US-Japan collaboration on particle source for future collider

KEK

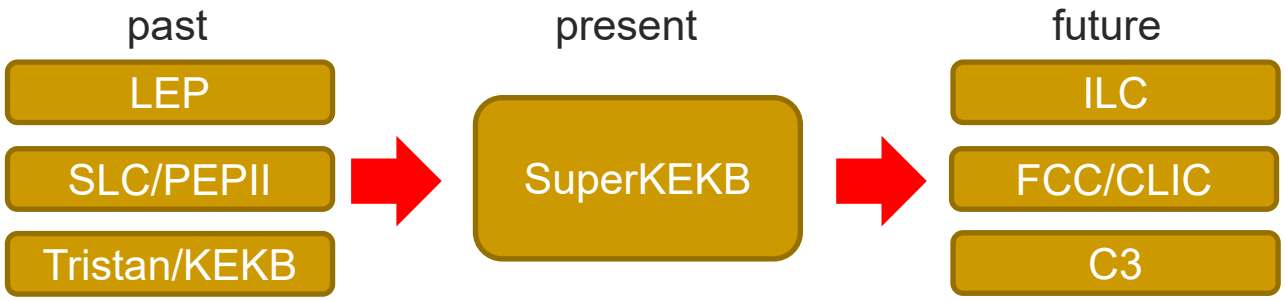
Yoshinori ENOMOTO

My idea

- Start “loose” collaboration on particle source
  - Many kinds of scientific and engineering topics
    - Complicated simulation
    - Thermo-mechanical issues
    - Material
    - High voltage, vacuum…
  - Number of people involved in this field is not large
  - Exchanging and sharing experience and information is important to accelerate development speed

Status in KEK, ILC and Japan

- Pre-lab from FY2022 was not approved.
- Time critical work packages are proposed
  - Budget request is ongoing
  - Start from FY2023 (hopefully)
  - So-called pre-pre-lab
- New group on positron source and beam dump for ILC launched in sept. 2022
  - I moved from SuperKEKB project group.
  - Looking for collaborators both in Japan and in the world
  - Good timing to start new collaboration for us
- KEK have Long collaboration with CERN (LEP/FCC)
  - With this US-Japan collaboration, tie Europe, US and Japan in this field

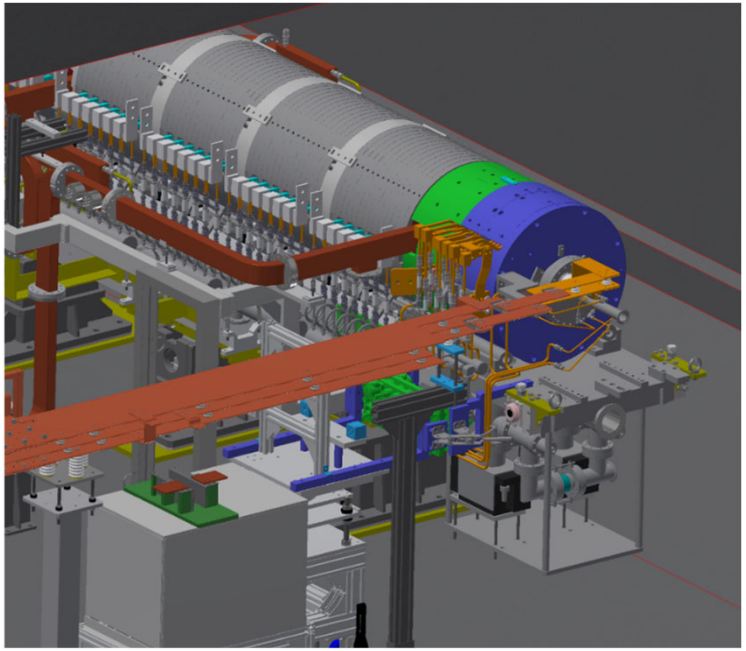


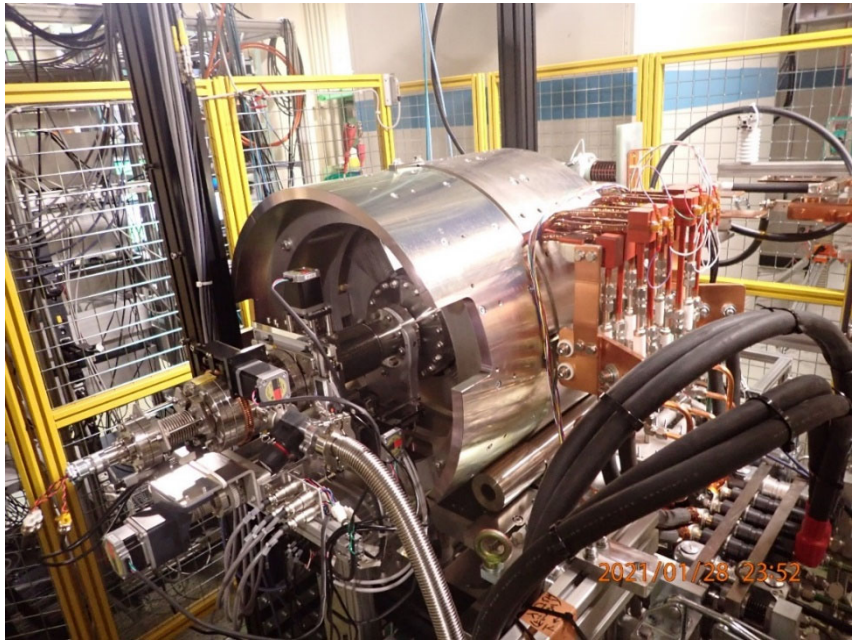
Member from KEK and our expertise

- Yoshinori Enomoto
  - Positron source
    - For SuperKEKB, slow positron facility and ILCs
- Tetsuo Abe
  - Accelerator structure
    - SuperKEKB ring cavity
    - X-band test facility (Nextef)
- Masahiro Yamamoto
  - Electron source
    - DC electron source for cERL

Main mission of positron source group

- Goals of ILC positron group in KEK till 2027 is demonstrate our design
  - Prepare
    - engineering design report (EDR)
    - 3D CAD model
    - Drawings for manufacturing
  - Arrange test environment
  - Construct prototype and test it





3D model and test bench of positron source for SuperKEKB
We are going to prepare similar ones for ILC

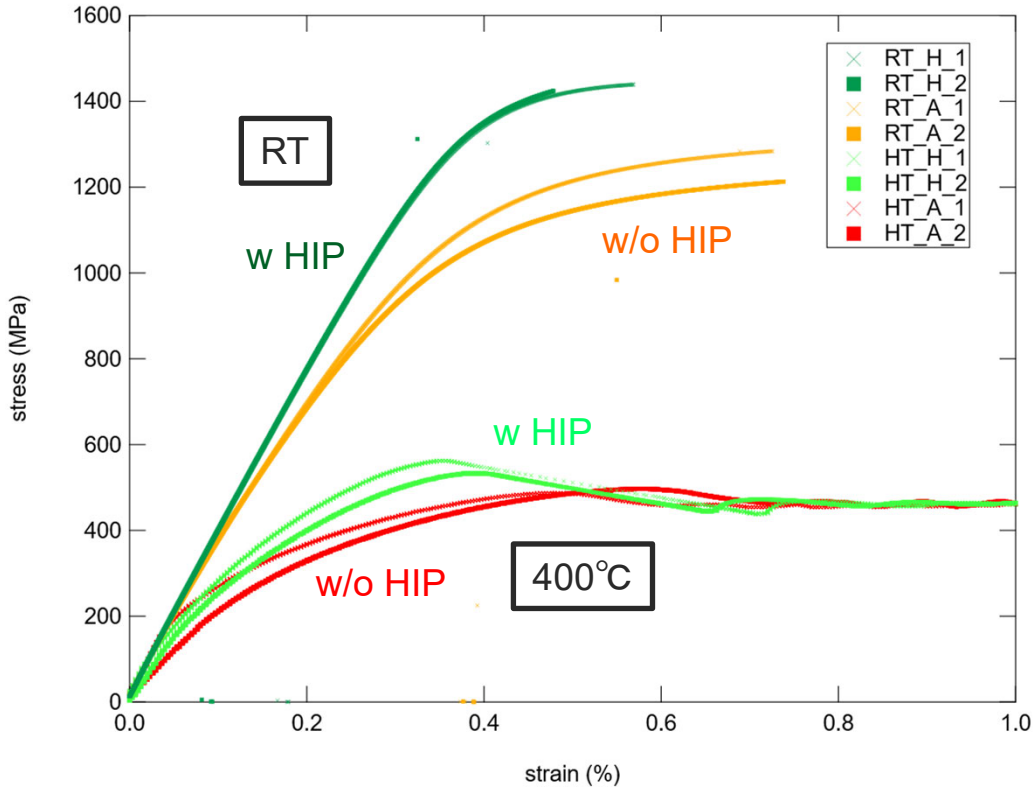
Key device and technology

- UHV compatible water-cooled rotating target
  - withstand 74 kW beam power
- Reliable W-Cu connection with high thermal conductivity and mechanical strength
  - Both experimental and simulation trials are important
  - Collaboration with an expert company and NIFS (National Institute for Fusion Science) started
- High current and repetition FC
  - ～20 times higher ohmic loss compared with that of FC for SuperKEKB
- Special accelerator structure just after the target
  - Usable under high radiation, heat load, complicated beam loading

Evaluation of W and W-Cu connection

Thermal and mechanical evaluation of W and W-Cu connection is important.
Similar tasks are important for plasm facing wall of Fusion facility.
Preparing collaboration with NIFS(National Institute for Fusion Science).

Strain-stress diagram of W

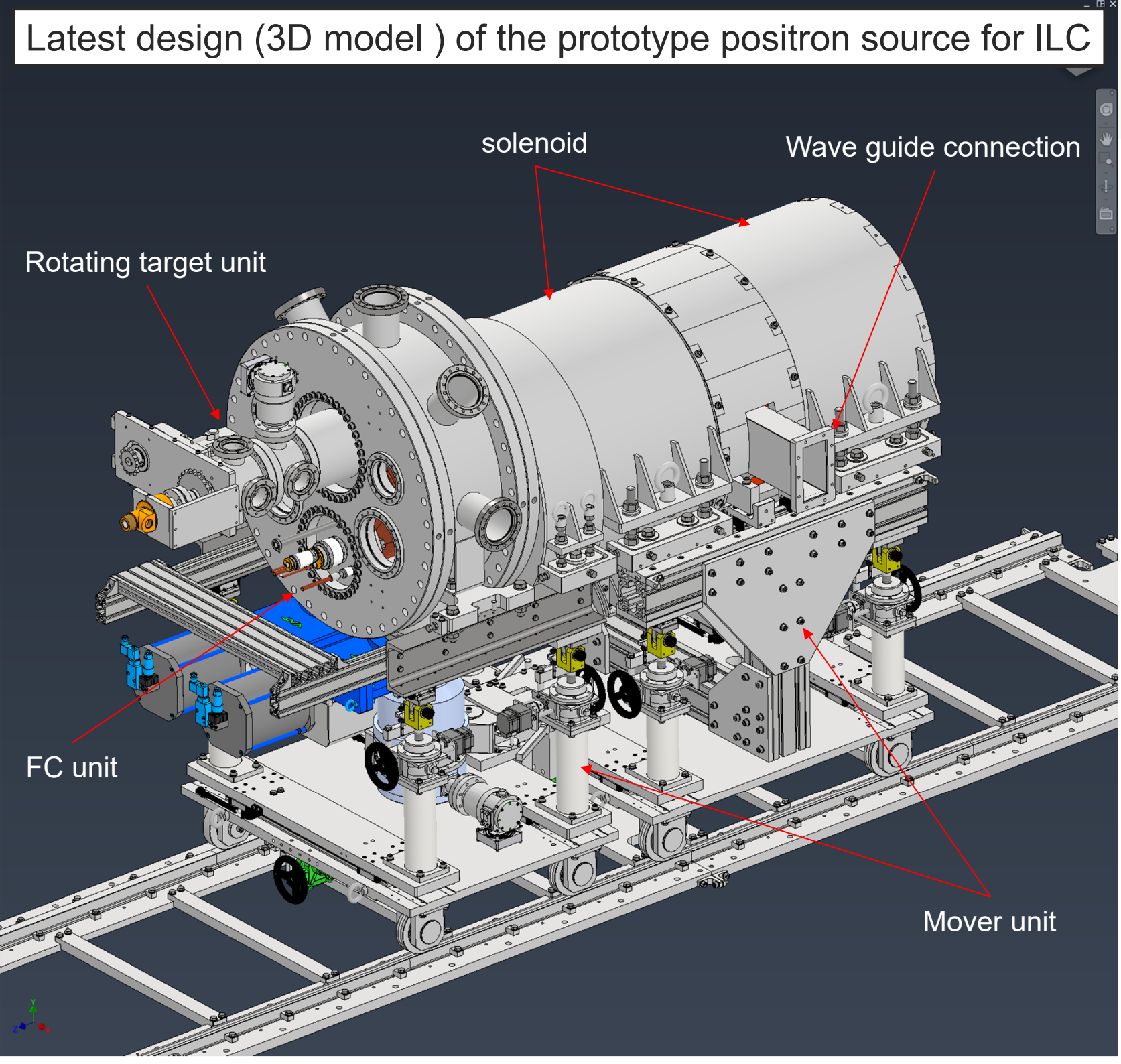


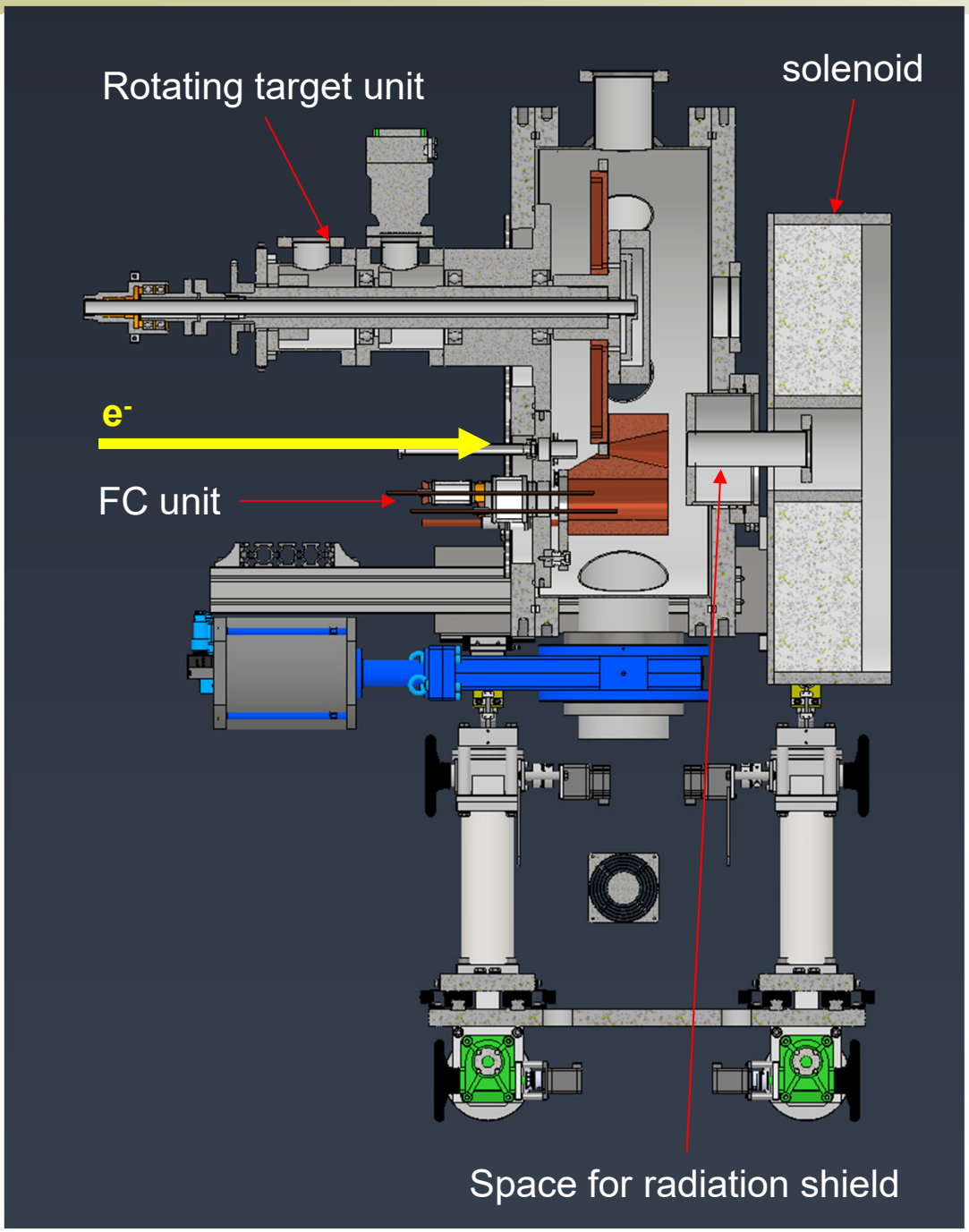
HIP condition : 1050℃, 150 MPa, 2 Hour

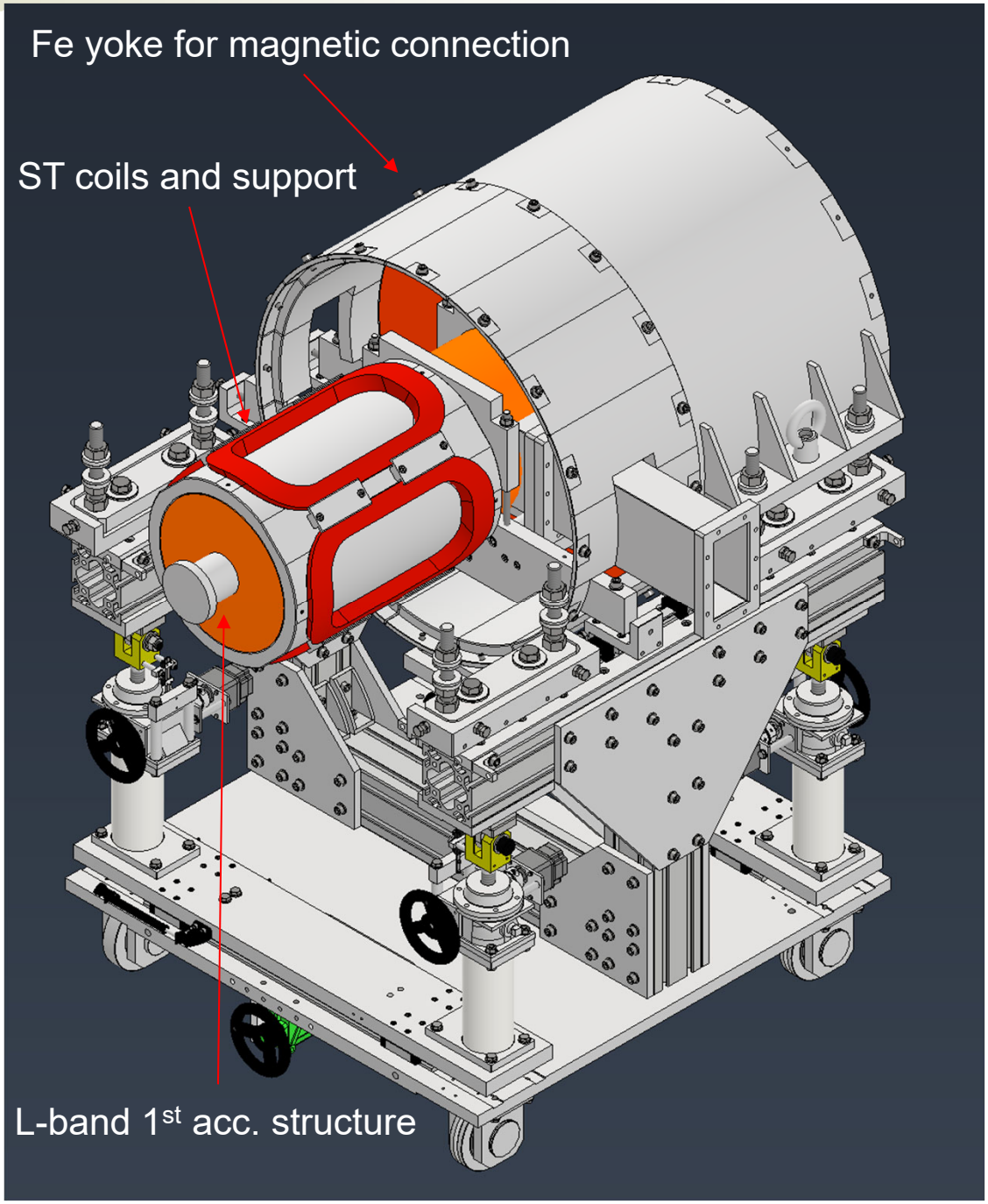
40 kV, 300 kW electron beam heating machine @ NIFS

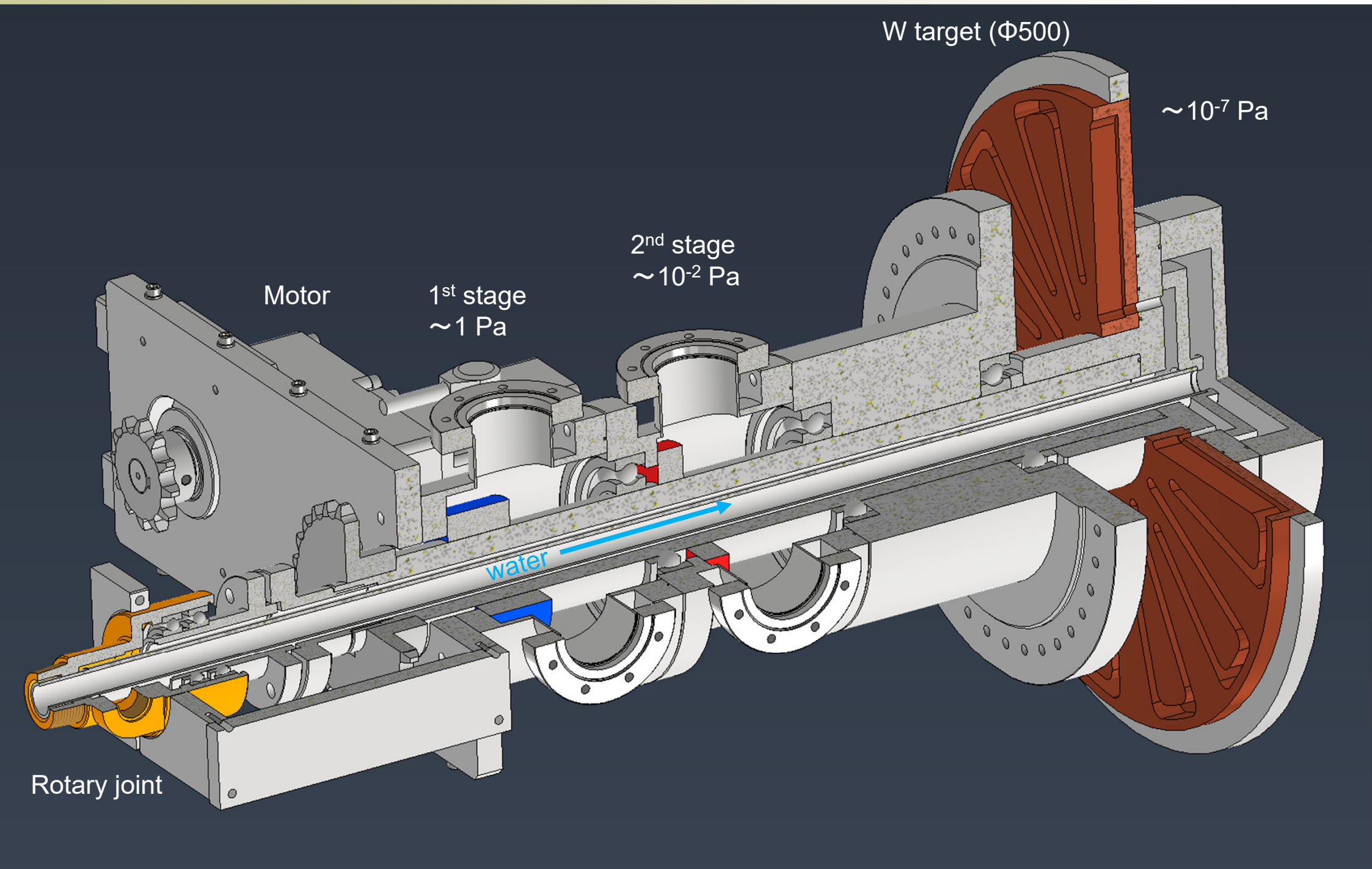
Plan to measure thermal resistance of W-Cu interface by this facility

Latest design (3D model) of the prototype positron source for ILC

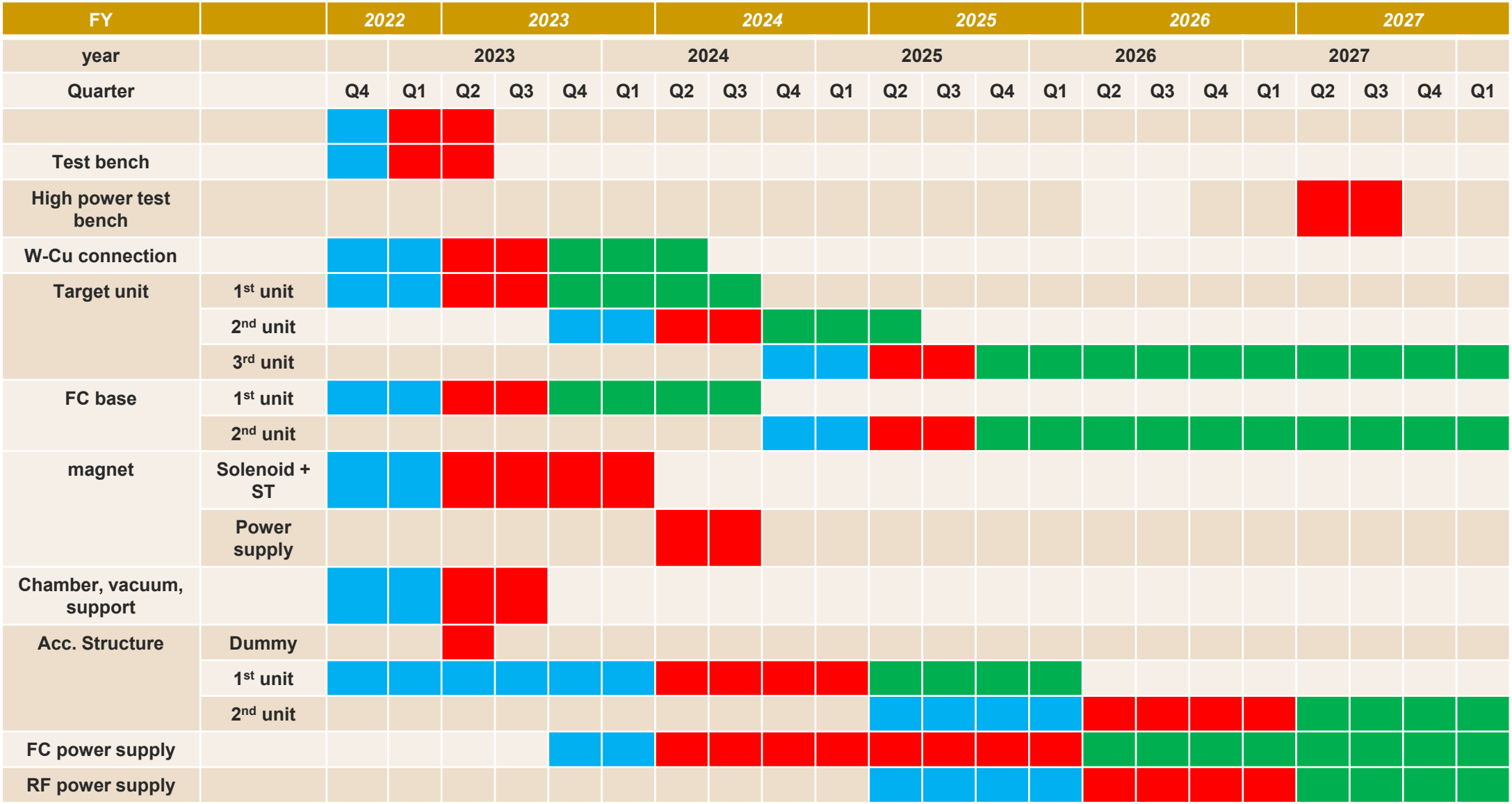



Rotating target unit
solenoid
e-
FC unit
Space for radiation shield


Fe yoke for magnetic connection
ST coils and support
L-band 1st acc. structure


W target (Φ500)
~10-7 Pa
2nd stage
~10-2 Pa
Motor
1st stage
~1 Pa
water
Rotary joint

five years development plan for positron source



Design
Manufacuring
test

Electron source

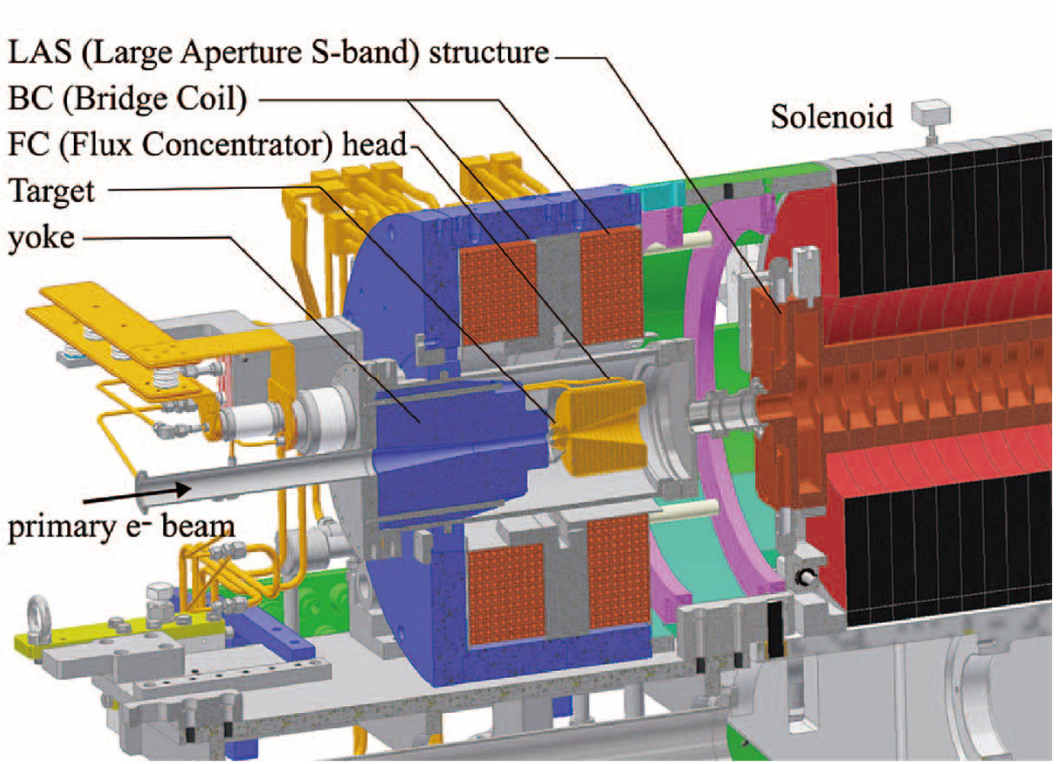
- Share know-how about conditioning of electron gun
  - Stable operation experience is useful for development of new machine
- Extremely high vacuum technique
  - Share experience and know-how
- High voltage insulator development
  - Evaluate insulator from different company under the same condition both in US and Japan.
  - Compact design improve maintenance workability and installation possibilities

DC Electron gun for cERL in KEK
Large chamber filled with SF_6 for suppressing discharge

Present pressure

Accelerator structure

- High gradient accelerator for
  - Primary electron acceleration to make positron (up to a few GeV)
  - Primary electron acceleration for slow positron facility
    - Shorter length means lower construction cost
- Special accelerator structure just after the positron target
  - High heat load
  - High radiation environment
  - Large aperture
  - Complicated beam loading effect and compensation
    - Multi-bunch
    - effective charge varies as bunching of e+ and e-
  - Accelerate secondary particle is rare
    - e.g. Future muon collider



Cross sectional view of positron source for SuperKEKB
1st acc. Structure is close to the target
Suffer from radiation and heat from particle shower

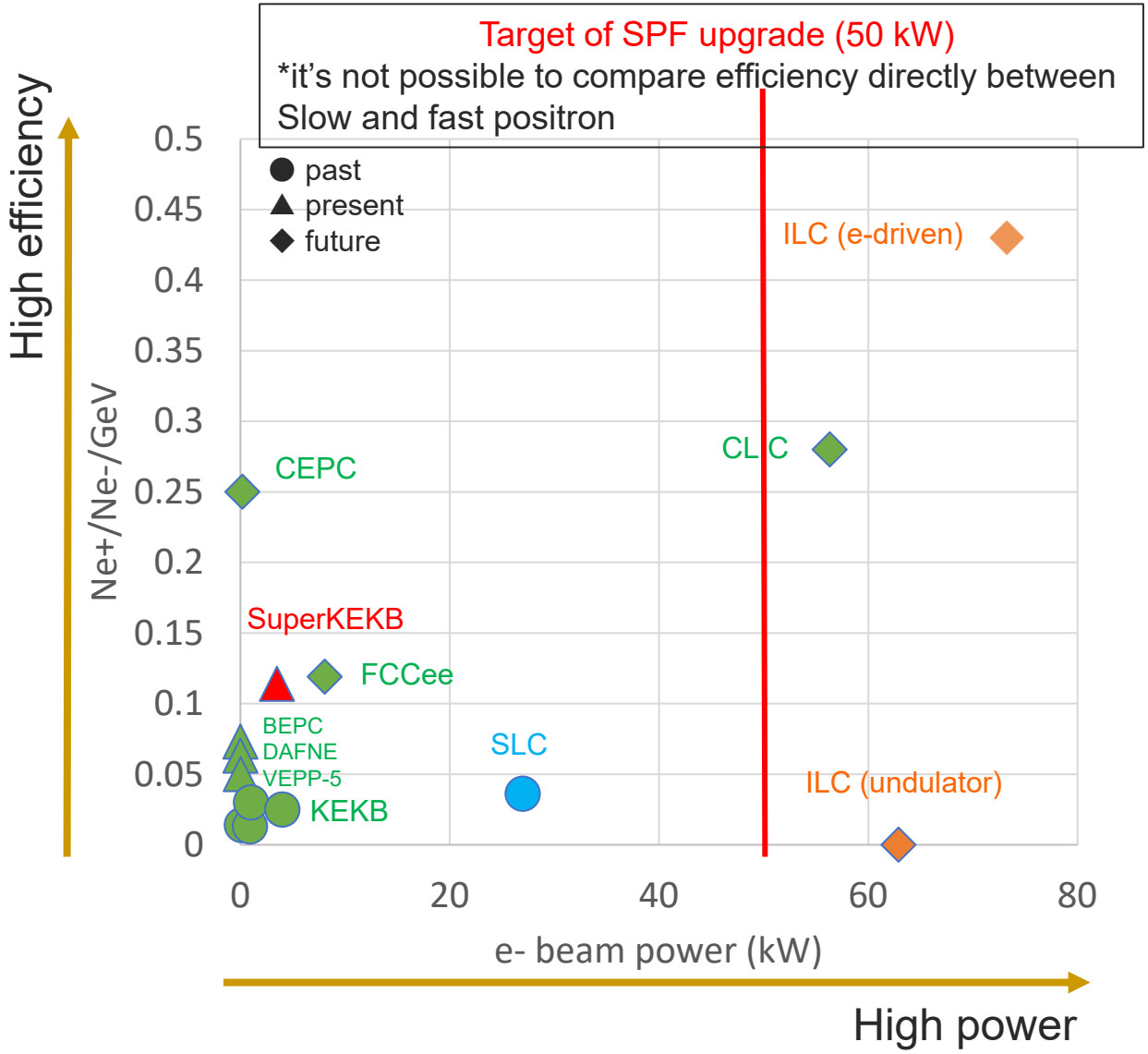
SPF upgrade plan and concept

- Upgrade beam intensity of Slow positron facility
  - Using knowledge and experiences obtained from
    - Positron source for SuperKEKB
    - X-band High gradient accelerating structure (Nextef)
  - To benchmark positron source for future collider
- Benefit for all the people working on
  - material science (main user of SPF)
    - X100 more e+
  - HEP who are longing for e+e- collider
  - high gradient accelerator
    - Beam operation experience
  - Particle source
    - Demonstrate design with beam

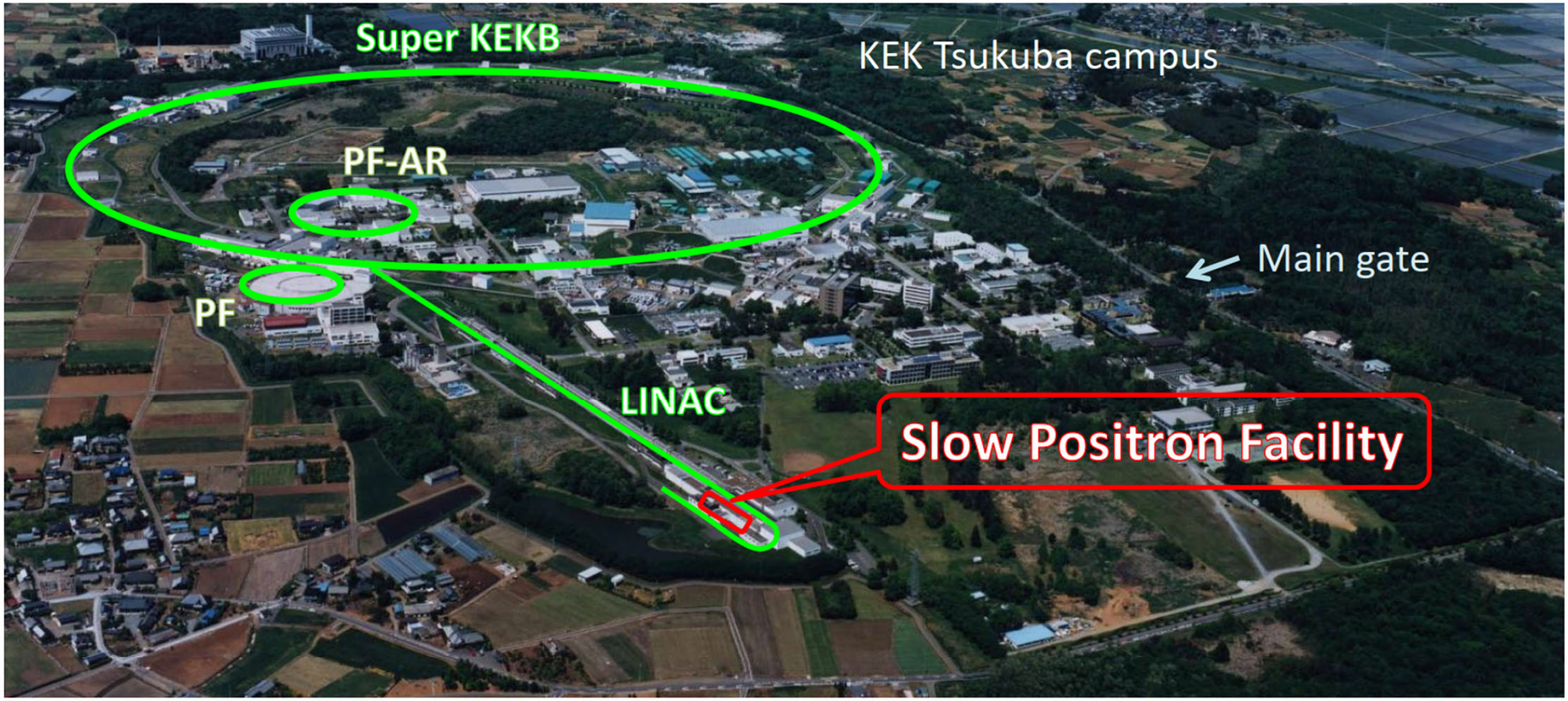
Parameter choice is important to realize these goals
○High energy low current operation
×Low energy high current or high repetition operation

Position of SPF upgrade plan projected on the HEP positron source

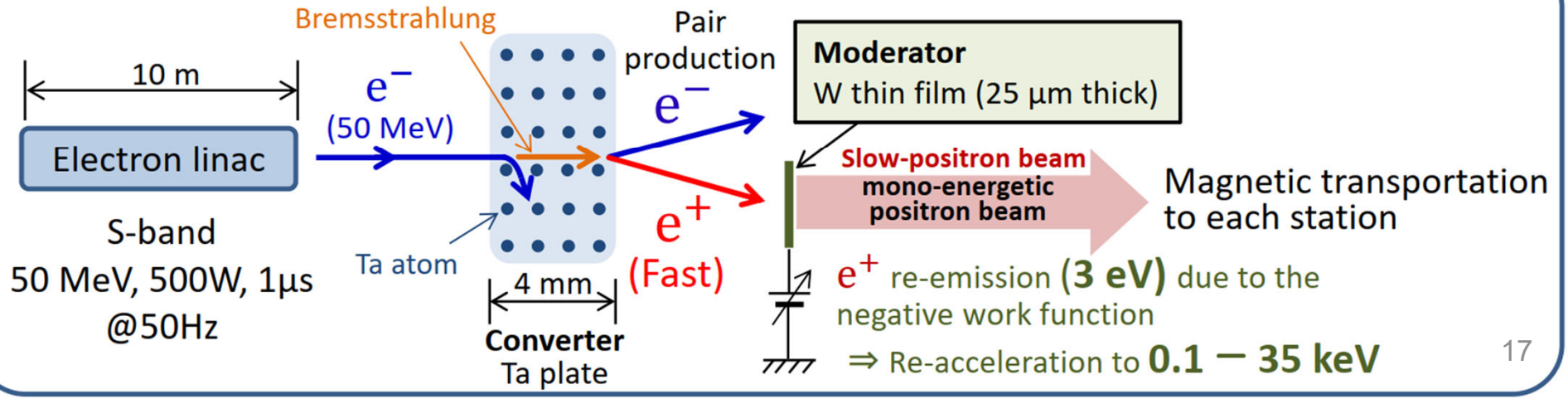
- Beam pawer : between SLC and ILC
- Demonstrate water-cooled rotating target
- No capture consideration = easier operation
- Beam operation experience is valuable experience



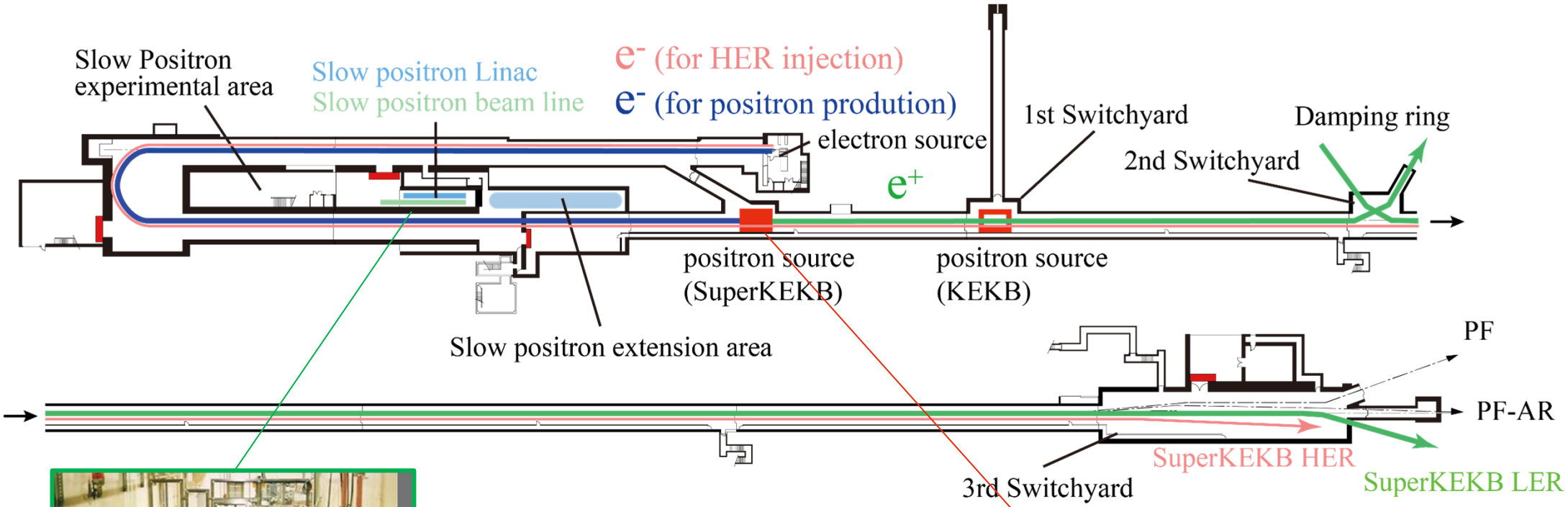
Slow Positron Facility (SPF) at IMSS

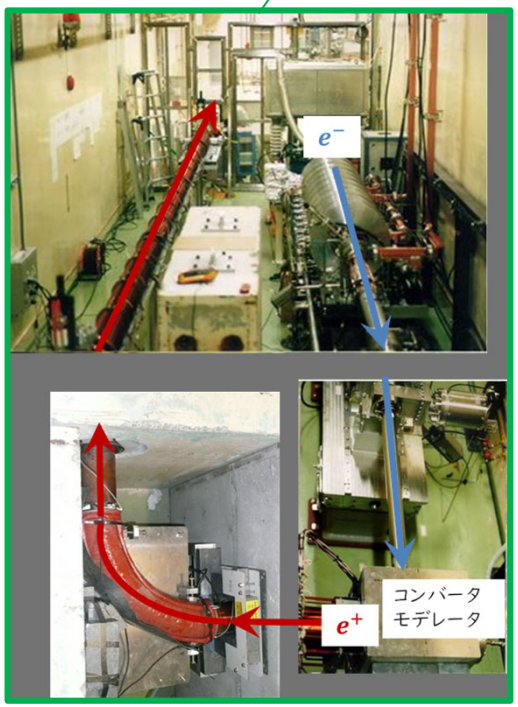


Generation of a slow-positron beam @SPF



KEK injector linac and SPF



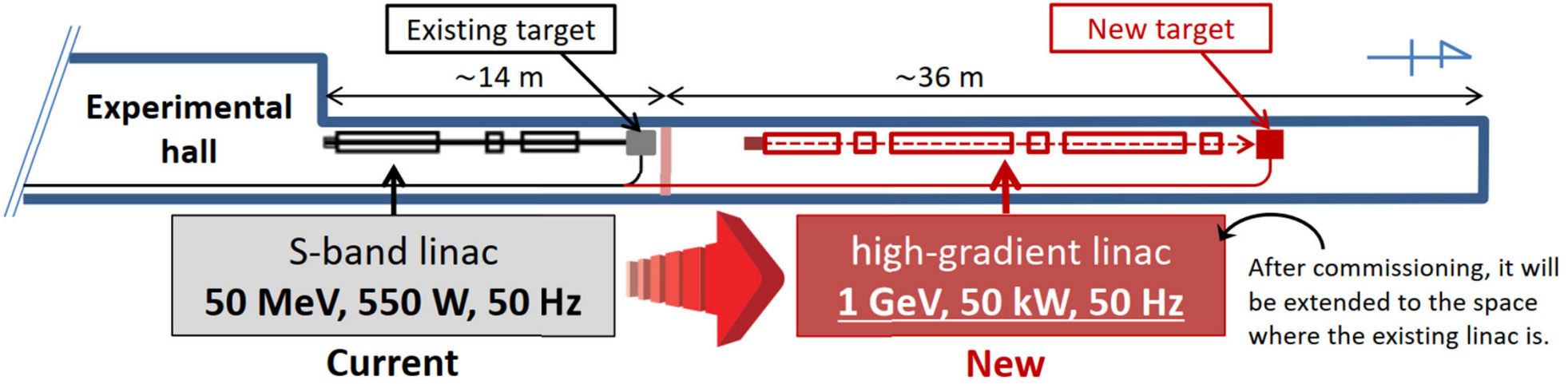


Only a few tens meter
In the same tunnel

Beam intensity upgrade of the Slow Positron Facility

We will realize **the world's most intense slow-positron beam** by applying the technologies of **high-gradient acceleration** and **high-intensity positron source** developed at KEK.

100-fold increase ⇒ 1×10^{10} slow-e^+/s



This will dramatically improve experiments of **"Positron Diffraction" (an ideal surface structural analysis method)** and bring breakthroughs in the fields of surface science.
⇒ **next-generation electronic devices** and **advanced catalytic materials**.

We will address **concerns over high-intensity positron sources** for the future **electron-positron colliders** with the new system in advance.

A target that withstands high power, radiation shielding and resistance, the effect of high-current multi-bunch beams on the following acceleration tubes, etc…

Specifications of the new high-gradient linac to be developed

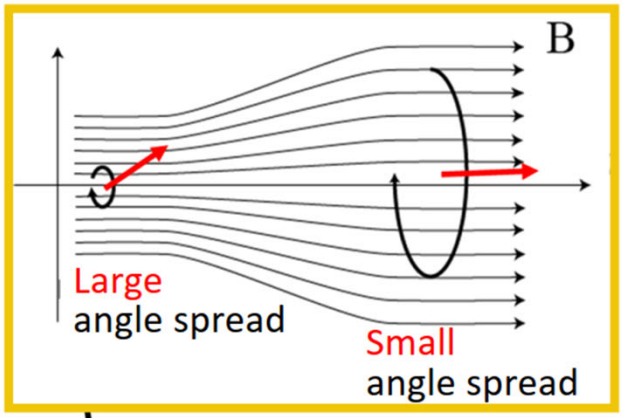
Similar parameters

Low-energy High-current / High-energy	Current SPF (achieved)	SuperKEKB (design value)	SLC (achieved)	ILC (conventional) (design value)	LLNL (design value?)	Present (design value)
energy	0.05 GeV	3.5 GeV	33 GeV	**3 GeV**	0.1 GeV	**1 GeV**
Beam power	0.50 kW	3.5 kW	27 kW	**74 kW**	45 kW	**50 kW**
Repetition	50 Hz	50 Hz	120 Hz	**100 Hz**	300 Hz	**50 Hz**
Pulse width	1 μs	Single x2	Single	**Single x 66**	3 μs	**4 μs**
Ave. current	10 μA	1 μA	0.8 μA	**24 μA**	450 μA	**50 μA**
Slow-e^+ intensity	1 x 10^8 /s		extrapolation/simulation		100 x 10^8 /s (not achieved)	100 x 10^8 /s

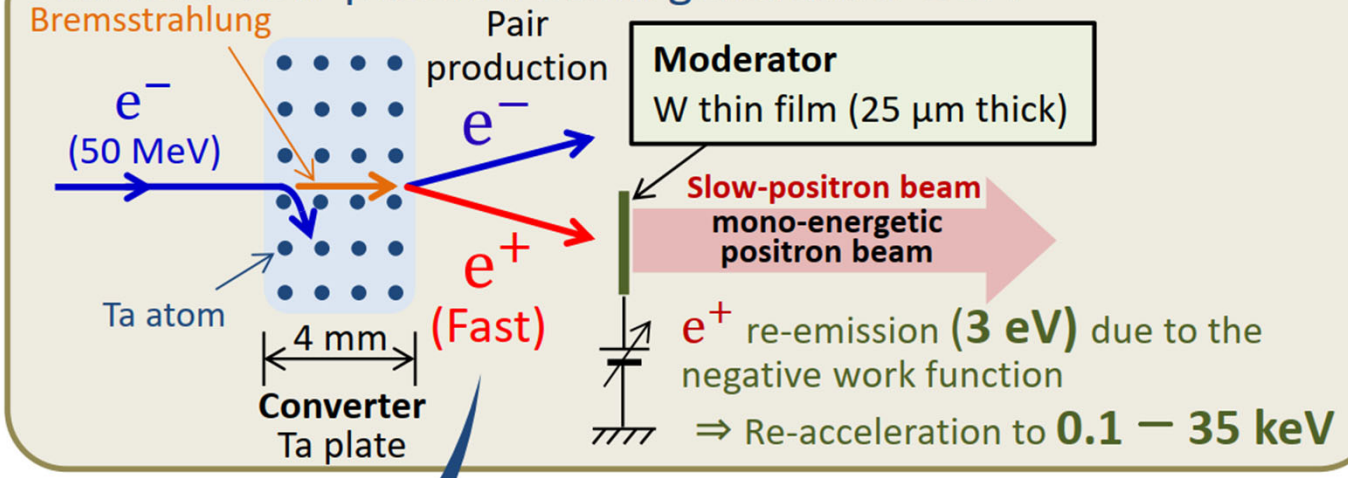
- **Parameters similar to those planned for ILC conventional positron source**
  ⇒ **Addressing concerns around the high-intensity positron source in advance**
  A target that withstands high power, radiation shielding and resistance, the effect of high-current multi-bunch beams on the following acceleration tubes, … No experimental data available since SLC (1980s - 1990s).
- **Effective use of an existing tunnel in a limited space for saving funds**
  ⇒ **A High-gradient linac** (cultivated by Nextef) with higher efficiency
  Acceleration tubes with a high shunt impedance, high-efficiecy klystrons and power supplies
  (long histories of development at the KEK linac group)
  ⇒ contribution to **Carbon neutrality**

Application of the SuperKEKB positron source technology

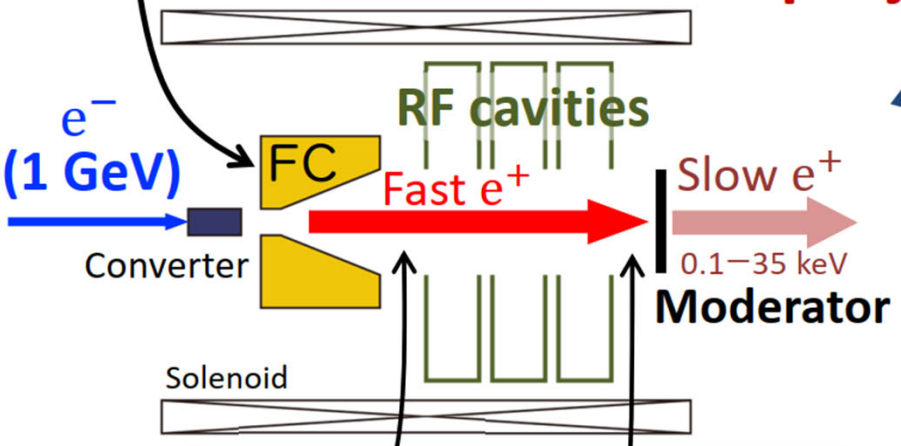
Reducing the angular spread by a **flux concentrator (FC)**

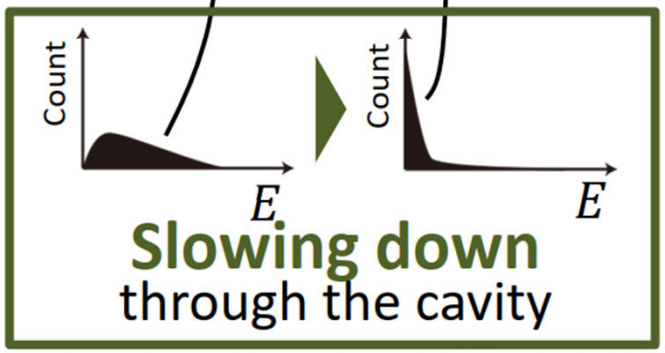


Current slow-positron beam generation @SPF



In this project …





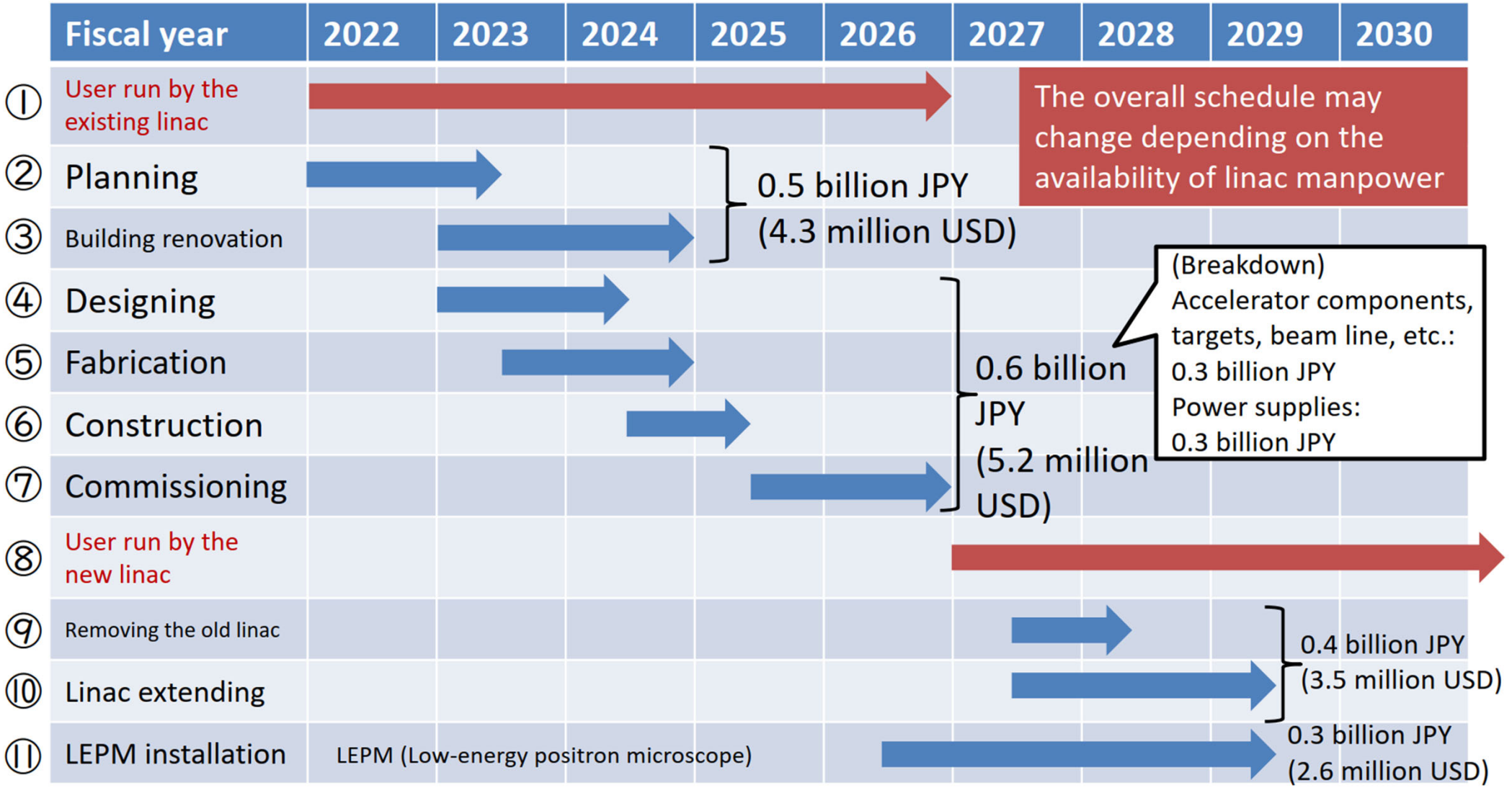
We will first Slow down the fast positrons
in the same way as SuperKEKB
and then let them go into the moderator

Improving the slow-e^+ conversion efficiency of the moderator **by a factor of ~50**

Historic breakthrough in the slow-positron beam technology!

Chemerisov et al., International Workshop on Positrons at Jefferson Lab, AIP Conf. Proc. 1160, 87 (2009)

Schedule and budget（～1.8 billion JPY or 16 million USD in total）



Relationship with the Master Plan of the Science Council of Japan

- **KEK Super B Factory Project (KEK)**
  (Priority Large Research Program)
- **New frontiers in surface and interface science using intense slow-positron beams (Japanese Positron Science Society, JPOSS)**
  Large-scale academic research projects (Category I)
  Support from JPOSS and KEK IMSS SPF user association, etc.

	Present	Plan A	Plan B	Plan C	Plan D	Plan E
Primary energy	0.05 GeV	1 GeV	1 GeV	1 GeV	1 GeV	1 GeV
Pulse width	1 us	1 us	5 us	1 us	1 us	2 us
Rep rate	50 Hz	50 Hz	50 Hz	200 Hz	50 Hz	100 Hz
pulse charge	200 nC	200 nC	1000 nC	200 nC	1000 nC	1000 nC
Bunch / pulse	2856	10000	50000	10000	10000	20000
Bunch charge	0.07 nC	0.02 nC	0.02 nC	0.02 nC	0.1 nC	0.05 nC
Pulse current	0.2 A/pulse	0.2 A/pulse	0.2 A/pulse	0.2 A/pulse	1 A/pulse	0.5 A/pulse
Primary e- num / pulse	1.25×10^{12}	1.25×10^{12}	6.25×10^{12}	1.25×10^{12}	6.25×10^{12}	6.25×10^{12}
Average current	10 uA	10 uA	50 uA	40 uA	50 uA	100 uA
Primary beam power	0.5 kW	10 kW	50 kW	40 kW	50 kW	100 kW
Positron yield	8×10^{-7}	1.6×10^{-5}	1.6×10^{-5}	1.6×10^{-5}	1.6×10^{-5}	1.6×10^{-5}
Positron / pulse	1×10^{6}	2×10^{7}	1×10^{8}	2×10^{7}	1×10^{8}	1×10^{8}
Positron / sec	5×10^{7}	1×10^{9}	5×10^{9}	4×10^{9}	5×10^{9}	1×10^{10}
Peak RF power [MW/linac]						
E_{acc}=100MV/m @room temp.		1440	1440	1440	2400	1800
E_{acc}= 50MV/m @room temp.		840	840	840	1800	1200
E_{acc}= 100MV/m @ 77K		480	480	480	1440	840
E_{acc}= 50MV/m @ 77K		360	360	360	1320	720

status

- This plan was proposed for KEK's next mid-term (2022-2028) project in FY2021
- Unfortunately, the plan was not adopted this time
- We will brush up it for the next chance
- Support from users are stable and strong
  - Very recently price of radioactive source (positron emitter such as 22Na) gets higher and higher
  - Demand for accelerator based slow positron facility are increasing in Japan