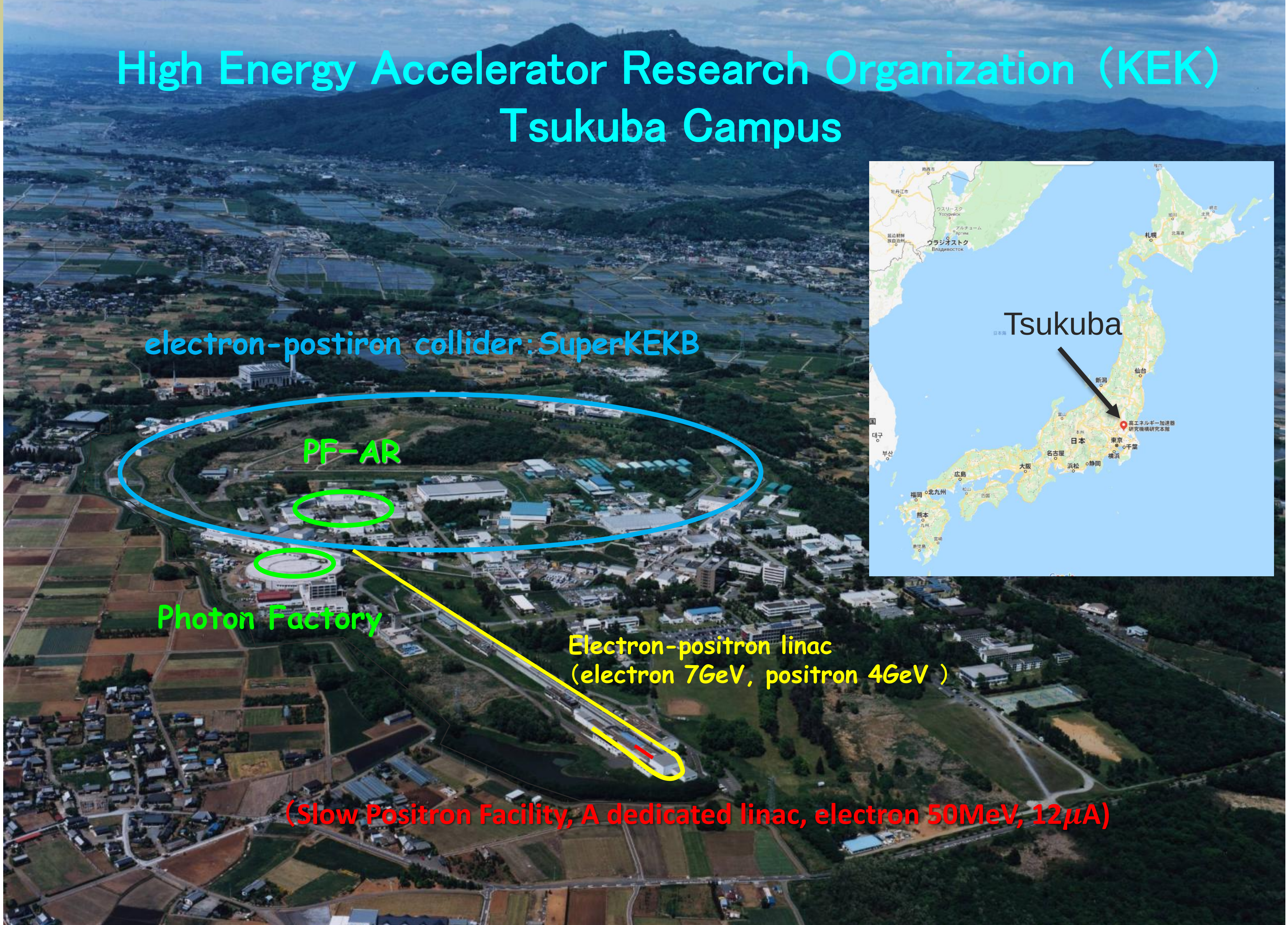
High Gradient Linac for High Intensity Positron Production

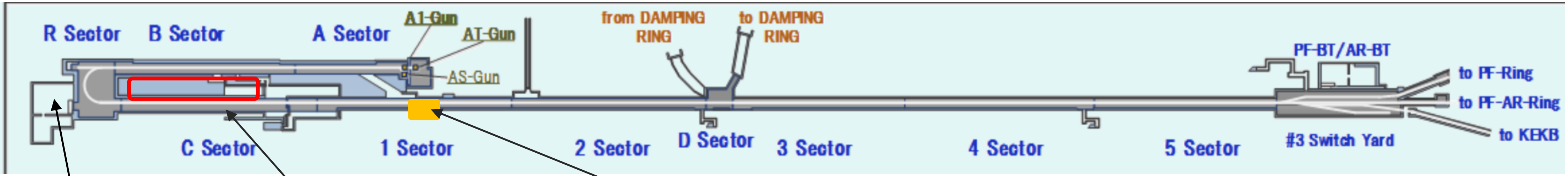
KEK accelerator division

Yoshinori Enomoto

On behalf of slow positron upgrade working group


High Energy Accelerator Research Organization（KEK）
Tsukuba Campus
Tsukuba
electron-postiron collider:SuperKEKB
PF-AR
Photon Factory
Electron-positron linac
(electron 7GeV, positron 4GeV)
（Slow Positron Facility, A dedicated linac, electron 50MeV, 12μA)

KEK Linac and positron source



500 m

Positron source for SuperKEKB

Slow positron facility

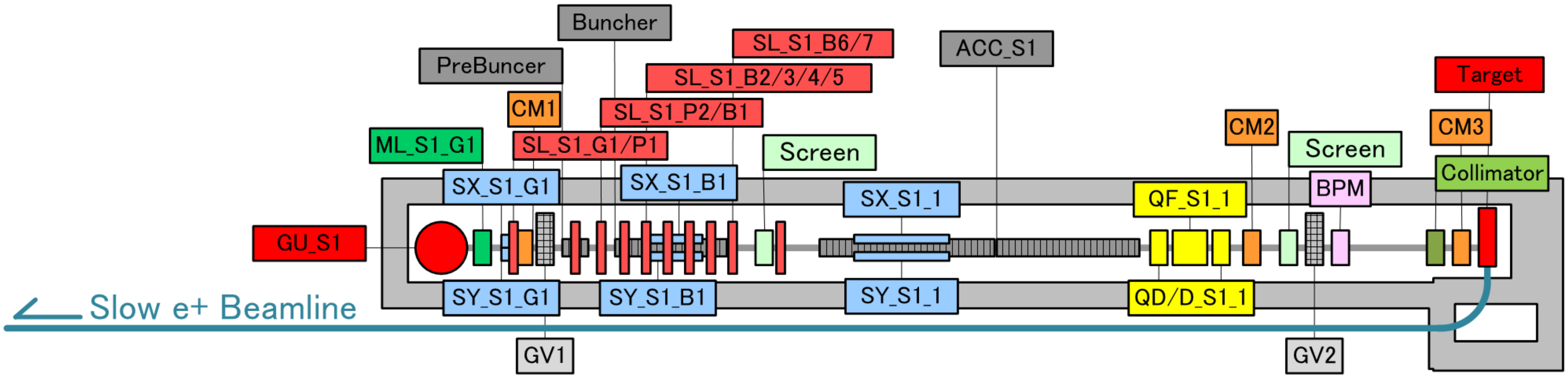
Nextef2

- KEK electron positron injector Linac
  - build in 1980
  - Have been providing electron and positron for more than 35 years for high energy collider experiments
  - Slow positron facility is operated for more than 25 years
  - Nextef / Nextef2 is next to the Linac

Slow positron facility

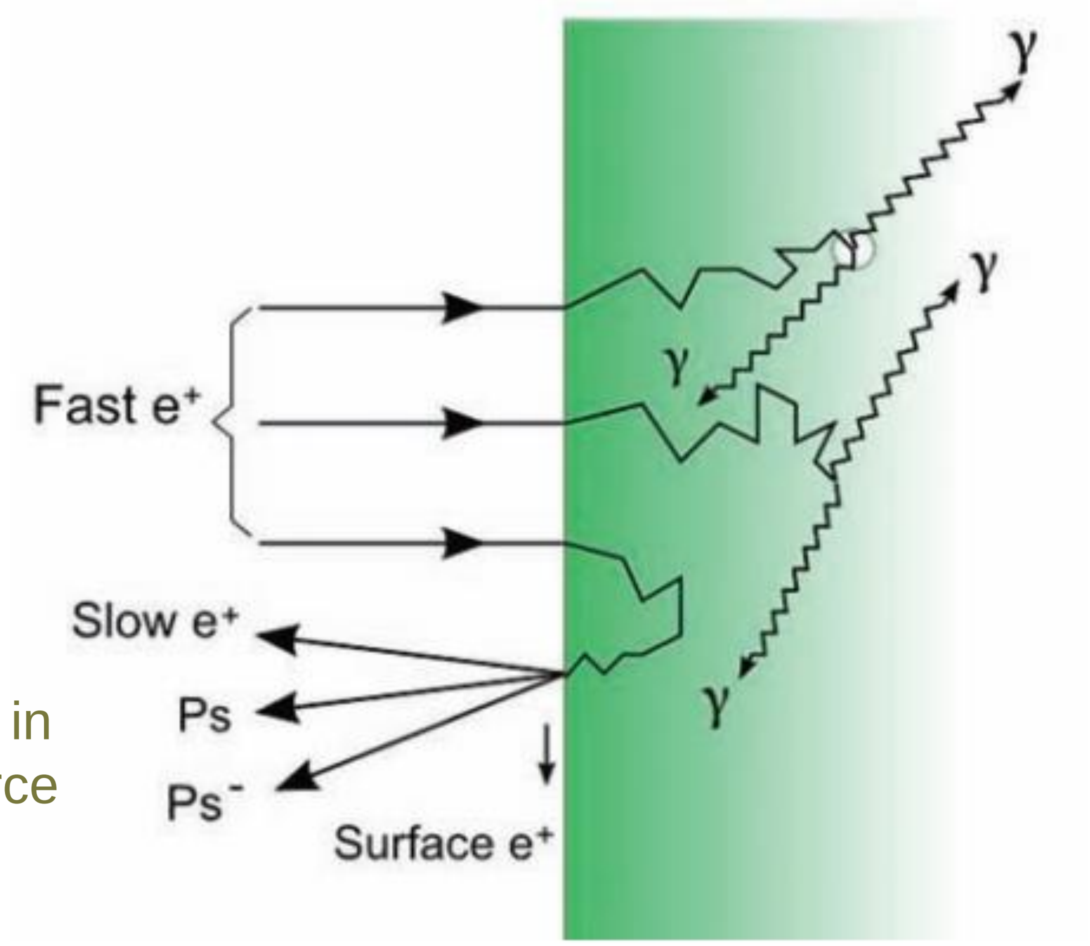
- Thermionic electron gun
- Pre buncher and buncher
- 2 x 2m S-band accelerator structure
- Ta Target and W foil moderator

Primary beamline is covered by concrete shield during operation



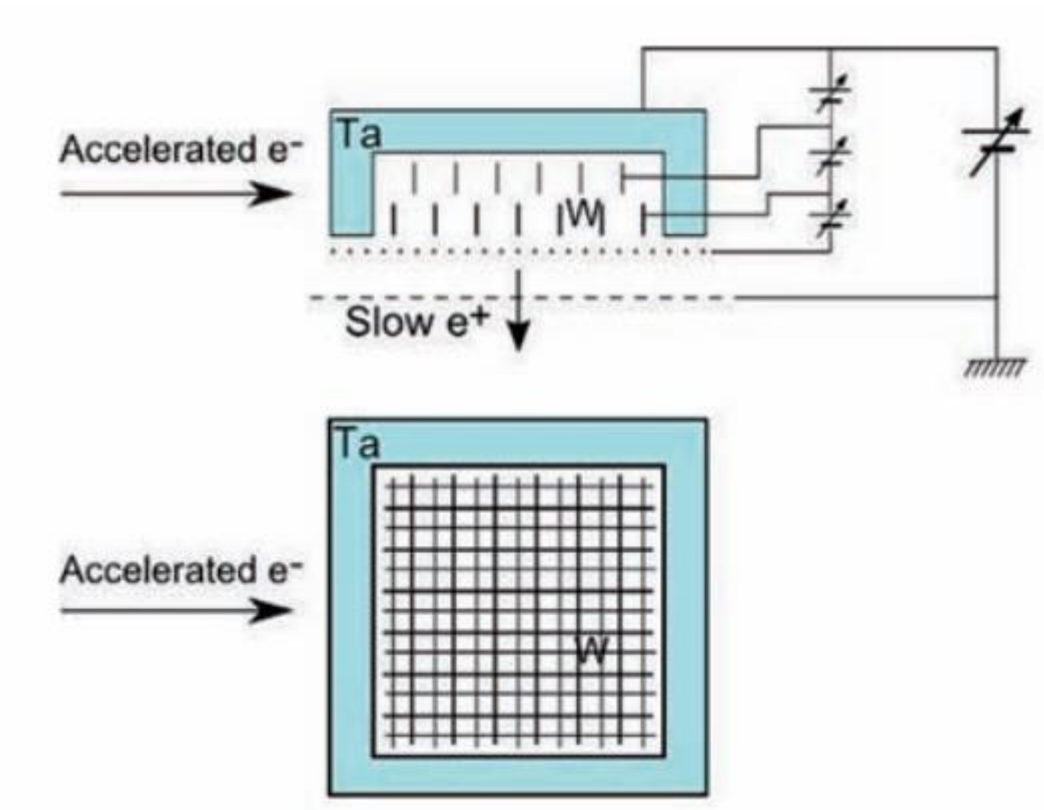
moderator

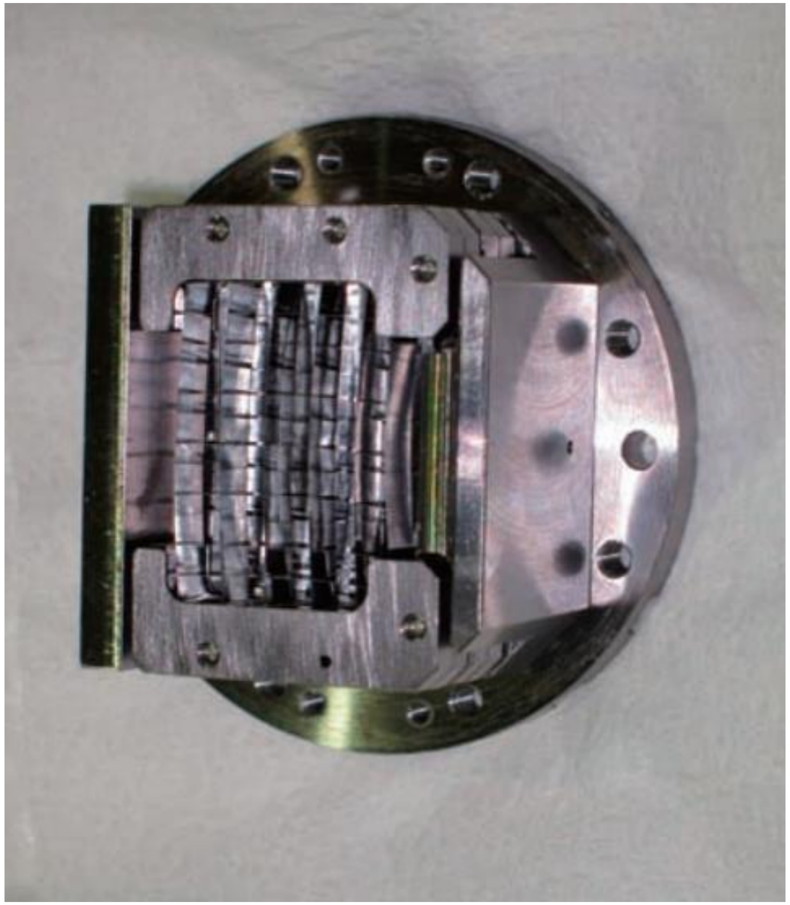
- Absorb positron from target
  - Created positron have very wide energy spread (0 ∼ MeV)
- Thermalize positron energy
  - through collisions in the material
- Re-emit positron from its surface
  - Diffused to surface
  - Negative work function
- Material of moderator
  - Solid Ne
    - Highest efficiency, but not used in accelerator based positron source
  - W foil, mesh
    - Widely used
  - There are many research for efficient moderator



Target and moderator

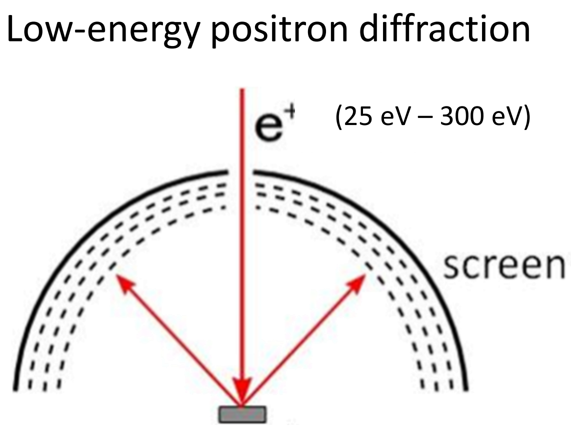
Target and moderator is floated from GND potential.
Floating voltage = energy of positron
(a few 100 eV ~ a few 10 kV)

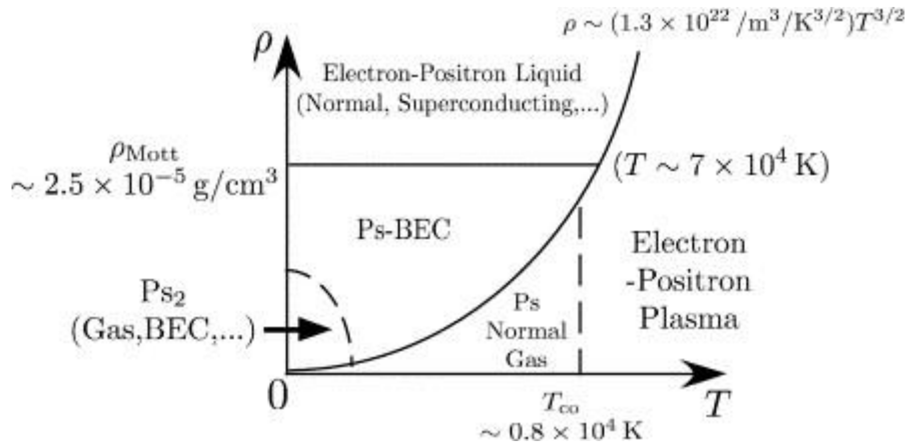




Applications of slow positron

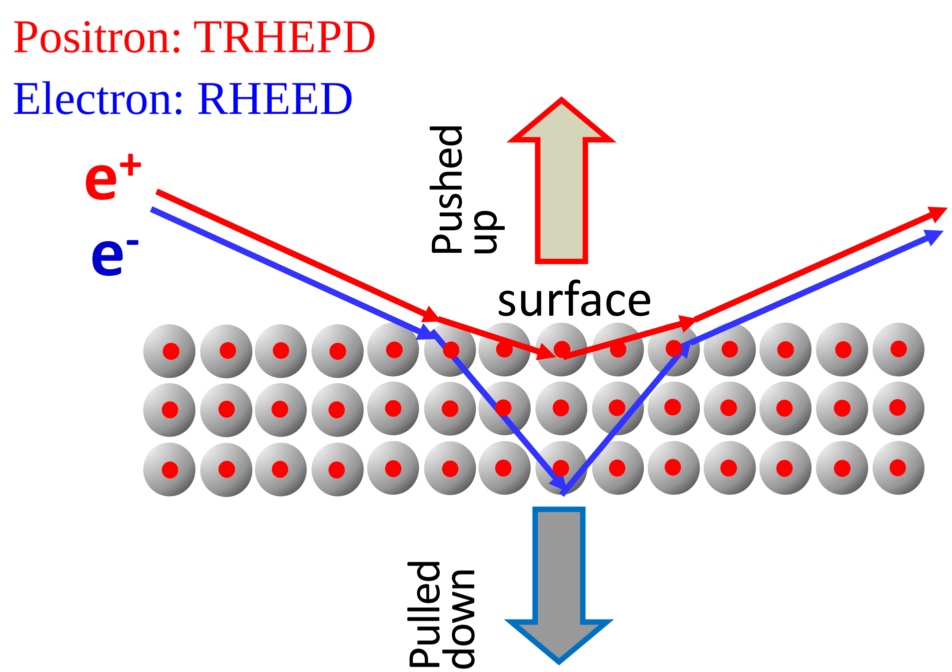
- Industrial use
  - Defect analysis
- Material science
  - Surface analysis
- Plasma physics
  - Electron-positron pair plasma
- Atomic physics
  - Positronium BEC

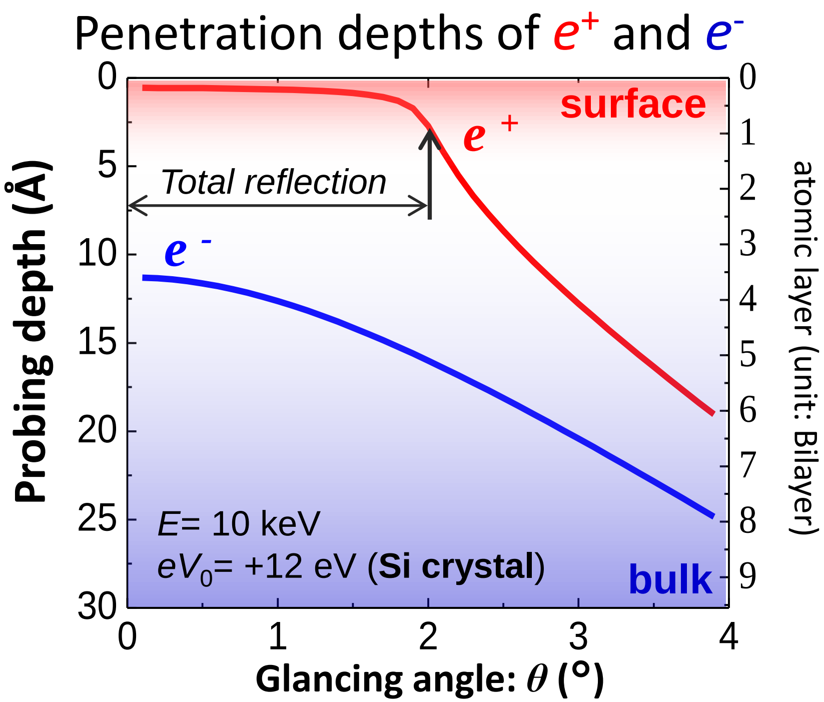




H. Yabu, NIM B **221** (2004) 144-148, “Many positron and positronium interactions”

TRHEPD –total reflection high energy positron diffraction





1. The critical angle for total reflection θ_C (2°-3°) lies in the middle of the TRHEPD measurement region (θ<6 °) (→ unique to the positron), accidentally, due to the values of m, e, h, etc. (size of atoms (lattice constant) , de-Broglie wave length, crystal potential)
2. $\theta_{in}<\theta_C$: positrons are totally reflected and see the topmost surface only.
3. $\theta_{in}>\theta_C$: positrons also see the immediate subsurface.
4. Probing depth is adjustable by varying θ_{in}.
5. No background from the deeper, bulk part at all.

Present situation in slow positron source

ITALIAN PHYSICAL SOCIETY

PROCEEDINGS
OF THE
INTERNATIONAL SCHOOL OF PHYSICS
"ENRICO FERMI"

COURSE CLXXIV

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VARENNA ON LAKE COMO
VILLA MONASTERO
7 – 17 July 2009

Physics with Many Positrons

2010

IOS Press

p.459

4. – Intense positron beams in the U.S., past and future

In this lecture, the two major intense positron beam facilities in the U.S. have been briefly presented. The NCSU PULSTAR reactor beam is currently in operation at $\sim 6 \times 10^8 e^+/s$ over a 3 cm diameter. Work is nearly complete on the Ps-PALS and e^+PALS spectrometers at NCSU. The Argonne APosS linac-based beam is currently capable of $1.5 \times 10^7 e^+/s$ over a few mm diameter, and further improvements are planned if funding is available.

In the past, there have been operational intense positron facilities in the U.S. that have contributed a great deal to our present understanding of positron-matter interactions. The first major facility was located at Brookhaven National laboratory and was a reactor-based ^{64}Cu beam capable of producing $\sim 10^8$ e^+/s initially over several mm [17]. Over roughly the same time period, intense linac beams at Oak Ridge National Laboratory [18, 19] and Lawrence Livermore Laboratory [13] were also in operation, with intensities in the range $> 10^8 e^+/s$ with beam sizes of a few mm. The intense beams in the U.S. at the $\sim 10^{10} e^+/s$ level envisioned in the 1990s' have not materialized, even though the concepts were technically sound. They included proposals for the 400 MeV linac at CEBAF [20], the ^{64}Cu beam based on the proposed but never built ANS reactor [21], and a ^{58}Co-based beam at Idaho National Engineering Laboratory INEL (INL) [22]. Intense beam efforts in Europe [23, 24] (Delft and NEPOMUC) and in Japan [25] (Tsukuba) have been steady and continuous over the past two decades.

Parameter consideration 1

- Primary Beam power
  - Number of positron is proportional to the primary beam power
    - Higher power is preferable

Positron source in GBAR

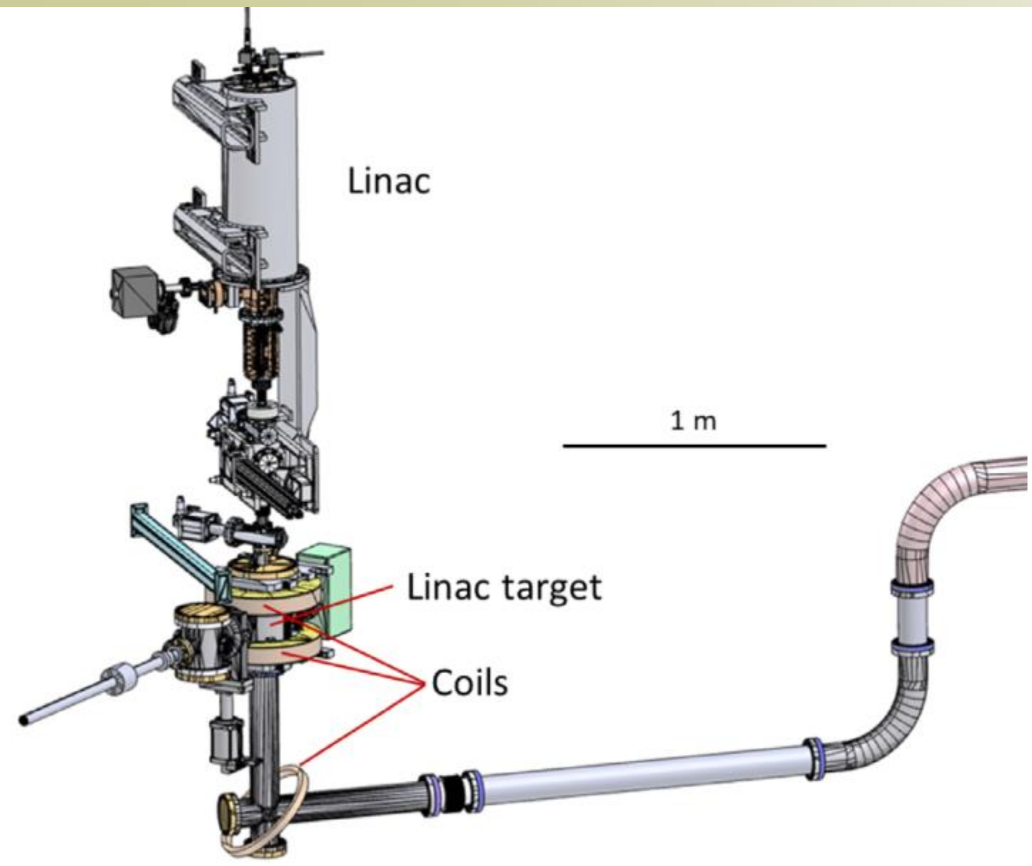


Fig. 1. Schematic view of the linac (vertical structure on the left) and the positron transfer line. The transfer fields are generated by solenoids wound around the beam pipes and by the two larger coils placed around the linac target. The coil at 45 degrees position is used to fine-tune the magnetic field at the point where the positron beam turns sharply. The beam line crosses the biological shield at the "S" shaped section on the right.

Nuclear Inst. and Methods in Physics Research, A 985 (2021) 164657

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

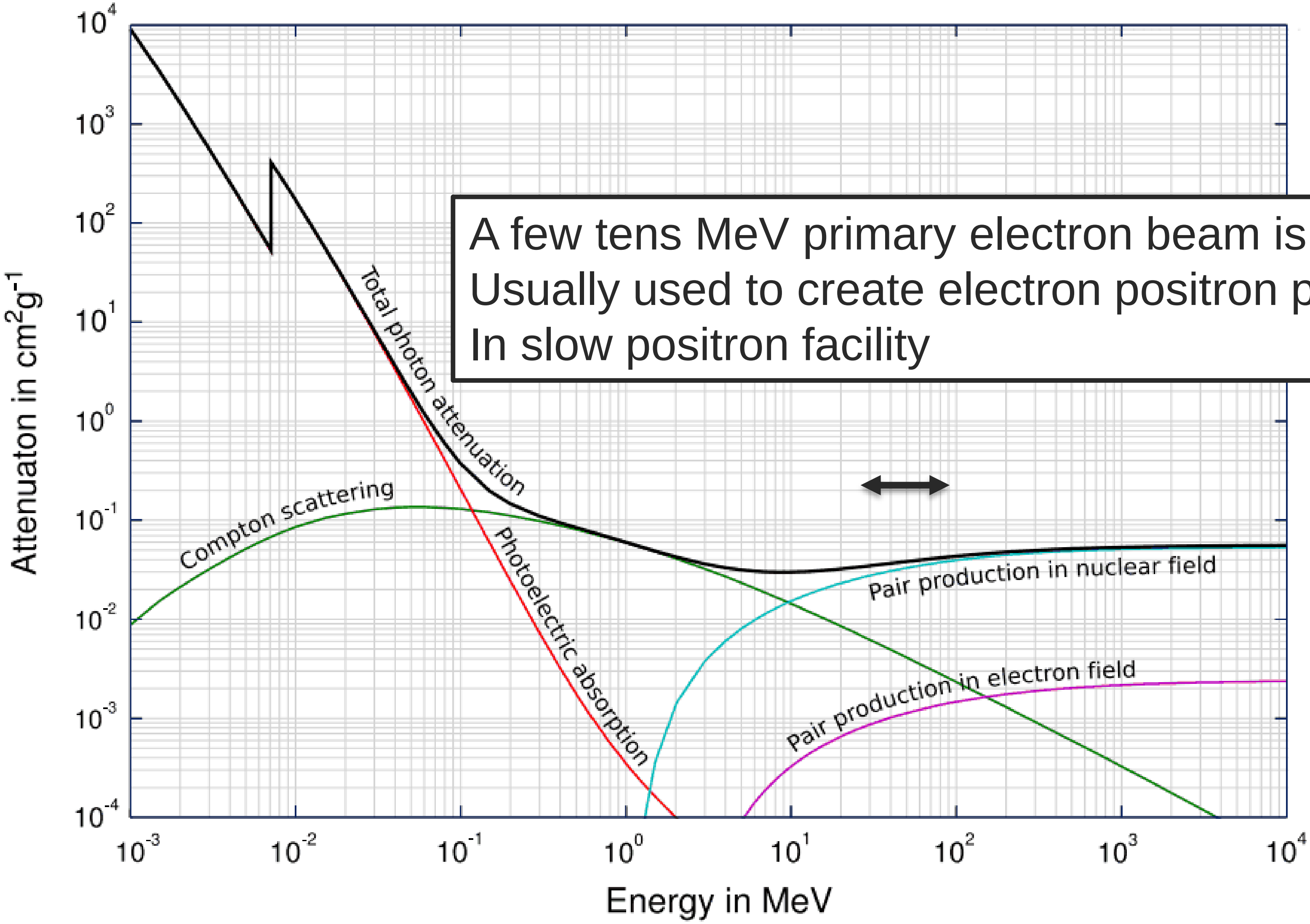
journal homepage: www.elsevier.com/locate/nima

Positron production using a 9 MeV electron linac for the GBAR experiment

M. Charlton [a], J.J. Choi [b], M. Chung [c], P. Cladé [d], P. Comini [f], P.-P. Crépin [d], P. Crivelli [g], O. Dalkarov [h], P. Debu [f], L. Dodd [a], A. Douillet [d,e], S. Guellati-Khélifa [d], P.-A. Hervieux [i], L. Hilico [d,e], A. Husson [j,1], P. Indelicato [d], G. Janka [g], S. Jonsell [k], J.-P. Karr [d,e], B.H. Kim [b], E.-S. Kim [l], S.K. Kim [b], Y. Ko [m], T. Kosinski [n], N. Kuroda [o], B. Latacz [f,2], H. Lee [b], J. Lee [m], A.M.M. Leite [f,3], K. Lévêque [i], E. Lim [l], L. Liszkay [f,*], P. Lotrus [f], T. Louvradoux [d], D. Lunney [j], G. Manfredi [i], B. Mansoulié [f], M. Matusiak [n], G. Mornacchi [p], V.V. Nesvizhevsky [q], F. Nez [d], S. Niang [f], R. Nishi [o], S. Nourbaksh [p], K.H. Park [b], N. Paul [d], P. Pérez [f], S. Procureur [f], B. Radics [g], C. Regenfus [g], J.-M. Rey [f,4], J.-M. Reymond [f], S. Reynaud [d], J.-Y. Roussé [f], O. Rousselle [d], A. Rubbia [g], J. Rzadkiewicz [n], Y. Sacquin [f], F. Schmidt-Kaler [r], M. Staszczak [n], B. Tuchming [f], B. Vallage [f], A. Voronin [h], A. Welker [p], D.P. van der Werf [a], S. Wolf [r], D. Won [b], S. Wronka [n], Y. Yamazaki [s], K.-H. Yoo [c]

9 MeV, 300 Hz, 2.5 kW
5 X 10^7 e+/s

Interaction of photon with matter



A few tens MeV primary electron beam is
Usually used to create electron positron pair
In slow positron facility

https://www.nuclear-power.net/nuclear-power/reactor-physics/interaction-radiation-matter/interaction-gamma-radiation-matter/

Parameter consideration 1

- Primary Beam power
  - Number of positron is proportional to the primary beam power
    - Higher power is preferable
- Synergy and Connection to a positron source for high energy physics
  - prototype of future high power positron sources for high energy physics (ILC, FCCee, CEPC, CLIC)
    - High energy low current short bunch is preferable compared with low energy high current scheme
- Limitation
  - Available tunnel space < 50 m
- Collaboration and environment
  - KEK Linac has long history of development on high gradient X-band accelerator structures –Nextef

1 GeV order primary beam by high gradient acceleration (50 MV/m)

Parameter consideration 2

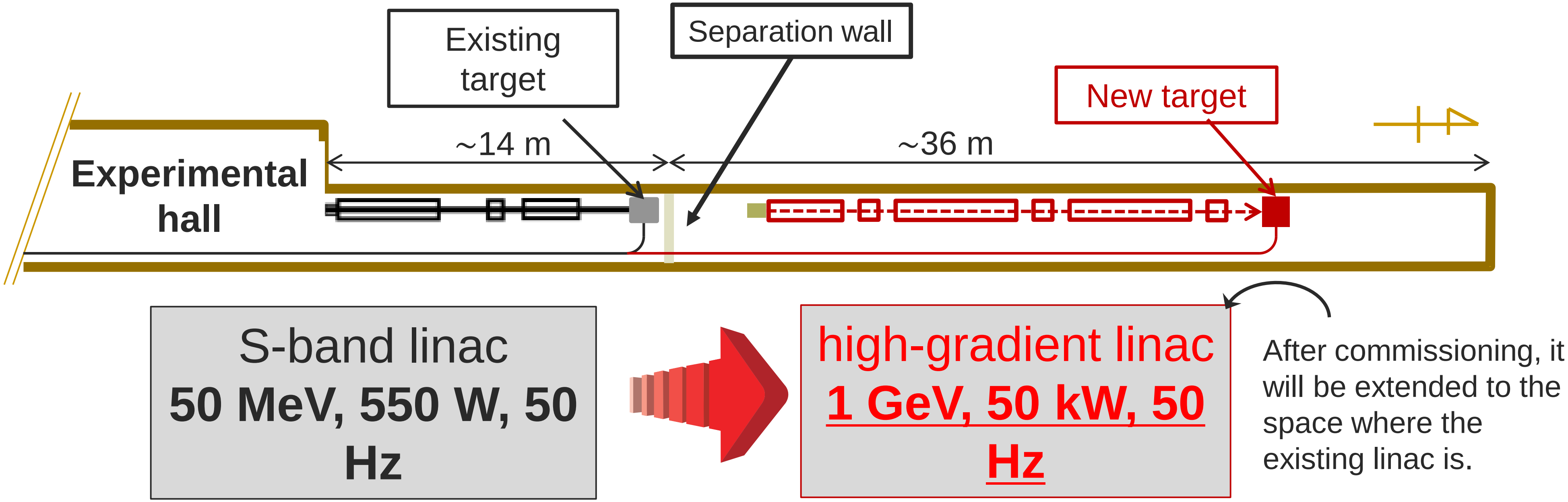
Parameters of this project are similar to that of ILC

project	SPF (achieved)	SuperKEKB (achived)	SLC (achieved)	ILC(e-driven) (design)	LLNL1999 (design)	This project (design)
Primary energy	0.05 GeV	3.5 GeV	33 GeV	3 GeV	0.1 GeV	**1 GeV**
Beam power	0.55 kW	3.5 kW	27 kW	74 kW	45 kW	**50 kW**
Repetition	50 Hz	50 Hz	120 Hz	100 Hz		**50 Hz**
Pulse width	4 us	Single x2	Single	Single x 66		**4 us**
Average current	11 uA	1 uA	0.8 uA	24 uA	450 uA	**50 uA**
Efficiency (e+/e-)	1.45×10^{-6}	0.4	1.0	1.25	3.2×10^{-6}	**32×10^{-6}**
Efficiency (e+/kW)	1.82×10^{8} /kW	0.71×10^{12} /kW	0.19×10^{12} /kW	2.7×10^{12} /kW	2×10^{8} /kW	**2×10^{8} /kW**
Number of positrons (/s)	1×10^{8} /s	2.5×10^{12} /s	5×10^{12} /s	200×10^{12} /s	90×10^{8} /s	**100×10^{8} /s**

High energy physics

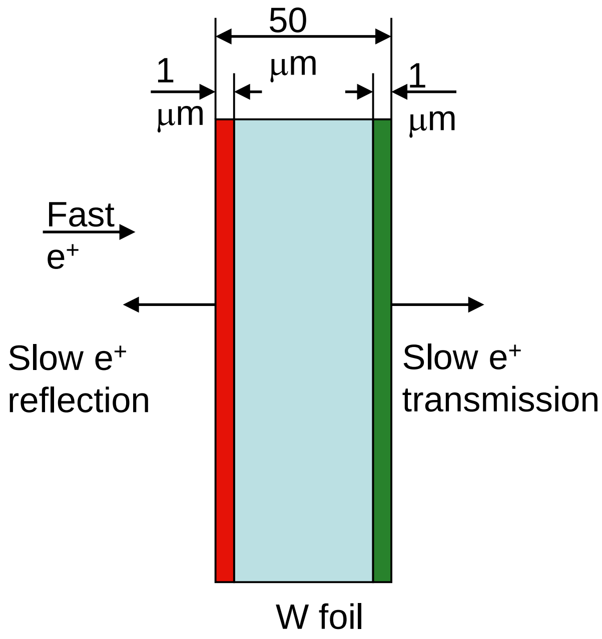
- SLC was the world's highest power positron source ever build (27 kW)
- SuperKEKB is the word's highest power positron source in operation (3.5 kW)
- Future project especially ILC and CLIC require further higher beam power (～74 kW)
- A few tens kW (more than 27 kW) positron source will give us new knowledge.

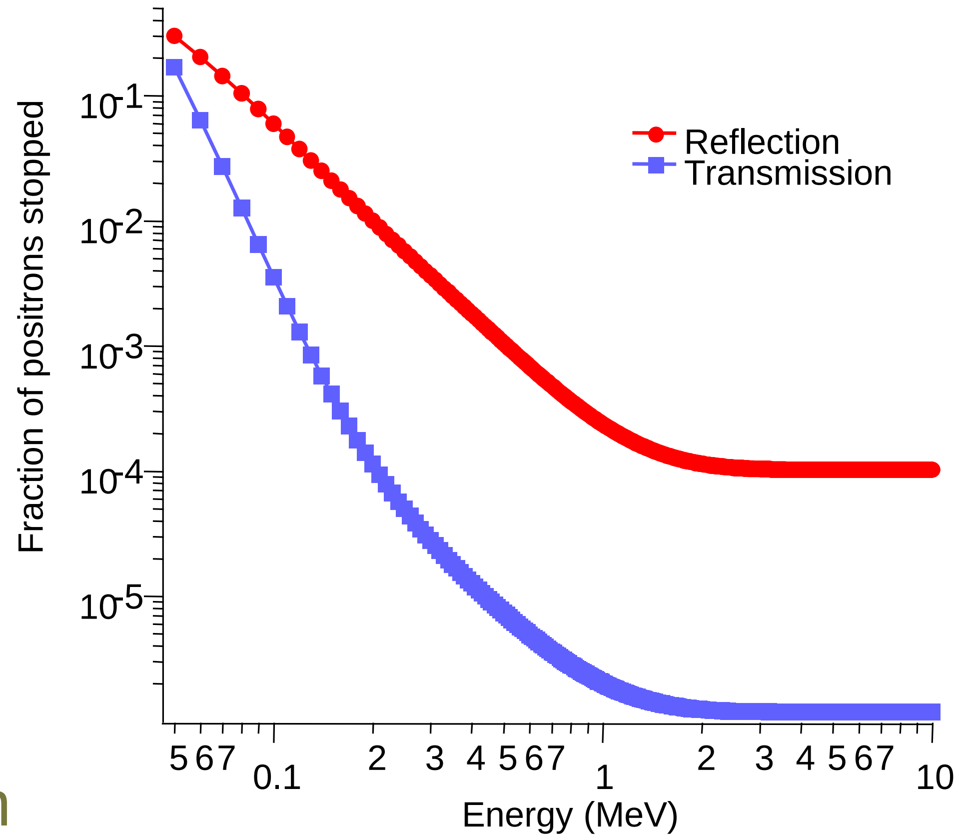
Layout and upgrade scheme



- New accelerator will be installed downstream side of the present Linac
- Separation wall will be removed after confirming the new positron source working correctly
- Present positron source will be removed and the new Linac will be extended

Efficiency of moderator vs positron energy





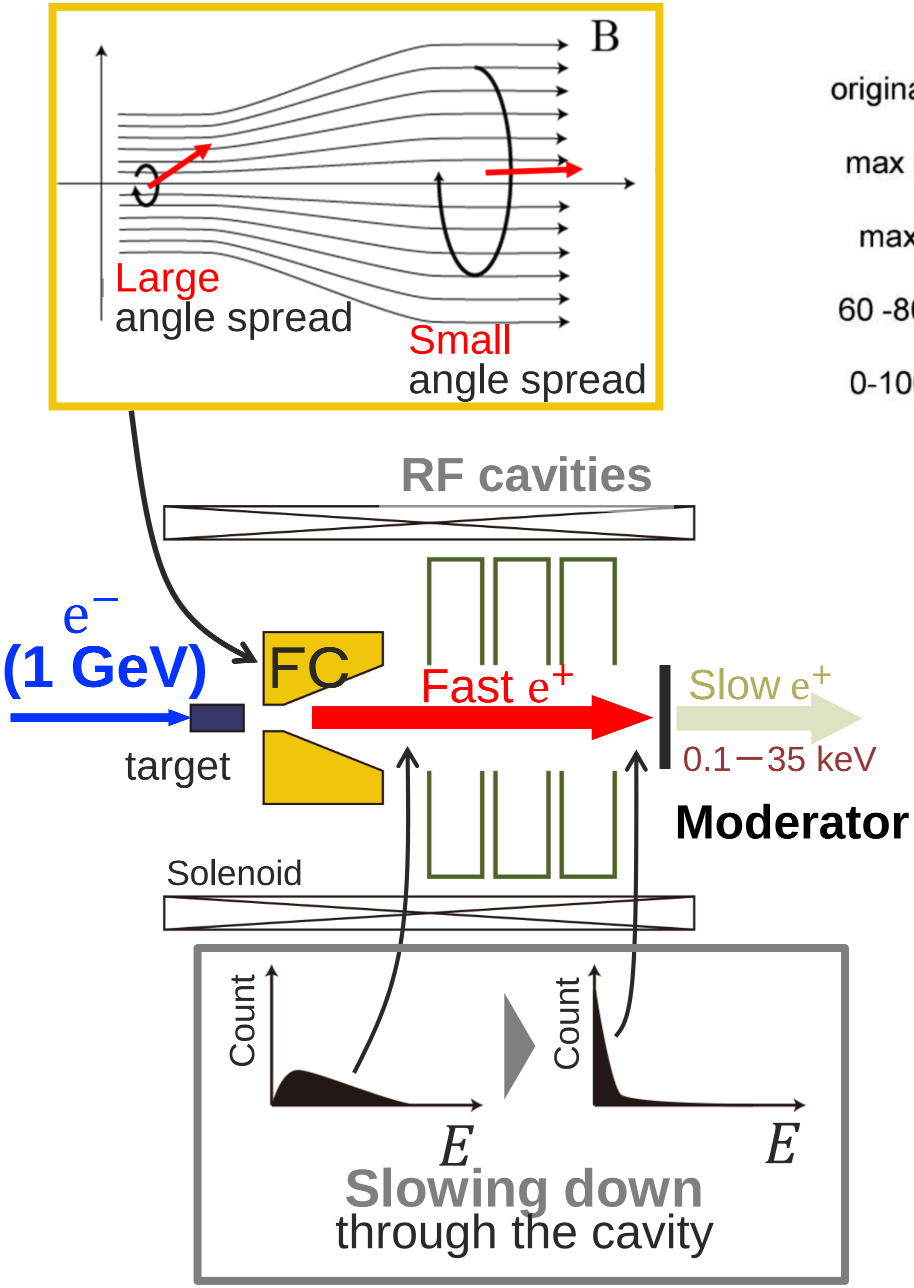
Fraction of the positron stopped in 1 µm layer of the moderator

- Efficiency of moderator is strongly depends on energy of fast positron
- Deceleration of positron from target before impinging into the moderator will increase efficiency greatly.

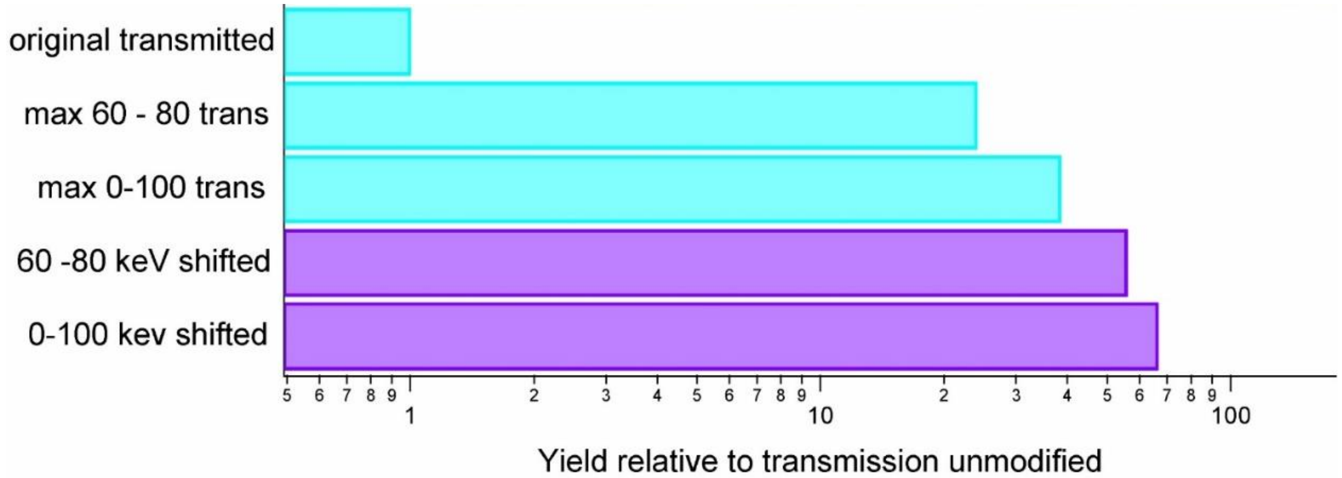
Sergey Chemerisov and Charles D. Jonah, Argonne National Laboratory, “Generation of High Intensity Positron Beam Using 20 MeV linac”

Increase moderator efficiency by deceleration

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

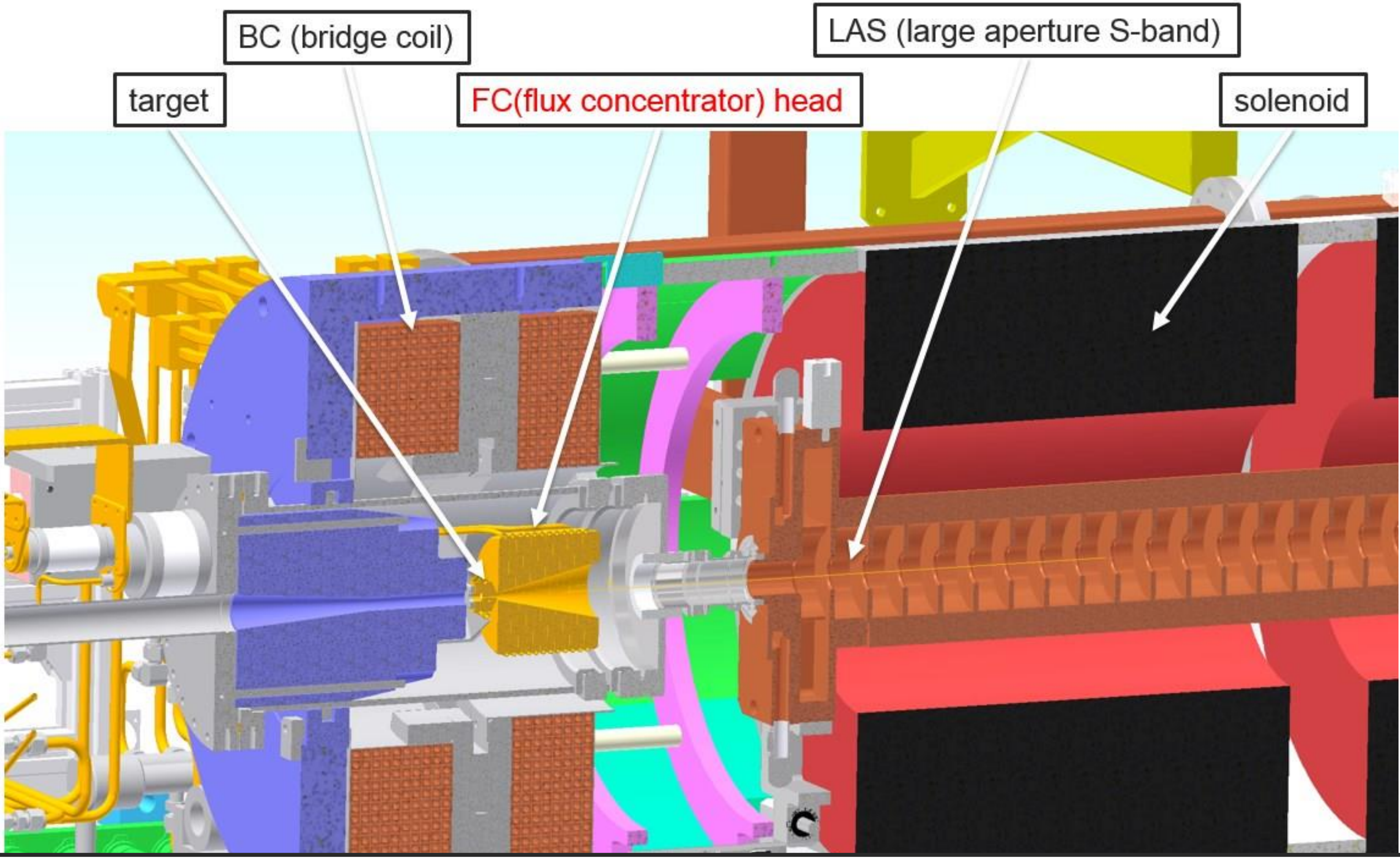


C. D. Jonah *et al*., Appl. Surf. Sci. **225** (2008) 25-28
"Development of the Argonne positron source APosS"



- More than 10 times increase of efficiency by slowing down positrons down less than 100 keV.
- Purple bars show the results when the energy is shifted 20 keV. (i.e. 0-100kV shifted = 20-120 keV)

Positron source for SuperKEKB

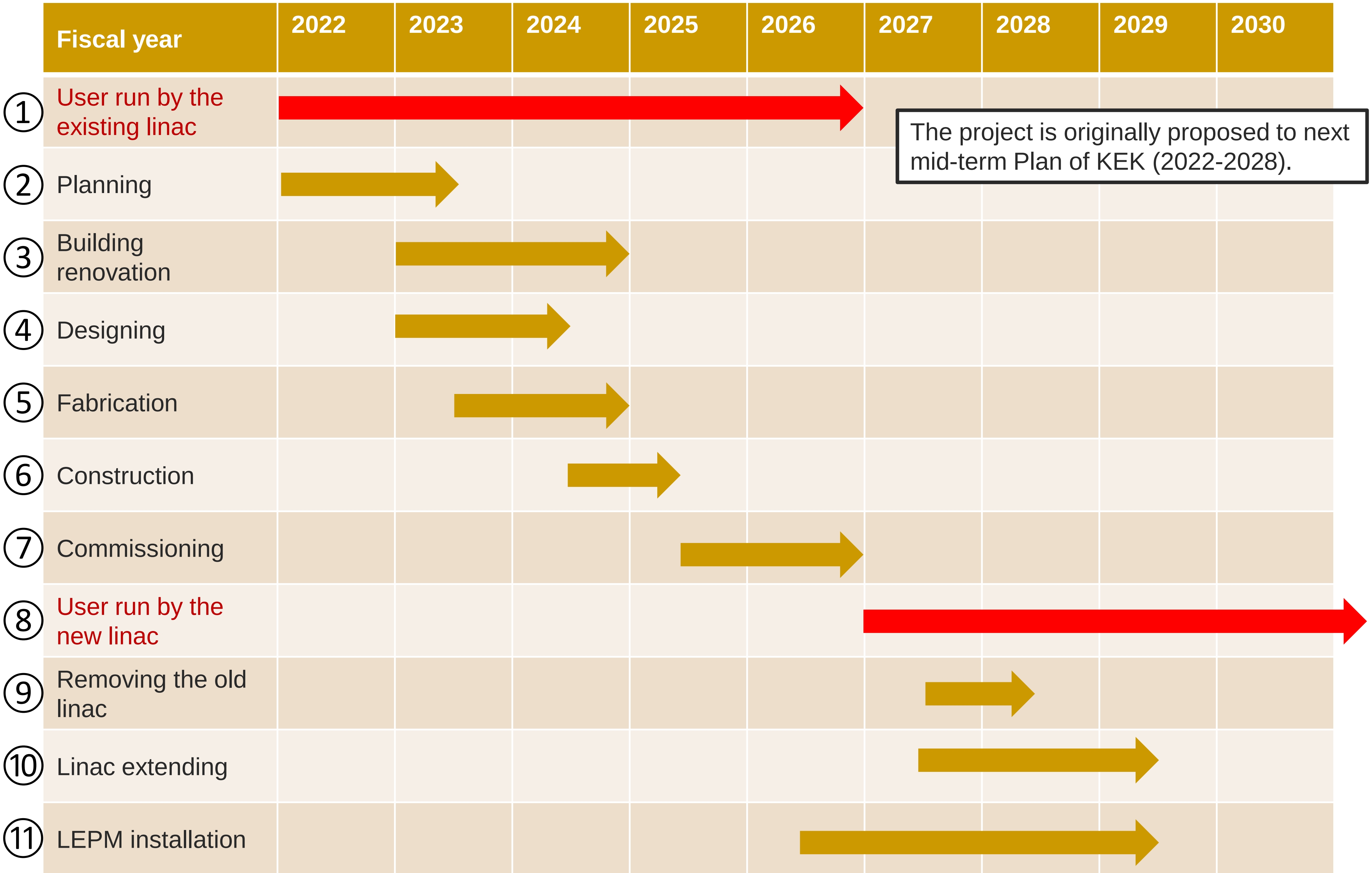


For capture and bunching, positrons are usually injected into deceleration phase of the accelerator structure at first stage, even in high energy positron source.

Summary

- 100 times intensity upgrade of the slow positron facility in KEK is proposed
  - For material and surface science
  - For technical development and prototyping of
    - High power positron sources for future collider
    - High gradient (X-band) accelerator of a few tens meter
  - Using technology developed by Nextef
  - Using technology developed by SuperKEKB positron source

Annual plan (original)



LEPM (Low-energy positron microscope)