ILC Technology Network (ITN): accelerator developments

KEK / IDT-WG2
Shin MICHIZONO (KEK)

- ILC Technology Network
  - SRF
  - Sources
  - Nanobeam
- ITN in progress
- Summary

IDT Scope for ILC Realization

-success oriented and asuming no major incident-

Technology Network Phase | **Preparatory Phase** | **Construction Phase** ~10 years for the construction and commissioning

2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 • • •

R&D and effort to gain a common view and understanding.

ILC preparation laboratory and intergovernmental discussion

2021 May

Technical Preparation and Work Packages (WPs) during ILC Pre-lab

Work Packages (**WPs**) for ILC Pre-Lab

2022 June

Time-critical WPs for the ILC construction

WP-Primes for Time Critical

ILC Technology Network (ITN)

-- global collaboration program---

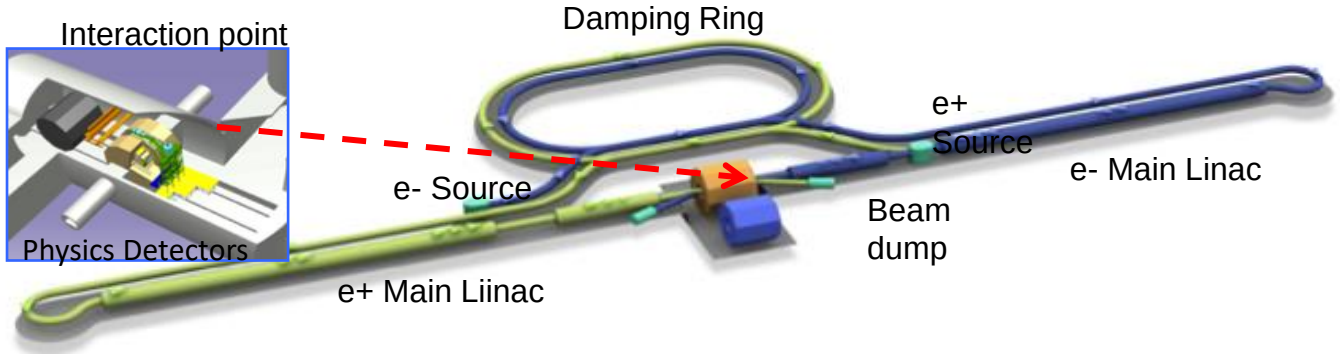
- **Acc. R&Ds** focusing on
  - SRF
  - e- & e+ Sources
  - Nano-beam

KEK obtained a budget for these R&Ds and started the activity from 2023.

http://doi.org/10.5281/zenodo.4742018

https://agenda.linearcollider.org/event/9649/attachments/38003/60567/Time-Critical_WPsV8b.pdf

ILC Technology Network



Not only for the **ILC** but also for **various application**

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

SRF

e-, e+ Sources

Nano-Beam

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

ILC Technology Network (ITN): accelerator developments

KEK / IDT-WG2

Shin MICHIZONO (KEK)

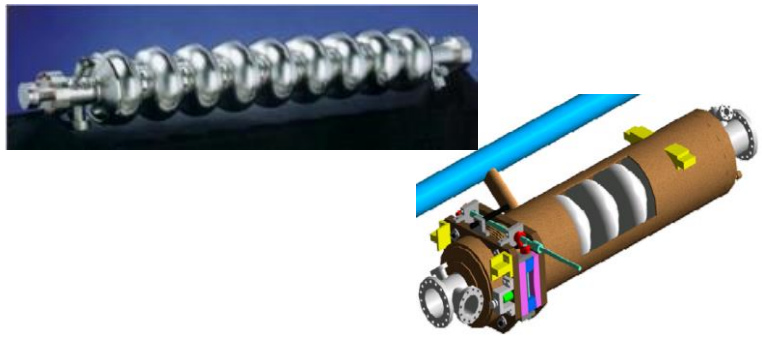
- ILC Technology Network
  - SRF
  - Sources
  - Nanobeam
- ITN in progress
- Summary

Applications of SRF technology

- **SRF technology** has matured through the construction and **stable operation of the European XFEL**.
- Superior **power efficiency** of SRF technology has been demonstrated, and its application is expected to expand.
  - Global efforts to **improve cavity performance** and reduce costs have progressed.(based on previous US-Japan collaboration)
  - Demonstration of the production of high-performance cavities, leading to various accelerator applications.
- SRF technology applications:
  - ex. Semiconductor **lithography**, **medical** application, environmental remediation, etc.

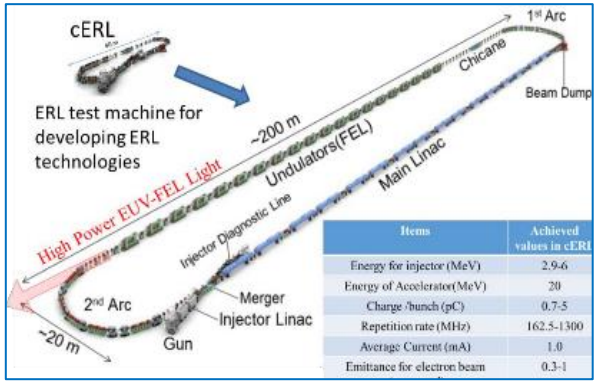
Topics at ILC Technology Network (ITN) (WPP-1~3)

- Establishment of international standards of the SRF cavity satisfying the **High-Pressure-Gas-Safety regulation**
- Advancement of SRF cavity and **surface treatment technology**, performance evaluation
- Optimization of **cryomodule (CM) design** and overall performance evaluation of cavity packages
- Efforts to apply advanced SRF cavity technology **such as crab cavity**



SRF cavity

Cryomodule



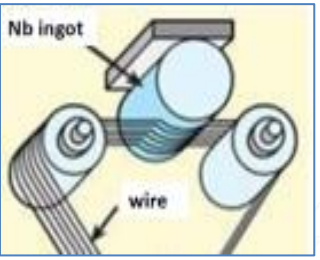
EUV-FEL (semiconductor lithography)

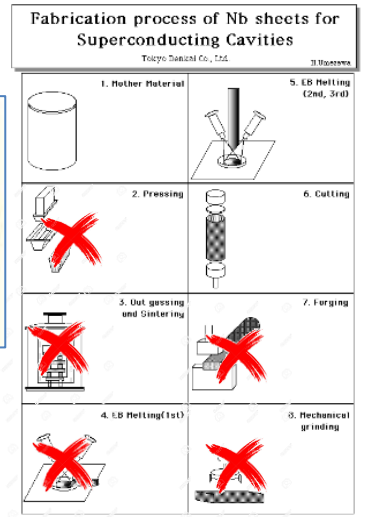
WP-prime 1: SRF Cavity
(Scoping the Industrial-Production Readiness)

- Research with single-cell cavities to establish the best production process including:
  - Advanced Nb sheet production method
  - Advanced surface treatment recipe(mainly developed by **FNAL**)
- Globally common design with compatible High Pressure Gas Safety (HPGS) regulation
- 24 nine-cell cavities are to be developed for industrial-production readiness
  - 8 cavities in each region
  - Production process encouraged to be optimized in each region
  - Cavity performance expected: E_{acc} = <35 MV/m> (+/− 20%), Q_0 = 1.0 x 10^{10}, Yield = ≥90%
- RF performance/success yield to be examined (including 2nd pass and further)
  - 3rd pass to be examined if effective

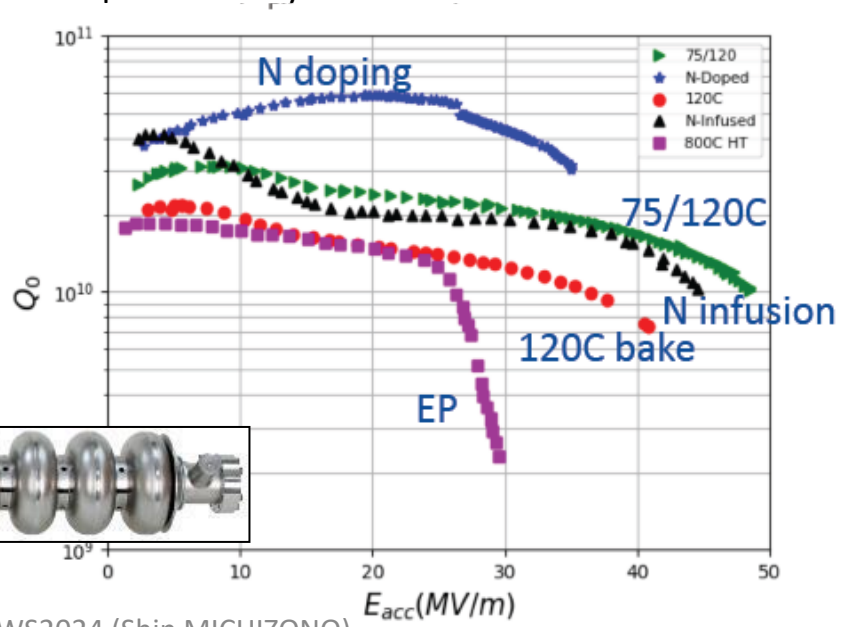
	# of cavities to be produced		
	Americas	Europe	JP/Asia
single-cell	2	2	2
nine-cell	8	8	8

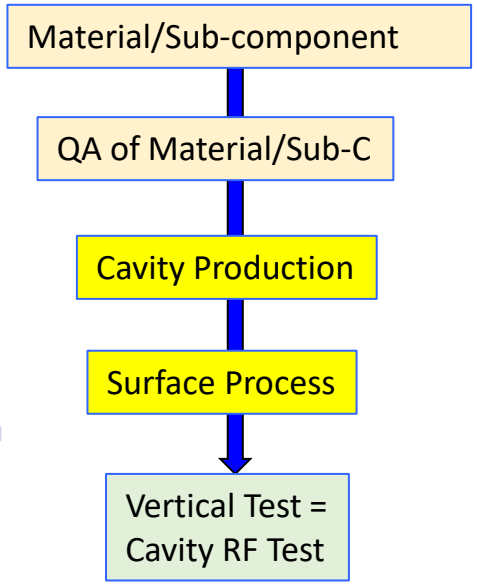
Advanced Nb sheet production by direct slicing





Advanced surface treatment technologies pioneered by **FNAL**





Production process

ILC Technology Network (ITN): accelerator developments

KEK / IDT-WG2

Shin MICHIZONO (KEK)

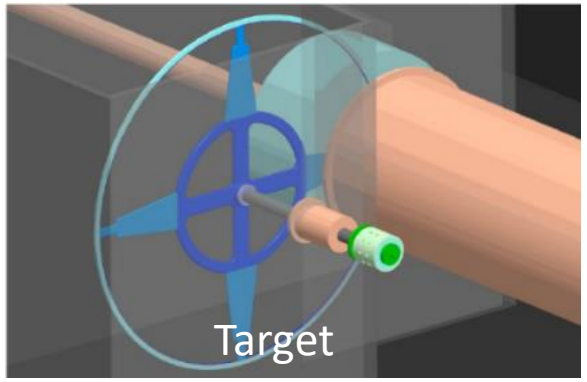
- ILC Technology Network
  - SRF
  - Sources
  - Nanobeam
- ITN in progress
- Summary

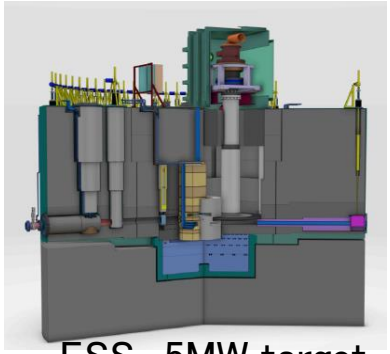
Applications of Sources technology

- **Polarized electrons** are also useful for observing of magnetism (Spin-Polarized Low Energy Electron Microscopy, **SPLEEM**).
- **Positrons** have been used in colliders such as SLC, SuperKEKB, DAFNE, and CESR.
- In the future, more **intense positron sources** will be needed for circular colliders such as FCCee and CEPC, linear colliders such as ILC and CLIC, and muon colliders (LEMMA).
- High-intensity **slow positrons** are expected for **surface structure analysis**.
- **Positron targets and beam dumps** are also closely related to **targets for neutron** and beam irradiation used in **industrial medical applications**.
- The development of SRF accelerators has increased the beam intensity, and the development of **target technology** that can effectively utilize this intensity is of **great interest worldwide**.

Topics at ILC Technology Network (ITN) (WPP-4~11)

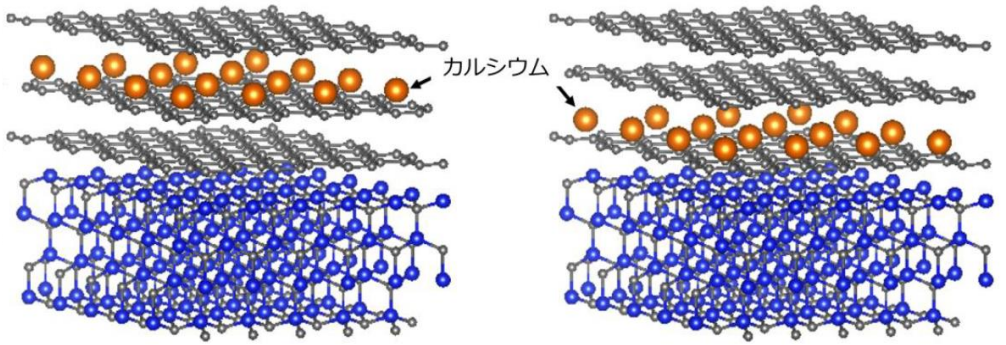
- **Electron source** including the recent development
- Undulator positron scheme: **rotating target, magnetic focusing**
- Electron driven positron scheme: **rotating target, magnetic focusing, capture cavity**
- **Target replacement**





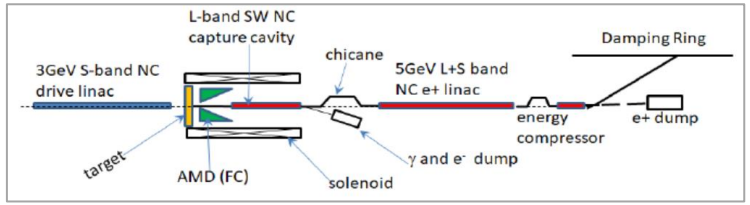
ESS 5MW target

DOI: 10.1109/ANIMMA.2013.6728029



Successful elucidation of atomic arrangement in graphene superconducting materials by using slow positron
https://www2.kek.jp/imss/spf/eng/topics/2019/successful-elucidation-of-atomic-arrangement-in-graphene-superconducting-materials---a-new-way-to-de-1.html

WP-prime 8~11:
Electron(e-) driven positron source (1/2)

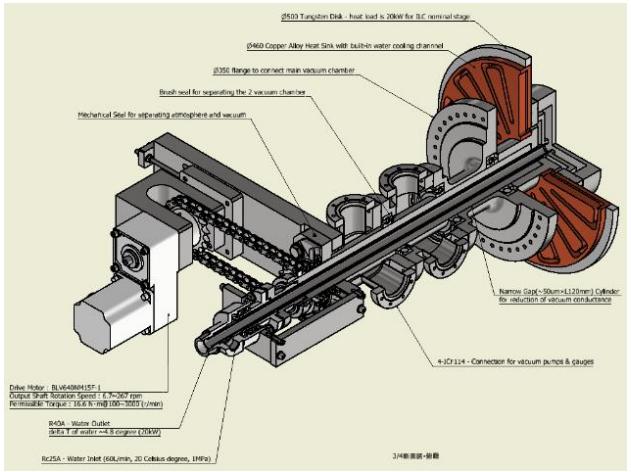


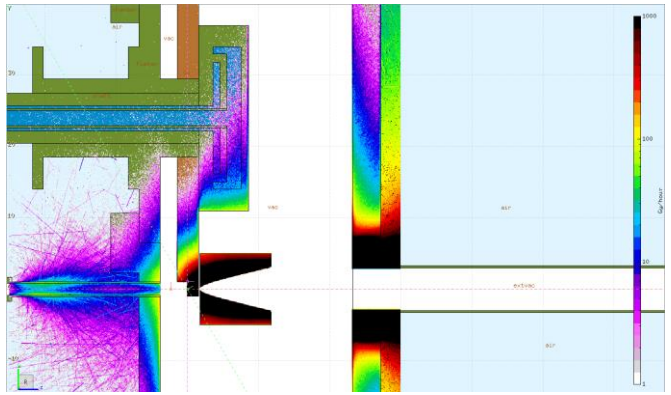
WP-prime 8: Rotating Target for e-Driven Scheme

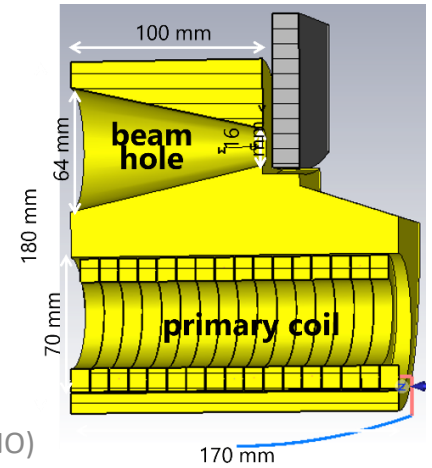
- Target specification
  - W or W-alloy, ~16 mm (5 X_0) thick, diameter 50 cm
  - Rotating at 5 m/s in vacuum
  - Water cooled.
  - Vacuum seal
- R&D items to be done in 2 years
  - Target stress calculation with FEM
  - Vacuum seal
  - Target module design and prototyping
  - W-Cu connection test and evaluation

WP-prime 9: Focusing System

- Flux Concentrator (FC) is chosen as the focusing device after the target
- The specification parameters such as max field, electric current and the dynamic force are satisfied in existing target, but the pulse energy and the heat load are higher.
- A prototype necessary after detailed design study
- R&D items as WP-prime
  - Flux concentrator conductor design (in first 2 years)
  - Conductor prototyping (in the remaining years)







Parameter	ILC FC	Unit
Max. B field	5	T
Max. surf. current	25	KA
Dynamic force	125	kA.T
Pulse energy	140	J
Average Power	13.7	kW

ILC Technology Network (ITN): accelerator developments

KEK / IDT-WG2

Shin MICHIZONO (KEK)

- ILC Technology Network
  - SRF
  - Sources
  - Nanobeam
- ITN in progress
- Summary

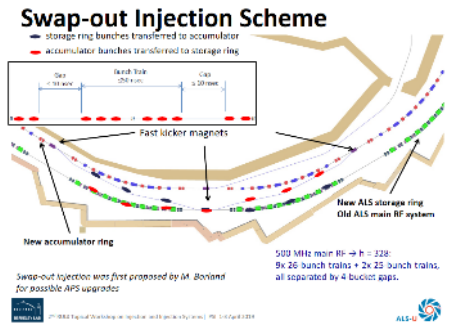
Applications of Nano-beam technology

- Pioneering achievements in nanobeam technology at KEK's **ATF** through international collaboration.
  - Realization of the **world's smallest beam** through improvement of beam quality and beam focusing technology.
  - Demonstration of nanosecond scale **fast beam injection/extraction** technology.
- Applications of nano-beam technology:
  - Nanobeam in **new-generation synchrotron light source**, application of microbeams to **industrial medical applications**.
  - Advancement of **beam diagnostics**, beam tuning by **machine learning, beam control technology** on the nanosecond scale can be applied to a **wide range of accelerators.**

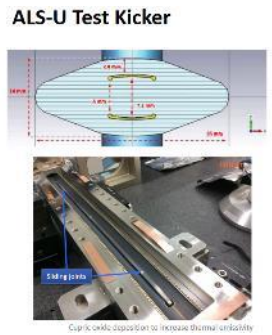
Topics at ILC Technology Network (ITN) (WPP-12~17)

- **Upgrade of beam diagnostics at ATF** through in-kind contribution.
- Establishment of nano-beam tuning technology utilizing ATF (including **machine learning**, etc.).
- Advancement of **high-speed beam injection/extraction** technology (nanosecond beam control).
- Establishment of megawatt-class **beam dump technology** (application to neutron target and beam dump).
- Optimization of **damping ring design**.
- **Vibration evaluation** of final SC magnets.

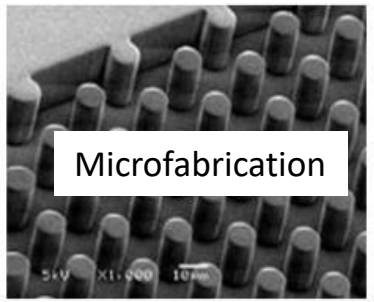
Nano-meter scale beam line at KEK-ATF

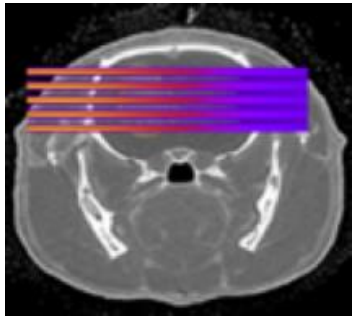


Fast kicker (injection/extraction)



Nanobeam application



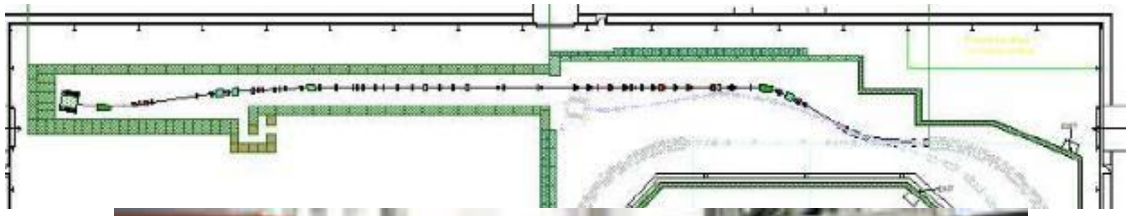


https://cerncourier.com/a/very-high-energy-electrons-for-cancer-therapy/

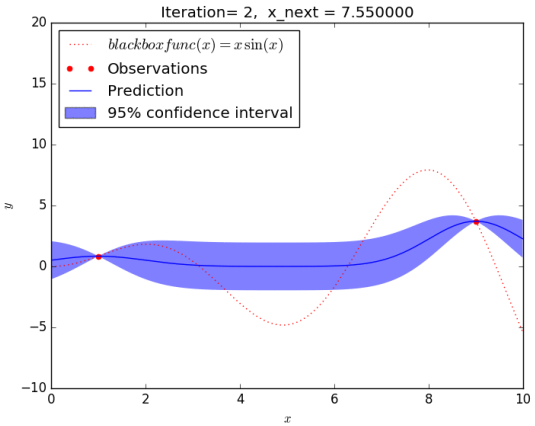
WP-prime 15: System design of ILC FFS

ATF collaboration

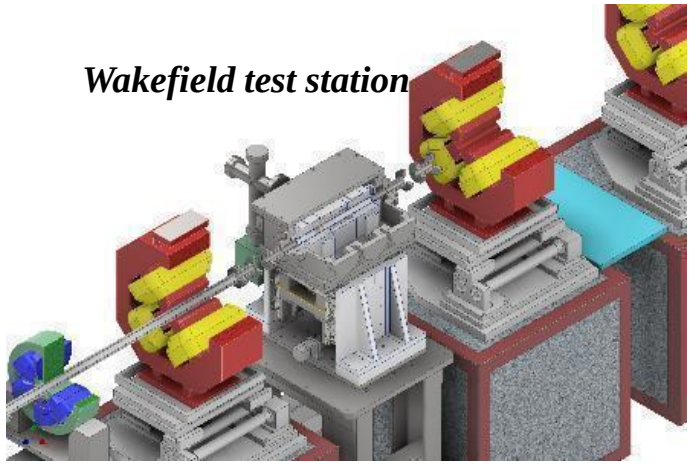
- ATF2 beamline is the only existing test accelerator in the world to test the final focus system (FFS) of linear colliders.
- The following 3 research topics are important to be pursued at the ATF.
  - wakefield mitigation
  - correction of higher-order aberration
  - training for ILC beam tuning (machine learning)
- The technical research at ATF2 beamline has proceeded and should continue to be based on the ATF international collaboration, or its extension (welcome to new collaborators).



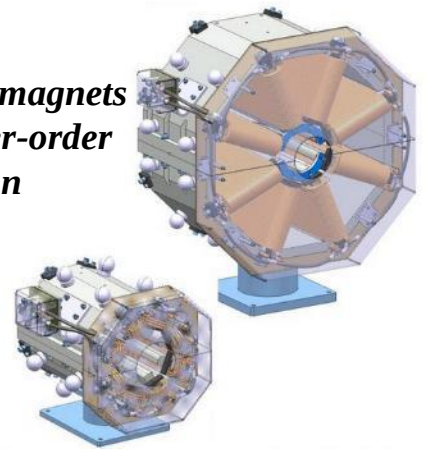
Maximum search algorithms to be applied to beam tuning (Machine Learning)



Wakefield test station



Octupole magnets for higher-order aberration



ILC Technology Network (ITN): accelerator developments

KEK / IDT-WG2

Shin MICHIZONO (KEK)

- ILC Technology Network
  - SRF
  - Sources
  - Nanobeam
- ITN in progress
- Summary

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

Topics

2023/07/08

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

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

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.

Explanation of ILC Technology Network by KEK/IDT delegation

PAL (Sep. 2023)

Korea University (Sep. 2023)

https://sejong.korea.ac.kr/user/boardList.do?boardId=1464&siteId=kr&id=kr_060200000000&boardSeq=188465&command=view

BNL (Oct. 2023)

Cornell University (Oct. 2023)

We also visited SLAC, FNAL, JLAB, …

ITN Information Meeting @CERN (Oct., 2023)

ILC Technology Network Information Meeting was organized by KEK and IDT.
The meeting was in a hybrid mode. Face to face at CERN with remote connection.

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

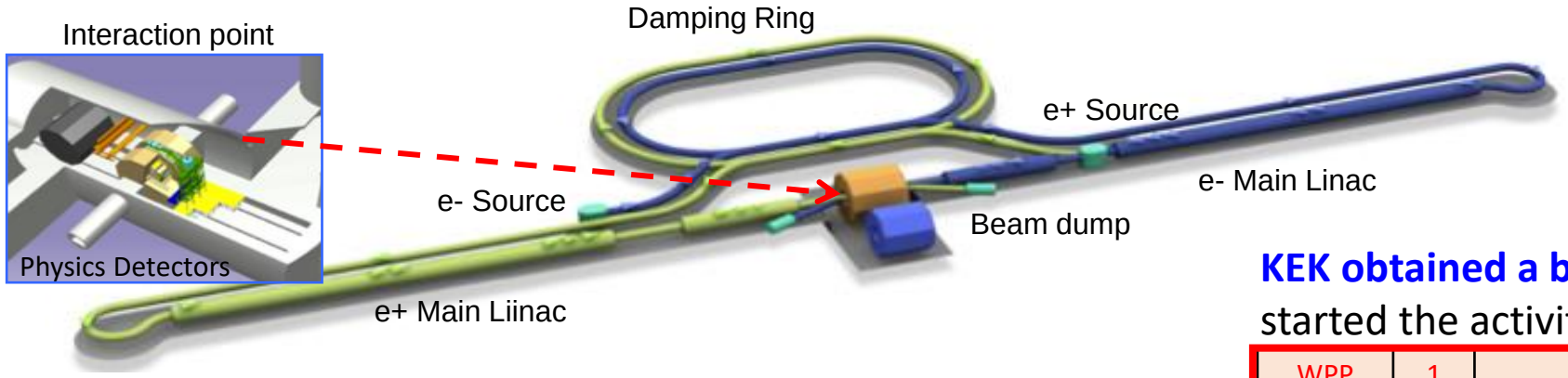
Around 70 joined to this meeting.
Lab's interests were shown from >20 institutes.

Preliminary list of the interests (to be confirmed by Labs).

SRF	WPP	1	Cavity production	✓		✓	✓	✓			✓	✓	✓				✓	✓	✓			✓	✓	✓	✓	
	WPP	2	CM design	✓				✓				✓			✓	✓	✓	✓	✓			✓		✓	✓	
	WPP	3	Crab cavity			✓	✓							✓					✓				✓	✓		✓	✓
Sources	WPP	4	E- source			✓						✓							✓			✓			✓		
	WPP	6	Undulator target				✓												✓	✓				✓			
	WPP	7	Undulator focusing				✓												✓	✓				✓			
	WPP	8	E-driven target	✓		✓												✓	✓								
	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	✓			✓		✓		✓							✓				✓			✓		
	WPP	16	Final doublet	✓	✓													✓									
	WPP	17	Main dump	✓			✓					✓															

Second ITN meeting will be held on July 12, 2024.

KEK's efforts



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

KEK obtained a budget for these R&Ds and started the activity from April,2023.

SRF	WPP	1	Cavity production
	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
	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
	WPP	16	Final doublet
	WPP	17	Main dump

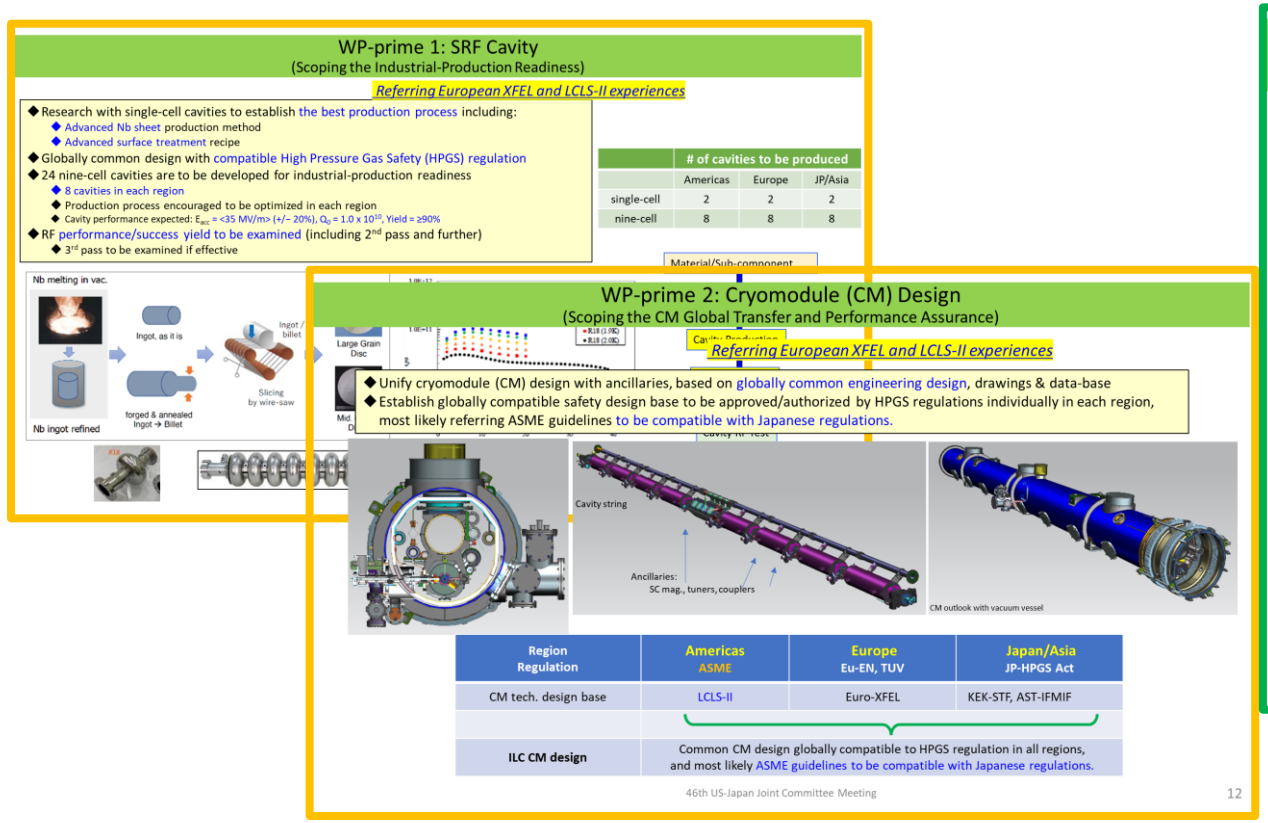
Collaboration with Europe, Korea, Americas

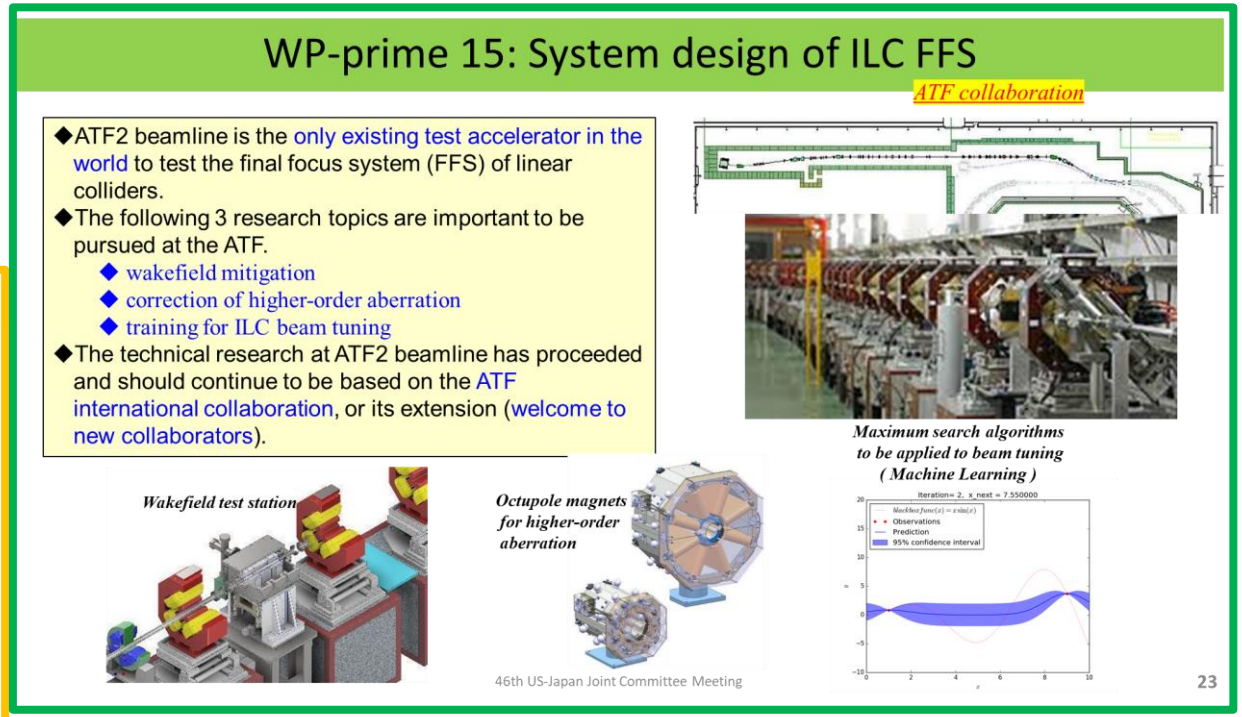
Experiences at SuperKEKB

ATF collaboration

ITN in progress

For WPP-1&2 (SRF cavity, CM), we started technical discussions with researchers in Europe and Korea. Single cell cavity production in Korea/Europe will start soon.
JAI (UK) started WPP-13 (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.
In the U.S., part of the ILC Technology Network (ITN) activities on **SRF and positron sources** have started as the U.S.-Japan Science and Technology Cooperation Program.





ILC Technology Network (ITN): accelerator developments

KEK / IDT-WG2

Shin MICHIZONO (KEK)

- ILC Technology Network
  - SRF
  - Sources
  - Nanobeam
- ITN in progress
- Summary

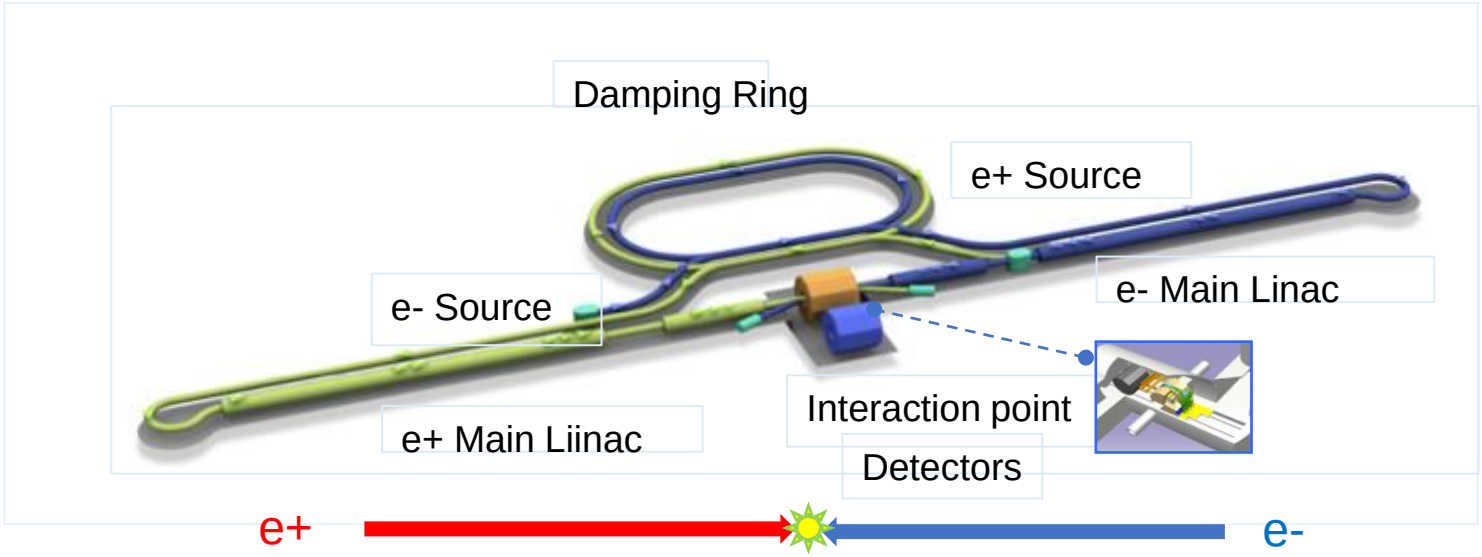
Summary

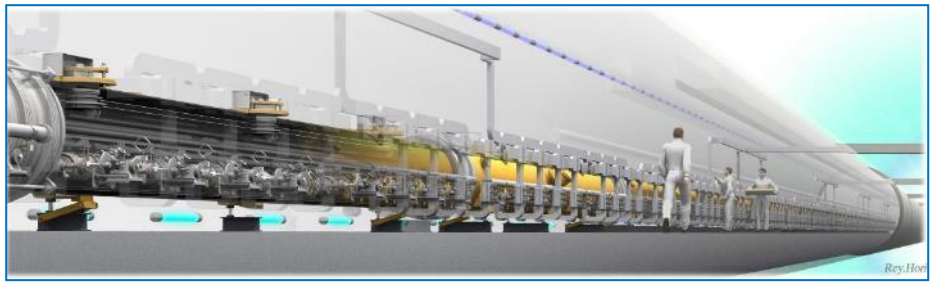
- The ILC key technologies of "**SRF**", "**Sources**" and "**Nano-beam**" .
  - **Matured** to be ready for an e+/e- Higgs Factory based on the **Linear Collider** technology.
- IDT-WG2 identified important and time-consuming WPs, which are carried out through "**ILC Technology Network**" (ITN).
- ITN WPs (**SRF, Sources and Nano-beam**) can **be applied to various advanced accelerators (and industry/medical).**

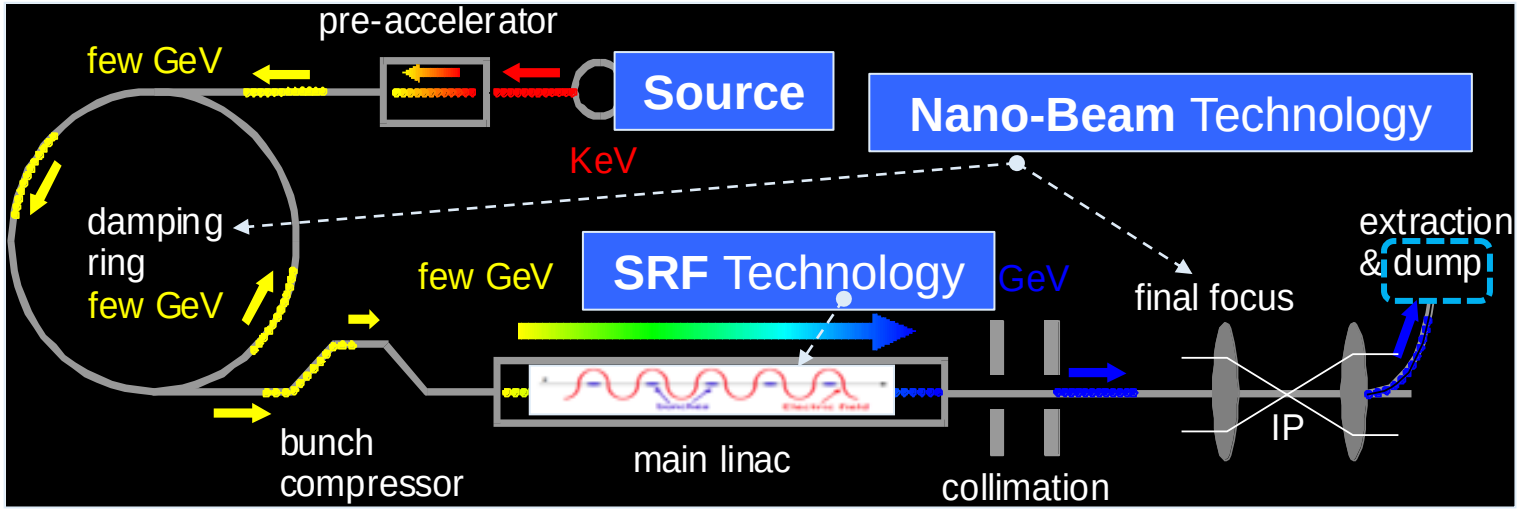
- **KEK obtained a budget** for these R&Ds and started the activity from April,2023.
- **European and Korean activities** at SRF/nano-beam have also started.
- In the U.S., part of the ILC Technology Network (ITN) activities on SRF and positron sources have started as the U.S.-Japan Science and Technology Cooperation Program.

Thank you for your attention

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