accelerator

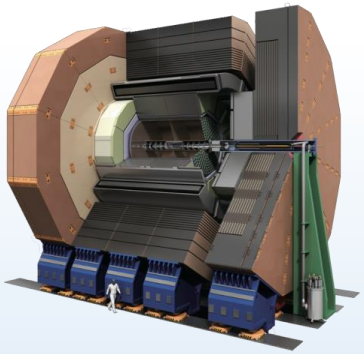
e+, e- Main Linac

Beam Energy : 125GeV + 125GeV = 250 GeV
Total accelerator: 20.5km
SRF Accelerator: 5km + 5km
Number of Klystrons: 218
Number of Cryomodules: 906
Number of SC cavities: 7800

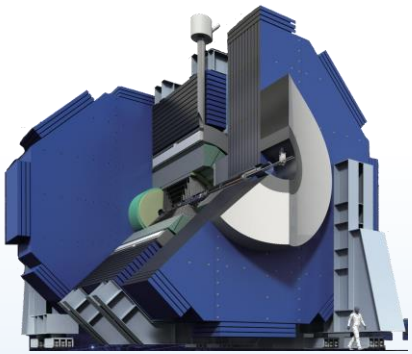
Damping Ring



Main Linac Accelerator



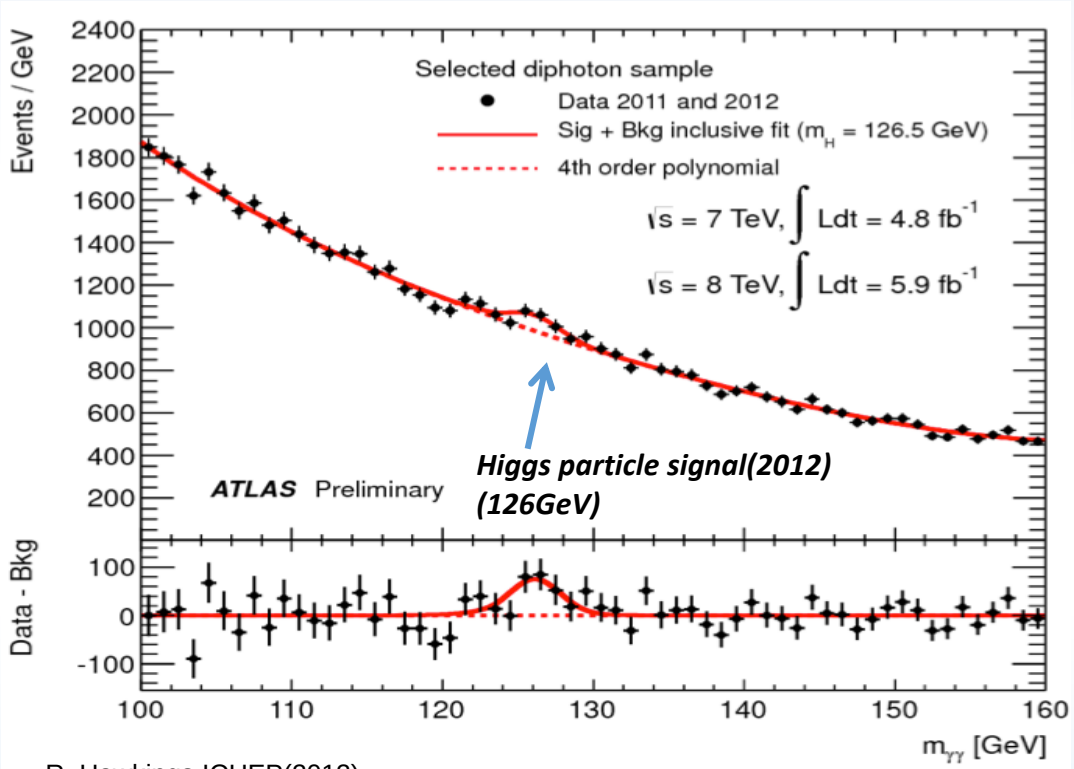
ILD Detector



SiD Detector

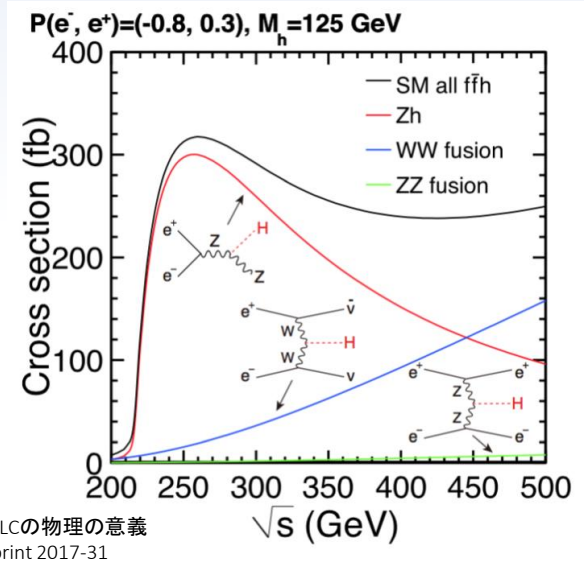
LHC run-II results and ILC250GeV

Higgs particle was found, but no other particle was found upto 1TeV region.
ー＞ Study of Higgs particle (coupling to other particles) is urgent.
ILC has an ablities of precise measurements of Higgs.



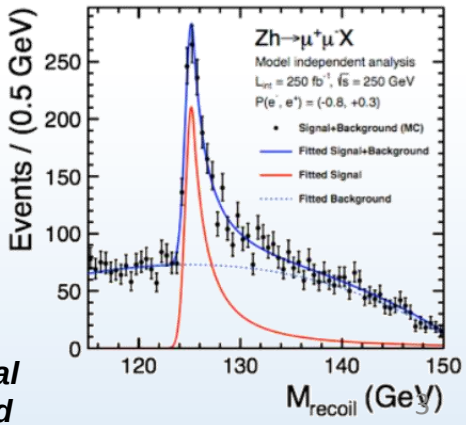
R. Hawkings ICHEP(2012)

ATLAS higgs signal



250GeVILCの物理の意義
KEK preprint 2017-31

ILC Higgs Generation simulation

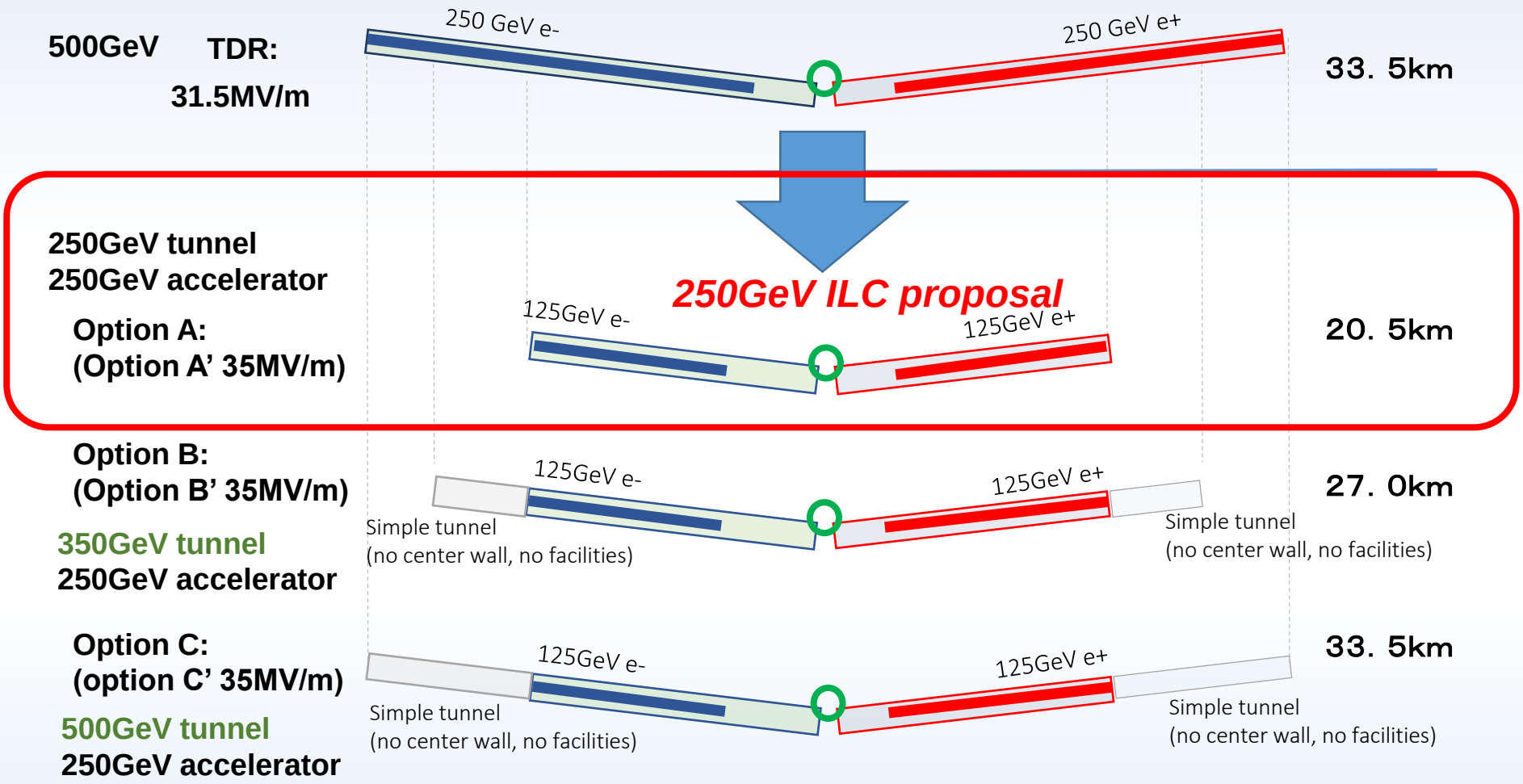


Clear signal Is expected

[Li et.al. (ILD Collaboration)]

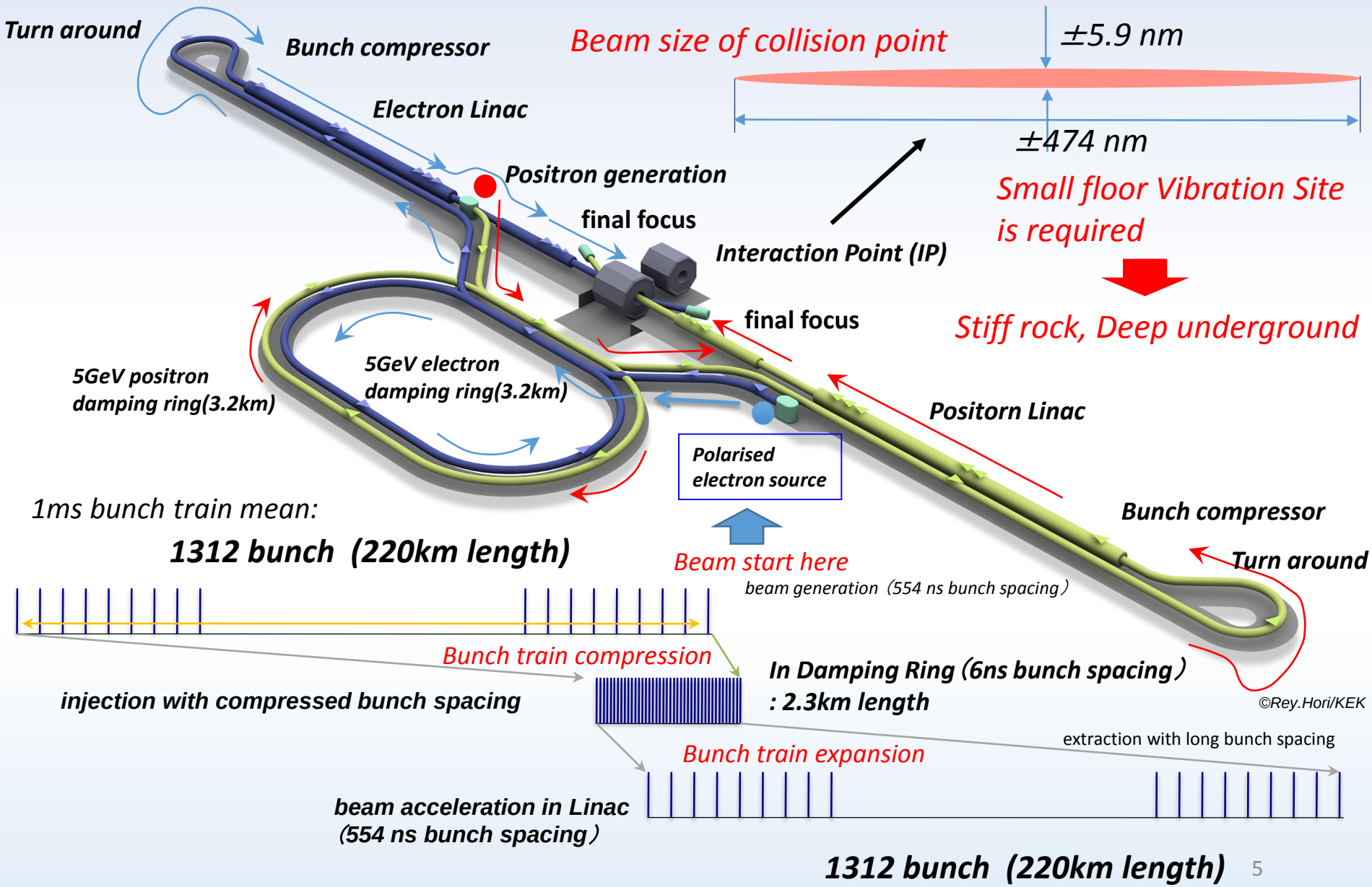
ILC Accelerator Staging Plan

Step-wise construction and experiment (staging) was proposed, and plan of the accelerator at the beginning is 250GeV.

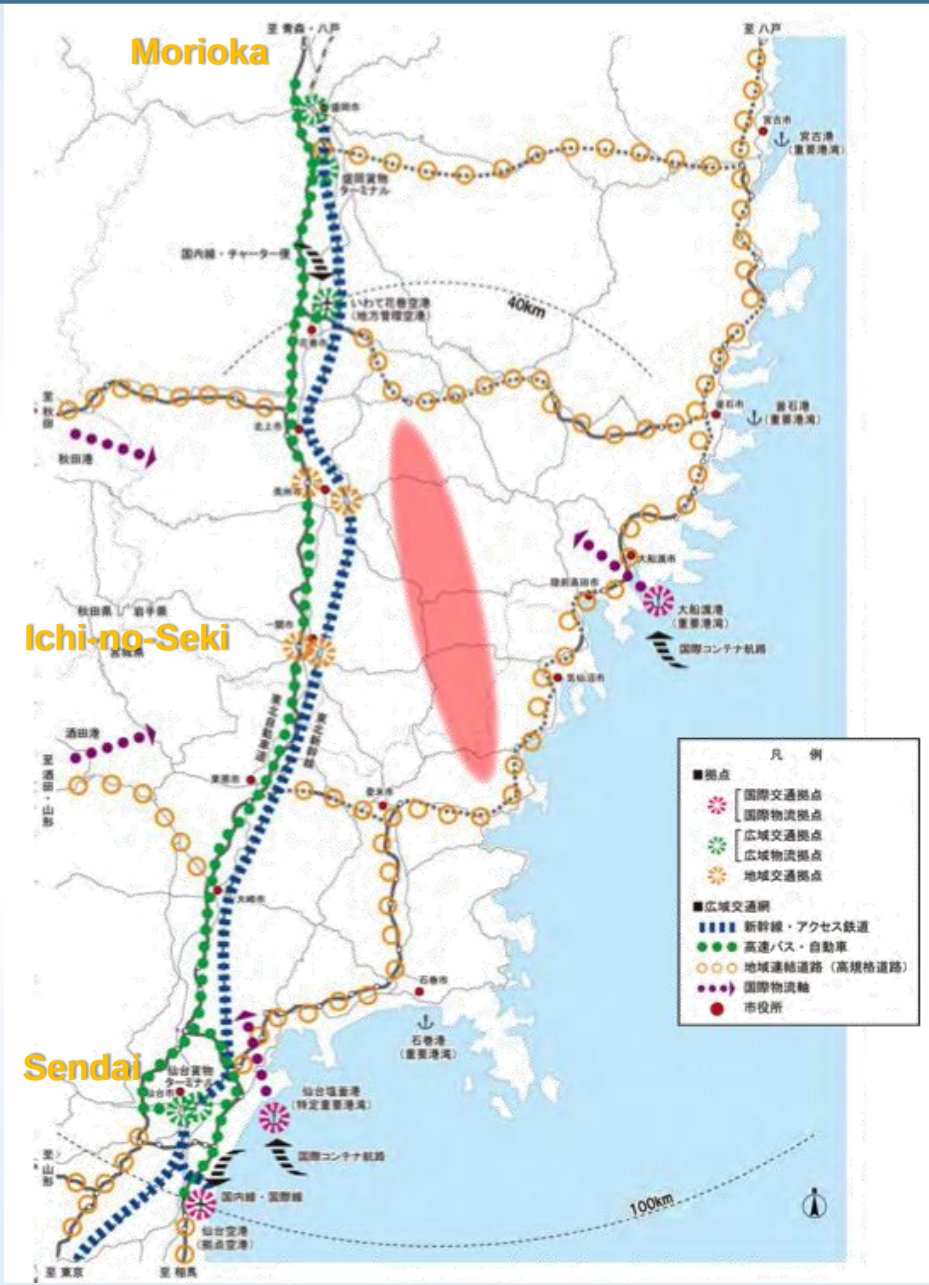


For Option A', 35MV/m、Q_0=1.6x10^{10} is assumed.

Beam Acceleration Sequence

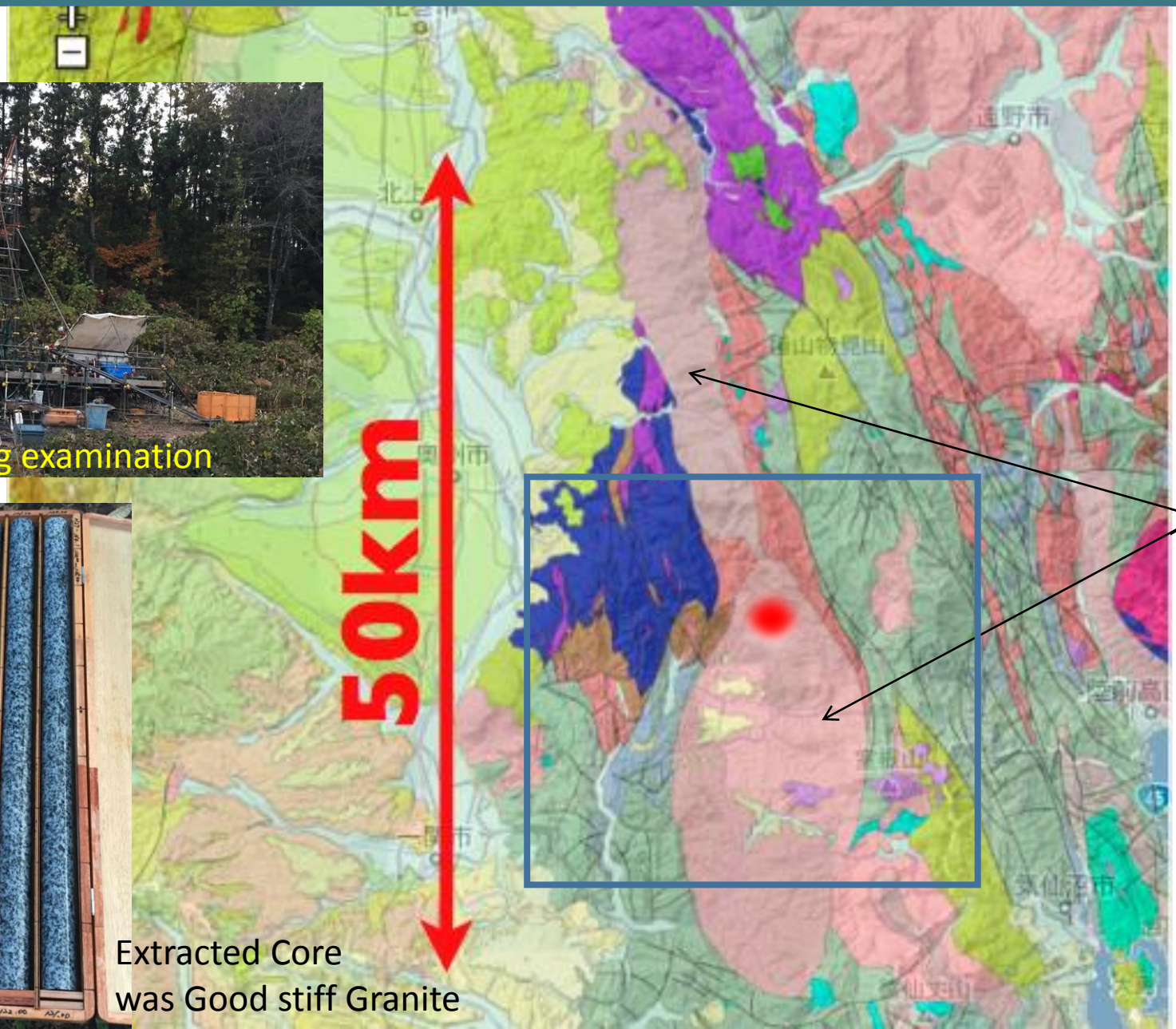


Kitakami Candidate Site



Kitakami Candidate Site

Extracted Core
was Good stiff Granite

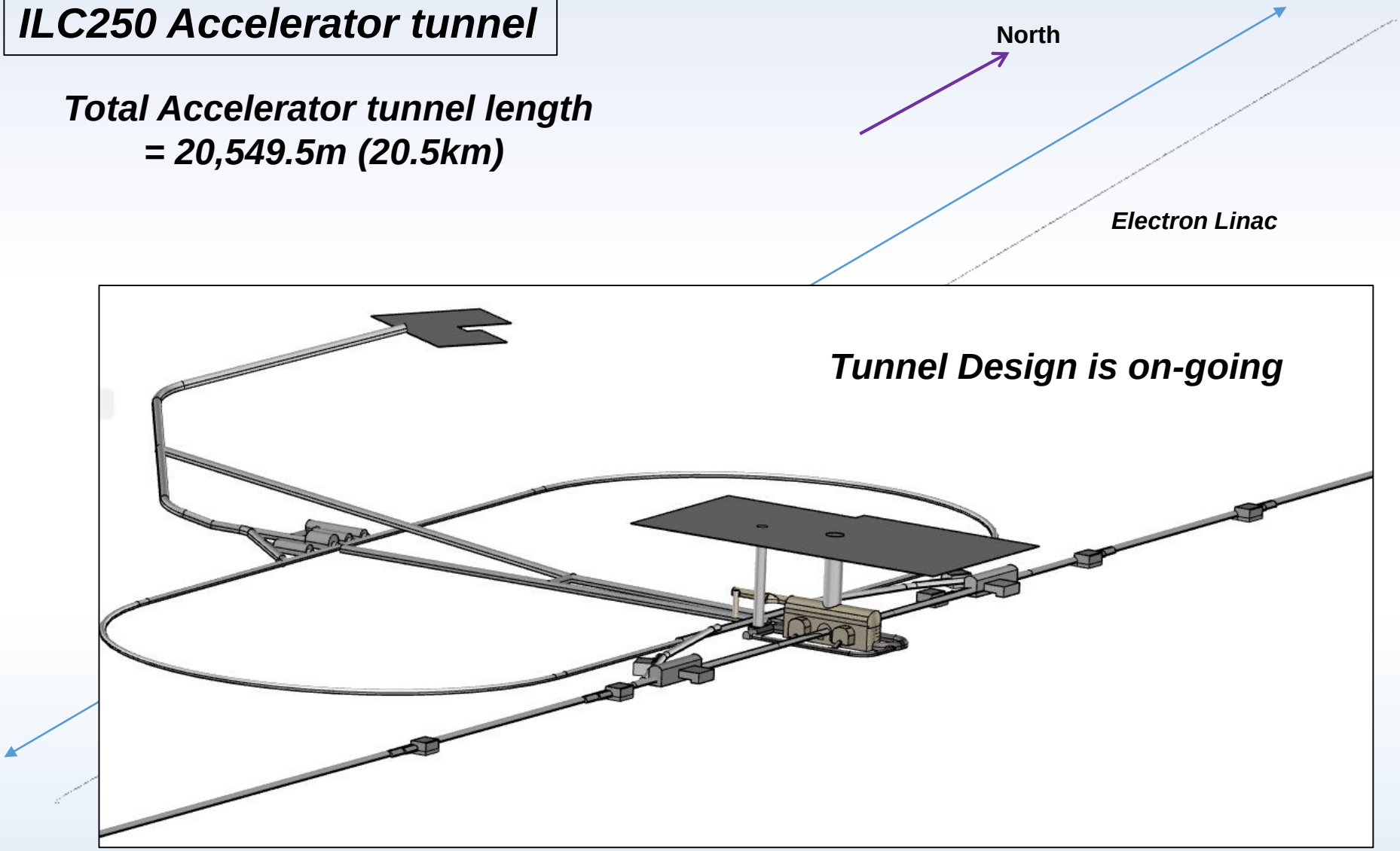


Long
Granite
bed
(pink)

ILC Accelerator: Lattice design and tunnel design

ILC250 Accelerator tunnel

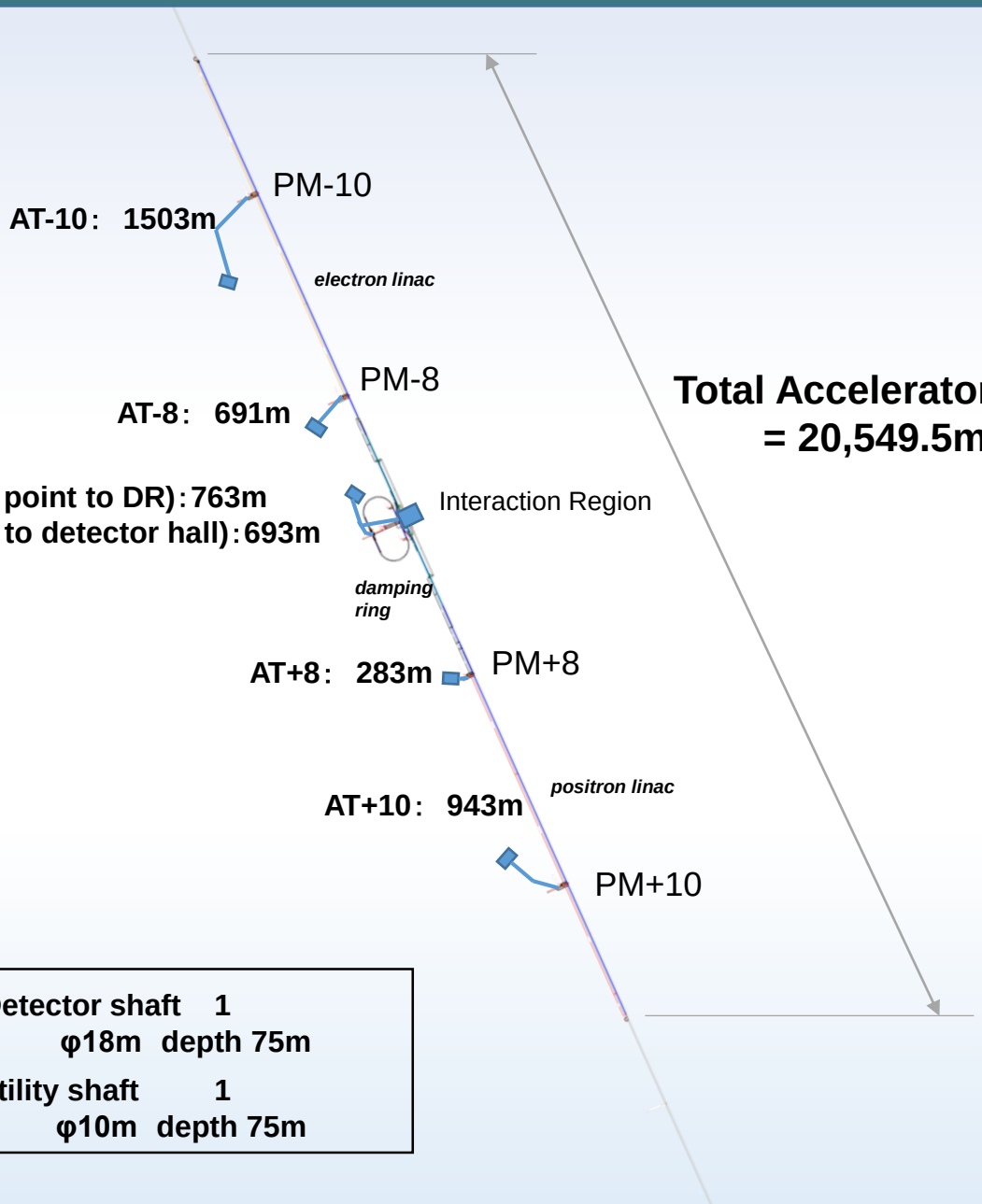
Total Accelerator tunnel length = 20,549.5m (20.5km)



Overall siting plan to fit Kitakami Candidate Site

Access Tunnels

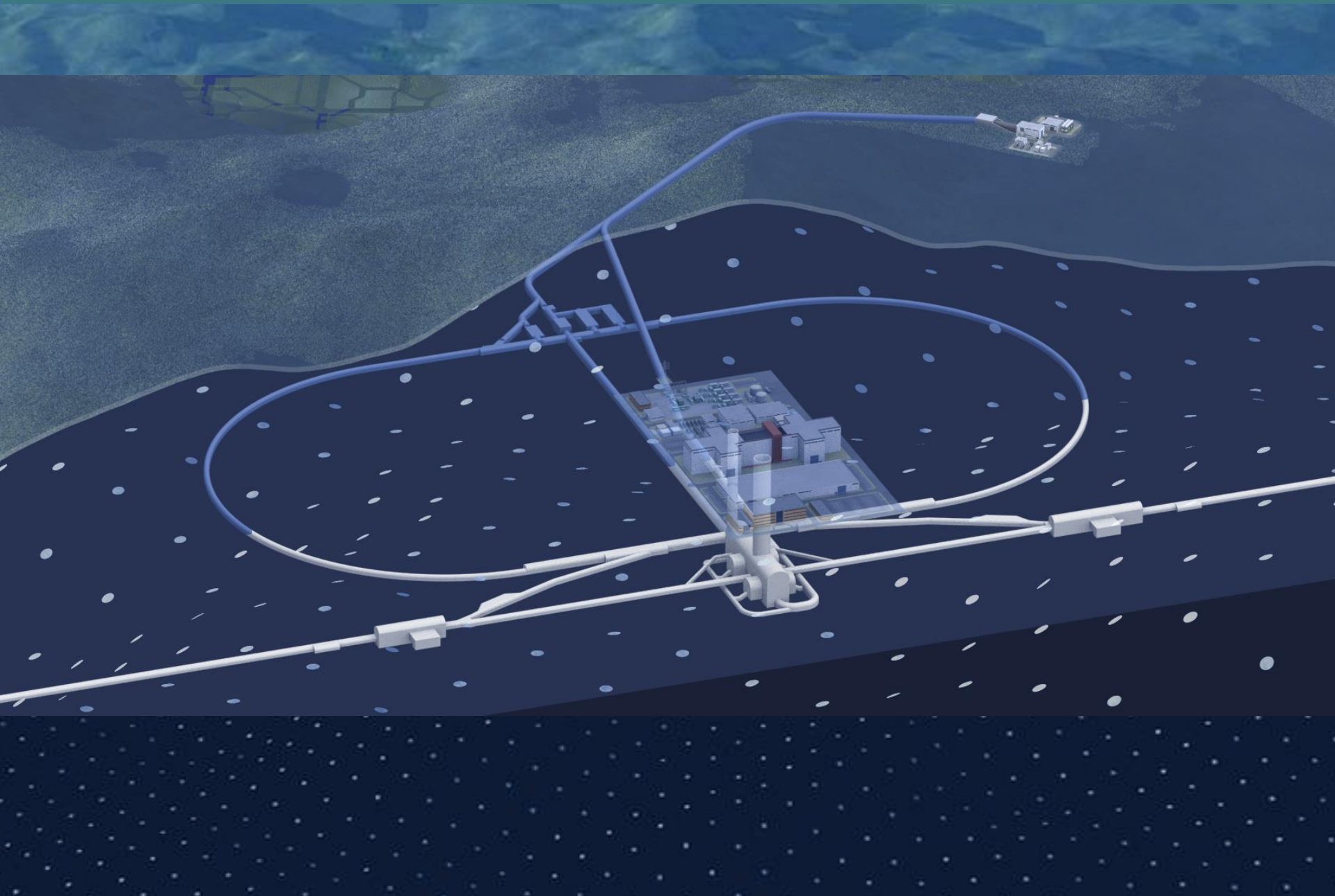
Site-specific design of Access tunnels



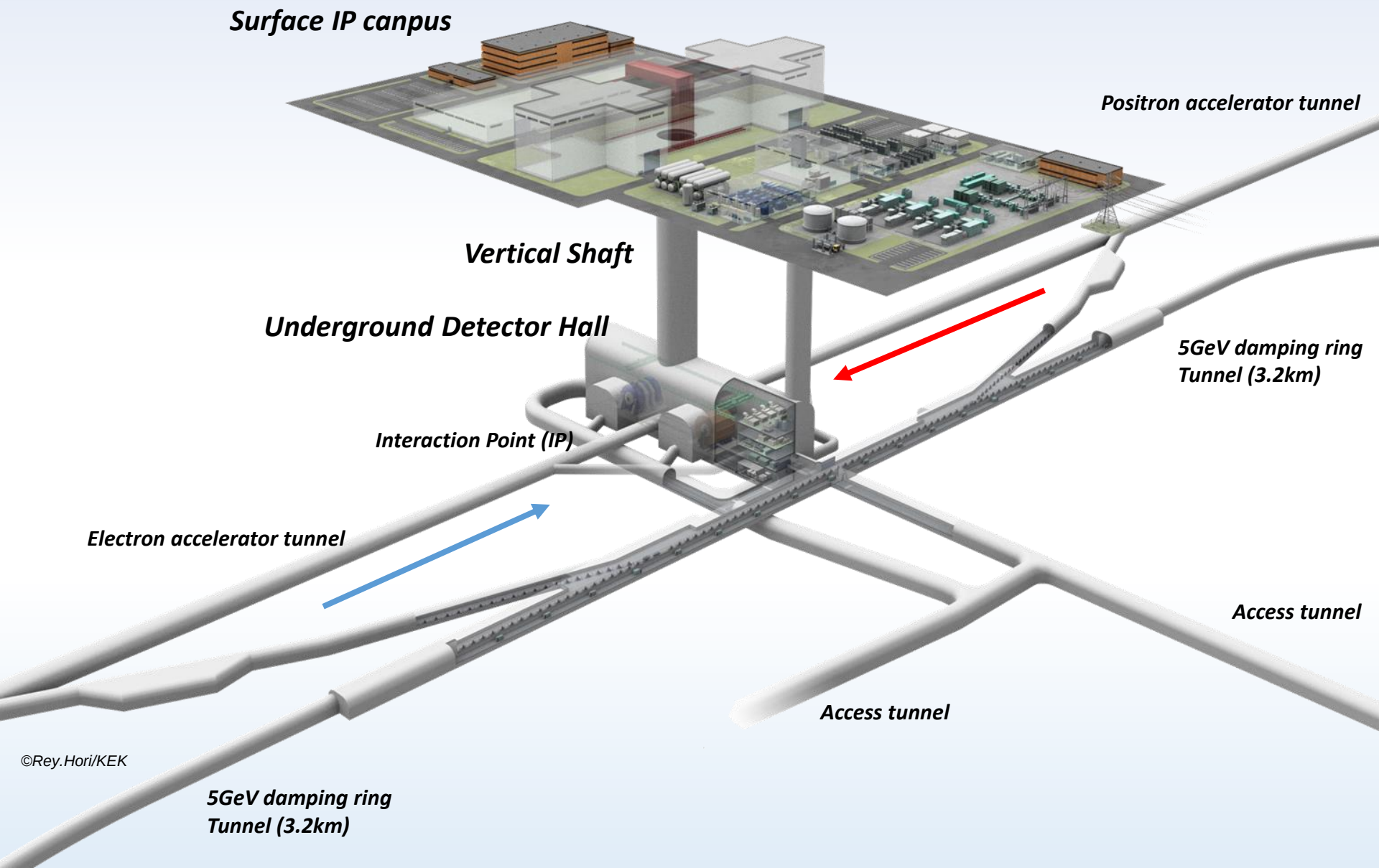
Total Accelerator tunnel length = 20,549.5m (20.5km)

access tunnels 5	**Detector shaft 1**
total length 4876m	**φ18m depth 75m**
	Utility shaft 1
	φ10m depth 75m

Bird's eye view of ILC in Kitakami candidate site

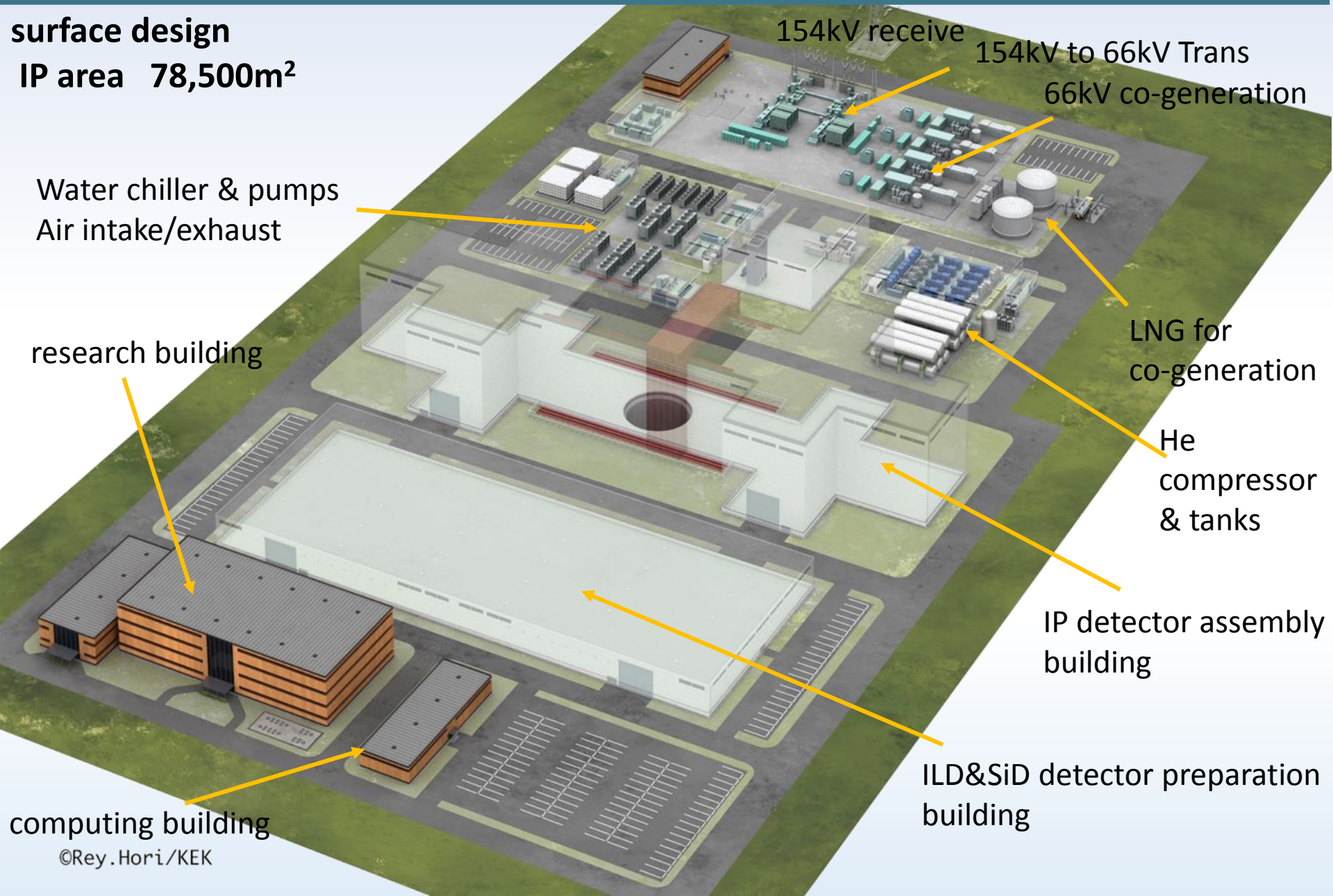


Plan of Interaction point

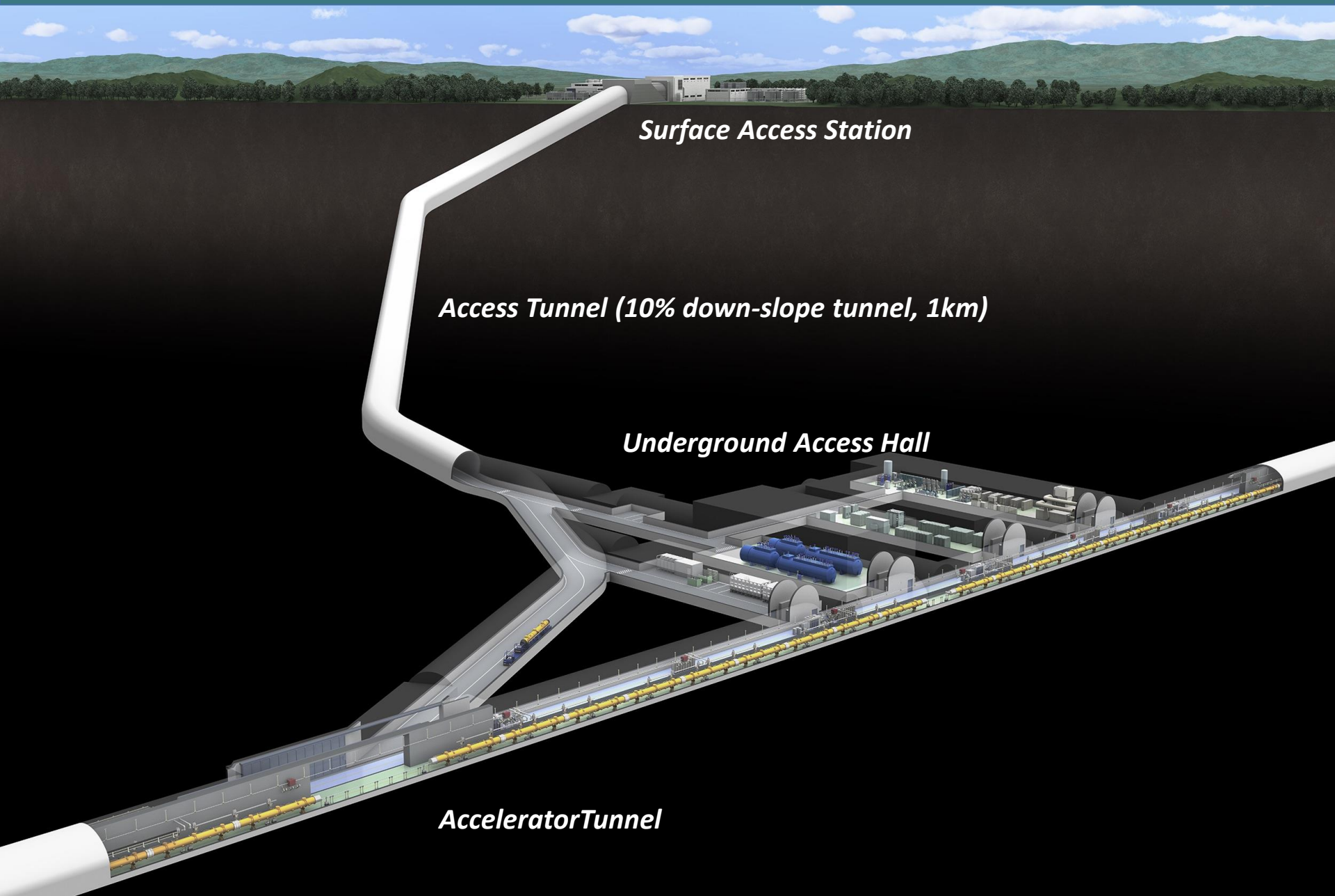


Interaction Point Campus at Surface

surface design
IP area 78,500m²

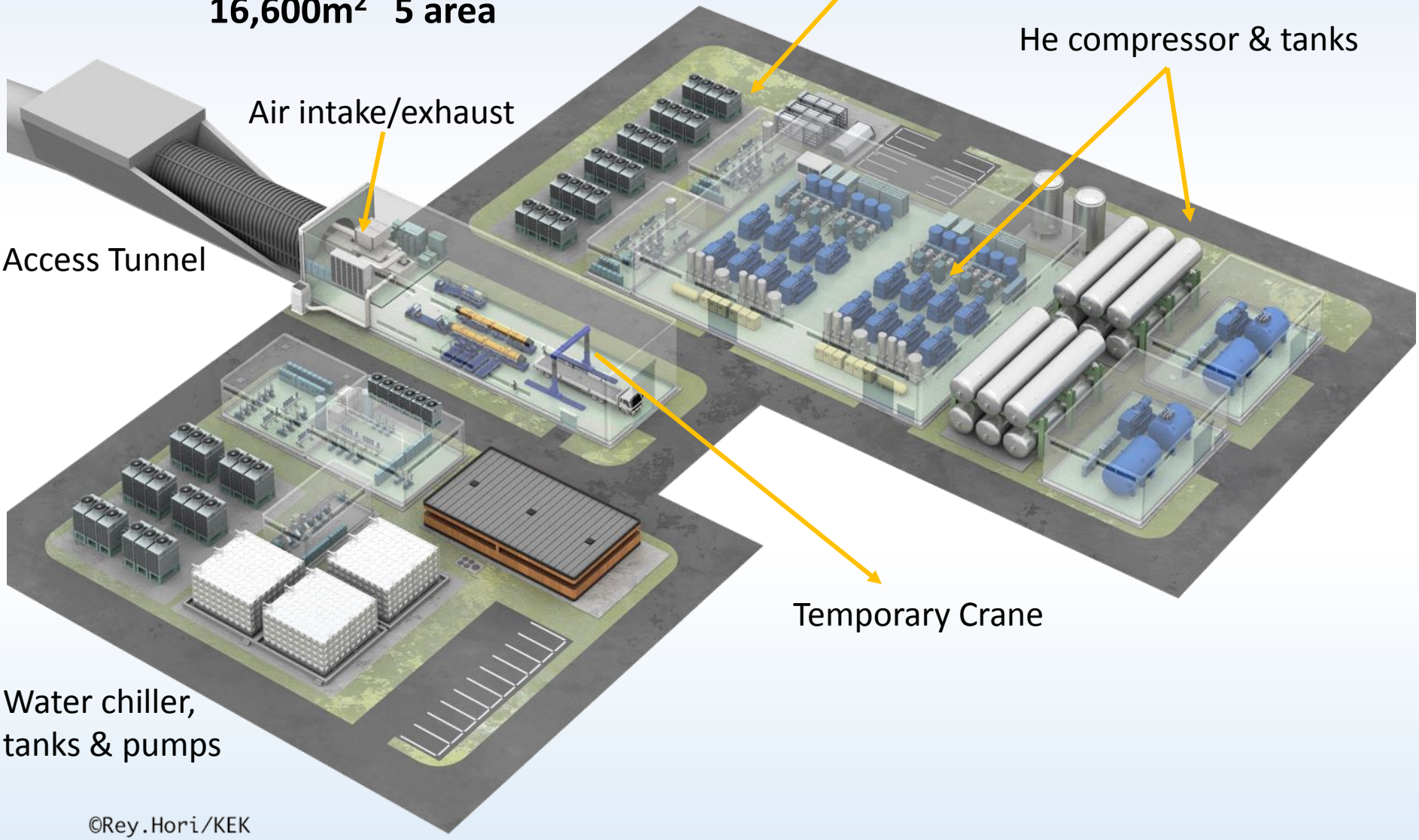


Surface-to-Underground access-tunnel

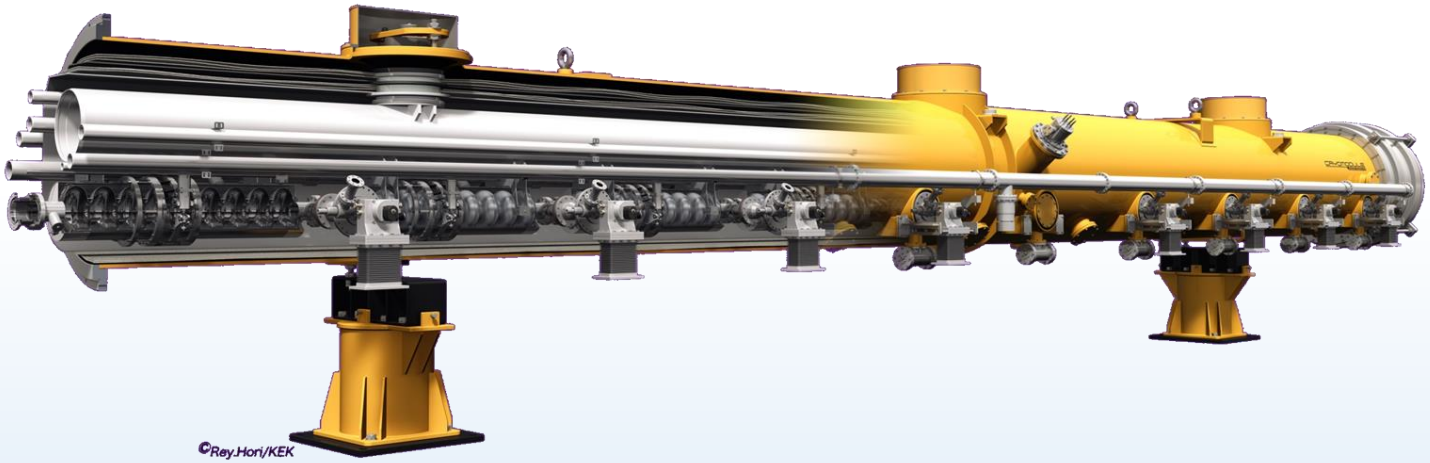


Access-station at Surface

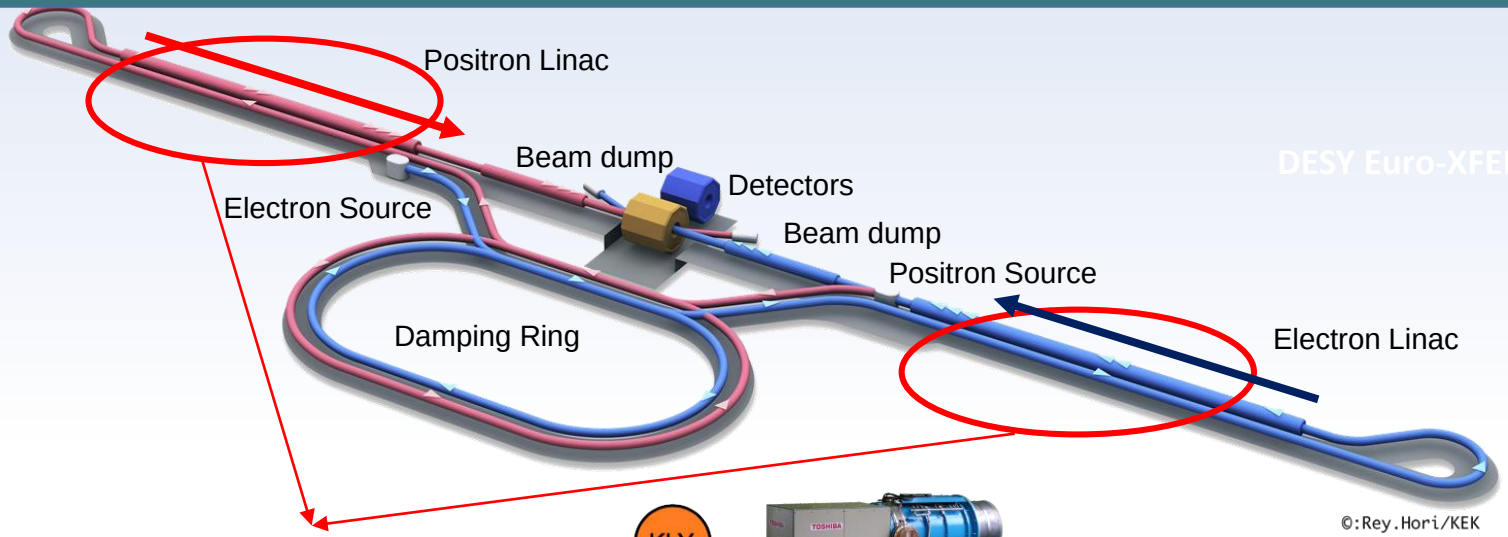
surface design
access stations
16,600m² 5 area



Beam acceleration by Superconducting Cavity



Beam Acceleration in Main Linac



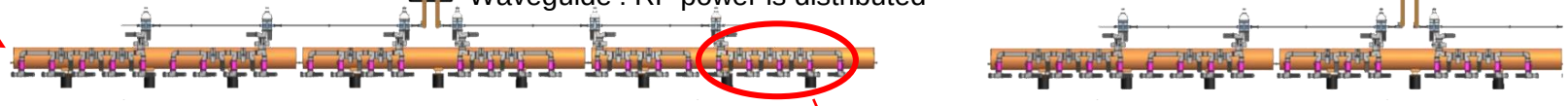
Superconducting Accelerator

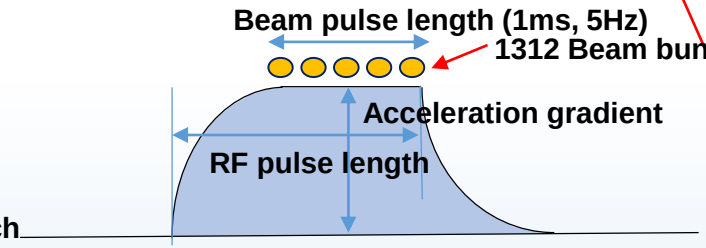
RF unit (below) is placed repeatedly in a line

Klystron: RF power is generated

Cryomodule

Waveguide : RF power is distributed

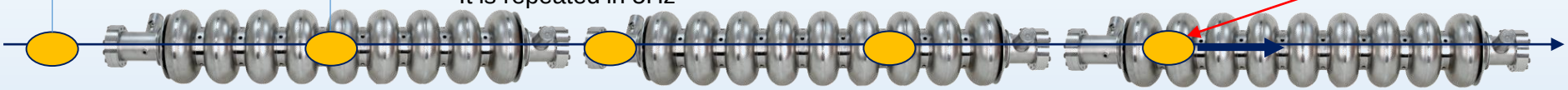




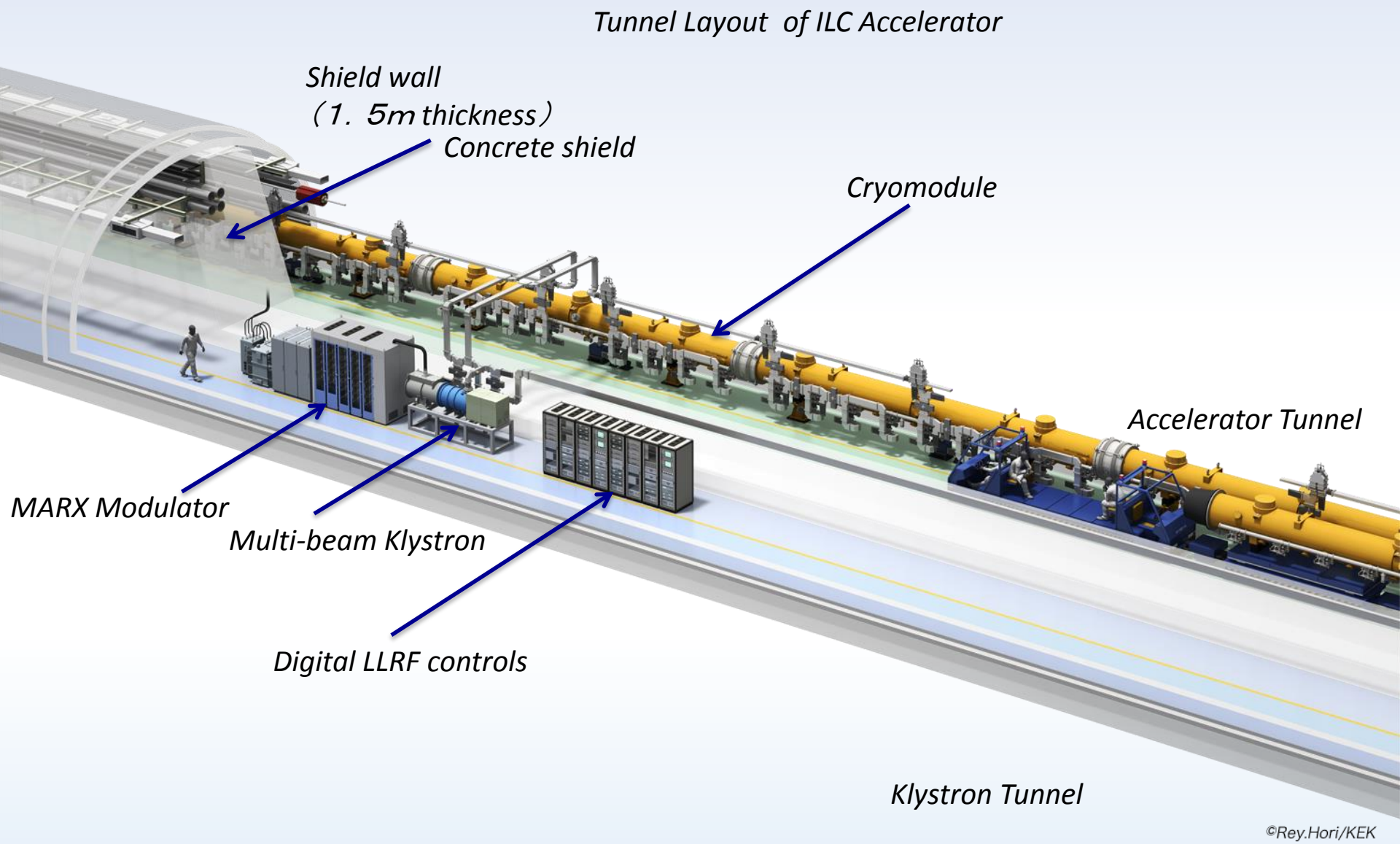
Accelerating field in cavity
It is repeated in 5Hz

Cryomodule: 8 cavities are included。

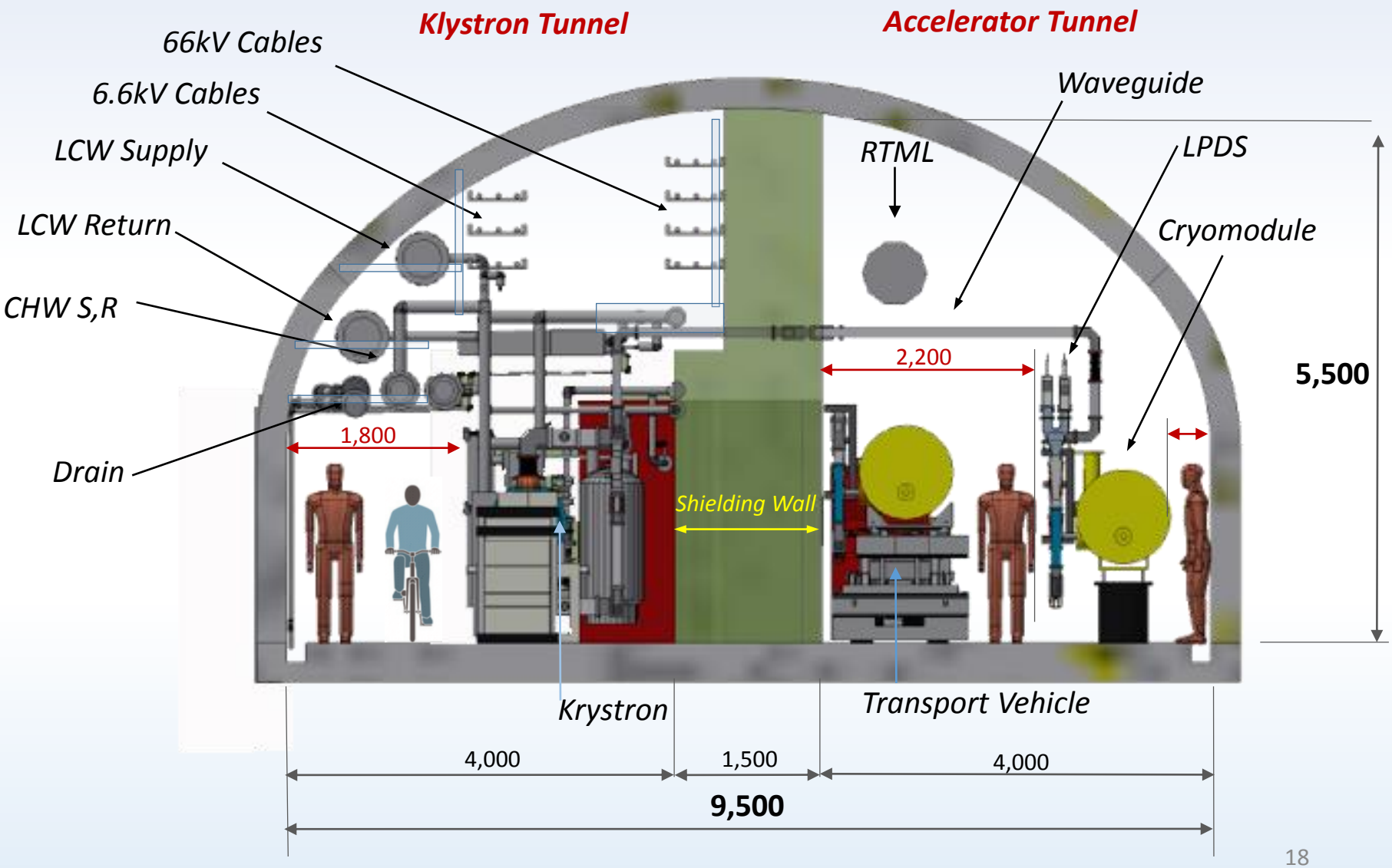
Beam bunch:



Tunnel layout of ILC Main Linac



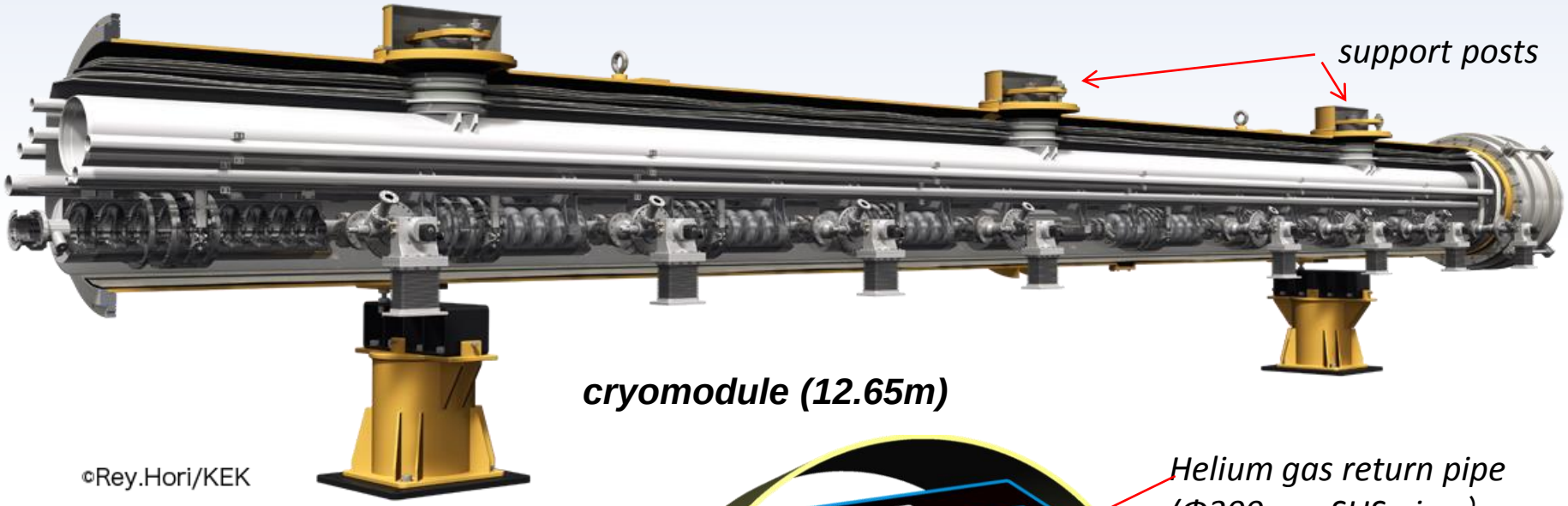
Cross-section of ILC Main Linac Tunnel



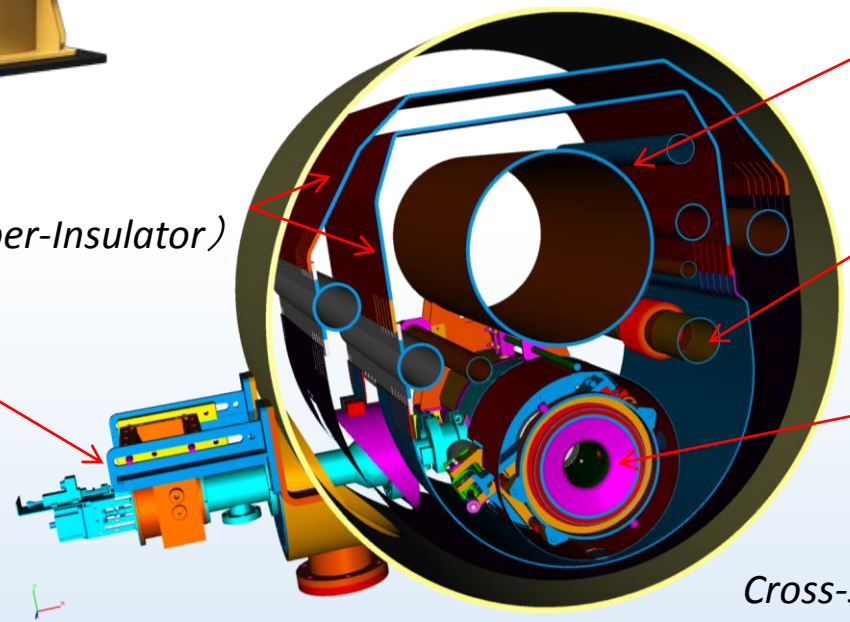
Cryomodule

Type-A (9cavities） *604*
Type-B(8cavities+SC-Q magnet） *302*

Number of Cryomodules: 906



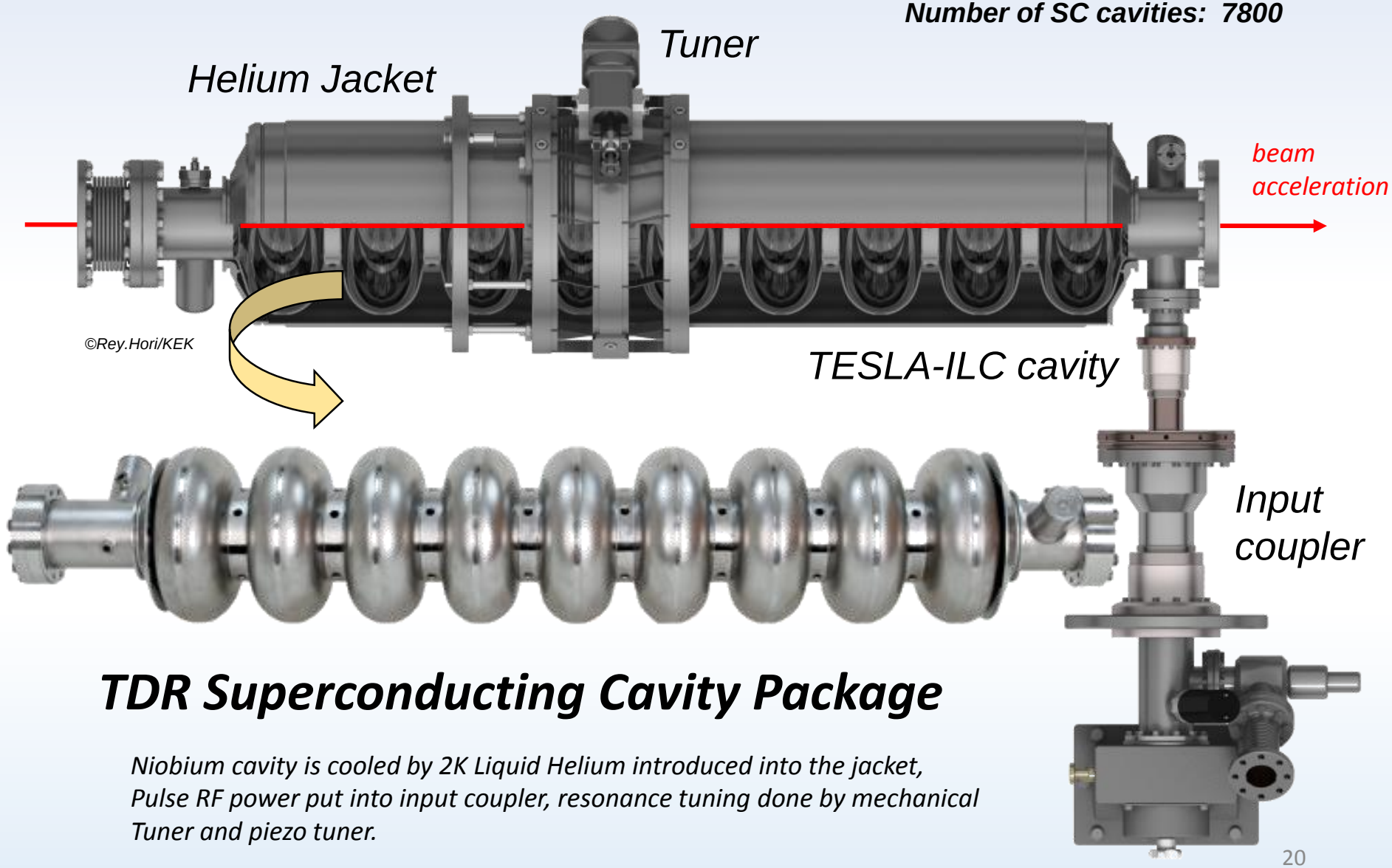
cryomodule (12.65m)



Cross-section from D. Kostin

1.3GHz Superconducting Cavity Package

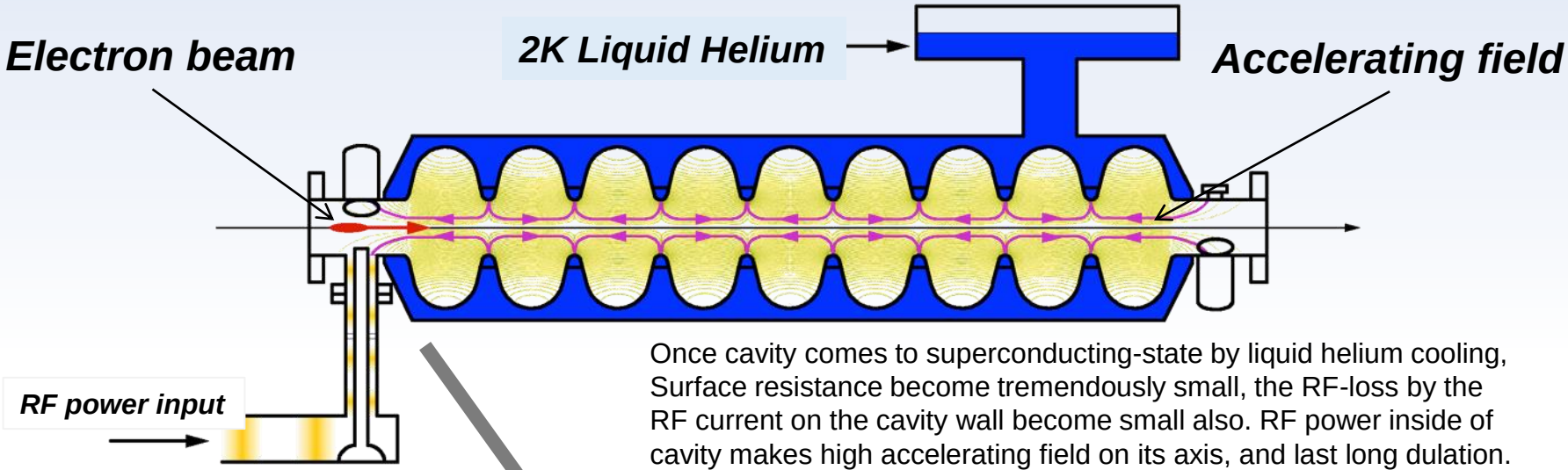
Number of SC cavities: 7800



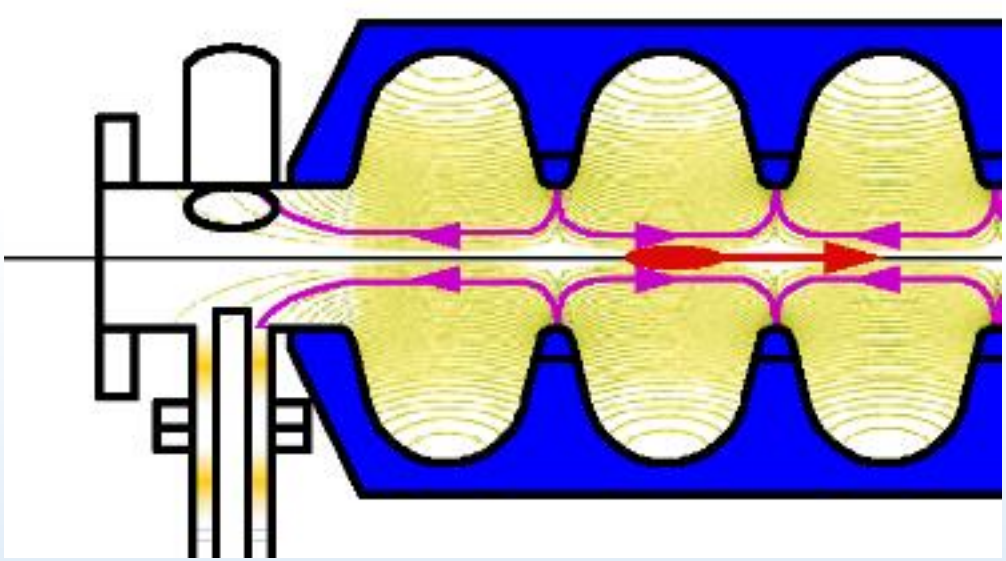
TDR Superconducting Cavity Package

Niobium cavity is cooled by 2K Liquid Helium introduced into the jacket, Pulse RF power put into input coupler, resonance tuning done by mechanical Tuner and piezo tuner.

Beam Acceleration by 1.3GHz RF field



Once cavity comes to superconducting-state by liquid helium cooling, Surface resistance become tremendously small, the RF-loss by the RF current on the cavity wall become small also. RF power inside of cavity makes high accelerating field on its axis, and last long dulation.



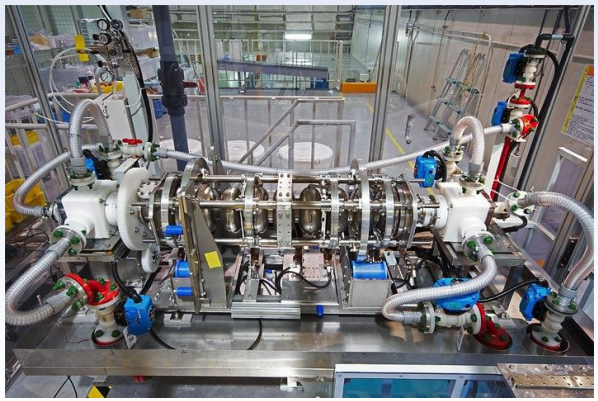
Yellow lines and pink lines represent accelerating field. Its direction alters 180 degrees by the speed of light velocity. Electron beam also moves by the light velocity, so that electric field direction and electron beam moving direction can be adjusted by choosing appropriate beam injection timing.

TM_{010} π – mode
1.300 GHz

Technologies for high performance SRF cavity

Press

EP



EBW

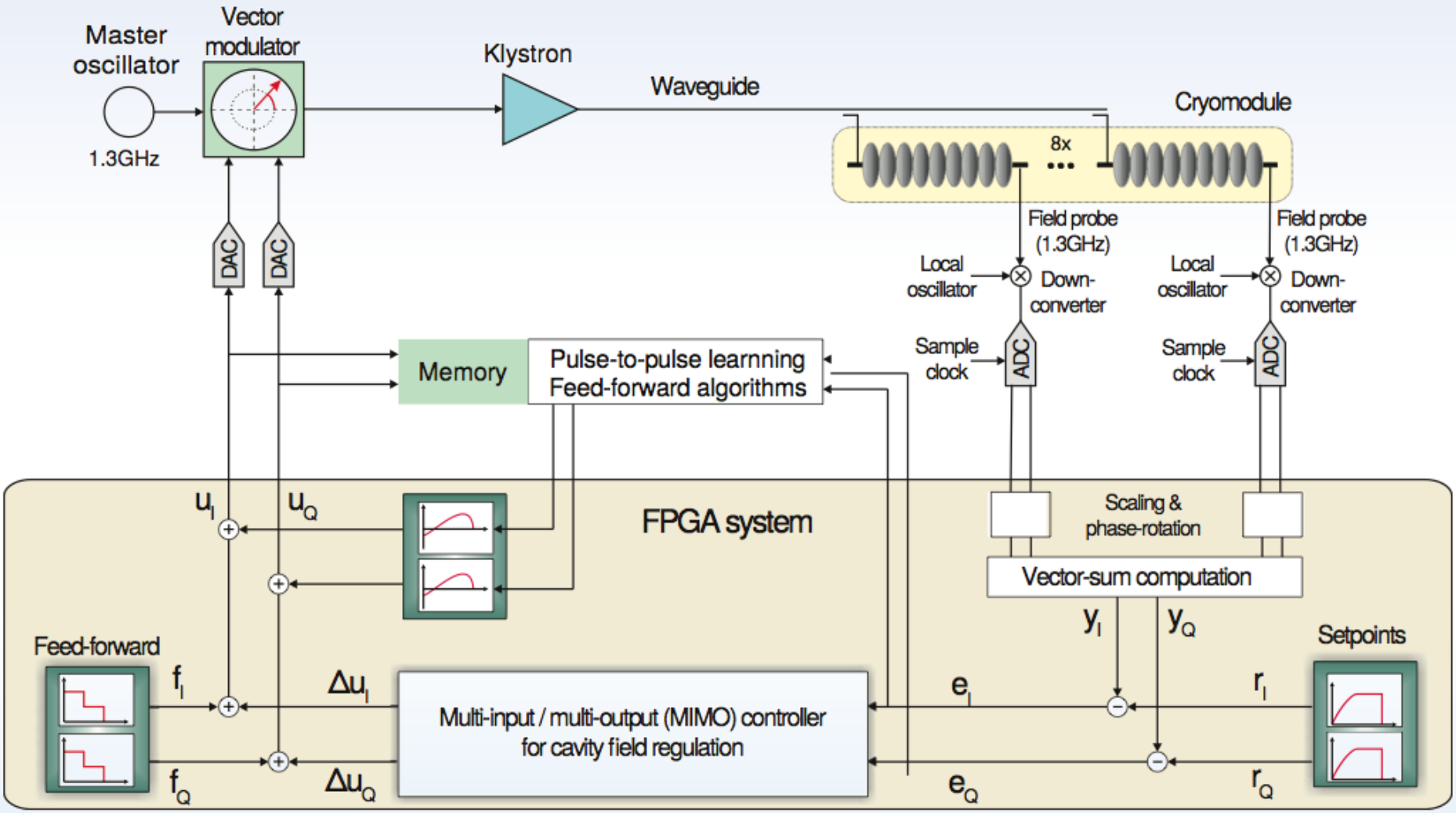
Cavity inspection camera

Clean Room

Cavity frequency tuning

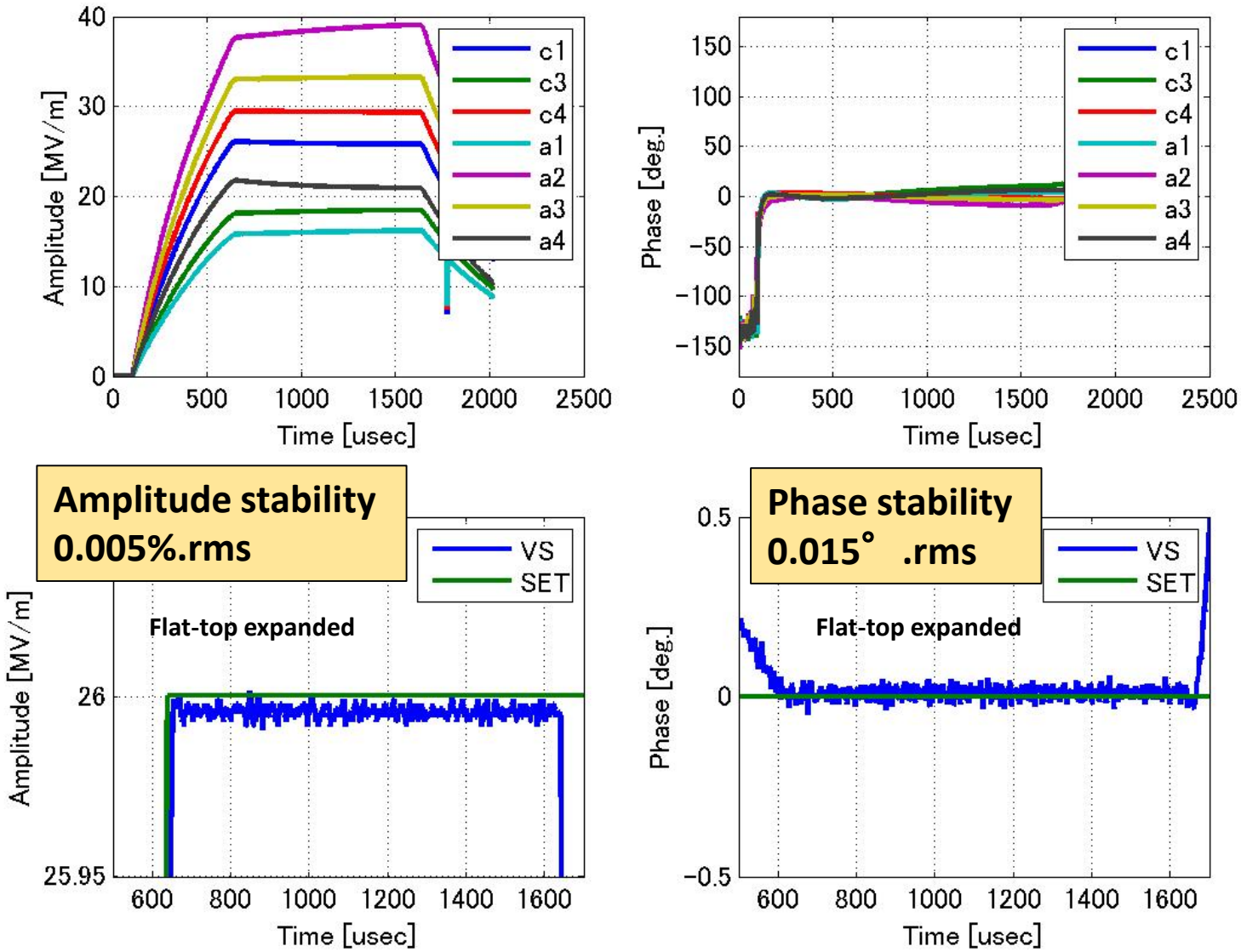
Cryomodule assembly

RF Amplitude & Phase stabilization by digital feedback



Stabilized RF amplitude and phase

Vector sum operation of 7 cavities with LLRF control as an example

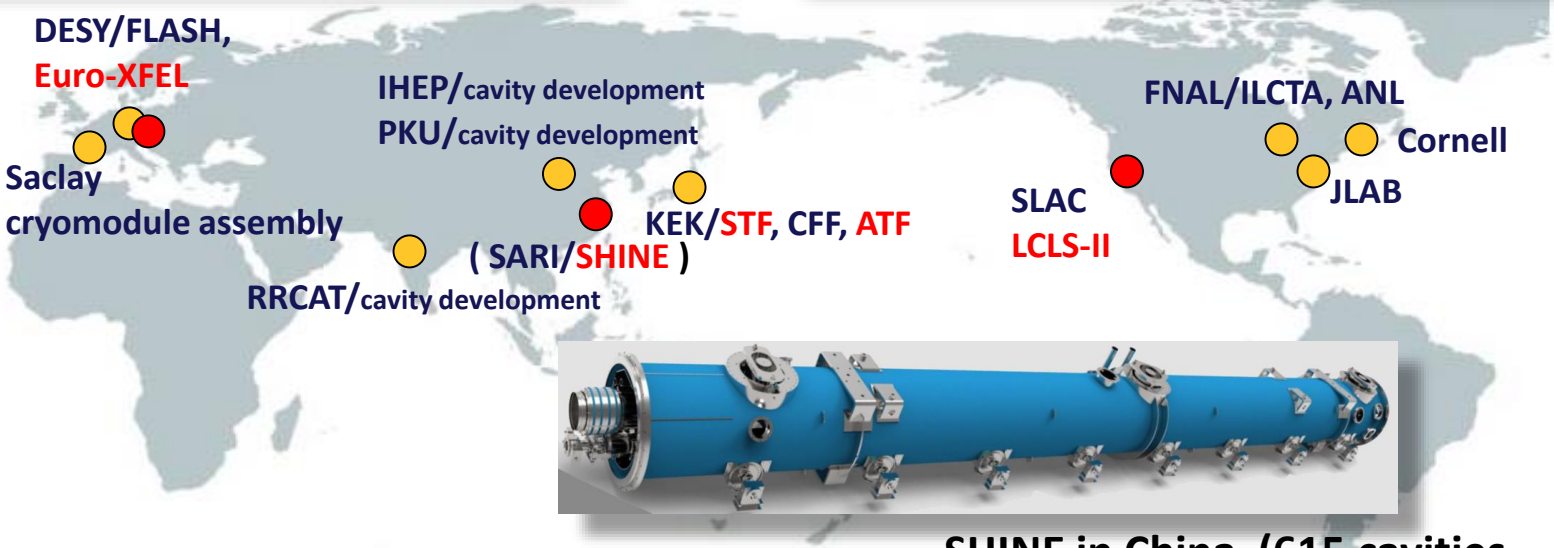


ILC SRF accelerator development

Number of SC cavities in ILC: 7800

Euro-XFEL in Germany (800 cavities)

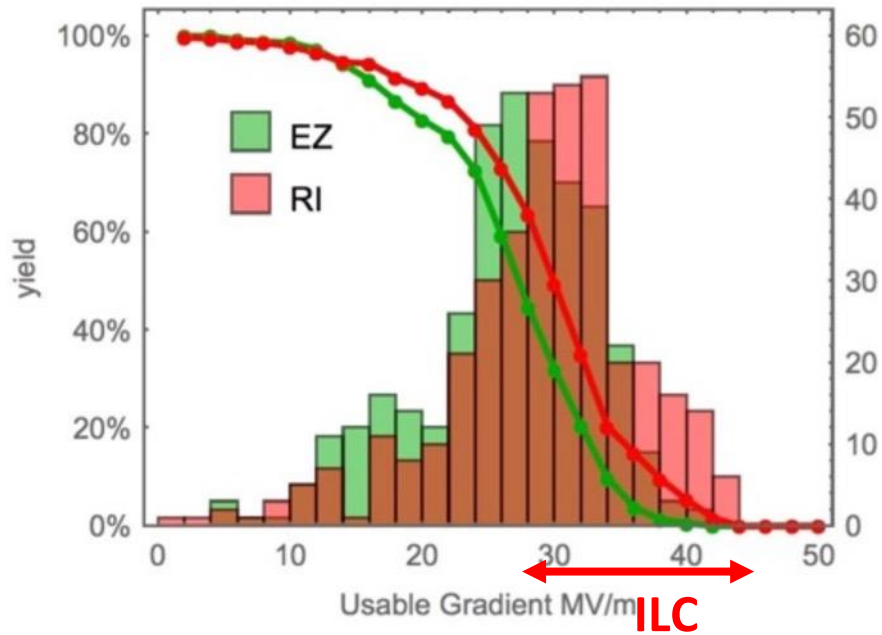
LCLS-II in US (280 cavities)



SHINE in China (615 cavities to be fabricated**)**

ILC accelerator/SRF technologies development by International Collaboration

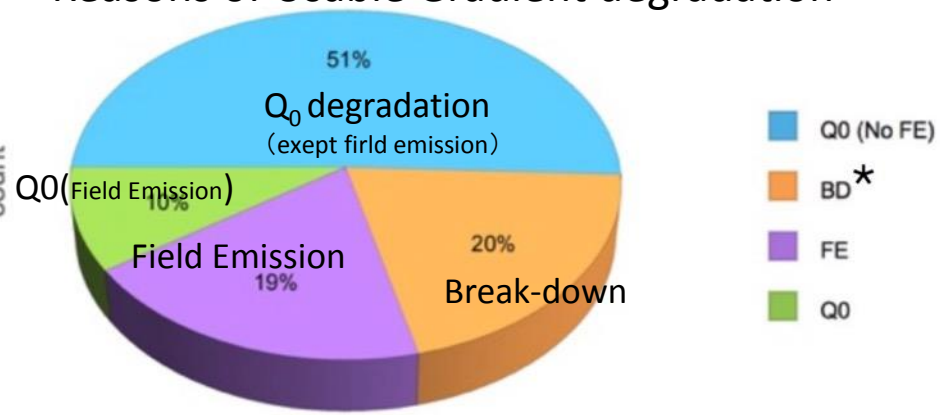
Test results: USABLE GRADIENT



	RI	EZ	Total
Tests	375	367	742
G_{AVG} (MV/m)	29.1	26.4	27.8
G_{RMS} (MV/m)	7.4	6.6	7.1
yield @ 20MV/m	89%	83%	86%
yield @ 26MV/m	73%	59%	66%
yield @ 28MV/m	63%	45%	54%

"As received" test

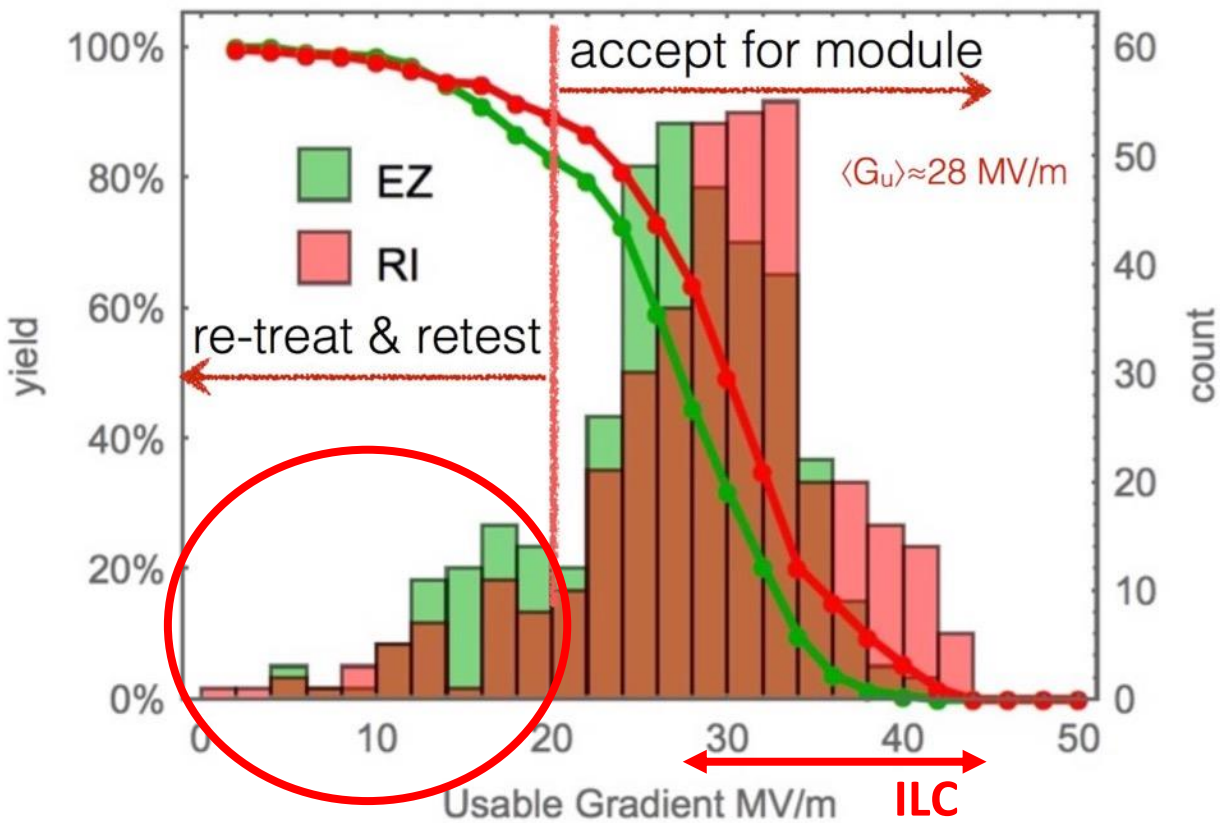
Reasons of Usable Gradient degradation



* few cases of power limitation, HOM coupler heating etc.

Average loss from max: ~4 MV/m

Test results: Re-treatment



"As received" test

In general, first re-treatment is a standard High-Pressure Rinse (HPR)

Second (if required) is BCP

HPR treatment for <20MV/m cavities in 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

ILC specification : >=90% yield

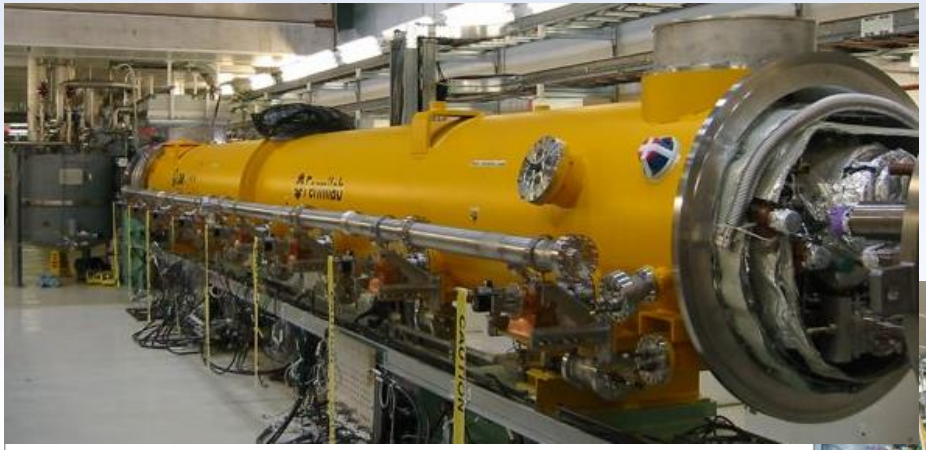
RI results only (ILC recipe)		ILC TDR (assumed)	XFEL max	XFEL usable
First-pass	Yield >28 MV/m	75%	85%	63%
	Average >28 MV/m	35 MV/m	35.2 MV/m	33.5 MV/m
First+Second pass	Yield >28 MV/m	90%	94%	82%
	Average >28 MV/m	35 MV/m	35.0 MV/m	33.4 MV/m
First+Second+third pass	Yield >28 MV/m	-		91%
	Average >28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

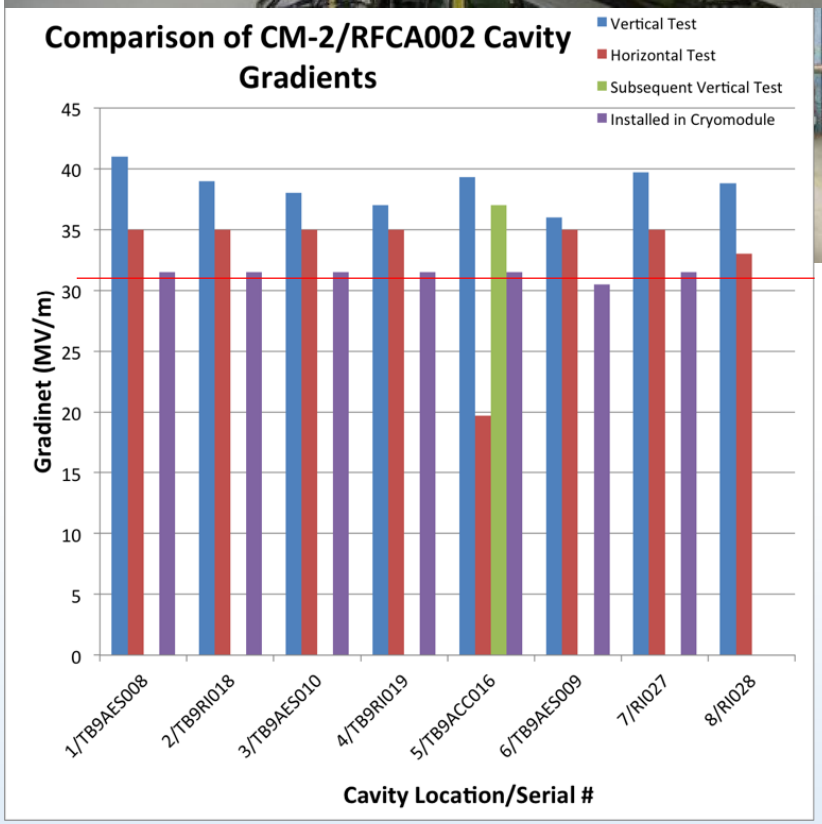
but close!

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

$$$

FNAL :Test Cryomodule Performance





ILC Milestone
31.5MV/m

FNAL CM-2 has achieved the average cavity gradient of 31.5 MV/m with all 8 cavities powered simultaneously

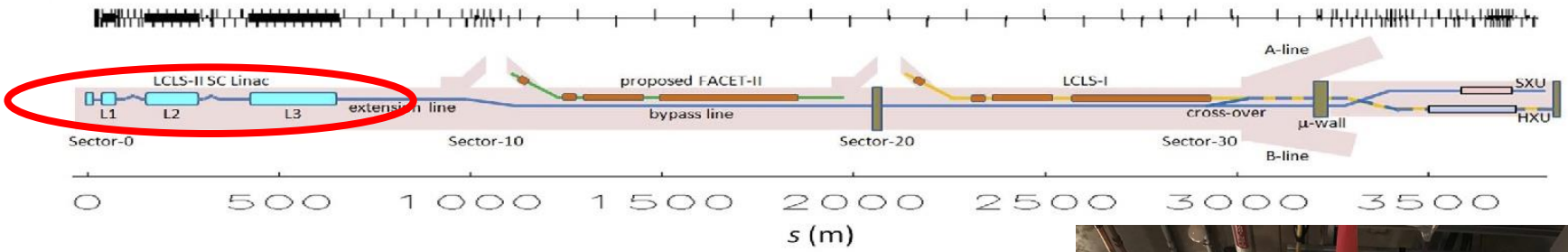
KEK-STF :Superconducting RF Test Facility

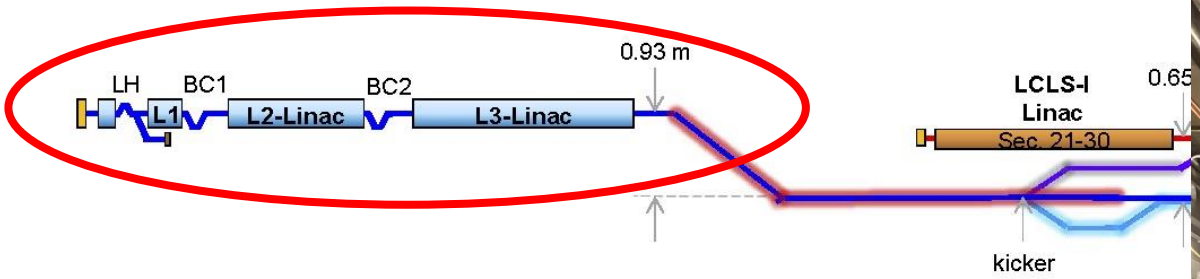
Test Accelerator to test ILC cryomodules

Combined 8 cavities in cryomodules with vector-sum LLRF, were operated at 30.5 MV/m in 2016, just RF filling.
In March 2019, average 32MV/m beam acceleration was confirmed.

LCLS-II superconducting accelerator in SLAC tunnel

LCLS-II linac will occupy 700m of 3 km linac tunnel





The 1,000m "copper" linac in Sectors 0-10 will be replaced by a superconducting linac, occupying 700m(room to grow)

The SC linac will provide electrons to either or both undulators

The existing linac in "middle" 1,000m of the tunnel will be left Intact (likely use: R&D on plasma wake field acceleration). Electrons from SC linac transported past this linac in a separate channel

The LC
30 will
with SC
electror

"glowing" sections indicate these are not in the vertical pla

LCLS-II Cryomodule production at JLAB, FNAL

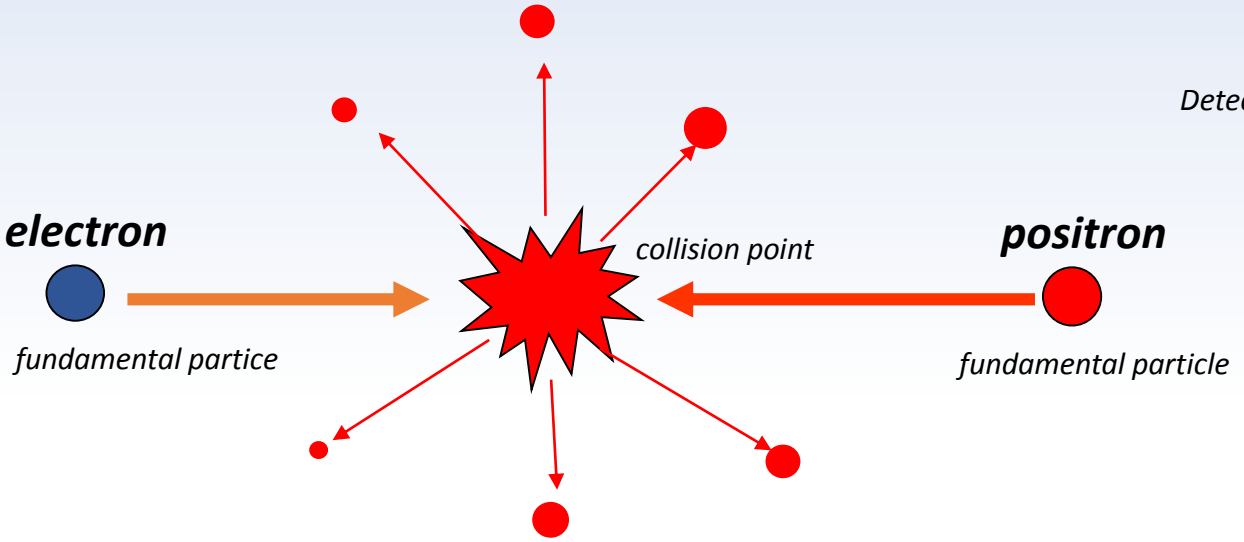
LCLS-II (FNAL, JLAB) will fabricate 35 cryomodule (280 cavities)

JLAB Production Line

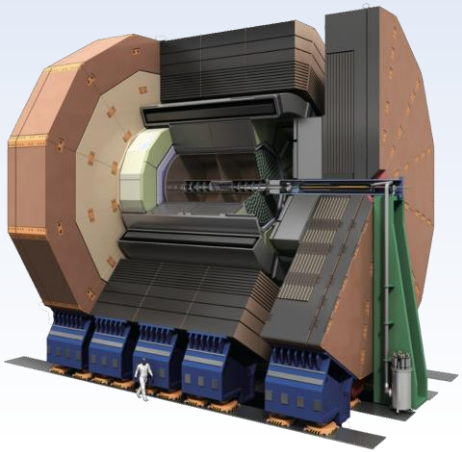
FNAL Production Line

Beam Collision

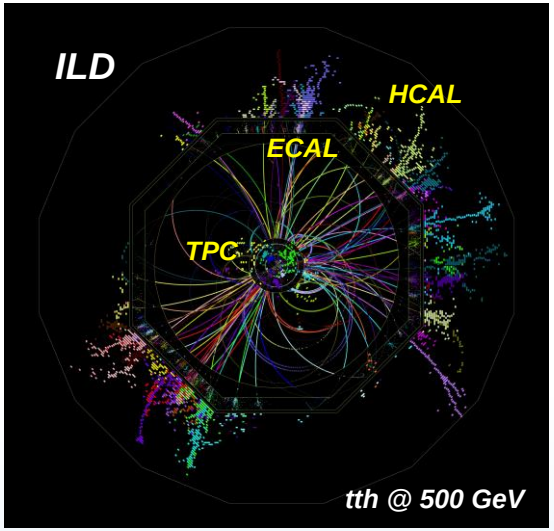
Electron and Positron collision



Detector

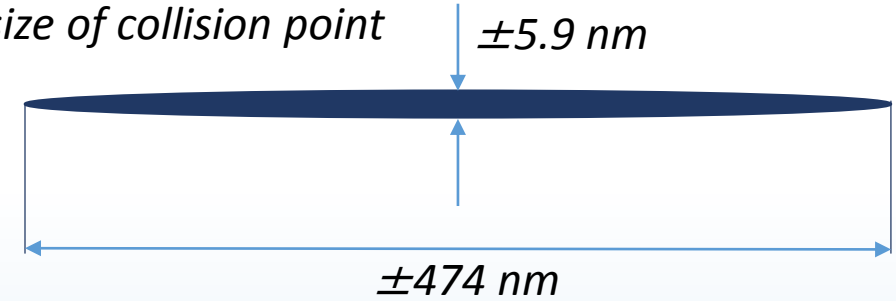


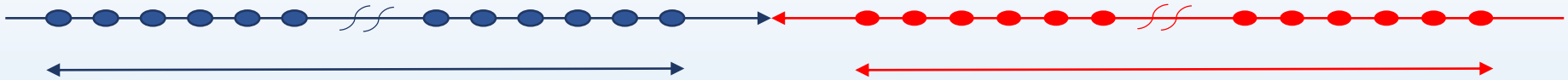
simulation of collision event in ILD



Beam = group of electrons (positrons)

Beam size of collision point



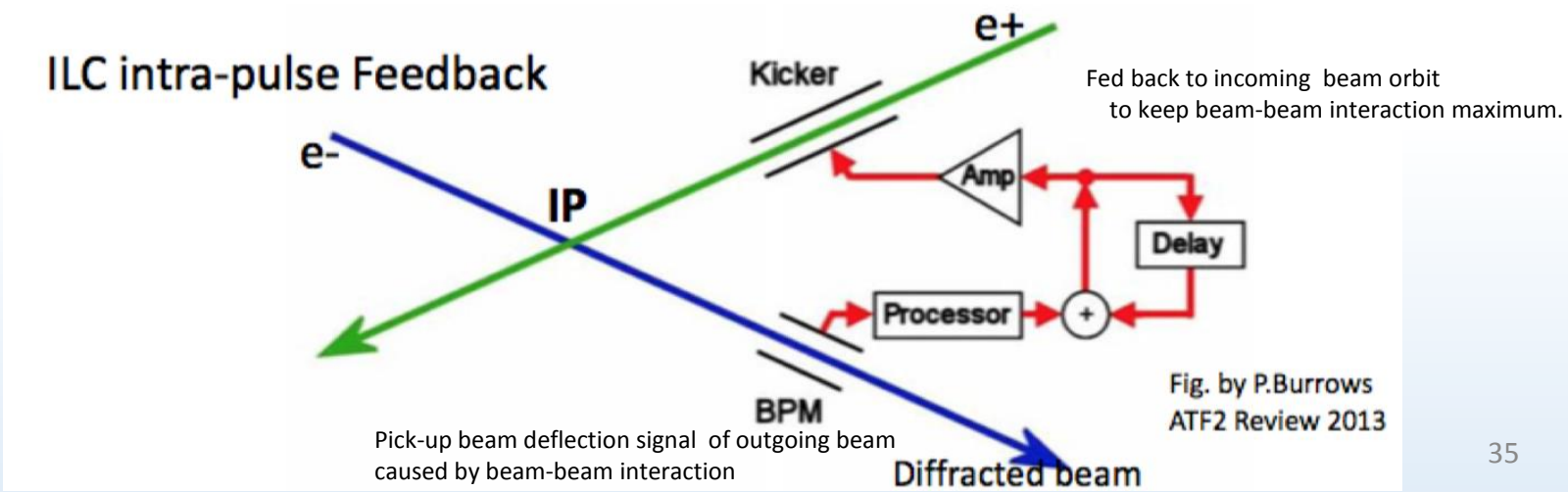


Electron buch 1312
length 300μm bunch spacing 166m
repetition 5Hz Energy 125 GeV

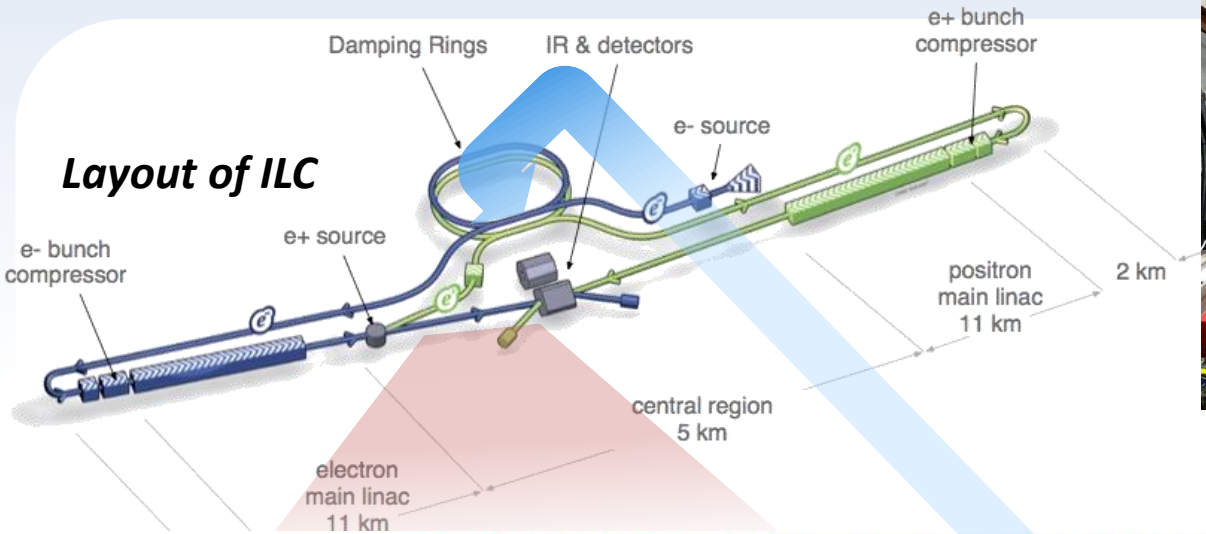
Positorn bunch 1312
length 300μm Bunch spacing 166m
repetition 5Hz Energy 125 GeV

Keep the beam size small, keep the collision stable

- ***Damping Ring is to realize beam emittance ultra-small***
- ***Final Focus Beam Line is to make vertical beam size ultra-small***
- ***No-vibration accelerator Floor requires***
  - > Deep undergroud, stiff rigid Rock-base mountain
- ***Fast Beam feedback is to keep beam collision stable***



ATF : Accelerator Test Facility in KEK, Japan

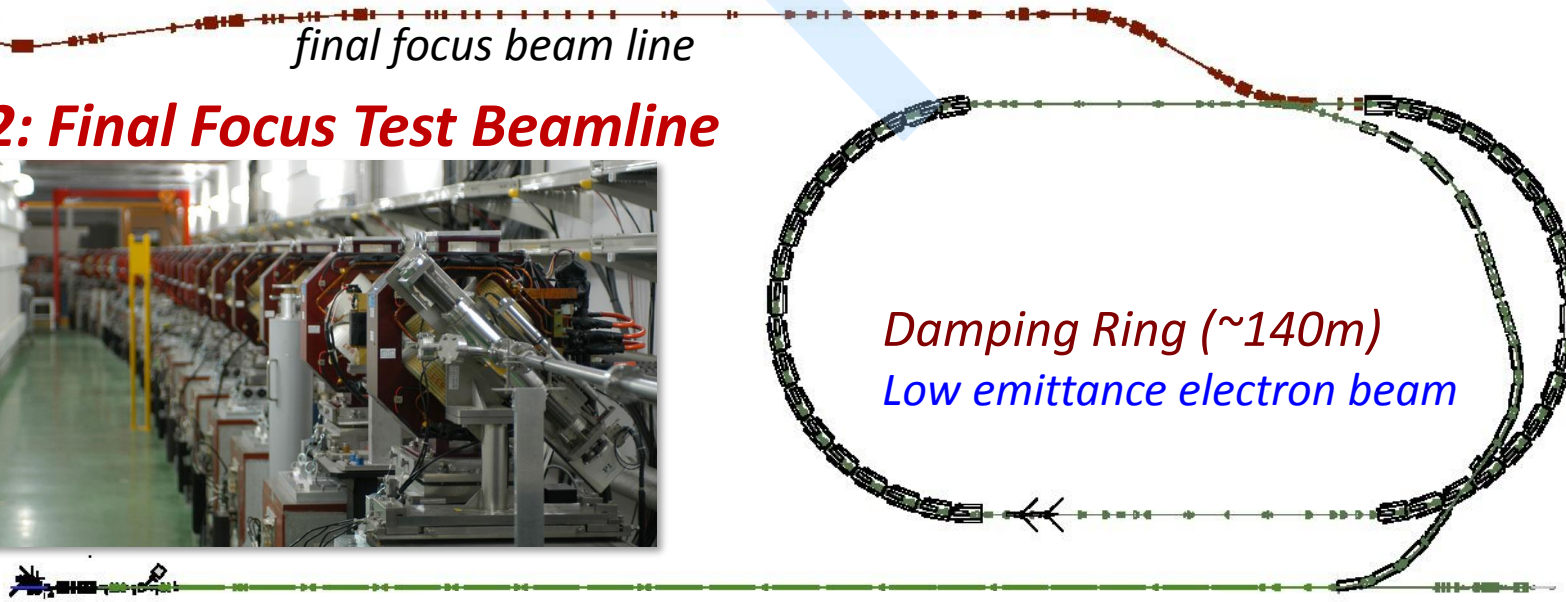


ATF Damping Ring

target low emittance is already attained

final focus beam line

ATF2: Final Focus Test Beamline



1.3 GeV S-band Electron LINAC (~70m)

Development of beam focus with low energy (ATF2)

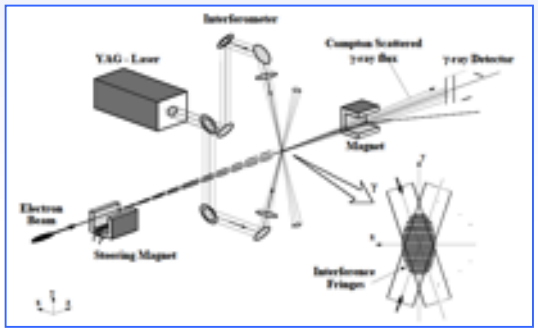
- ***Nano-beam development by international collaboration***

  25 laboratories with more than 100 researchers
- ***The same optical design of ILC final focus beam line***
- ***Scale down of beam energy to 1.3GeV***
- ***Target of beam size***

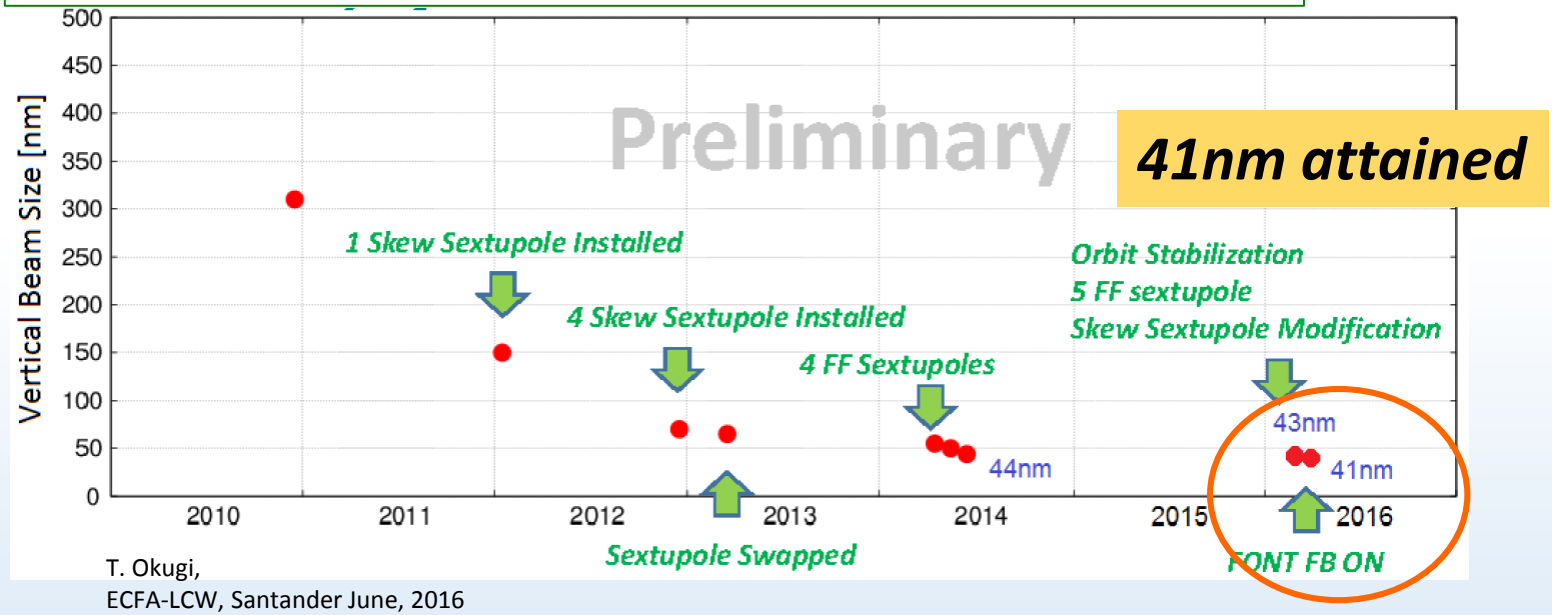
  37 nm vertical size (→ correspond to ILC 5.9 nm)
- ***Recent Status***

  41 nm beam size (with FONT Feedback)

  Parameters dependence to beam size are under research



Beam size monitor using laser interferometer



T. Okugi,
ECFA-LCW, Santander June, 2016

ILC political Status of Japan

SCJ committee Discussion for ILC250

MEXT ⇄ SCJ

July, 2018 →

← Dec., 2018

http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-24-k273-en.pdf

Commissioned Survey by NRI (2014-17)

1) WW Research trend (FY14)
2) Technology issues (FY15)
3) Large Int'l project (FY16)
4) Risk/safety issues (FY17)

ILC advisory panel report (in English) is available from http://www.mext.go.jp/component/b_menu/shingi/toushin/__icsFiles/afieldfile/2018/09/20/1409220_2_1.pdf

ILC Adv. Panel

Organized from 2014 to 2018

- **Physics WG** — Organized in 2014-15 & 2018
- **TDR Validation WG** — Organized in 2014-15 & 2018
- **Human Resource WG** — Organized in 2015 -16
- **Organization & Manage.WG** — Organized in 2017

Review committee for ILC250

Tasks of the committee

- The academic significance of the ILC, importance of the ILC in the elementary particle physics
- Importance of the ILC in the whole academic research
- Significance of the ILC in Japan
- Preparation status for the ILC, budget and human resources necessary for construction and operation

Sub-committee

Tasks of the subcommittee

1 Technical feasibility of large facilities
2 Cost evaluation
3 Economic ripple effect
4 Environmental assessment

SCJ : Science Council of Japan
日本学術会議
MEXT : Minister of Education, cluture and sports, Science and Technology Japan
文部科学省

SCJ report and Executive summary

http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-24-k273-en.pdf

- The SCJ recognizes the importance of the Higgs physics. "It is agreed upon Japanese high energy physics community that the precision measurement of the Higgs coupling is an important one".
- *"Judging from the plan and preparatory status of the project presented at the moment, the Science Council of Japan does not reach a consensus to support hosting the 250GeV ILC project in Japan."*

Their main concerns are *"Japan's large share of the overall cost required for the project implementation"*, *"matter of concern for the implementation of the project* (for technical issues)", and *"the uncertainty surrounding proper international cost-sharing with respect to the long-term commitment to large budget allocation "*

ICFA/LCB meeting at Tokyo (Mar.07,2019)

ICFA/LCB 集合写真　　2019年3月7日

S. Komamiya

MEXT's view in regard to the ILC project

MEXT's view in regard to the ILC project

Executive Summary

March 7, 2019

Research Promotion Bureau, MEXT

- Following the opinion of the SCJ, MEXT has not yet reached declaration for hosting the ILC in Japan at this moment. The ILC project requires further discussion in formal academic decision-making processes such as the SCJ Master Plan, where it has to be clarified whether the ILC project can gain understanding and support from the domestic academic community.

- MEXT will pay close attention to the progress of the discussions at the European Strategy for Particle Physics Update.

- The ILC project has certain scientific significance in particle physics particularly in the precision measurements of the Higgs boson, and also has possibility in the technological advancement and in its effect on the local community, although the SCJ pointed out some concerns with the ILC project. Therefore, considering the above points, MEXT will continue to discuss the ILC project with other governments while having an interest in the ILC project.

Summary

***ILC** (International Linear Collider) uses **superconducting accelerator** for the electron-positron collision experiment (**7800 cavities**).*

Euro-XFEL(DESY, Saclay, INFN) fabricated 100 cryomodules (800 cavities) for the superconducting accelerator,
The cavity performance was very close to ILC requirement.

LCLS-II(FNAL, JLAB, SLAC) is fabricating 35 cryomodule (280 cavities)
SHINE(SARI) will fabricate 75 cryomodule (615 cavities)
FNAL, KEK-STF is developing superconducting test accelerator,

KEK-ATF and ATF2 are developing damping ring and beam focus and achieved 41nm beam size.

Summary

Plan of ILC installation into Tohoku-area are presented.
Tunnel, buildings and water&air will be prepaired by Japan,
High-tech accelerator part will be shared by US, Europe, and Asia.

On March 7, MEXT did not say hosting ILC,
but express their interest to ILC.
International cost share discussion WG has been started by MEXT,
Waiting for listing ILC on "master plan of SCJ", this year.

ILC is very close to go.

END

Thanks for your attention

Cost-down of Main Linac

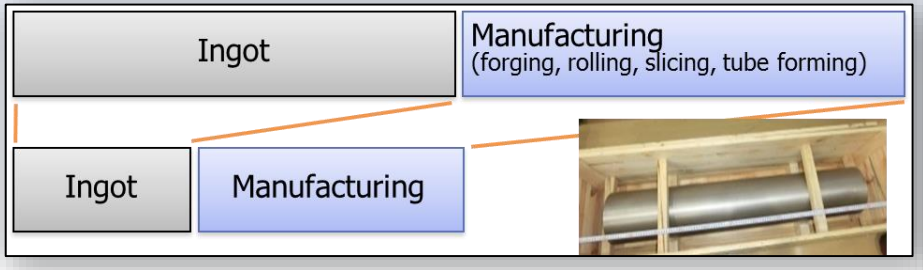
US-Japan cost down R&D

In 2016, MEXT(Japanese government) and US-DOE agreed to have cost-down R&D by US-Japan collaboration, to make ILC realize

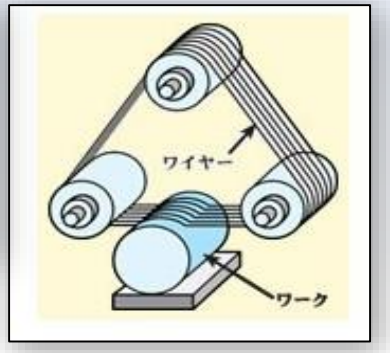
ILC 250GeV Cavity Package ***7800 unit***

US-Japan Cost-down R&D Items

(A-1) Nb material cost-down by Ingod-slicing



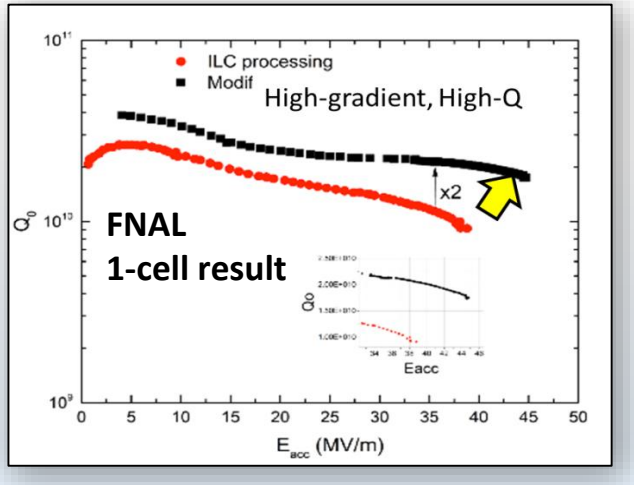
Cost down by Mid-RRR-ingod material + slicing to sheet

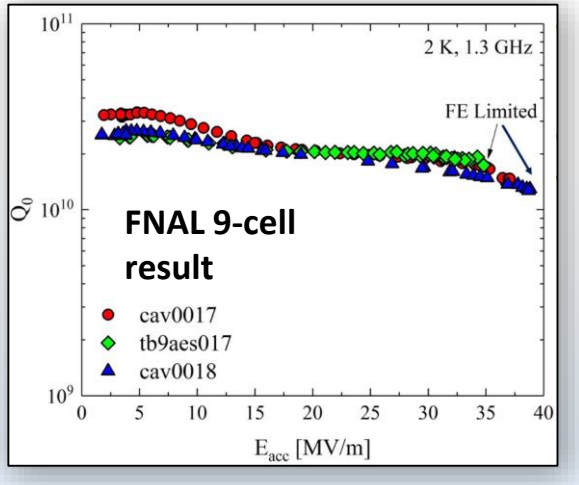


LG cell-material

Development of gradient performance and ensureing Nb sheet strength and press-forming availability

(A-2) High-Q High-G of cavity by N-infusion





ILC operation specification

31.5MV/m 1x10^{10}

35MV/m 1.6x10^{10}

Introduction of clean furnace for N-infusion, search of infusion parameter range

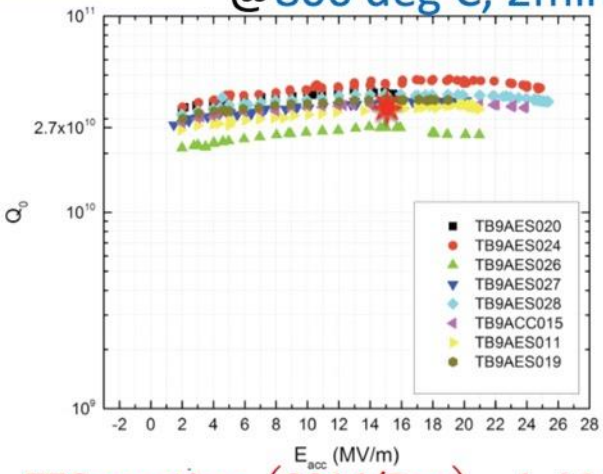
N-dope(2013) and N-infusion(2013) were developed

A. Grassellino et al.,2013 Supercond. Sci. Technol. 26 102001

A. Grassellino et al., arXiv:1305.2182, 1701.06077

N-dope

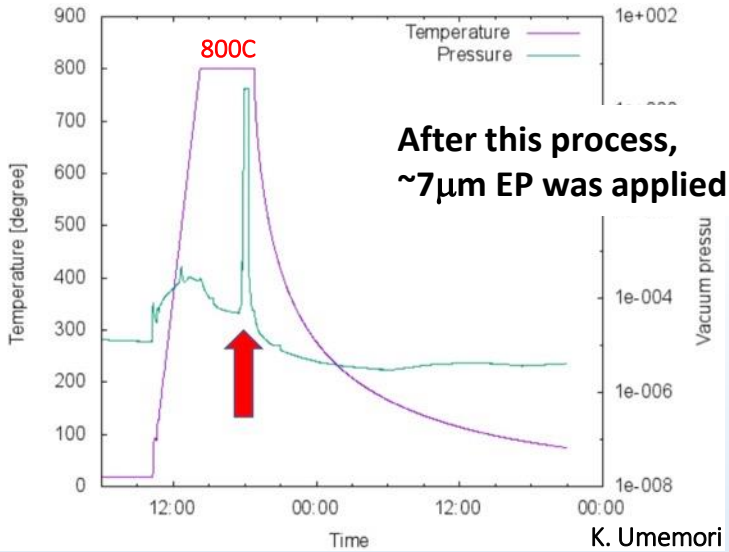
25mTorr N2
@800 deg C, 2min



High-Q

低損失

TTC meeting（2014/Dec） A. Melnychuk
「Update on N doping at Fermilab」

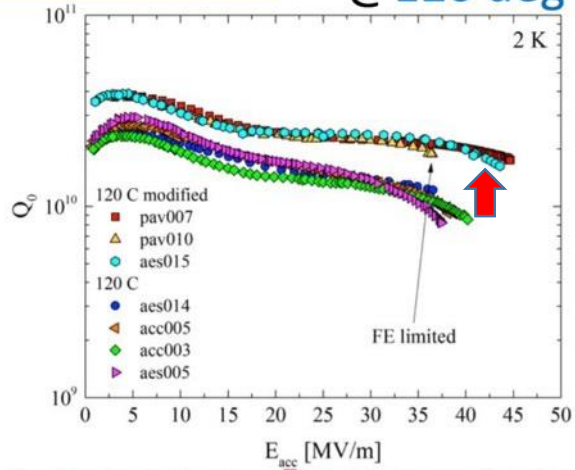


After this process,
~7μm EP was applied

K. Umemori

N-infusion

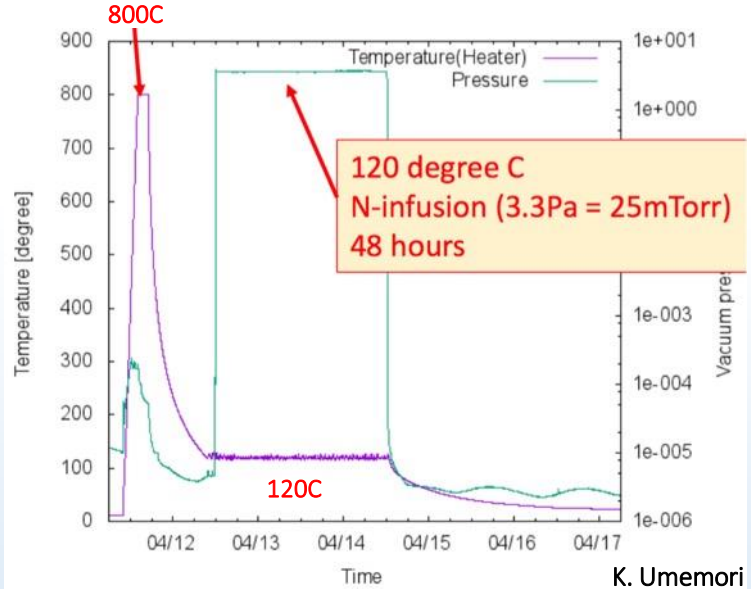
25mTorr N2
@120 deg C, 48hours



High-Q &
High-G

低損失
高電界

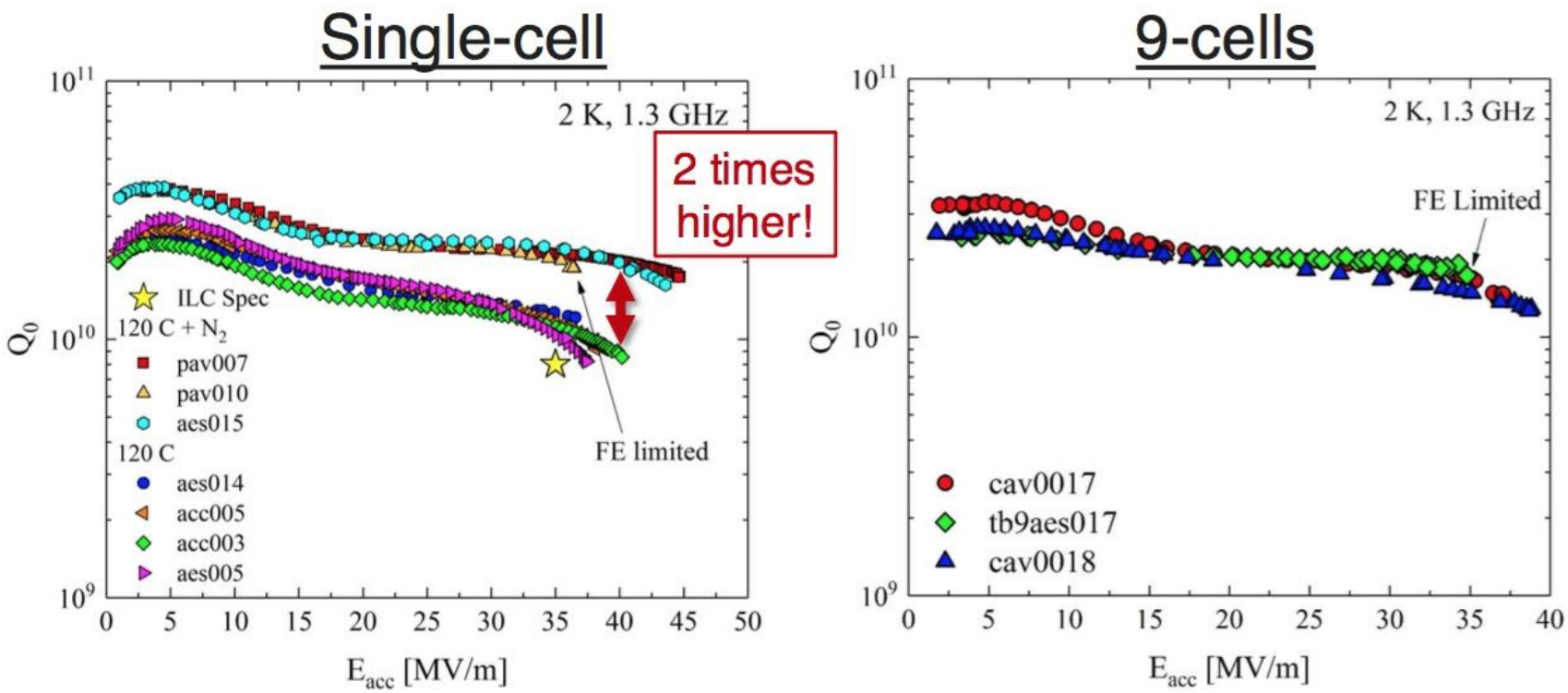
A. Grassellino 「High grad/high Q via N infusion」(LCWS2016)



K. Umemori

N-infusion was applied both 1-cell and 9-cell cavities

120 C N-infusion: high Q_0 at high gradients



Higher Q-factor at higher field may allow for higher duty-cycles and therefore higher luminosity!

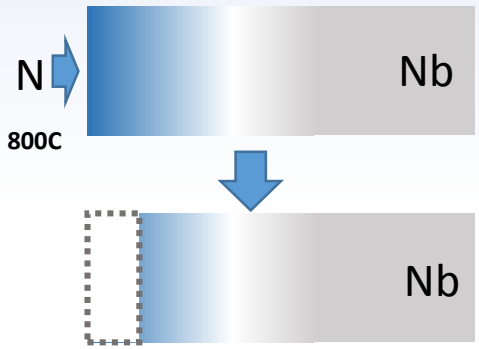
A. Grassellino *et al.*, **arXiv:1701.06077** (in publication to SUST)

Fermilab

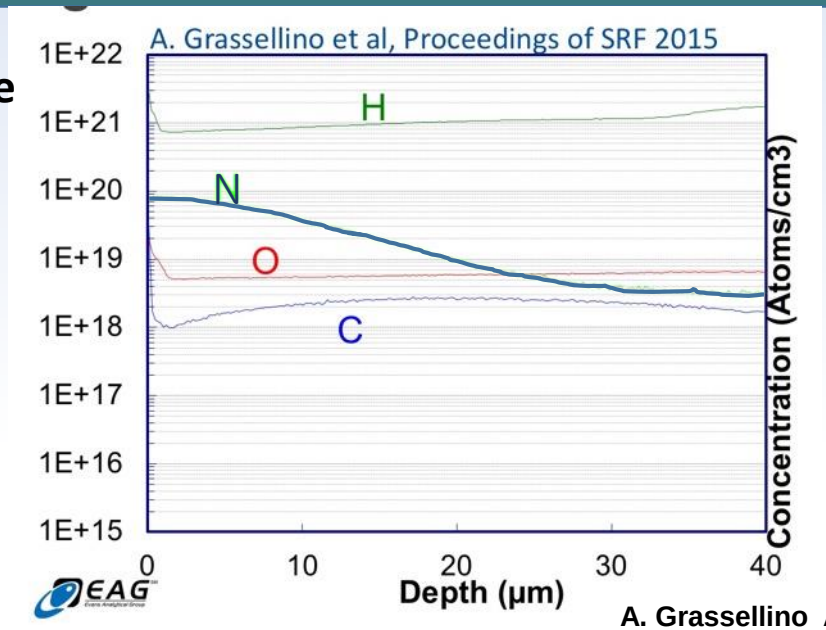
Surface structure of N-dope and N-infusion

Diffusion of N into Nb surface

N-dope



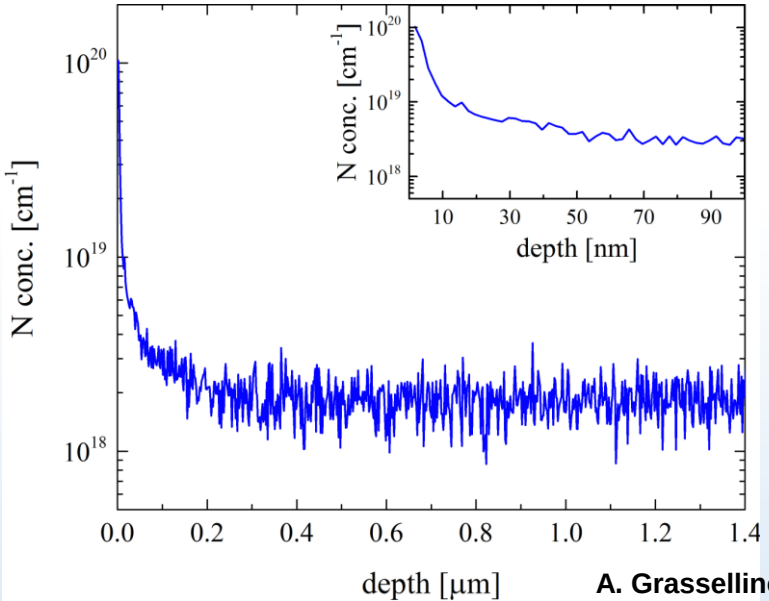
Removal by EP



Diffusion of N into Nb surface 20 – 30 μm

A. Grassellino ALCW2016

N-infusion

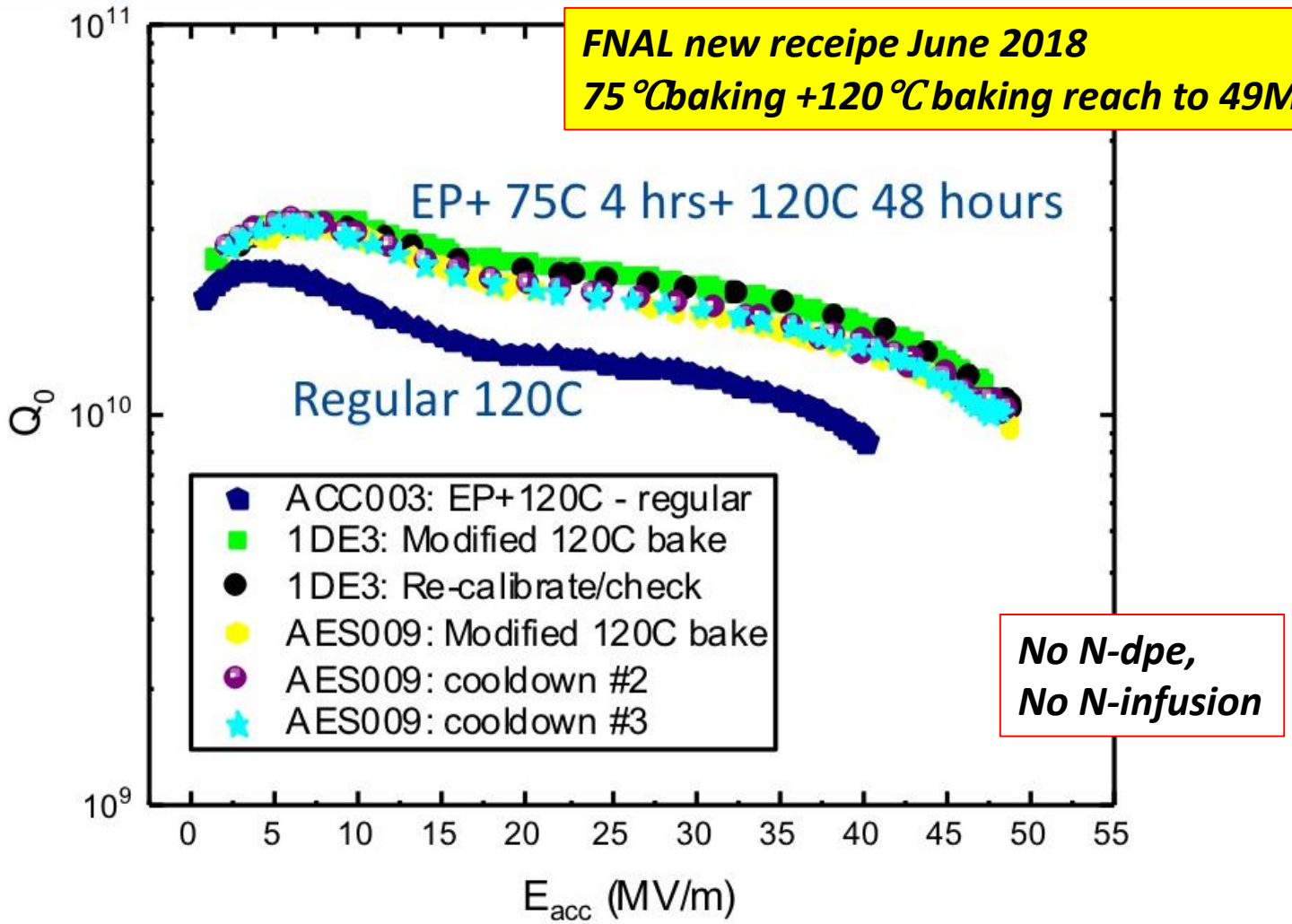


Diffusion of N into Nb surface around 200 nm

A. Grassellino ALCW2016

High-Q/High-G surface only by baking!!

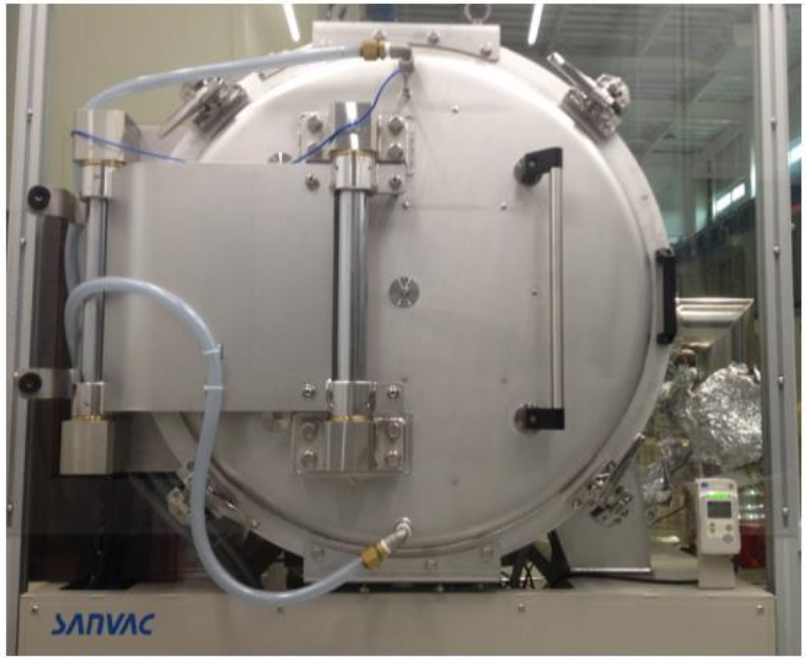
Repeated on second cavity TE1AES009 (fine grain, AES, WC)

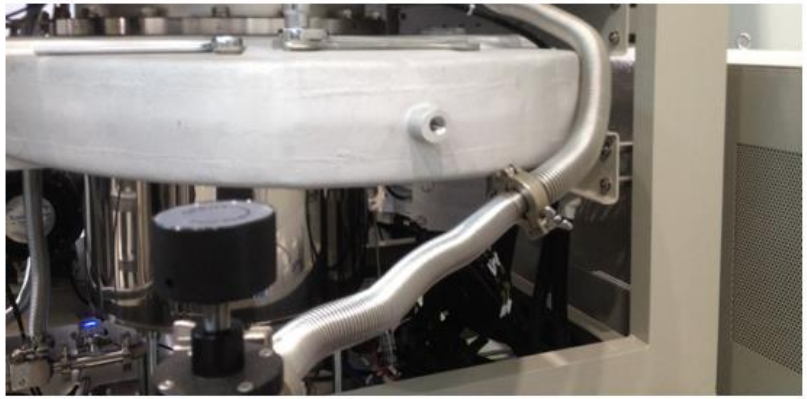


A. Grassellino et al, https://arxiv.org/abs/1806.09824

New Furnace for N-infusion R&D at KEK

KEK new furnace(located at COI)





- Completed at the end of FY2017
- Cryopump for main pump, oil-free pumping system.
- Molybdenum is used for heater, reflector, table etc.
- TMP is used during N-injection, can reach ~2e-5Pa.
- Clean-booth surround entrance door.

K. Umemori

Summary of KEK N-infusion

Summary of N-infusion @KEK new furnace

#	Day (N-inf / VT)	Cavity name	# of cell	Nb	Treatment	Results	Eacc (MV/m)	Comment
1	Jun-6 / Jun-21	R-6	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	No Q-degradation	35	
2	Jun-13 / Jul-2	R-9b	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	No Q-degradation	26	Quench due to defect
3	Jun-20? / Jul-5	R-10	3	LG	800C, 3h + 120C, 48h, 3.3Pa N2	No Q-degradation	27	F.E. limited
Summer shutdown								
4	Sep-9 / Oct-5	R-2	1	FG	800C, 3h + 160C, 48h, 3.3Pa N2	Strong Q-degradation	19	No defects found
5	Oct-6 / Oct-18	R-6	1	FG	800C, 3h + 120C, 48h (without N2)	Q-degradation (like J-PARC)	32	
6	Nov-23 / Dec-5	R-8	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	Better Q than reference	36	
7	Dec-21 / Jan-23	R-9b	1	FG	800C, 3h + 160C, 48h, 3.3Pa N2	Q-degradation (like J-PARC)	24	Quench due to defect
8	Jan-31 / Feb-14	AES018	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	No Q-degradation	38	No reference data at KEK

K. Umemori