Future Linear Collider and its LLRF system

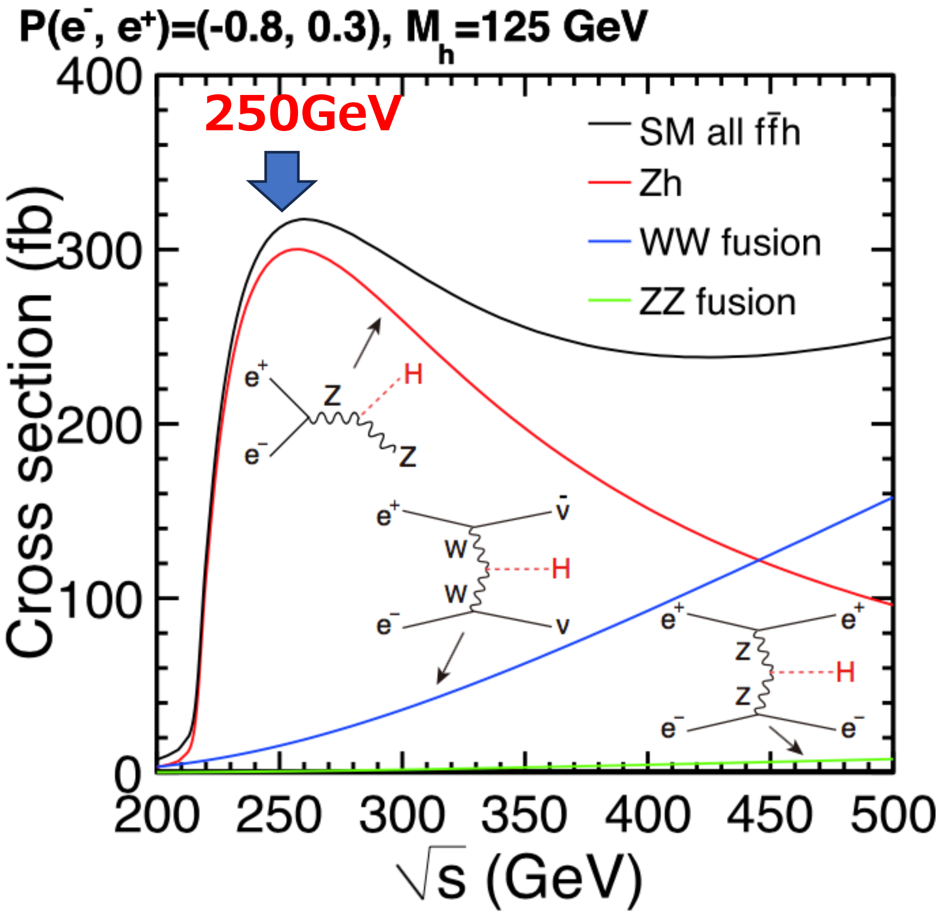
KEK / IDT-WG2
Shin MICHIZONO (KEK)

- Higgs factory
- International Linear Collide (ILC)
- RF system for the ILC
- Digital Feedback system
  - Brief History @KEK
  - Proto-type of the ILC llrf
- Current status of ILC R&Ds
  - ILC Technology Network
  - Worldwide activities

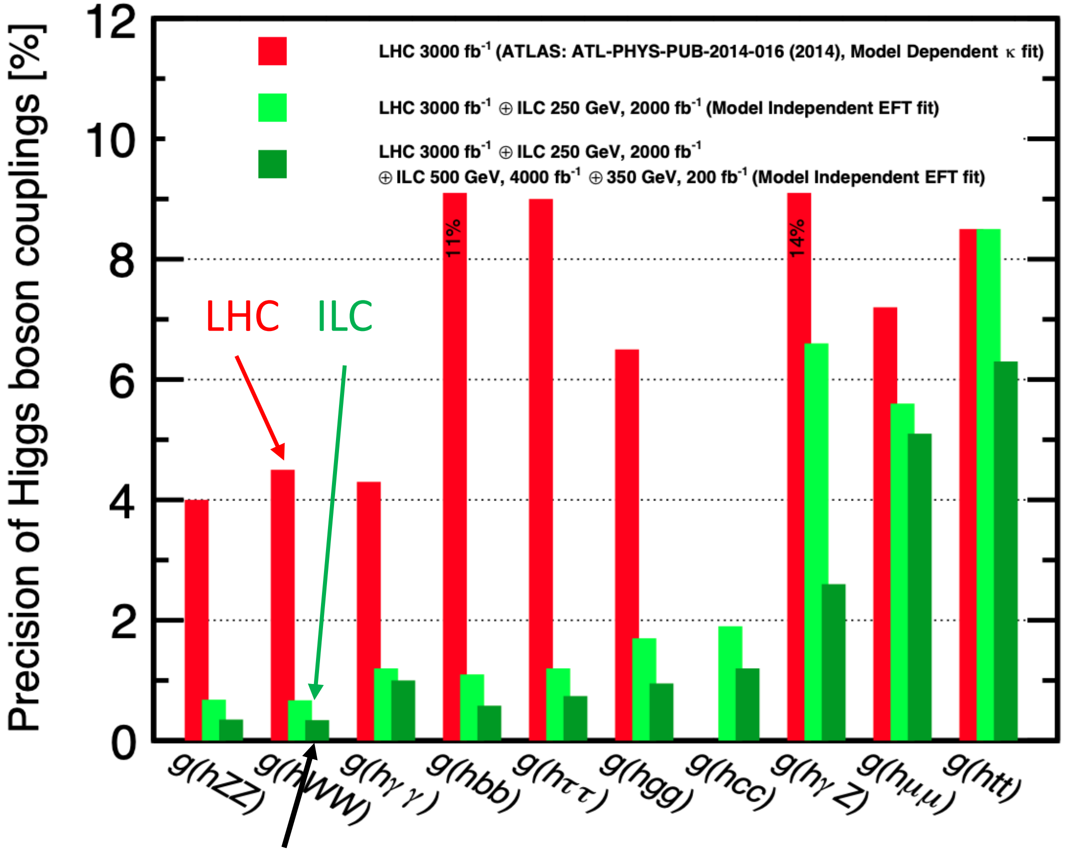
Physics of Higgs factory (including ILC) (Target of energy and precision)

Courtesy of M.Ishino.

Jorge de Blas, "Physics case for e+e- Higgs/Electroweak factories" LCWS2024.



Example :Higgs coupling (LHC & ILC)



Need e-e+ CM energy **above 250GeV**.
For example, 350GeV and 500GeV physics in the future.

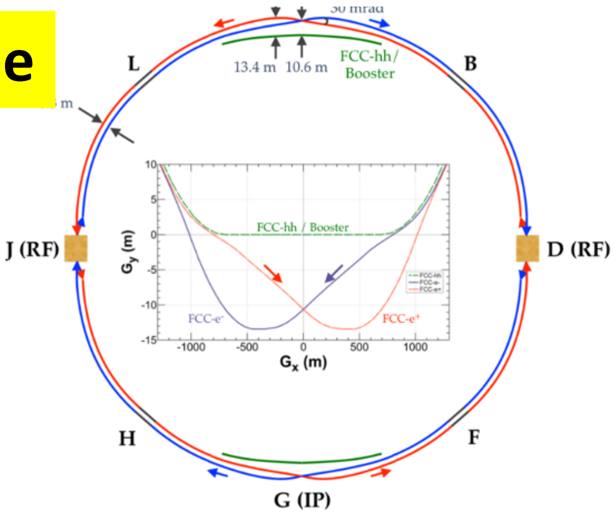
Higgs coupling was precisely measured by ILC than LHC.

e+e- collider can precisely measure the properties of Higgs particles.

Candidates of Future e+e- colliders for a Higgs factory

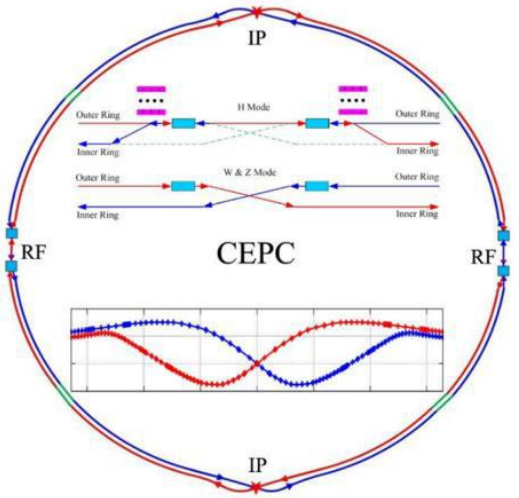
- **Circular Collider**

FCC-ee



Circumference 90~100km

CEPC



Merit:
Based on circular collider technology

Demerit:
SR loss is very severe. Energy upgrade is difficult for more than 350 GeV CM.

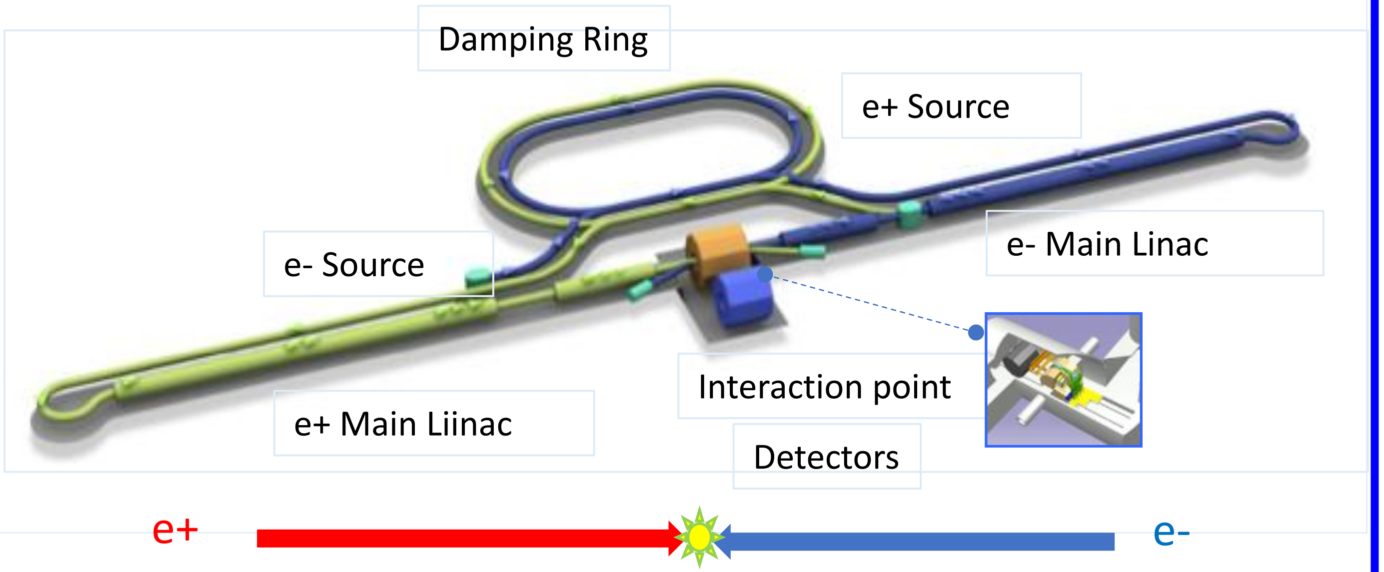
Frank Zimmermann, CERN, "Highlights from the future Circular Collider feasibility study and path to construction" IPAC'25, Friday

- **Linear Collider**

Today's focus

ILC (International Linear Collider)

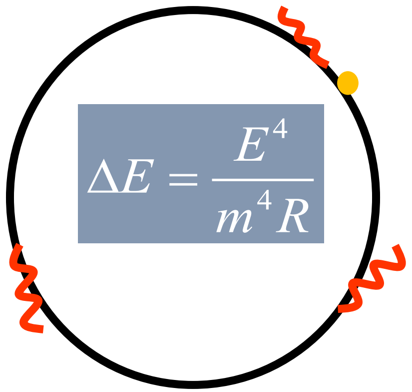
Global project



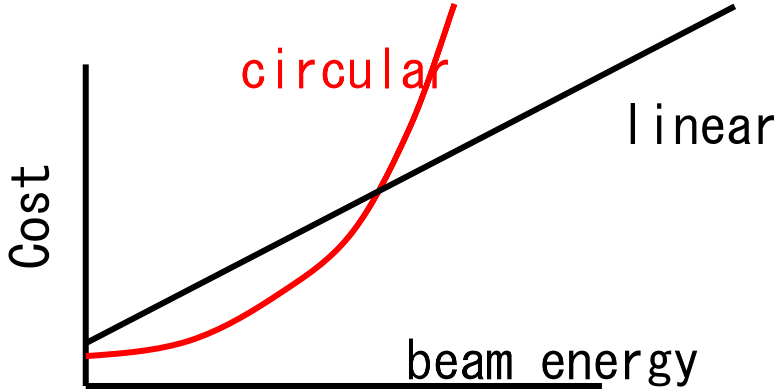
ILC250 focuses on Higgs Factory;
Length becomes 20km
Shorter than LHC

Main advantages of the ILC

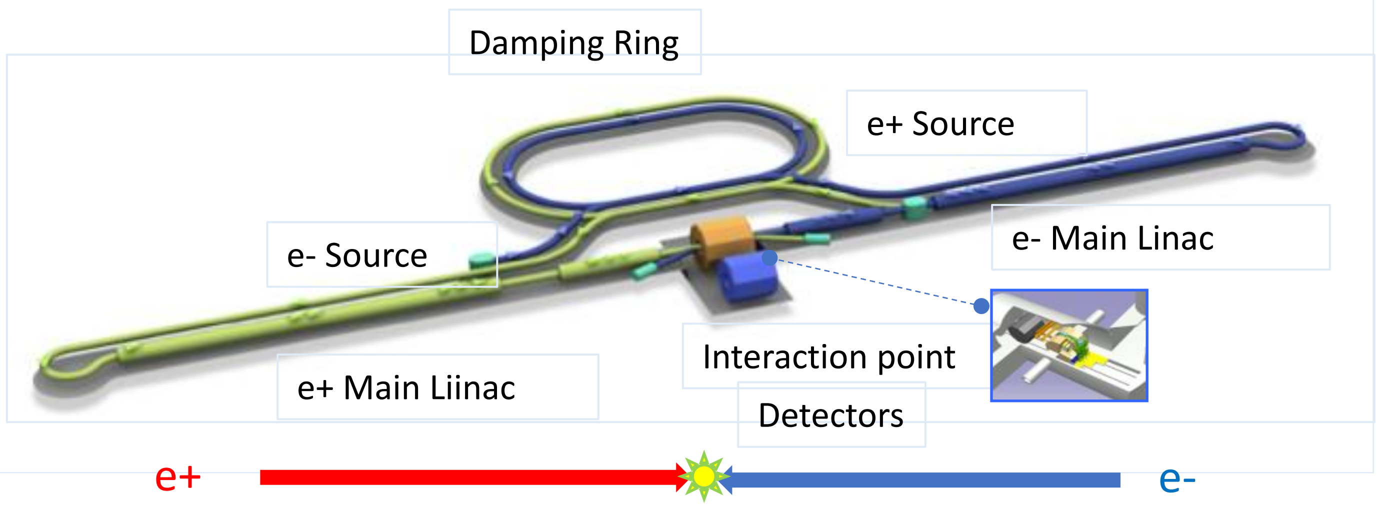
- A linear accelerator is more advantageous for accelerating electron and/or positron beams to higher energies.
- The spin of the electron and/or positron beam can be maintained during the acceleration and collision. This can help significantly improve measurement precision.
- The small surface resistance of the SRF accelerating structure (cavity) made of Nb enables the efficient power transfer from the AC power source to the beam.

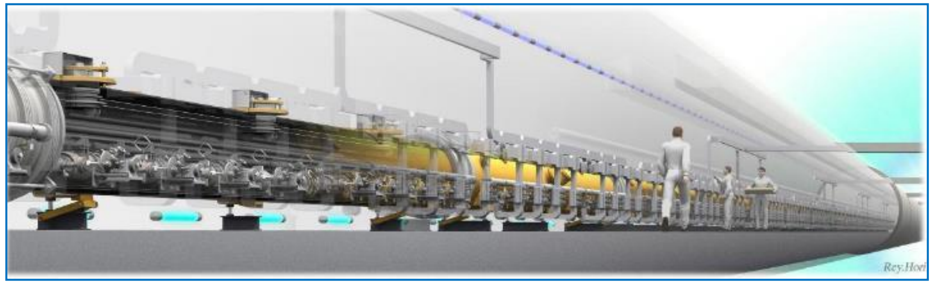


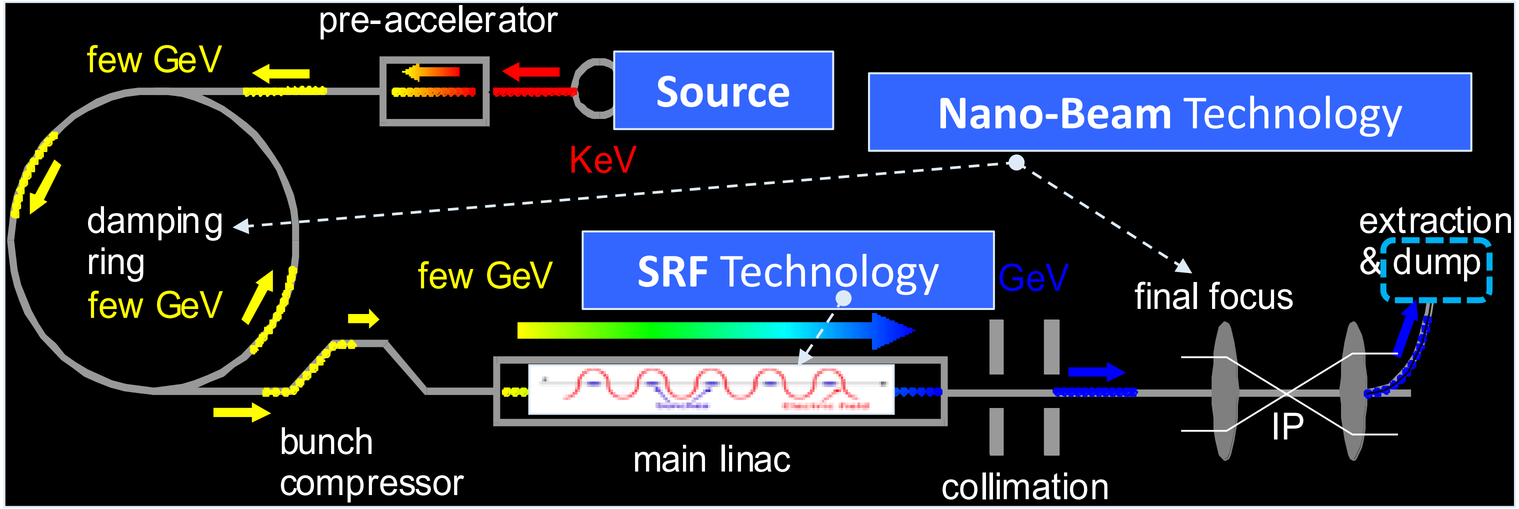
Circulating beam loses energy by synchrotron radiation.
Linear collider can extend its collision energy by longer tunnel/ higher gradient.



ILC and the Accelerator Technology







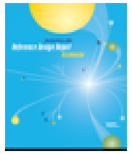
Parameters	Value
Beam Energy	125 + 125 GeV
Luminosity	1.35 / 2.7 x 10^{34} cm^2/s
Beam rep. rate	5 Hz
Pulse duration	0.73 / 0.961 ms
# bunch / pulse	1312 / 2625
Beam Current	5.8 / 8.8 mA
Beam size (y) at FF	**7.7** nm
SRF Field gradient	< 31.5 > MV/m (+/-20%) Q_0 = $1x10^{10}$
#SRF 9-cell cavities (CM)	~ 8,000 (~ 900)
AC-plug Power	111 / 138 MW

History of ILC Collaboration

2004 ‘06 ’07 ’08 ‘09 ‘10 ‘11 ‘12 ‘13 ‘14 ‘15 ‘16 ‘17 ‘18 ‘19 ‘20 ‘21 ’22 ’23 ’24 ‘25

RDR | ILC-GDE | **TDR** | LCC

LC Technology Selection by ITRP

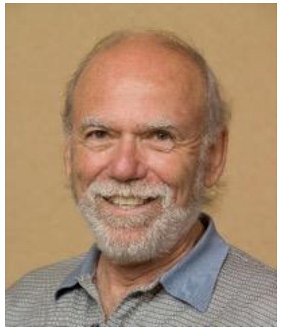


ILC technical design

TDR:
49 countries
392 institutions
>2400 researchers

International ***D***evelopment ***T***eam

Tatsuya Nakada (EPFL)
IDT chair



Barry Barish
GDE director
(the Nobel Prize winner in 2017)

Lyn Evans
LCC director
(former LHC project manager)

LHC

European XFEL

LCLS-II

SRF technology matured after European XFEL/LCLS-II

IDT organization

ICFA

ILC International Development Team

Executive Board

Americas Liaison Andrew Lankford (UC Irvine)
Working Group 3 Chair Jenny List (DESY)
Working Group 2 Chair Shinichiro Michizono (KEK)
Executive Board Chair and Working Group 1 Chair Tatsuya Nakada (EPFL)
KEK Liaison Kazunori Hanagaki (KEK)
Europe Liaison Steinar Stapnes (CERN)
Asia-Pacific Liaison Geoffrey Taylor (U. Melbourne)

Working Group 1
Pre-Lab Setup

Working Group 2
Accelerator

Working Group 3
Physics & Detectors

International Expert Panel
Decision Process for a global project applicable to the ILC

IDT-WG2

IDT-WG2 has about 50 accelerator researchers from around the world participating in discussions on ILC accelerator development research.

ILC Cost Reassessment in Proposal for European Strategy

https://ilc-japan.org/document/

	250GeV ILC(2017)		250GeV ILC(2024)		FCC-ee*	
	TDR-scaled[1]	日本円評価 [Oku-yen] [2]	ESPPU'26[3]	日本円評価 [Oku yen]	[MCHF]	[Oku yen]**
加速器及び測定器建設経費 (Accelerator & Detectors)		8,033		13,765		
加速器建設費 (Accelerator)	n/a	7,028	n/a	12,381		
土木建築+加速器本体 (CE + Accelerator)	5.26 BILCU	5,830	n/a	10,824	13,730	24,714
土木建設（施設工事費）(CE)	1.01 BILCU	1,290	196 BJPY	1,958	6,160	11,088
設備（電気・機械等）(CF)	0.71 BILCU	840	1.38 BILCU	1,791	2,840	5,112
加速器本体 (Accelerator)	3.54 BILCU	3,700	5.40 BILCU	7,075	4,730	8,514
研究所人員・据付人員 (HR)	10.1 k p.yr	1,198	10.1 k p.yr	1,557	---	---
測定器建設経費 (Detectors)	n/a	1,005	n/a	1,383		
測定器本体 (Detectors)	0.707BILCU	766	n/a	1,072[4]	1,590	2,862
人員 (HR)	2.15 k p.yr	239	2.15 k p.yr	311[4]	---	---
年間運転経費 (Operation)	n/a	392	n/a	633		
保守 (Maintenance)	0.19 BILCU	186	0.27 BILCU	346		
電力 (Electricty)	0.83 TWh[5]	130	0.73 TWh[6]	188		
研究所人員 (HR)	638 FTE	76	638 FTE	99		

*https://agenda.infn.it/event/44943/timetable/#20250624.detailed Michael Benedikt, FCC-ee (incl. common infrastructure)
** 180 yen/CHF

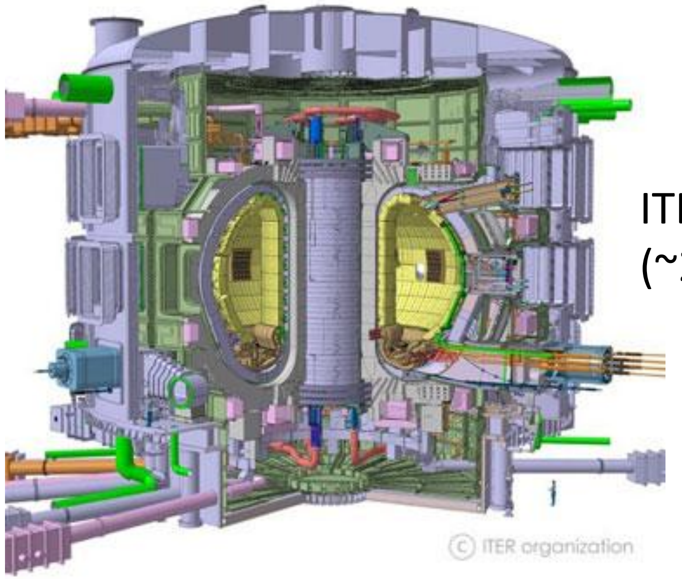
BILC=B$(2024)

1) The International Linear Collider Machine Staging Report 2017: https://arxiv.org/pdf/1711.00568
2) 国際リニアコライダー（ILC）に関する有識者会議　ILC計画の見直しを受けたこれまでの議論のまとめ: https://www.mext.go.jp/component/b_menu/shingi/toushin/__icsFiles/afieldfile/2018/09/20/1409220_1_1.pdf
3) European Strategy Input from IDT:https://indico.cern.ch/event/1439855/contributions/6461661/
4) 測定器本体の物件費についてはインフレーションを考慮して1.4倍とした。測定器人員は人件費上昇を考慮して1.3倍とした。全体に占める割合は10%程度で総建設費に与える影響としてはコンティンジェンシーの範囲に収まると想定。
5) 年間の70%（6130時間）運転（129MW）、30%（2630時間）を保守（12MW）と想定。
6) 2019年に運転時の電力の見直しを行った。年間の70%（6130時間）運転（111MW）、30%（2630時間）を保守（20MW）と想定。

Global project

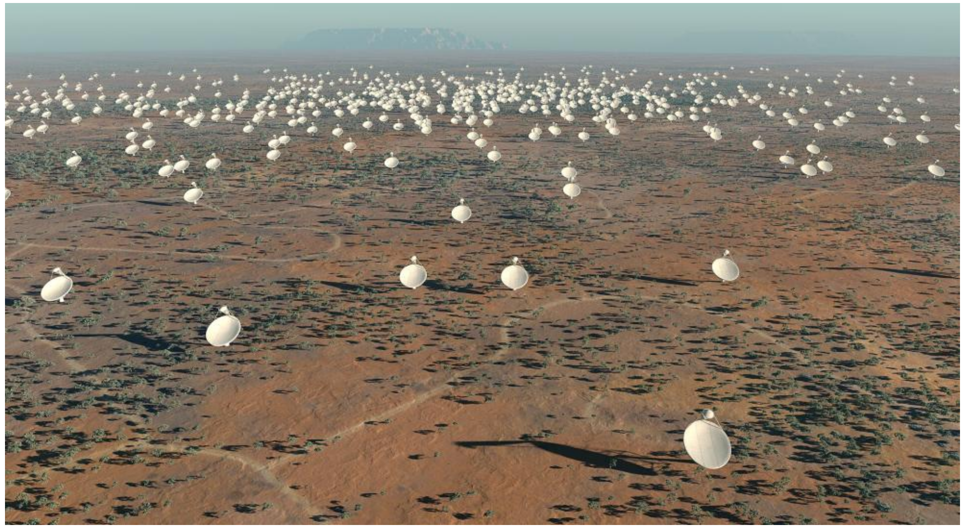
Global project: Starts and evolves as a collaborative project of partner countries who make collective decisions on all aspects of the project, such as the scheme for cost and responsibility sharing, project organisation, and host and site location. The ownership is shared among the partners. ITER (an example of top down approach) and SKA(Square Kilometer Array) (an example of bottom up approach) are examples of large global projects, while HEP projects to date have been international projects.

International project: Initiated as a project of a laboratory with a limited international participation, a total of *O*(10~20%) of the accelerator, like HERA (started as a DESY project) and LHC (started as a CERN project). This fraction may become larger but the ultimate ownership remains with the initiator.



ITER
(~25B-Euro)

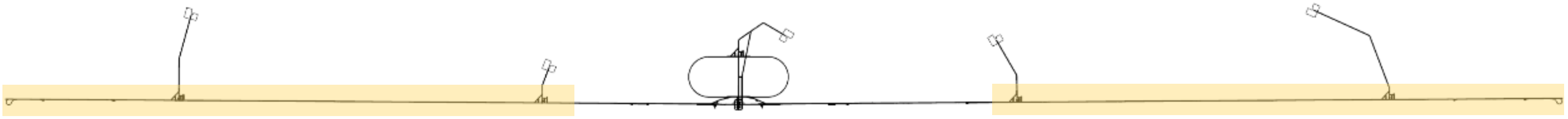
https://www.fusion.qst.go.jp/ITER/iter/page1_1.html



SKA
(~2.2B$)

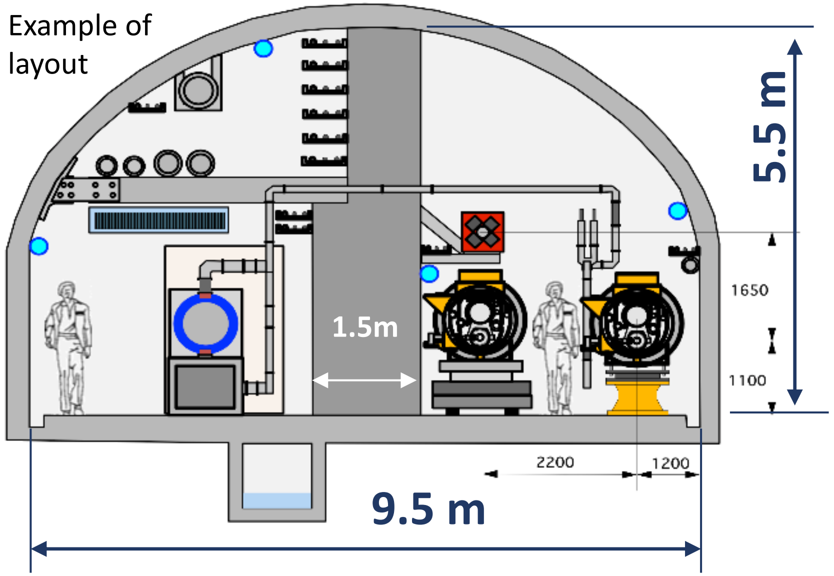
https://en.wikipedia.org/wiki/Square_Kilometre_Array

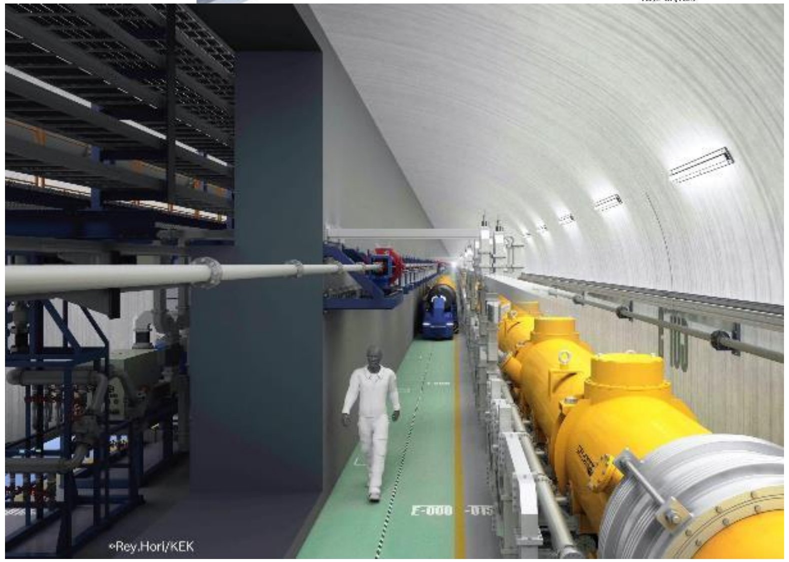
Main Linac (ML) tunnel



- 66 kV distribution cables
- Cooling water pipes
- Fan Coil Units
- Low power and signal cables
- RF klystrons and modulators
- Electric Power Stations

■ 15 km in (e+e-) total
■ follow the geoid in vertical
■ **Kamaboko 9.5m X 5.5m**
■ **1.5m central radiation shield**
■ Further optimization will be done.





- **ML Cryomodules**
- **RTML**
- Low power and signal cables

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RF system of the ILC

Table 3.19
Bunch Compressor RF dynamic errors, which induce 2 % luminosity loss.

Error	RMS amplitude	RMS phase
All klystron correlated change	0.5 %	0.32°
Klystron to klystron uncorrelated change	1.6 %	0.60°

Table 3.20
ML RF dynamic errors, which induce 0.07 % beam energy change.

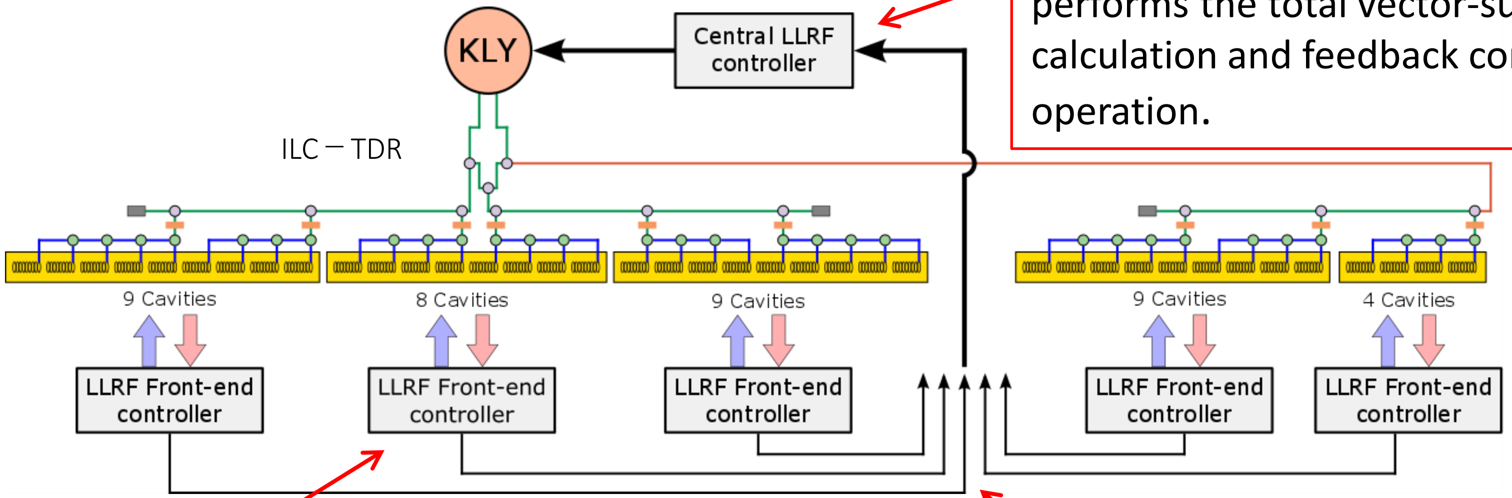
Error	RMS amplitude	RMS phase
All klystron correlated change	0.07 %	0.35°
Klystron to klystron uncorrelated change	1.05 %	5.6°

One RF Station:

- One 10-MW klystron
- 39 superconducting cavities

RF parameters:

- Pulsed mode
- Freq. = 1.3 GHz
- RF Pulse width = 1.65 ms
- Repetition rate = 5 Hz
- Gradient = 31.5 MV/m

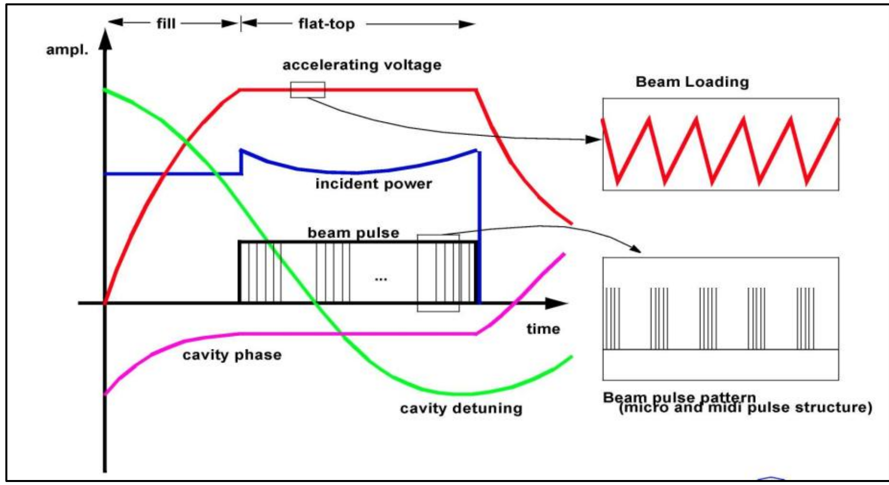


The central LLRF controller performs the total vector-sum calculation and feedback control operation.

Each front-end controller computes partial cavity-field vector-sums and sends those to the central LLRF controller.

Optical Communication Link

Master → Central controller
Slave → Front-end controller



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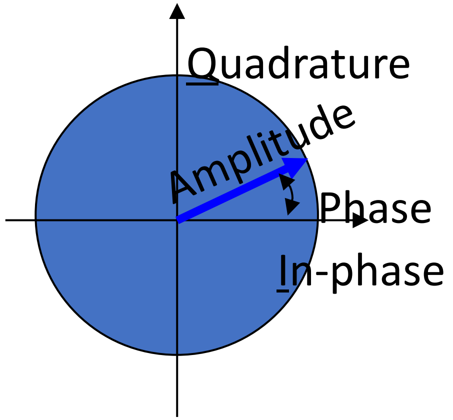
Digital LLRF System

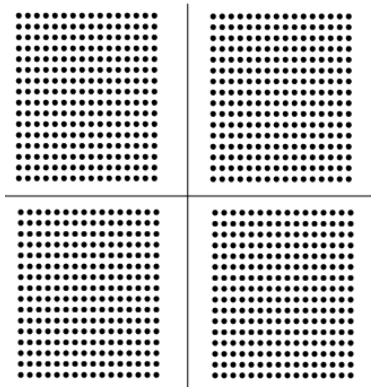
Analog FB(~100ns) : ～1% ~1990
High speed, but lacks flexibility and complex processing capabilities.
↓
DSP（~μs) : ～0.1% 1990~2000
Good for superconducting cavities, but too late for normal conduction.
↓
FPGA（Field Programmable Gate Array、~100ns) : ＜0.1% 2000~
(Not suitable for complex logic circuit processing, but simple FB calculations are possible.)

Thanks to advances in digital communications and other technologies, low-cost, high-performance high-frequency components and ADCs are now available.

Higher precision is required at digital llrf system.

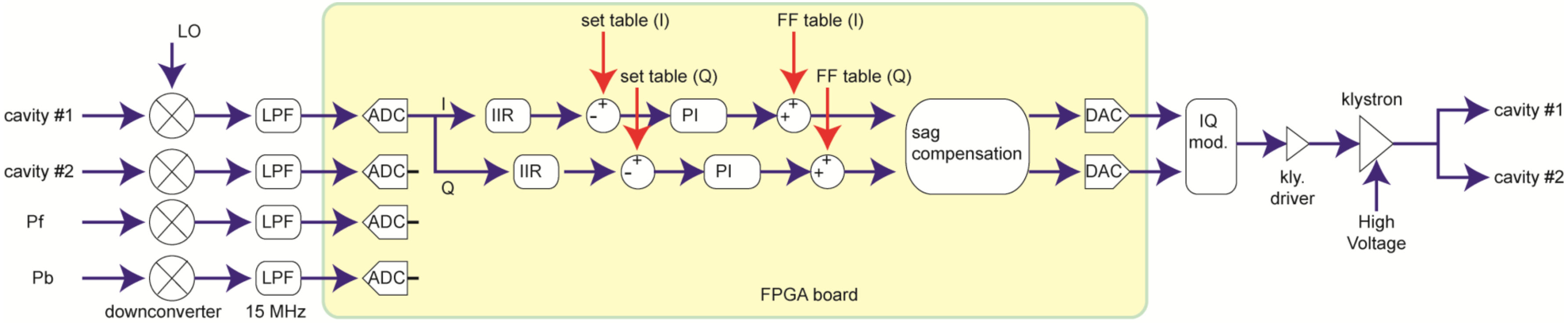
3,600,000 points (0.1%,0.1deg.) ⇔ 1024QAM (IEEE802.11ax)





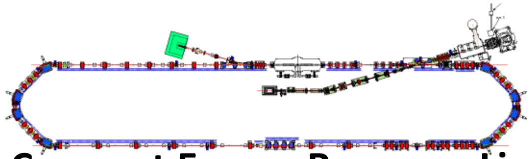
J-PARC linac adopted FPGA-based LLRF system in **1999**.

	Beam	Cavity	Amplitude	Phase
J-PARC,SNS	Proton	Normal	+/-1%	+/-1deg.
ILC	Electron	Super	0.1%	0.1deg.
XFEL/ERL	Electron	Super	0.01%	0.01deg.

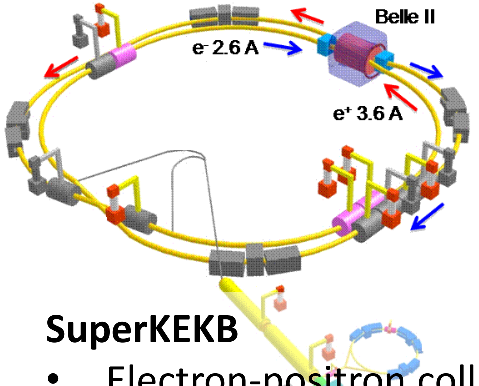


Facilities using TCA Hardware at KEK-Tsukuba and J-PARC

Superconducting RF Test Facility (STF)
- ILC R&D facility



Compact Energy Recovery Linac (cERL)
- Test facility for EUV-FEL



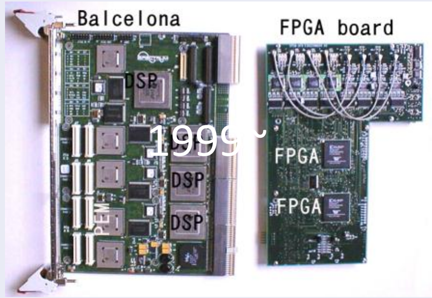
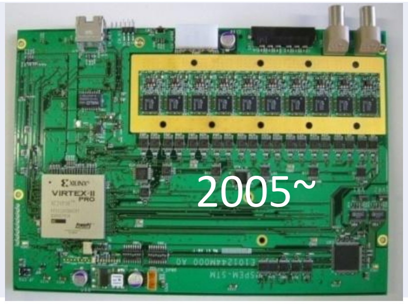
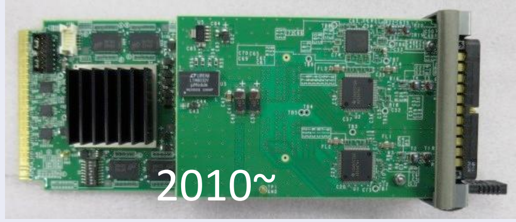
SuperKEKB
- Electron-positron collider
- Explore new physics beyond the standard model

PF
- 2.5GeV Light source

J-PARC (Japan Proton Accelerator Research Complex)

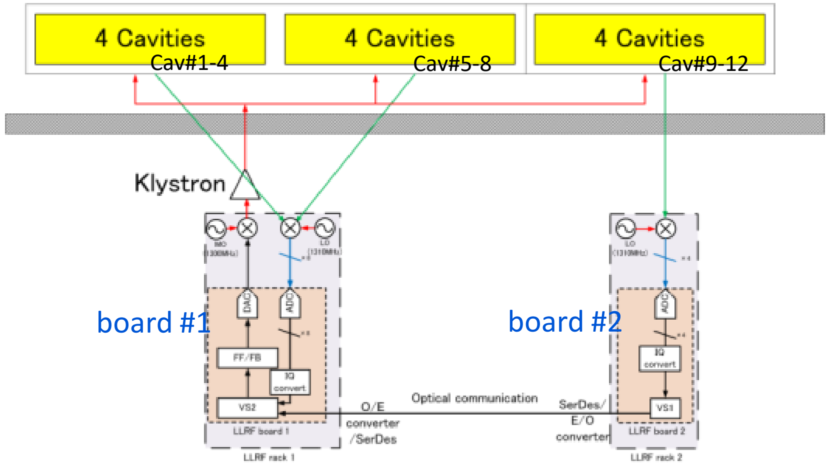
*Joint project of KEK and JAEA(Japan Atomic Energy Agency)

KEK's brief history of digital llrf system

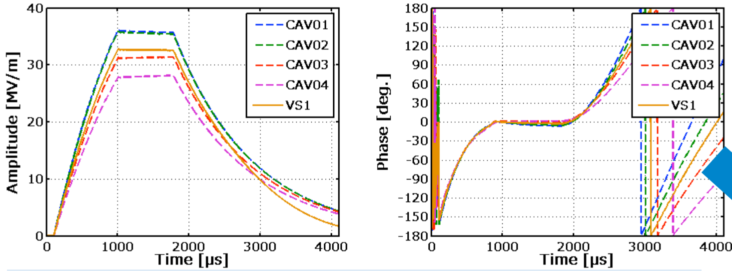
<table>
<tr><th></th><th>cPCI (PICMG 2.x)</th><th>uTCA</th><th>MTCA.4</th><th>MTCA.4</th></tr>
<tr><td>Area</td><td>J-PARC Linac (NC, pulse)
4ch 14bit ADCs (65MSPS)
4ch 14bit DACs (100MSPS)</td><td>STF (SC, pulse)
SuperKEKB (CW)
cERL (SC CW)
4ch 16bit ADCs (130MSPS)
4ch 16bit DACs (500MSPS)</td><td>STF (SC, pulse)</td><td>PF (CW)
J-PARC Linac (NC, pulse)</td></tr>
<tr><td></td><td>
</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Area</td><td>STF (SC, pulse)
8 cav. Vector sum
10ch 16bit ADCs (105MSPS)
2ch 14bit DACs (100MSPS)</td><td>STF (SC, pulse)
SuperKEKB (CW)
2ch 14bit ADCs (400MSPS)</td><td></td><td></td></tr>
<tr><td></td><td>
</td><td>
</td><td>14ch 16bit ADCs (80MSPS)
2ch 16bit DACs (160MSPS)</td><td>8ch 16bit ADCs (370MSPS)
2ch 16bit DACs (500MSPS)</td></tr>
</table>

STF-LLRF: Prototype of ILC

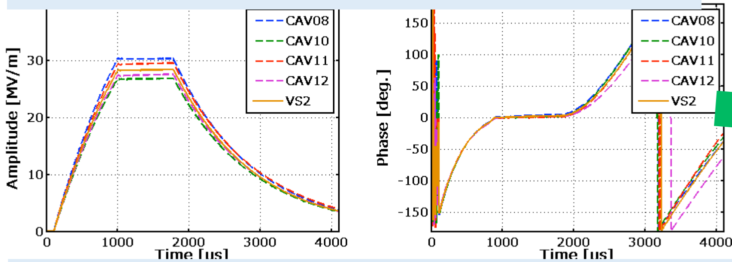
- Vector-sum feedback control with two digital boards connected by **optical communication** was demonstrated.



Cavity-field vector-sum in digital board #1



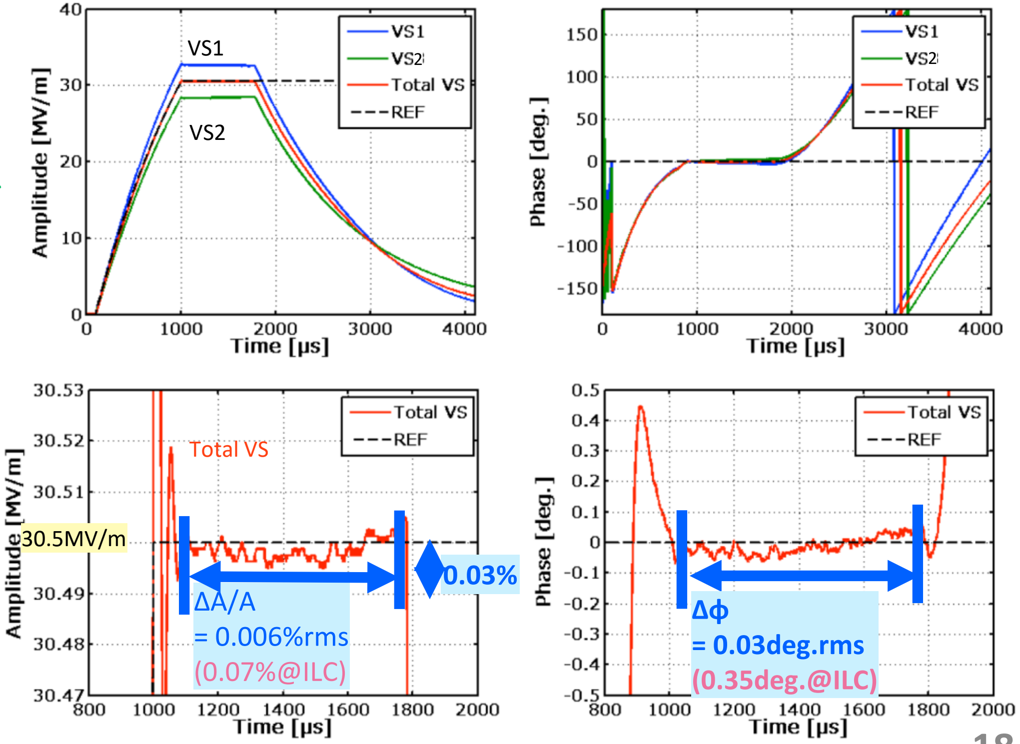
Cavity-field vector-sum in digital board #2



- MTCA.4 standard hardware.
- Zynq-7000(XC7Z045), Spartan6(XC6SLX)
- 14ch ADCs (AD9650, 16bit)
- 2ch DACs (AD9783, 16bit)
- FPGA clock = 162.5 MHz
- ADC/DAC clock = 81.25 MHz

VS1

VS2



- 8 SC cavities were operated with average 30.5 MV/m under vector-sum feedback control.
- Two digital boards connected by optical communication were demonstrated and the regulation stability performance satisfies the ILC requirements (ΔA/A = 0.07%, Δϕ = 0.35°).

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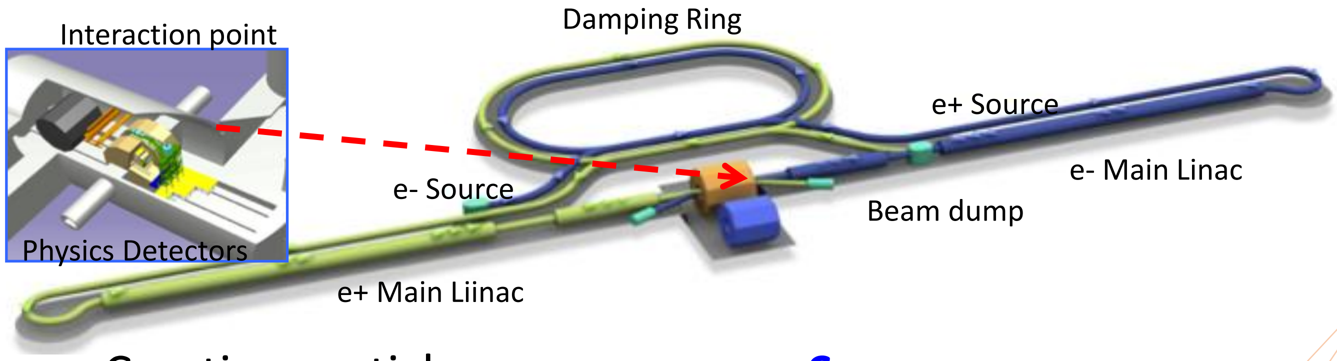
ILC Technology Network

Time-consuming and essential work packages for ILC are summarized as **ILC Technology Network (ITN)**.
https://linearcollider.org/wp-content/uploads/2023/09/IDT-EB-2023-002.pdf



- Creating particles — ***Sources***
  - polarized elections / positrons
- High quality beams — ***Damping ring***
  - Low emittance beams

ITN is useful not only for the ILC but also **for various advanced accelerators**.

- Acceleration — ***Main linac***
  - superconducting radio frequency (SRF)
- Getting them collided — ***Final focus***
  - nano-meter beams
- Go to ***Beam dumps***

ILC Technology Network (ITN)

-- global collaboration program--

- **Acc. R&Ds** focusing on
  - SRF
  - e- & e+ Sources
  - Nano-beam

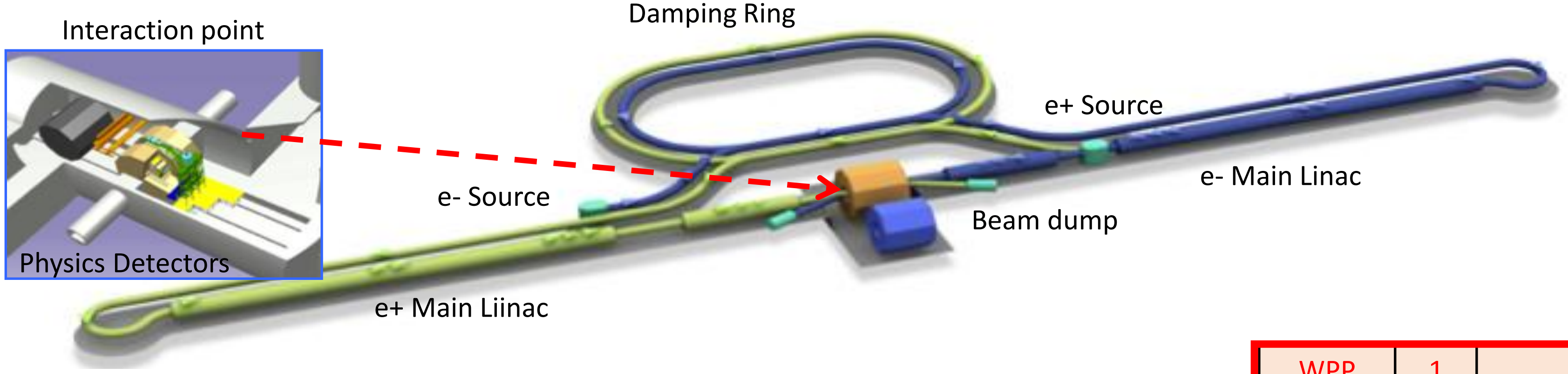
SRF

e-, e+ Sources

Nano-Beam

WPP	1	Cavity production	Jp., Eu. ,Kr.
WPP	2	CM design	Jp., Eu. ,Kr.
WPP	3	Crab cavity	
WPP	4	E- source	
WPP	6	Undulator target	Ger.
WPP	7	Undulator focusing	Ger.
WPP	8	E-driven target	Jp.
WPP	9	E-driven focusing	Jp.
WPP	10	E-driven capture	Jp.
WPP	11	Target replacement	Jp.
WPP	12	DR System design	Jp., Kr., Au.
WPP	14	DR Injection/extraction	UK
WPP	15	Final focus	Jp., Eu., Kr.
WPP	16	Final doublet	
WPP	17	Main dump	Jp.

KEK's efforts



KEK started the activity from April,2023.

令和５年度

将来加速器の性能向上に向けた重要要素技術開発
（先端加速器共通基盤技術研究開発費補助金）

公募要領

MEXT Development of key element technologies to improve the performance of future accelerators Program
文科省補助金　将来加速器の性能向上に向けた重要要素技術開発
advanced Accelerator element Technology Development (MEXT-ATD)

文部科学省　研究振興局
令和５年２月

SRF	WPP	1	Cavity production	Collaboration with Europe, Korea,
	WPP	2	CM design	
	WPP	3	Crab cavity	
e-, e+ Sources	WPP	4	E- source	
	WPP	6	Undulator target	
	WPP	7	Undulator focusing	
	WPP	8	E-driven target	Experiences at SuperKEKB
	WPP	9	E-driven focusing	
	WPP	10	E-driven capture	
	WPP	11	Target replacement	
Nano-Beam	WPP	12	DR System design	
	WPP	14	DR Injection/extraction	
	WPP	15	Final focus	ATF collaboration
	WPP	16	Final doublet	
	WPP	17	Main dump	

Superconducting RF (SRF)

WPP-1: Cavity production

Cavity fabrication
↓
Surface treatment
↓
Performance test（cavity only）
(called as vertical test)
↓
(WPP-2: to cryomodule)

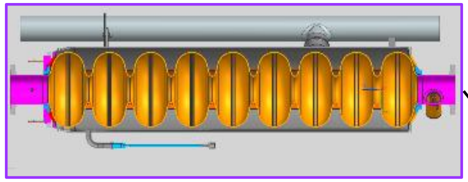
WPP-2: Cryomodule design

Design of CM and ancillaries
↓
Production of components
↓
Cavity string assembly
↓
CM assembly
↓
CM test

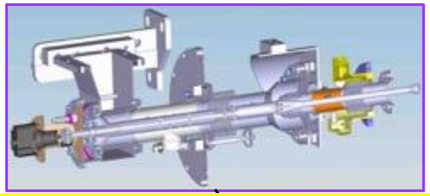
Under WPP-2, we only need to design the ITN cryomodule. However, **the cavity performance test is also important after cryomodule assembly** to fulfill our target of ILC.

Target values of cavity performance
◆vertical test (cavity only):
E_{acc} = <35.0 MV/m >, $Q_0 = 1.0 \times 10^{10}$
◆Cryomodule test :
E_{acc} = <31.5 MV/m >, $Q_0 = 1.0 \times 10^{10}$

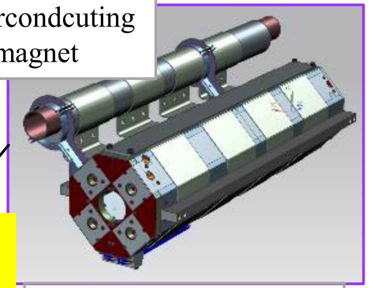
cavity



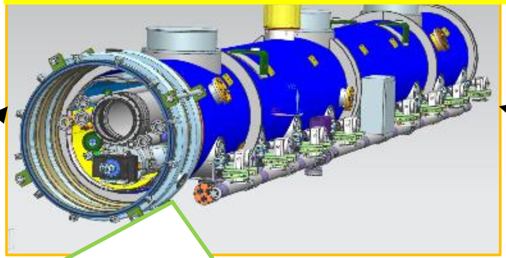
Input coupler



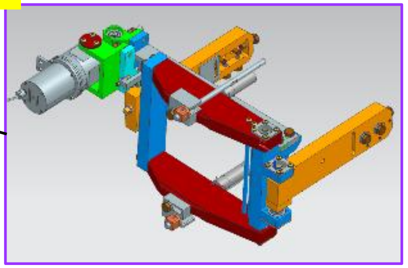
Supercondcuting magnet



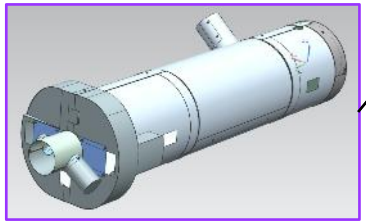
Build high performance SRF cryomodule



Freqency Tuner



Magnetic shield



We perform the cryomodule test by gathering Japan and other countries (EU and so on) (under ITN collaboration)

design ILC-CM under ITN

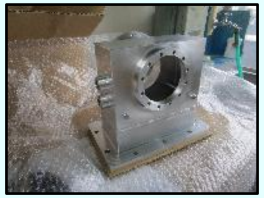
8 cavities will be delivered globally and assembled to one CM, and tested

WPP-1/2 cavity production & cryomodule(Japan)

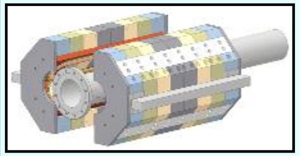
Production ~2025

L-band SC 9-cell cavity

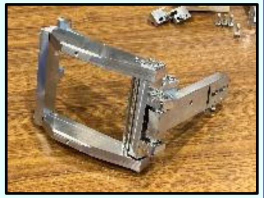
Power coupler



SCQ magnet



Frequency tuner

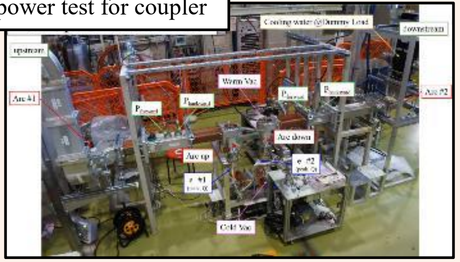


Magnetic shield

Component Test 2025/26

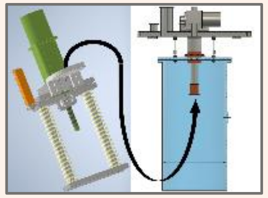
Vertical test for cavity

High power test for coupler



Conduction cooling system for SCQ

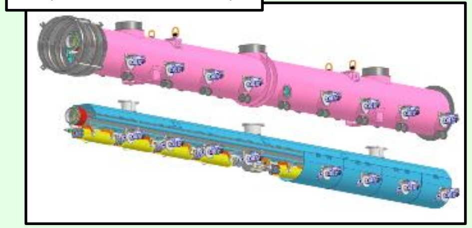
Cold test for motor



Installation ~2026

Demagnetization of cryo-vessel

Cryomodule assembly

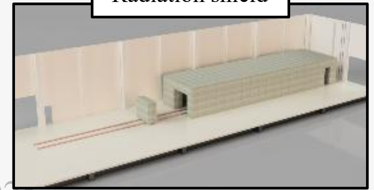


Preparation

Cryogenic

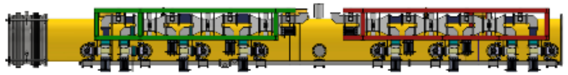
CM assembly hall

Radiation shield



CM Test ~2027

Waveguide assembly



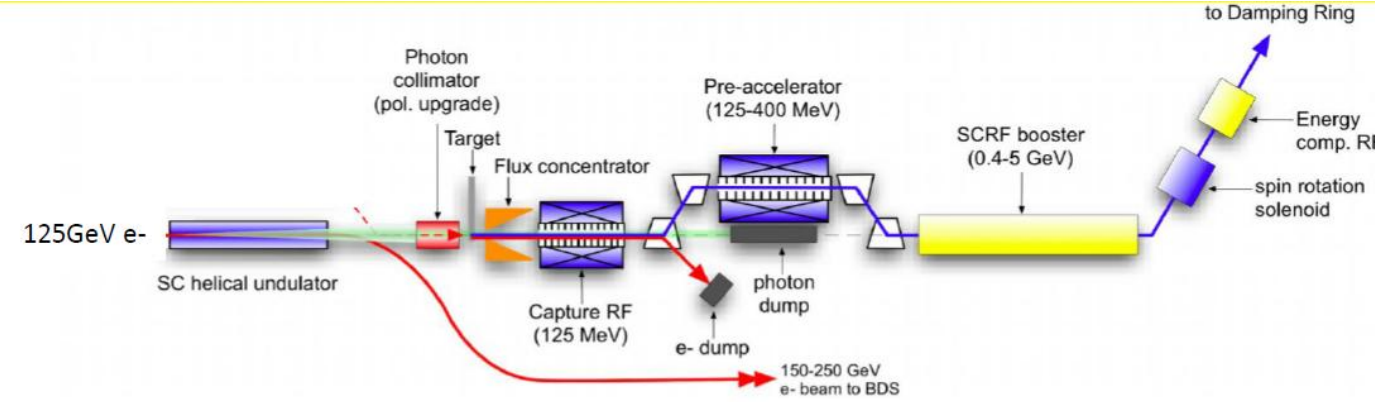
One CM test

Installation into bunker

Cold test at bunker

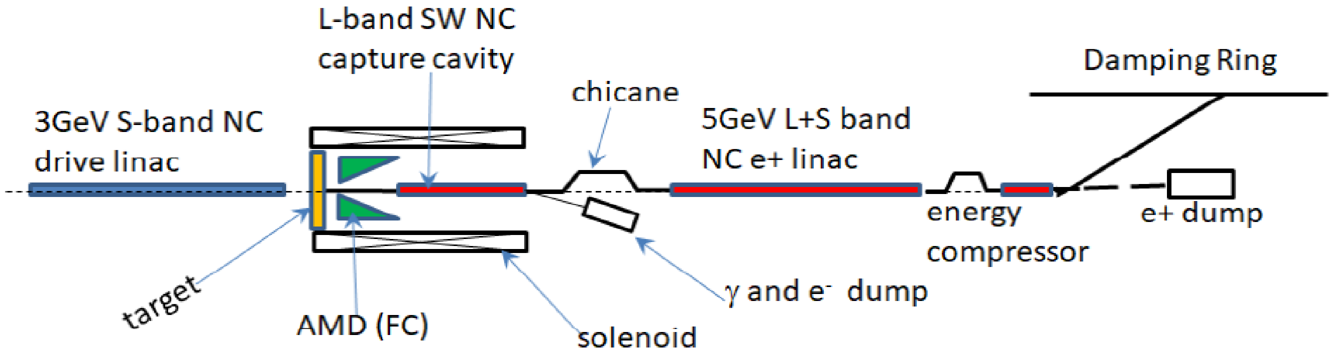
Positron source

Undulator scheme: 125 GeV electrons are passed through a helical undulator, and the produced gamma rays hit the target to produce electron-positron pairs. Polarized positrons (30%) are obtained. Need 125 GeV electron beam.



Developed in mainly EU.

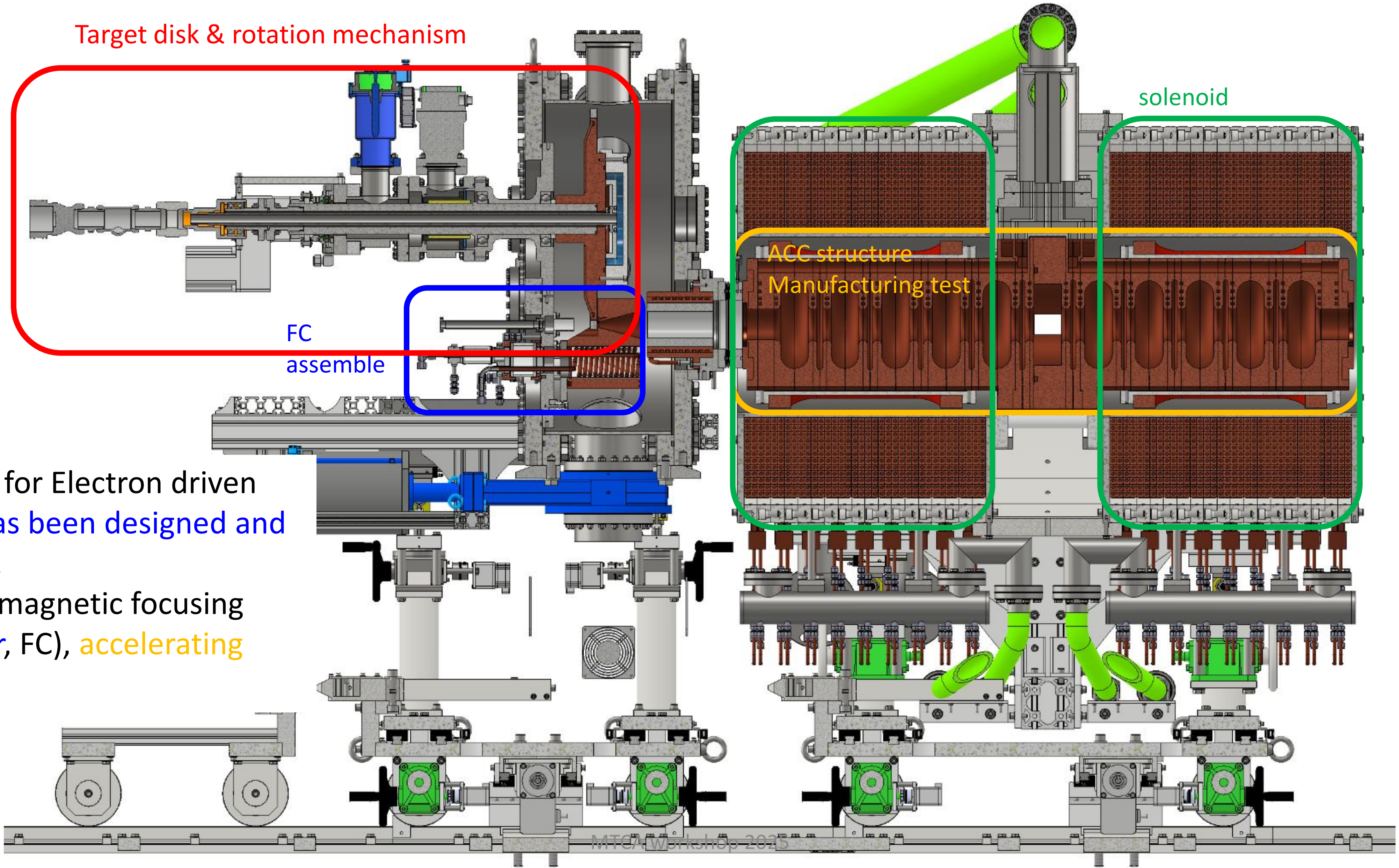
Electron driven scheme：3GeV electrons hit the target to produce electron-positron pairs. High-energy electrons are not necessary, and the commissioning of the positron production is independent from electron beam commissioning.



Developed mainly in Japan.

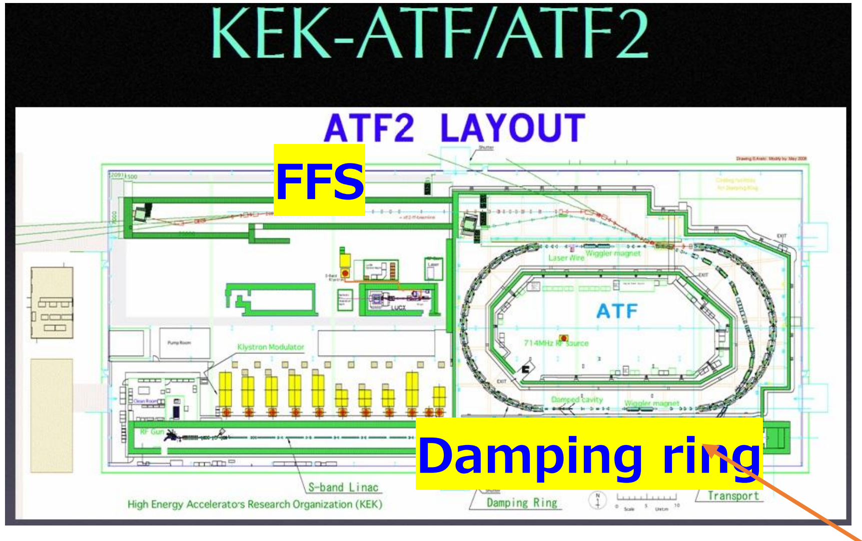
Both needs strong target and sophisticated design of Flux concentrator and capture section (cavity and solenoid) **→ In KEK, prototype of positron source based on e-driven method start to develop.**

WPP-8/9/10: e-Driven positron source (JFY2023-2024)



Key components* for Electron driven positron source has been designed and partly prototyped.
* Rotating target, magnetic focusing (Flux Concentrator, FC), accelerating structure

Nanobeam



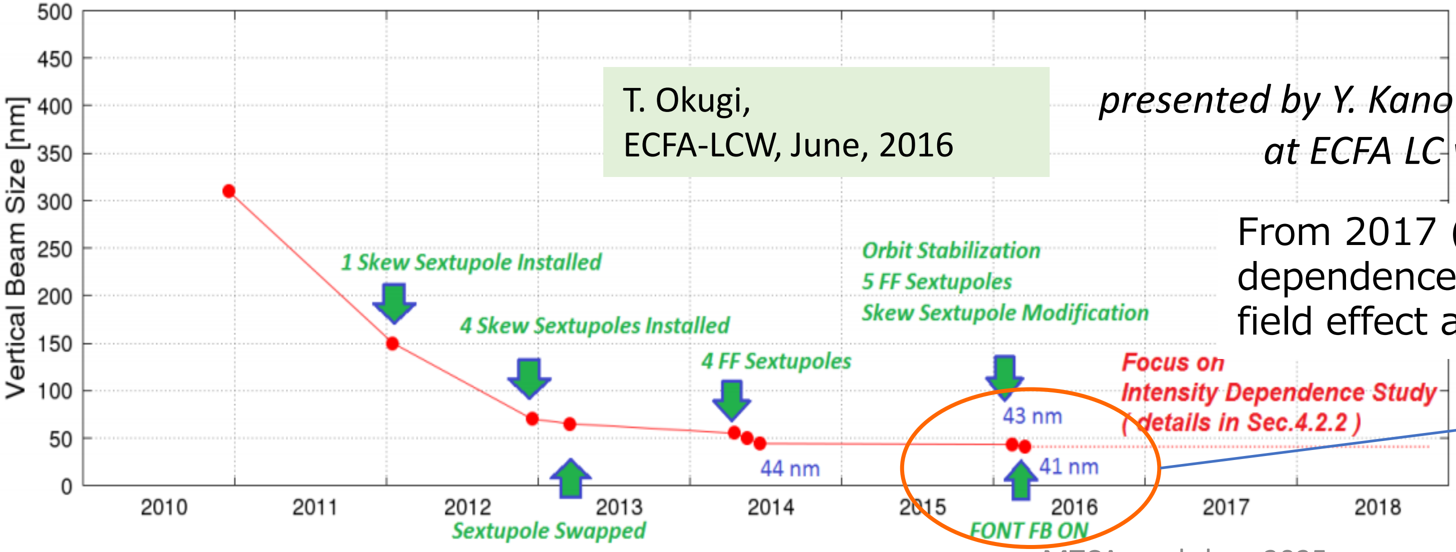
Goal 1:
Establish **the ILC final focus method with same optics** and comparable beamline tolerances (design optics for ILC and learn precise tuning of nanobeam operation)

- ATF2 Goal : **37** nm @1.28 GeV→ ILC **7.7** nm @ 125 GeV beam
  - Achieved **41** nm (2016) → more smaller

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) → to be confirmed and **need to be more stabilized**

Learn from SLC experience for feedback system.
Stability drastically improved in IP then previous SLC and could collide e+e- beam in IP on ILC.

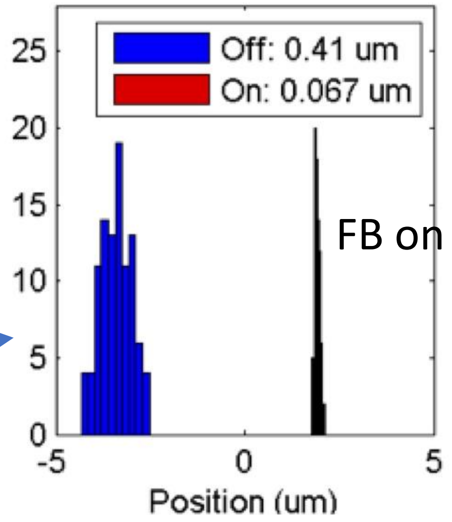


T. Okugi,
ECFA-LCW, June, 2016

presented by Y. Kano and T. Okugi at ECFA LC workshop 2016.

From 2017 (intensity dependence) like wake field effect and so on

Stability on final focus



https://agenda.linearcollider.org/event/7371/contributions/38027/attachments/30831/46133/LCWS_FONT_presentation.pdf

WPP-15: Final focus at ATF in KEK (JFY2023-2024)

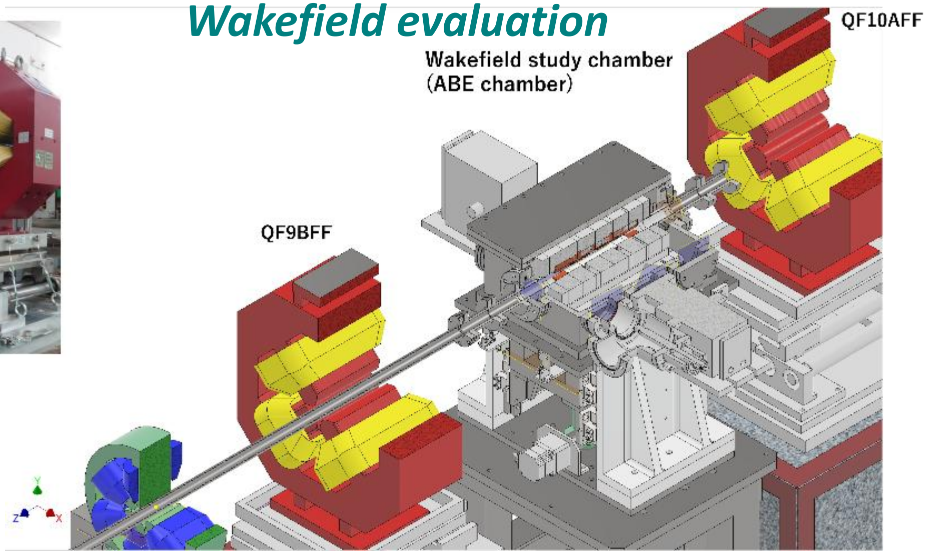
ATF collaboration

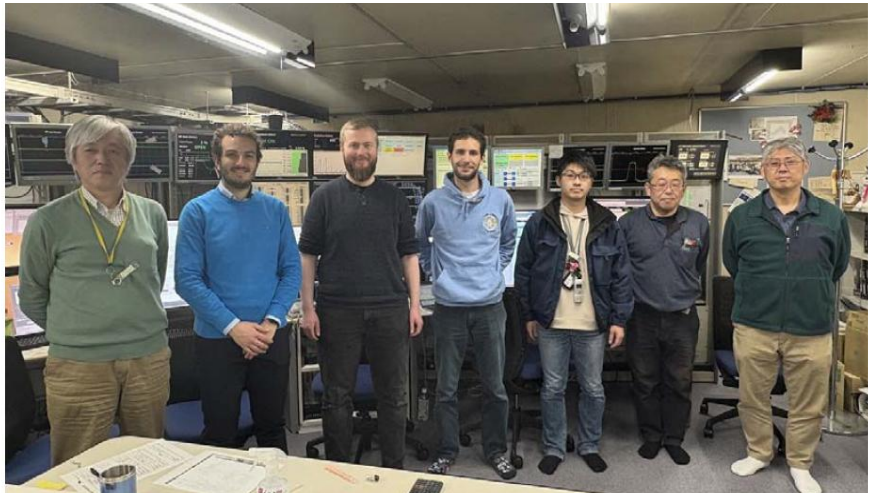
Skew Sextupole magnets

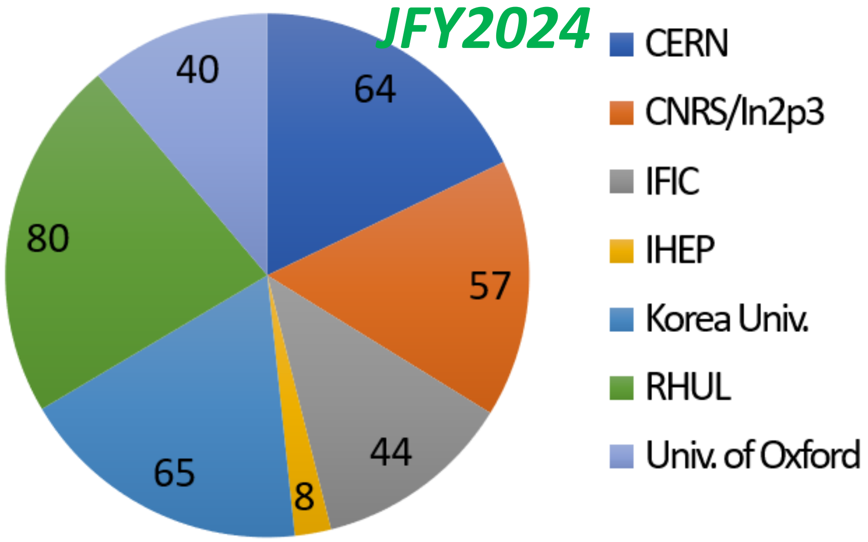
Install to ATF beamline step-by-step

Magnet mover control system

Wakefield evaluation







Future Linear Collider and its LLRF system

KEK / IDT-WG2
Shin MICHIZONO (KEK)

- Higgs factory
- International Linear Collide (ILC)
- RF system for the ILC
- Digital Feedback system
  - Brief History @KEK
  - Proto-type of the ILC llrf
- Current status of ILC R&Ds
  - ILC Technology Network
  - Worldwide activities

Agreement on R&D for the ILC

KEK and CERN Conclude Agreement on R&D for International Linear Collider

Topics

2023/07/08

Dr. Masanori Yamauchi and CERN Director General Dr. Fabiola Gianotti (left to right) (courtesy of CERN)

https://www.kek.jp/en/topics-en/202307081205/

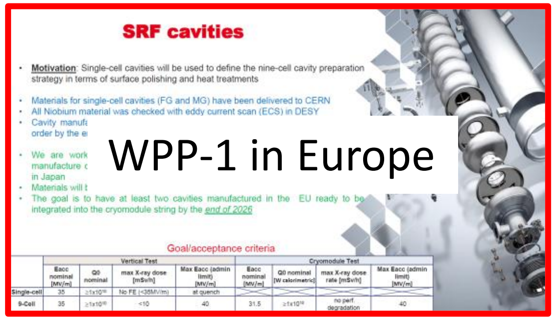
On July 7th, 2023, KEK and European Organization for Nuclear Research (CERN) concluded an agreement on "Support for the European International Linear Collider (ILC) Technology Network," concerning a new framework of research and development for the ILC: the ILC Technology Network (ITN).

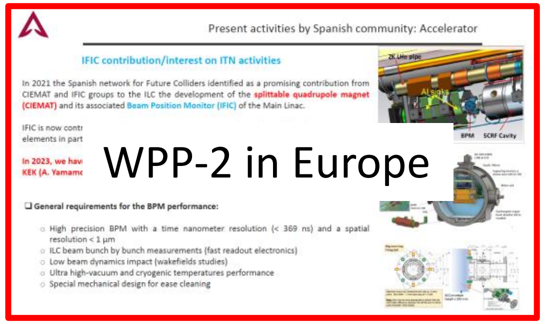
This Agreement was signed by KEK Director General Dr. Masanori Yamauchi and CERN Director General Dr. Fabiola Gianotti while DG Yamauchi was visiting CERN. It is stated in this agreement that CERN will cooperate for ITN specific studies and at the same time will act as a coordinating and facilitating hub for ITN-specific technology developments and studies in Europe.

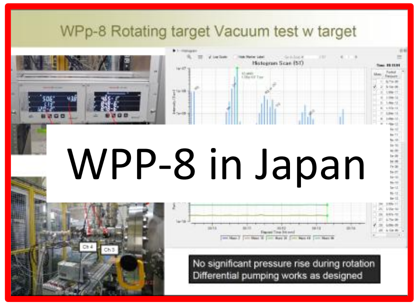
ITN is a framework to promote high priority tasks of the ILC accelerator development. It is based on bilateral arrangements, for instance a memorandum of understanding (MoU), an addendum to an existing agreement, or new agreement, between KEK and laboratories. This conclusion became the first agreement under this framework. KEK would like to conclude similar arrangements with other research institutes and expand this ITN framework.

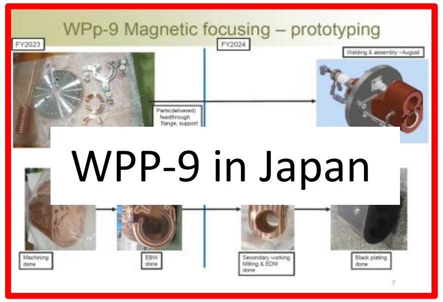
ITN in progress

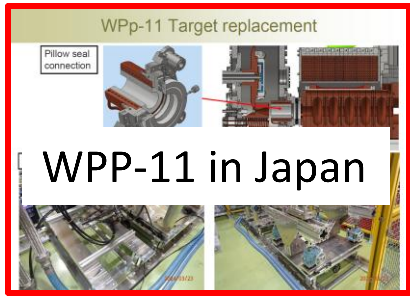
For **WPP-1&2 (SRF cavity, CM)**, single cell cavity production in Korea/Europe started.
JAI (UK) started WPP-14 (DR Injection/extraction, **synergy with Diamond Light Source upgrade**)
For **WPP-15 (Final Focus System)**, European and Korean researchers have joined to the ATF experiments since 2023.

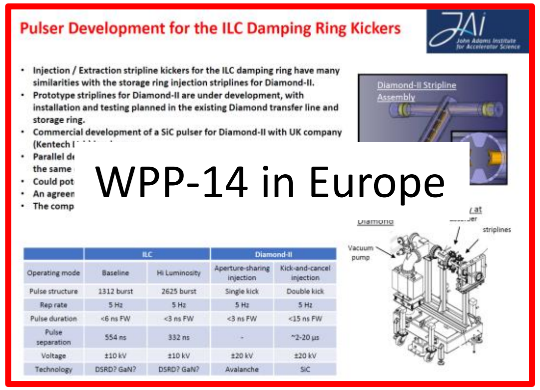


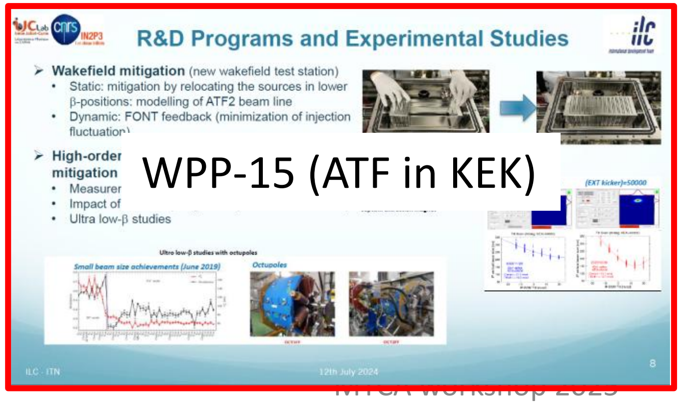


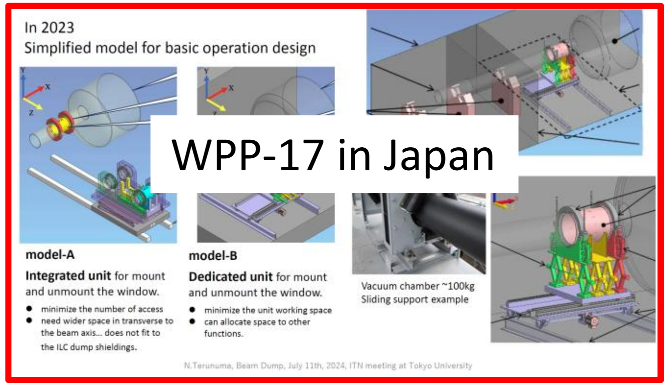












ITN Information Meetings

Two ILC Technology Network Information Meetings have been held.

1st meeting on Oct. 2023 @CERN/hybrid
Around 70 joined.
Lab’s interests were shown from >20 institutes.

https://www.kek.jp/en/topics/202311161700

3rd meeting will be held on Oct. 2025 @Valencia/hybrid

2nd meeting on July 2024 @Tokyo/hybrid
Around 40 joined.
ITN Progress was reported.

Advanced Accelerator Development through ITN

① SRF

- Superior energy efficiency has been demonstrated and is expected to be deployed in a wide range of applications (such as semiconductor lithography, compact accelerator for medical/industrial applications)

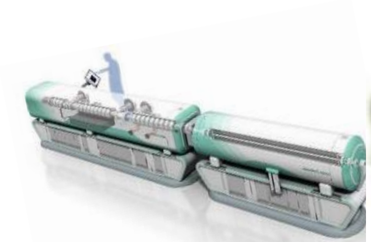
② Source (especially positron source)

- High-intensity positron sources will be required … and CEPC, linear colliders such as ILC and CLIC, m…
- Positrons are also useful for exploring physical properties, and high-intensity, slow-positrons are expected for surface structure analysis.
- Positron source targets and beam dumps are also closely related to targets for neutron generation and beam irradiation targets used in industrial/medical applications.

ITN WPs can be applied not only to ILC but also to a wide range of advanced accelerators

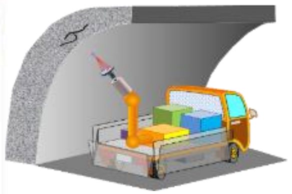
③ Nanobeam

- Nano-beam technology can be applied to new-generation synchrotron radiation facilities, etc..
- Advanced beam tuning techniques such as machine learning can be applied to a wide range of accelerators.

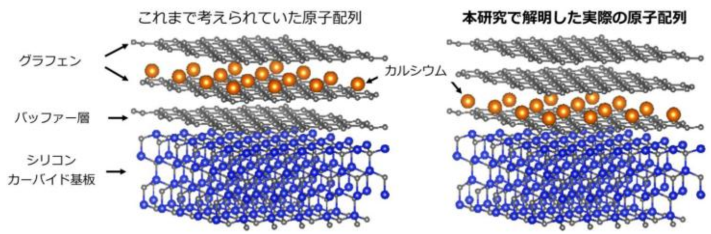


Compact accelerator

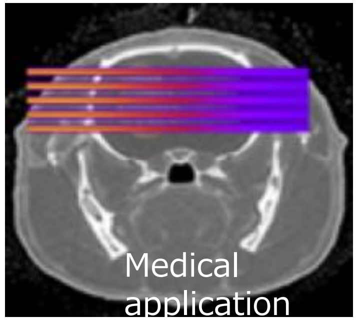
Extreme ultraviolet (EUV) lithography based on ERL technology



Mobile accelerator



Determination of atomic arrangement using slow positrons
https://www.kek.jp/ja/newsroom/attic/PR20191114.pdf



Summary

- ILC is the e-/e+ linear collider for **the Higgs factory**.
- Current global organization is **ILC International Development Teams (IDT) .**
- ILC is the **global project** like ITER and SKA.
- The ILC key technologies of “**SRF**”, “**Sources**” and “**Nano-beam**” .
  - **Matured** to be ready for an e+/e- Higgs Factory based on the **Linear Collider** technology.
- Total ~8,000 superconducting cavities will be used at the ILC.
- Digital FB system will be used for vector sum (39 cavities) control of the rf gradient.
- We started the digital LLRF system using FPGA at the J-PARC linac and have long experiences.
- MTCA.4 is the candidate of the ILC llrf control.
- IDT-WG2 identified important and time-consuming WPs, which are carried out through “**ILC Technology Network**” (ITN).
- ITN WPs (**SRF, Sources and Nano-beam**) can **be applied to various advanced accelerators (and industry/medical).**
- **KEK obtained a budget** for these R&Ds and started the activity from April,2023.
- **European and Korean activities** at SRF/nano-beam have also started.

Thank you for your attention