

# Linac upgrade

Accelerator Division V  
Injector linac RF group  
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# Linac upgrade “RF power upgrade”

- We are planning to upgrade RF units.
- We are developing new “Klystron”, as high-power and high-efficient RF source.
- High-power and high-efficiency are achieved using multi-beam klystron (MBK) technology.
- New modulators will also be introduced for the klystron.
- The new modulator is a modern system that uses semiconductors rather than vacuum tubes.
- This upgrade will introduce a highly-efficient modern system to realize a stable and powerful injector linac.

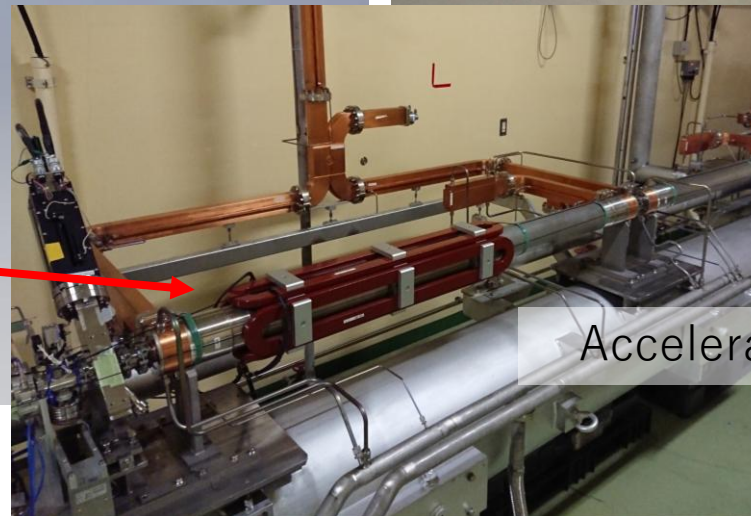
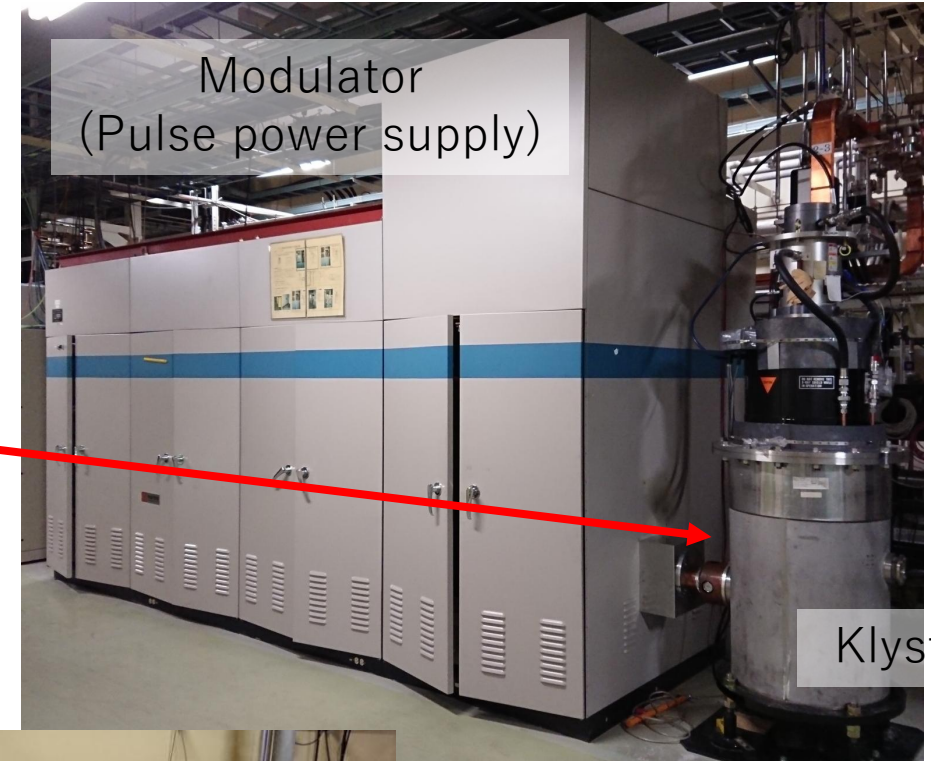
# Accelerator unit in the injector linac

**Pulse compressor**  
generating high peak RF wave  
114 MW 1  $\mu$ s

**Pulsed klystron**  
as an amplifier of high-power RF wave  
2,856 MHz 40 MW  
4  $\mu$ s 50 pps

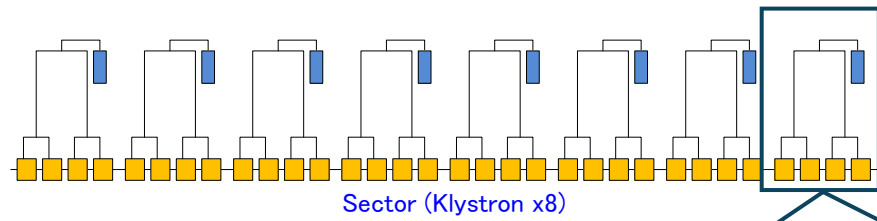
**Waveguide circuit**  
for transmission of high-power RF wave

**Four beam-accelerating structures**  
Unit acceleration voltage  
160 MV (21 MV/m)

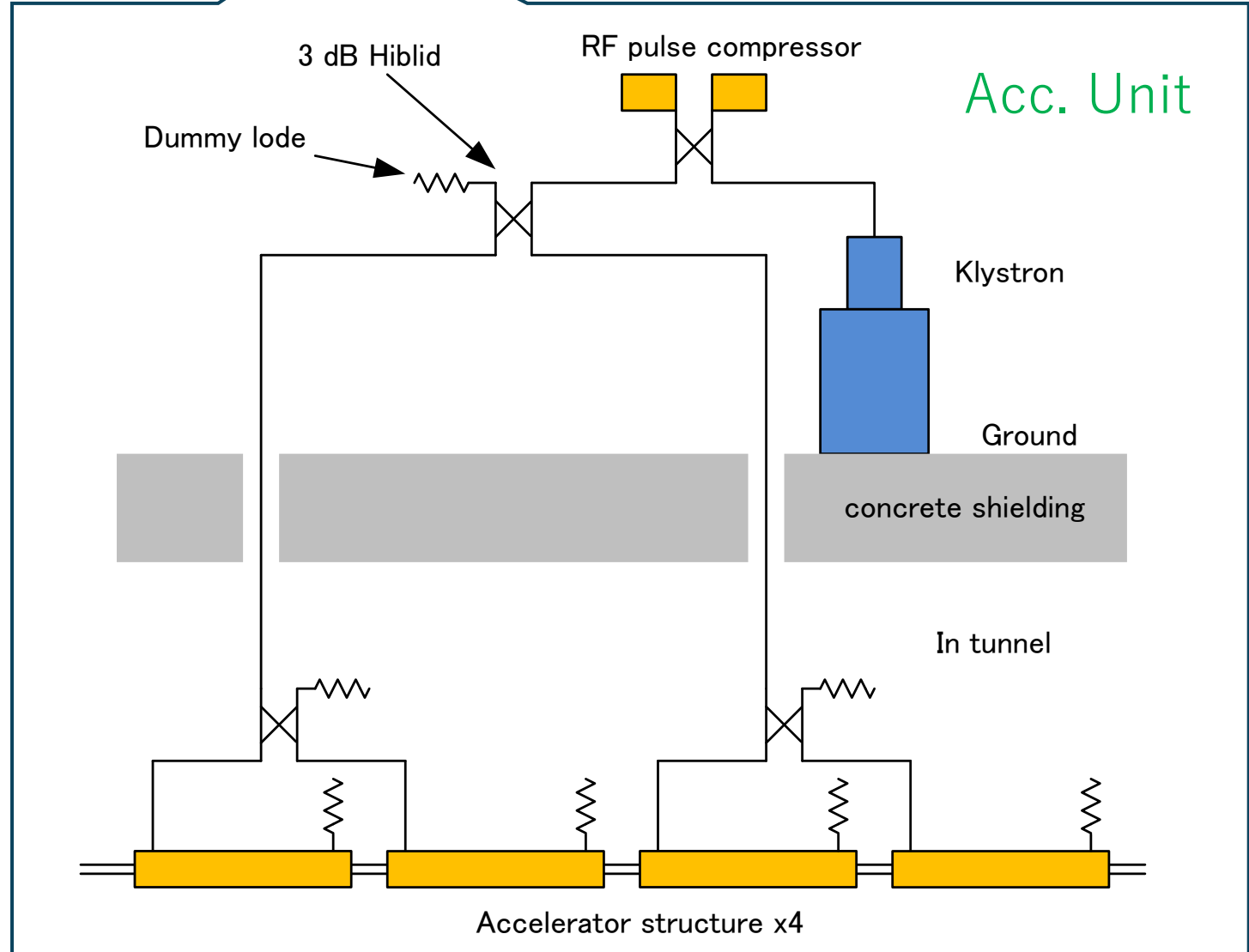


Accelerator structure x4

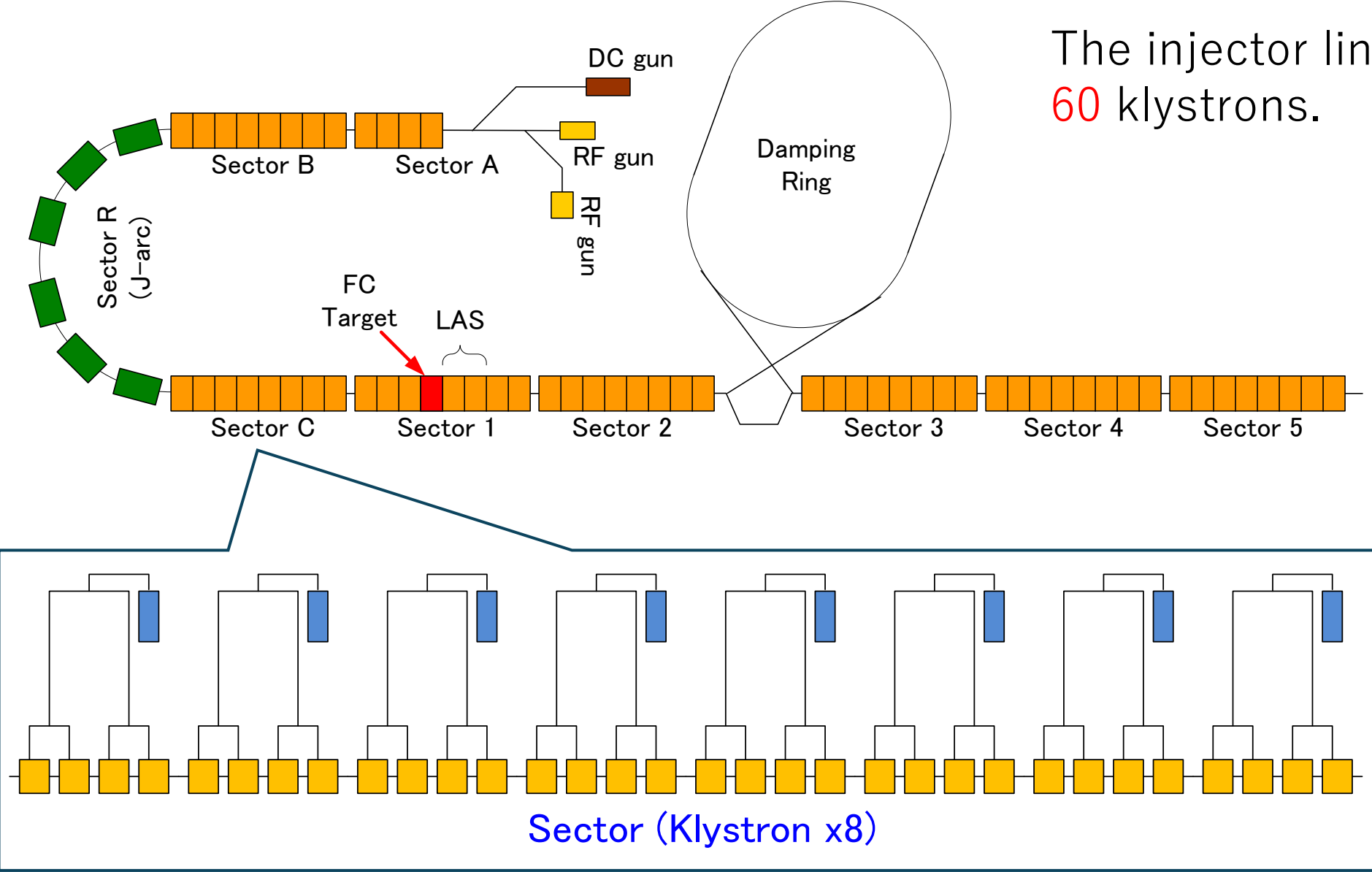
# Sector and Unit



Sector (Klystron x8)



# KEK injector linac



The injector linac has 60 klystrons.

# RF source

Modulator  
PFN type  
Installed in 1982  
Remodeled in 1995

Klystron  
Power 50 MW  
Efficiency 45 %  
Developed in 1995

This RF unit is installed  
for KEKB.  
This is very old system.



The upgrade plan mainly  
involves replacing the aging  
modulators and klystrons.

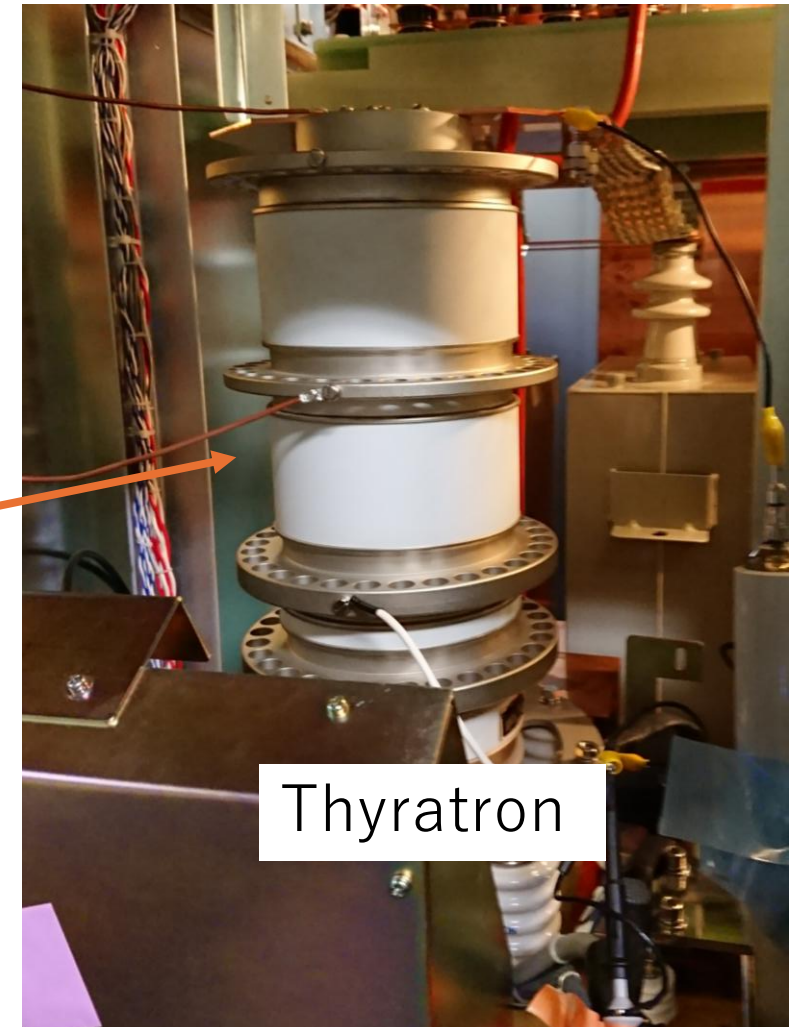
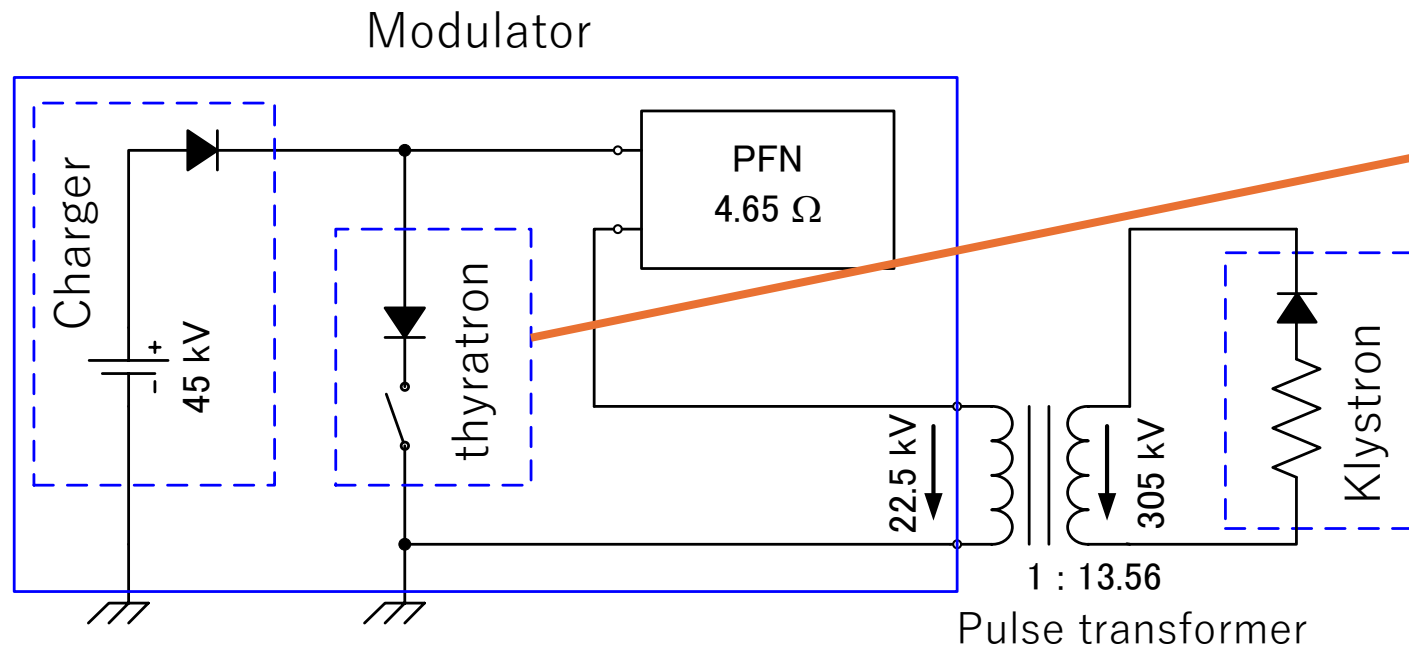


Modulator upgrade

# Thyratron and modulator

A thyratron is a switching device (vacuum tube) used in a klystron modulator.

Operation : 4.8 kA, 45 kV, 5 usec @50 pps

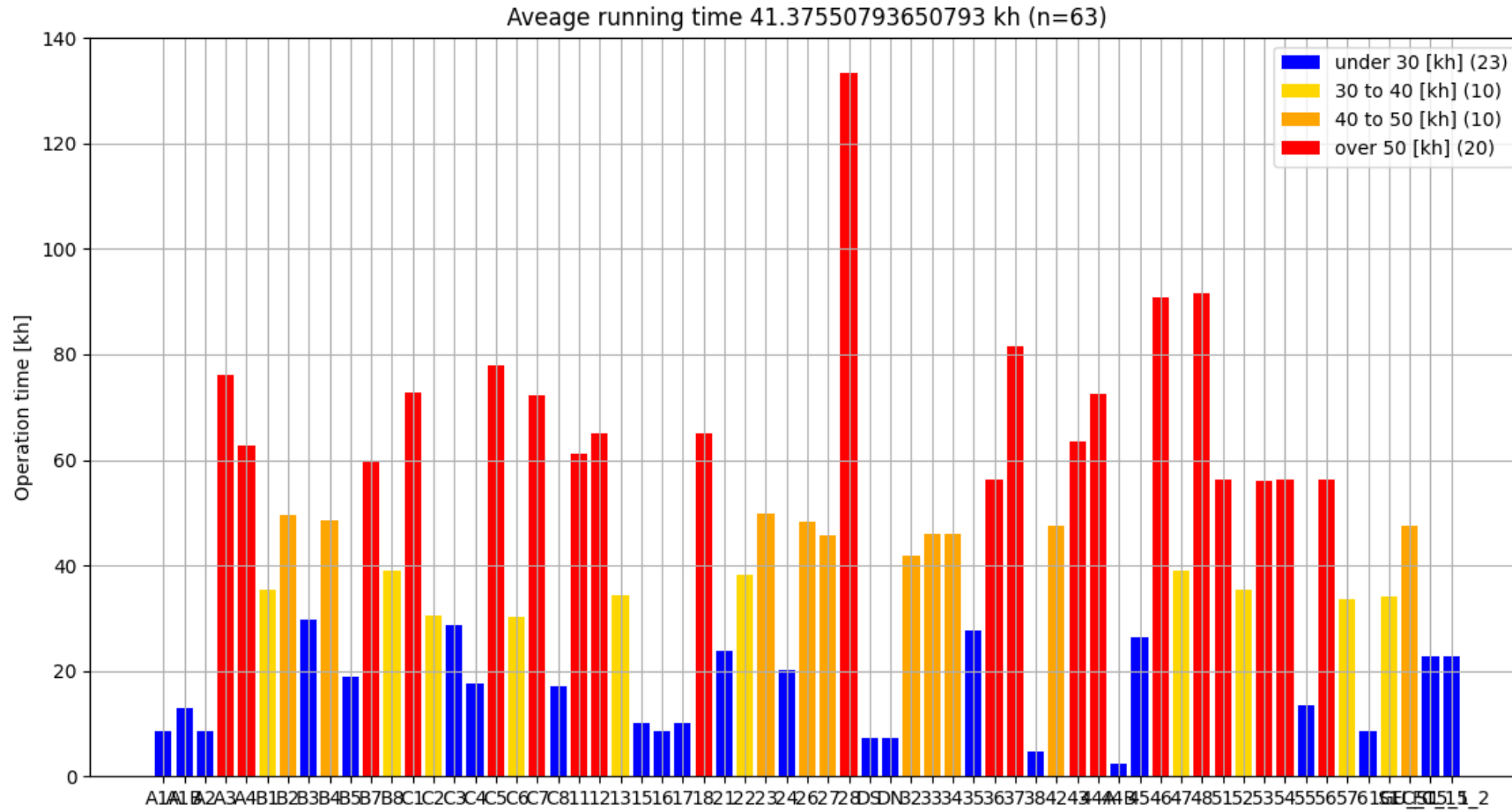


High voltage and large current switching device.  
Vacuum tube

The thyratron is an important device in the modulator.

# Thyratron operational status

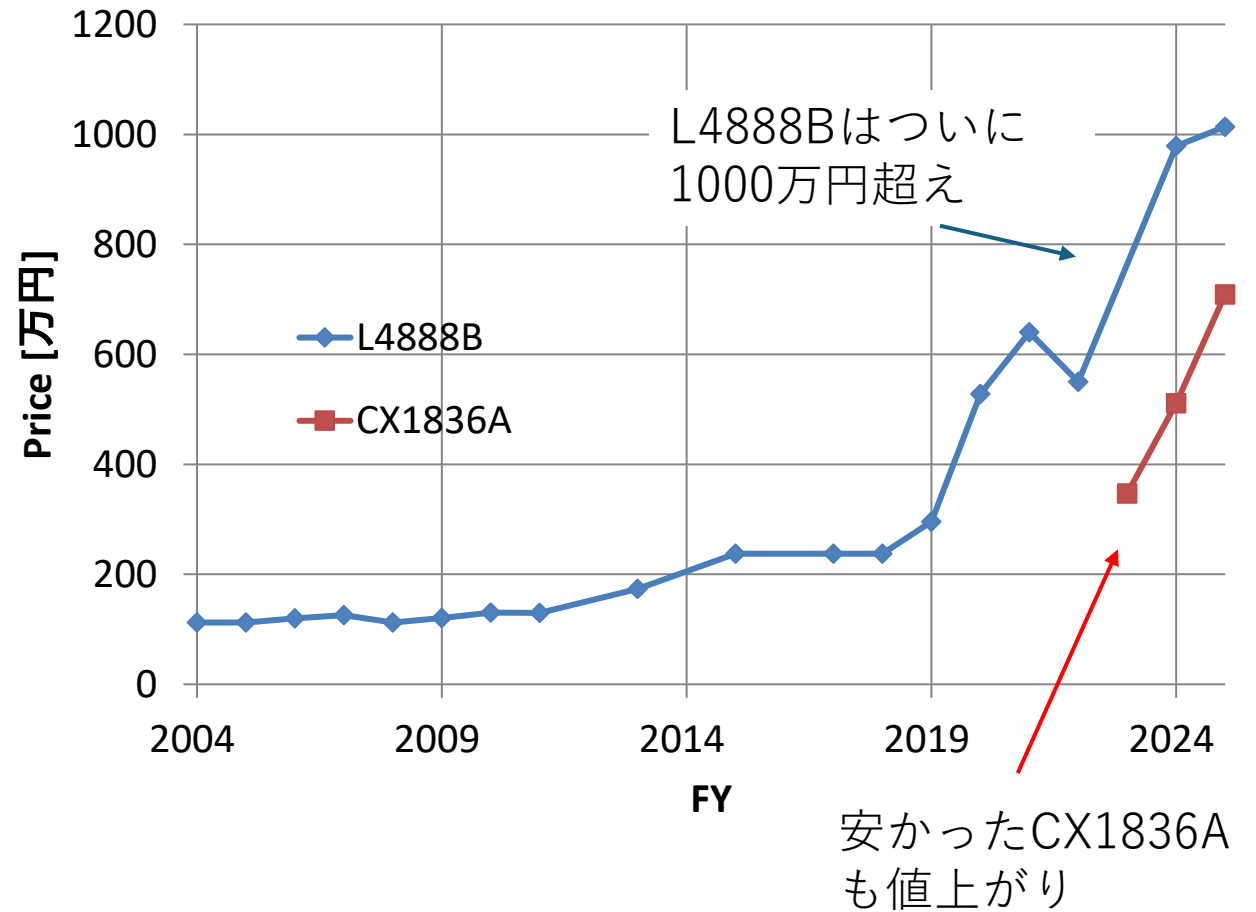
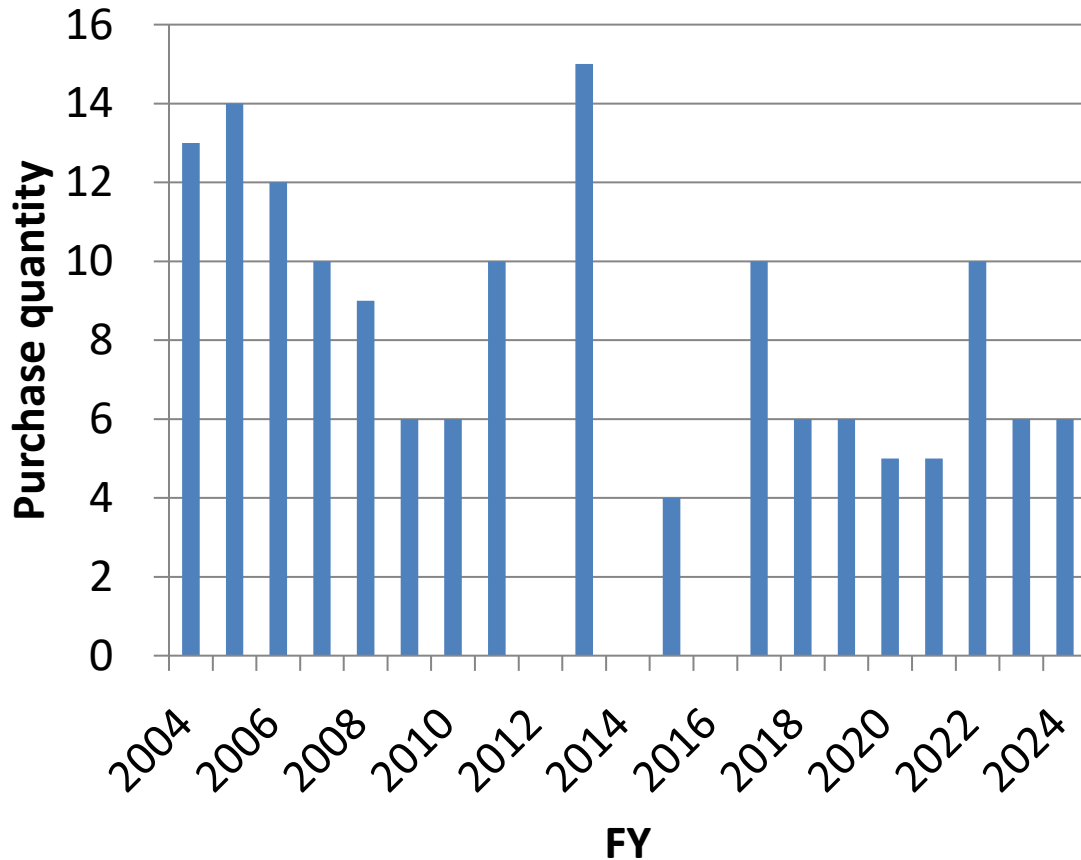
There are 63 thyratrons in operation in the injector linac, with an average operating time of 41.4 khr ( $\approx$  average lifetime)



Since the annual operating time of the injector is about 5,000 hours, the average lifetime can be calculated as about 8 years.

The number of thyatron that reach the end of their lifetime per year is  $63/8 = 7.9$

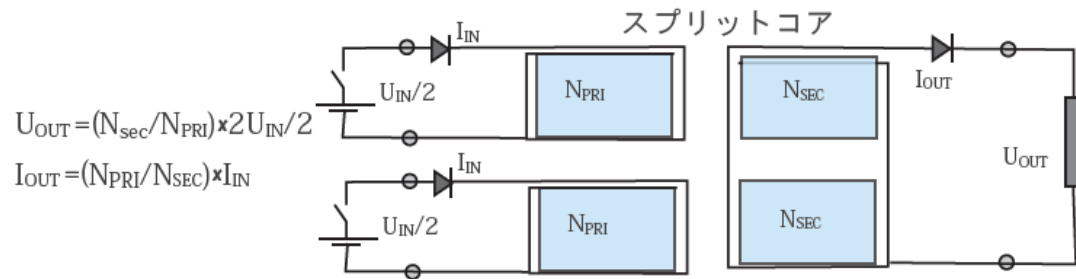
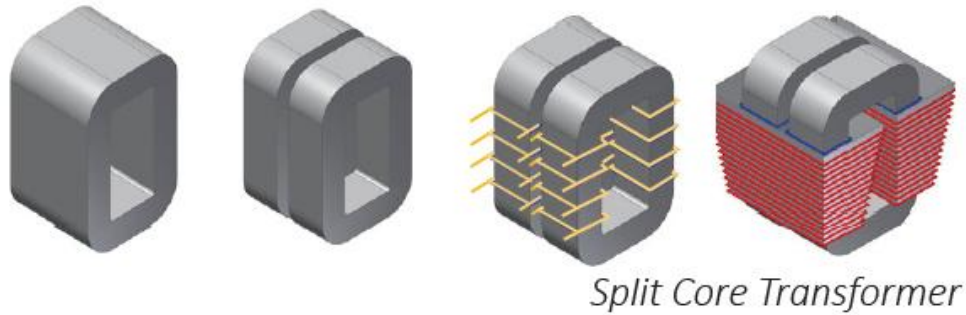
This means that we would need to purchase about eight thyratrons per year, but in recent years, due to rising prices, we have only been able to purchase six per year. This is a **critical situation** for continuing stable operation.



The price of the Thyatron L4888B we use has risen sharply, so in 2023 and 2024 we purchased the CX1836A made by e2v and continued testing, but the price of the CX1836A also soon rose.

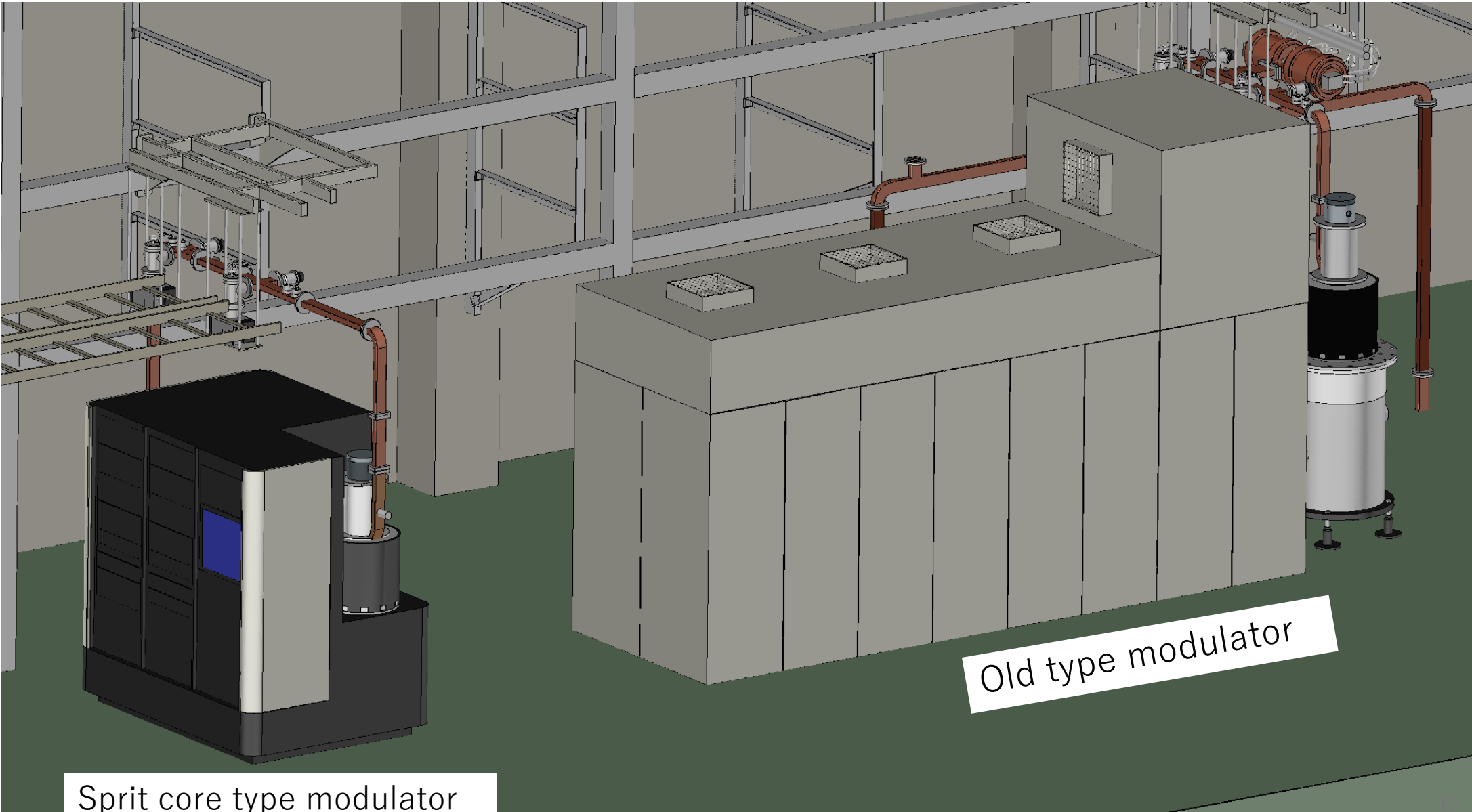
# New modulator (Thyratron-free system)

Semiconductor type modulator using the split core transformer.  
Stable output power jitter.



Thyratron-free system

# Schematic image of old type and new type modulator



Sprit core type modulator

Old type modulator

# Advantages of the new modulator

- Thyatron-Free
- Compact
- Stable (low pulse-to-pulse jitter)

# Klystron upgrade

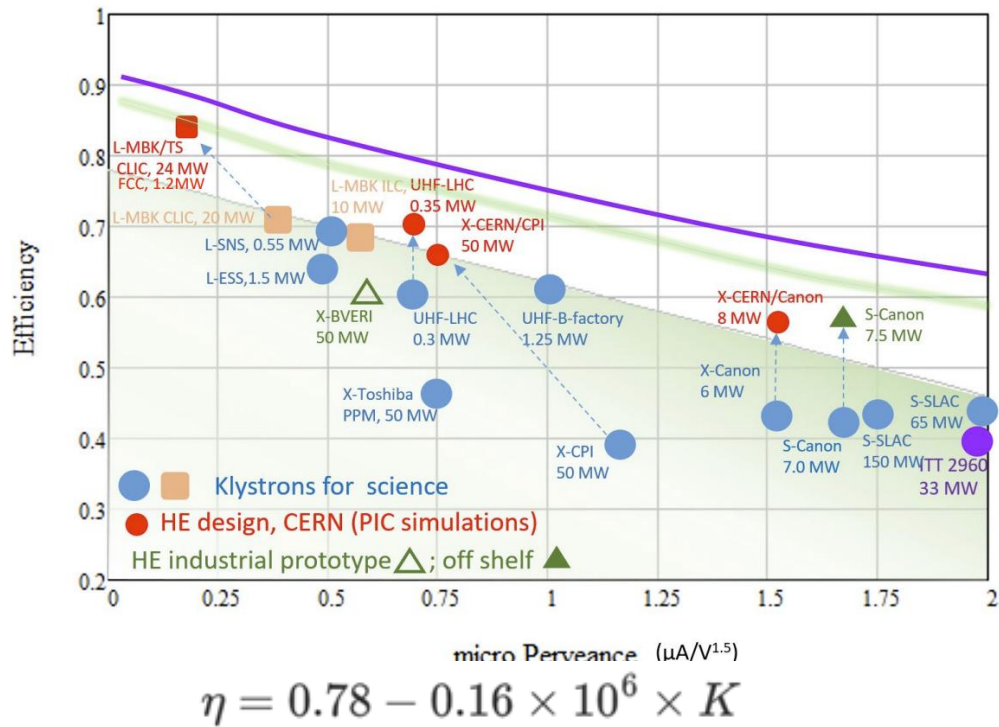
Klystron is RF source.

The high-power RF source is a klystron.

# High-power High-efficiency Klystron Multi-beam Klystron

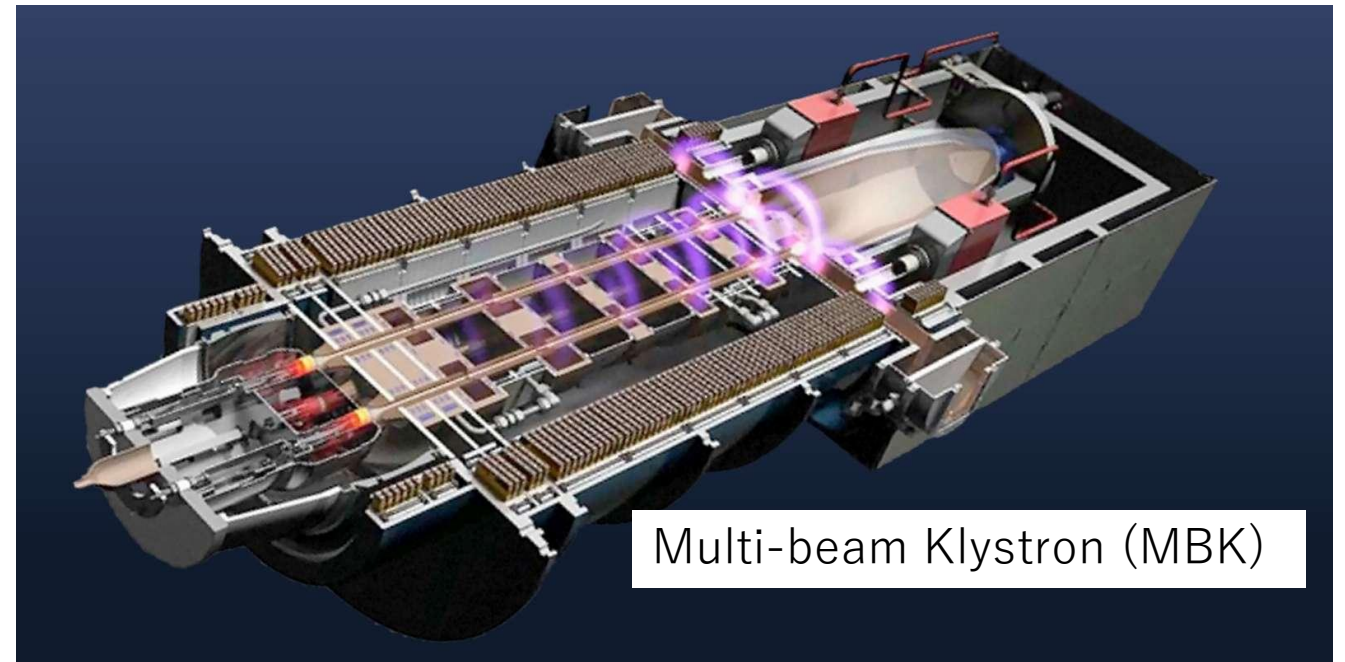
Igor Syratchev, HE klystron, HG2022

Efficiency performance of the selected commercial klystrons and the new HE klystrons (May 2022).



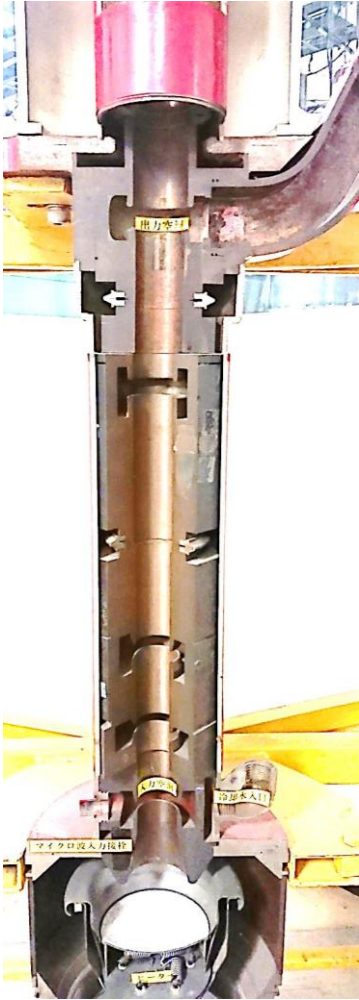
The efficiency of a klystron is limited by its perveance.

The klystron with low perveance will naturally have low output.

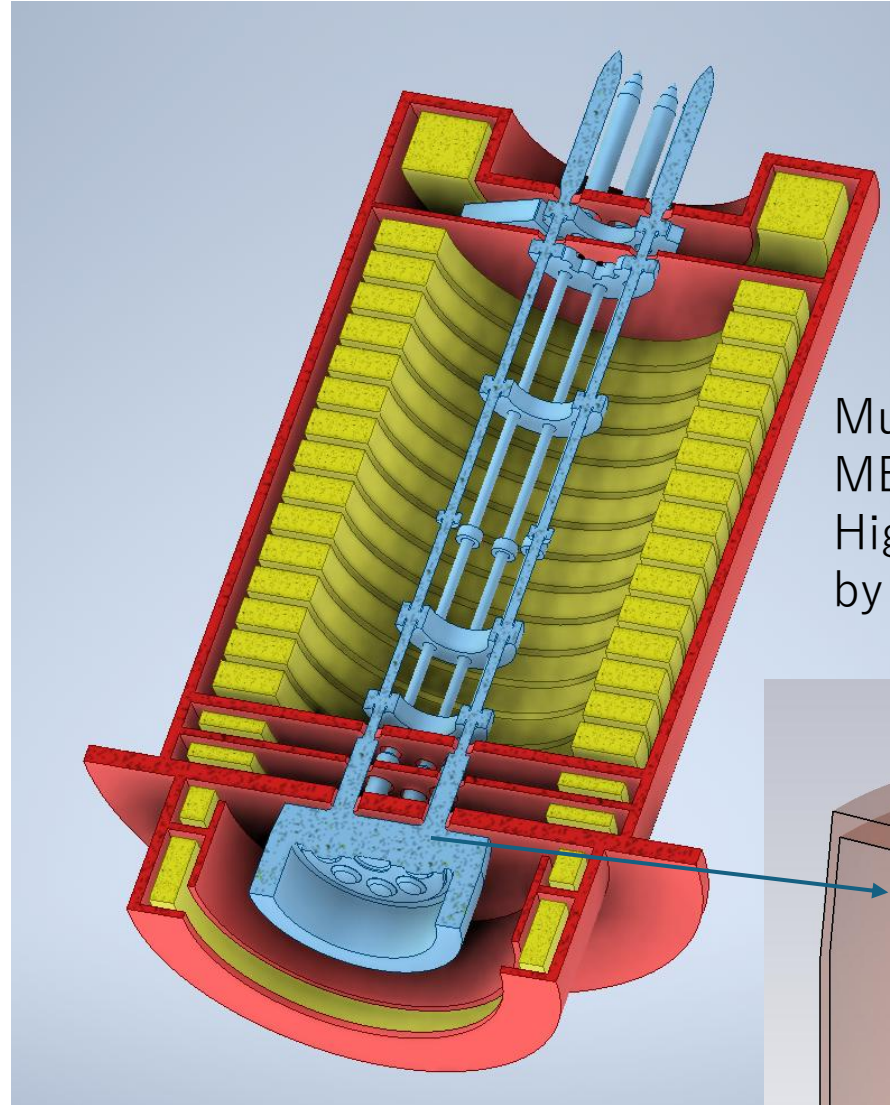


MBK was developed to achieve both high efficiency and high power.

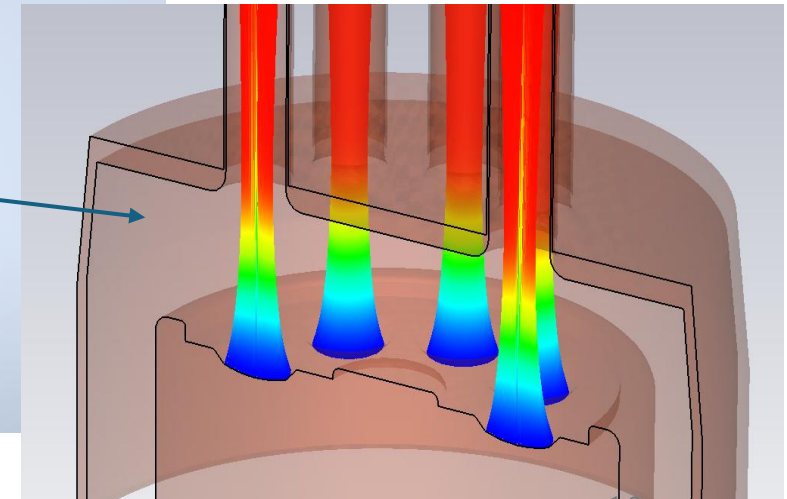
# “Single-beam klystron” vs “Multi-beam klystron”



Single beam klystron  
High power must be high perveance.  
High perveance will be low efficiency.

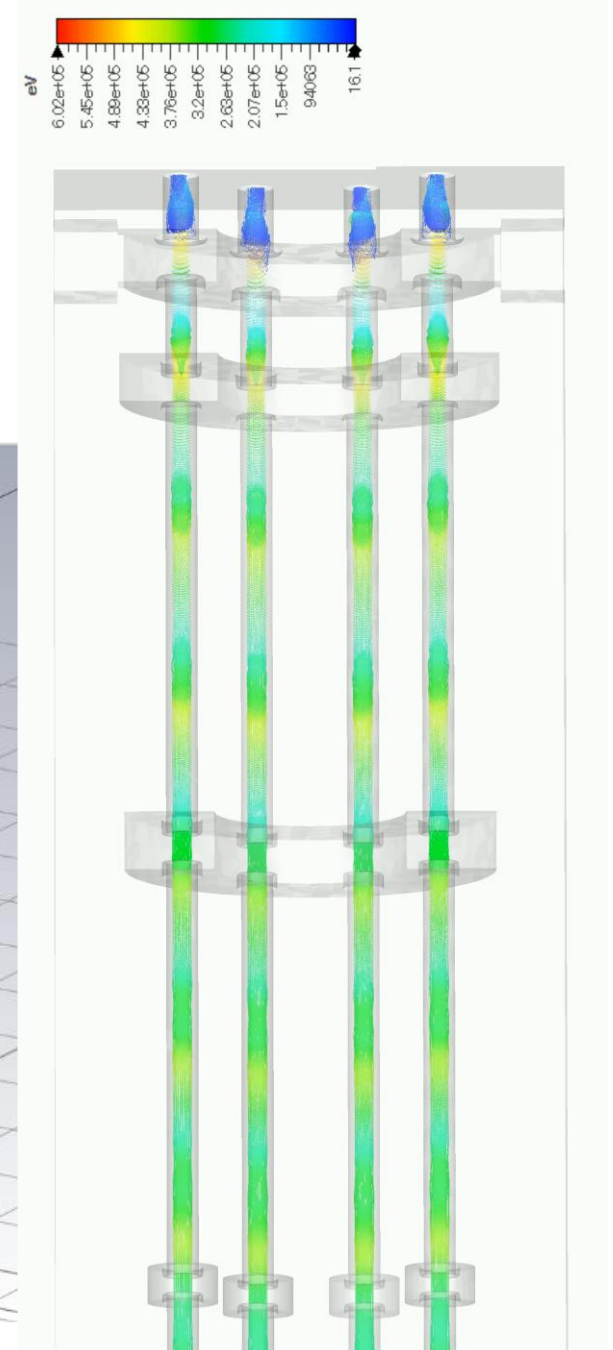
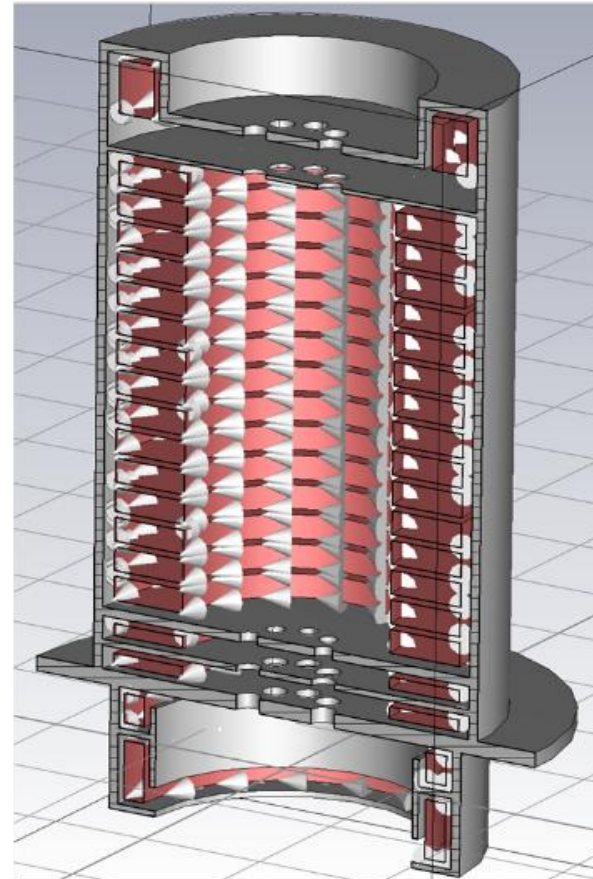
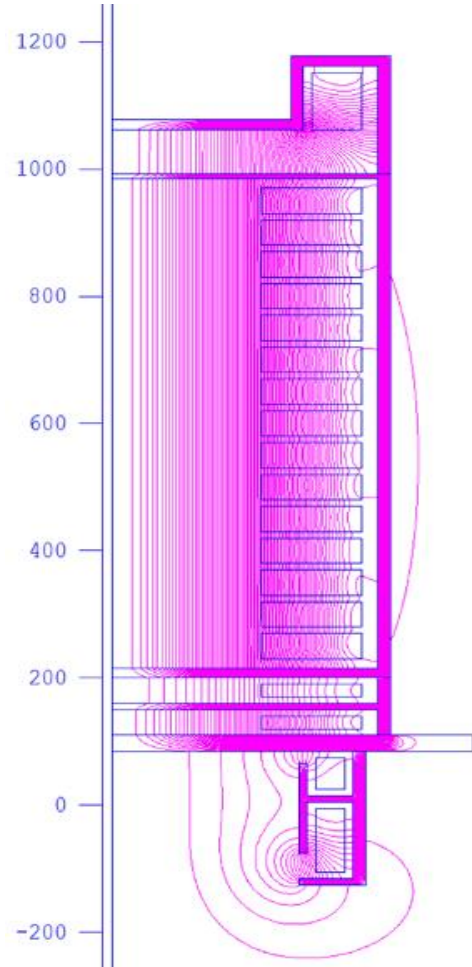
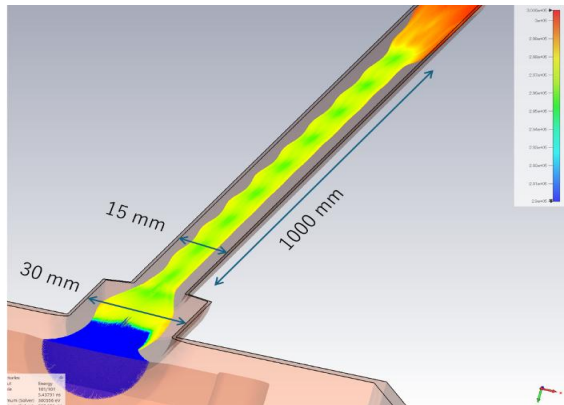


Multi-beam klystron  
MBK has many low perveance.  
High output power is achieved  
by bundling multiple beams.



# High-power High-efficiency Klystron Multi-beam Klystron

We are developing the MBK. We achieve 70 % efficiency in 3D simulation.  
The klystron is manufacturing.



# Spec of Multi-beam Klystron

	50MW E3730A	MBK (KMS80)
Power : MW	50	80
Efficiency : %	45	70
# of Beam	1	8
Perveance( $10^{-6}$ ).	2.1	2.2 ( $0.27 \times 8$ )
Cathode V : kV	312	304
Cathode I : A	362	376
Gain Min: dB	51	51
Pulse width (RF): us		4.0
Rep rate :pps		50

} High efficiency  
High power

} Beam power  
almost same.

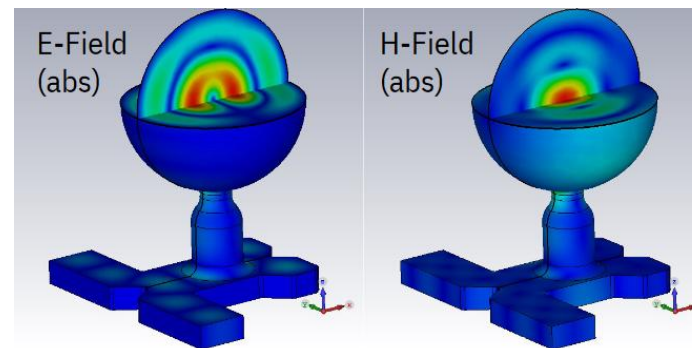
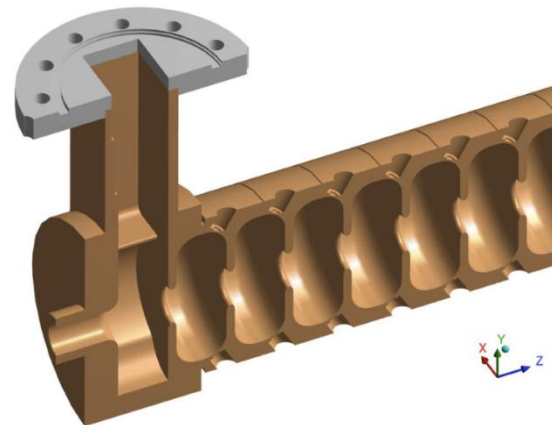
A 60% power increase corresponds to a **25% increase in acceleration voltage.**

If four units are installed, one unit can be used as a standby unit, which means that operation will be robust.

If we replace all the units, we can potentially get an accelerating voltage of 8.8 GeV.

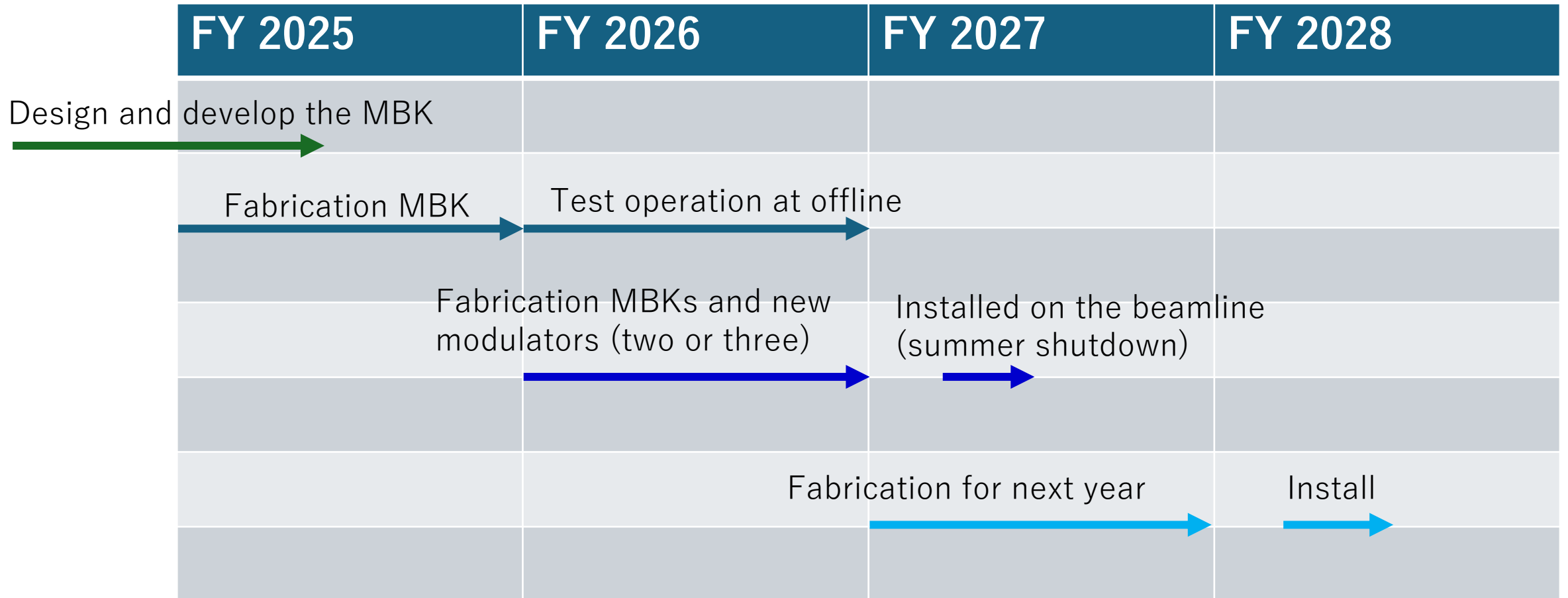
# Klystron upgrade using “MBK”

- We are developing the high-efficiency and high-power klystron using multi-beam technology.
- Higher output can be obtained with the same input power.
- By installing MBKs in combination with the new accelerating structures, a higher acceleration gain can be achieved.



Upgrade of acceleration structure is also on going.

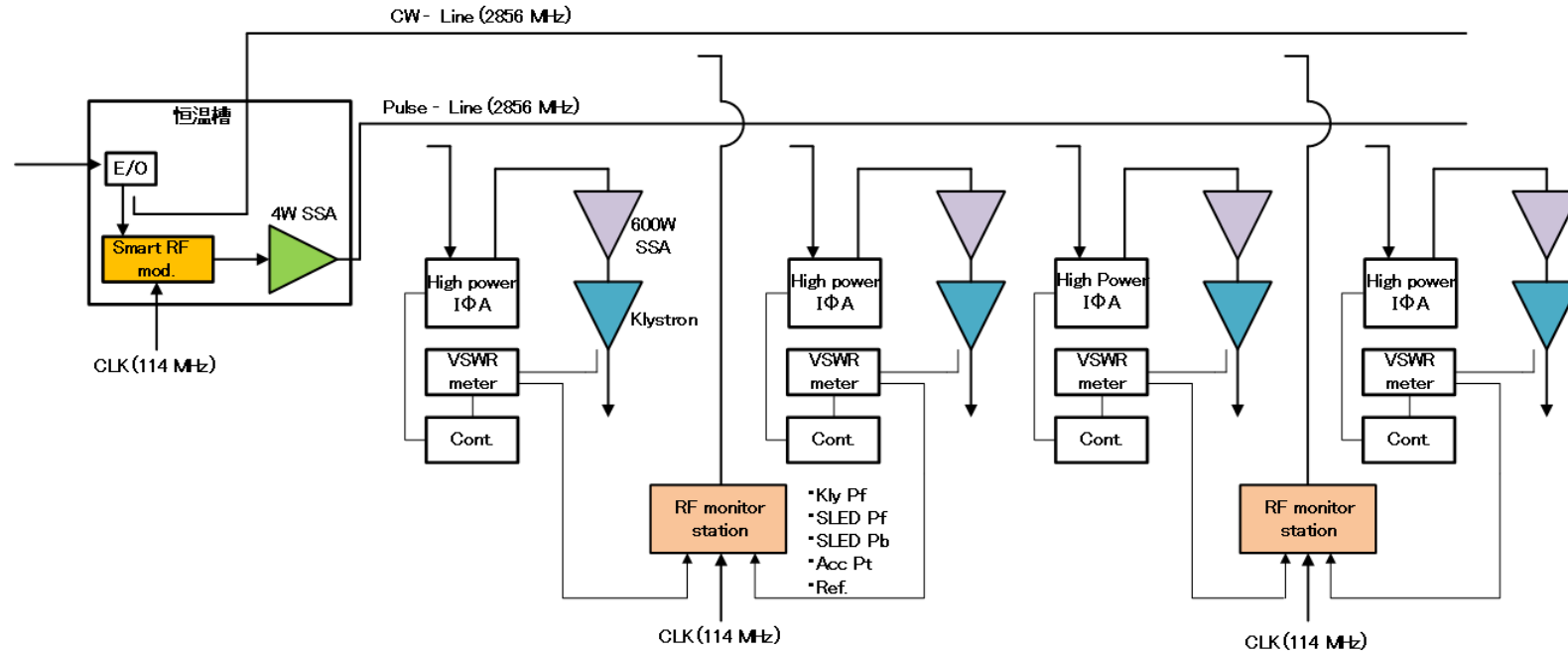
# RF unit Upgrade Schedule



# Low-level RF (LLRF) Upgrade

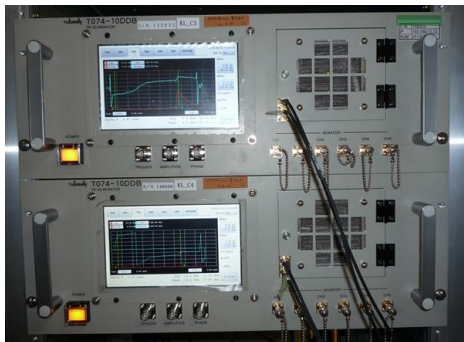
# ○ Plan of LINAC LLRF Upgrade -1-

2014: Upgrade to the Digital LLRF system (Smart RF mod. and RF monitor)



Over 10 years of operation,

- Requirement for stable operation for SuperKEKB,
- and
- Discontinuation of ML605
- Failure of the PS unit in the digital board.



RF monitors in the station



Internal photo of RF monitor

Xilinx ML 605  
(Commercial FPGA board)

10 ch, 14-bit ADC board  
(Daughter board)



Smart RF modulator  
Xilinx ML 605  
(Commercial FPGA board)

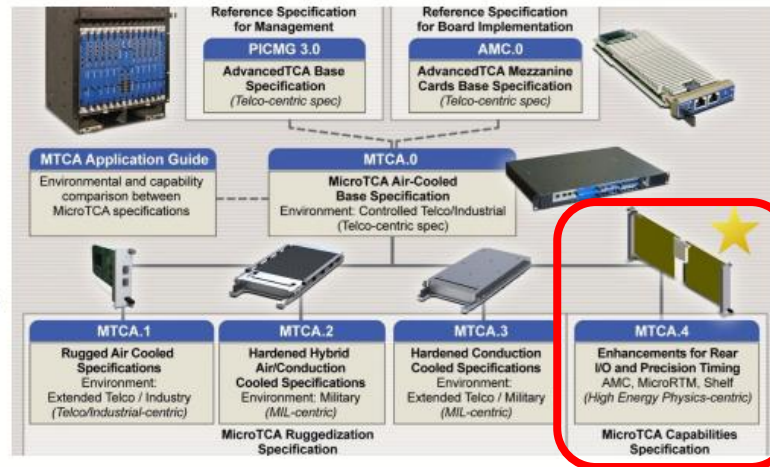
# ○ Plan of LINAC LLRF Upgrade -2-

## Adoption of the MTCA.4 standard

### Composition of the MicroTCA Standard

Introduction to the MicroTCA.4 Standard  
Dr. Patrick Nonn 04.07.2019 Page 7

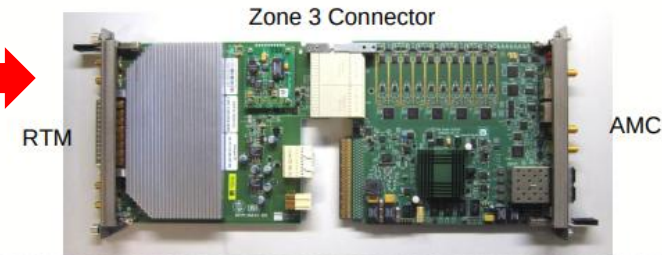
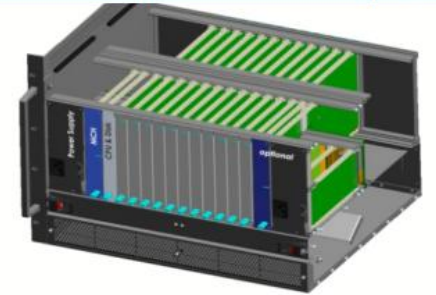
- MicroTCA.0
  - originates in telecommunication
  - base for subsequent standards
- MicroTCA.1 to MicroTCA.3 are various levels of ruggedized variants
- **MicroTCA.4 was developed with scientific application in mind**



### MicroTCA.4 Hardware: Overview

Introduction to the MicroTCA.4 Standard  
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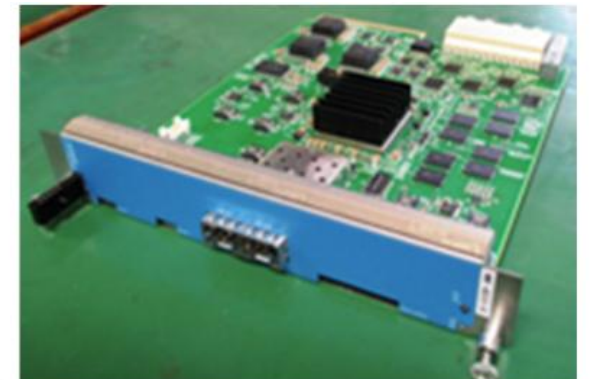
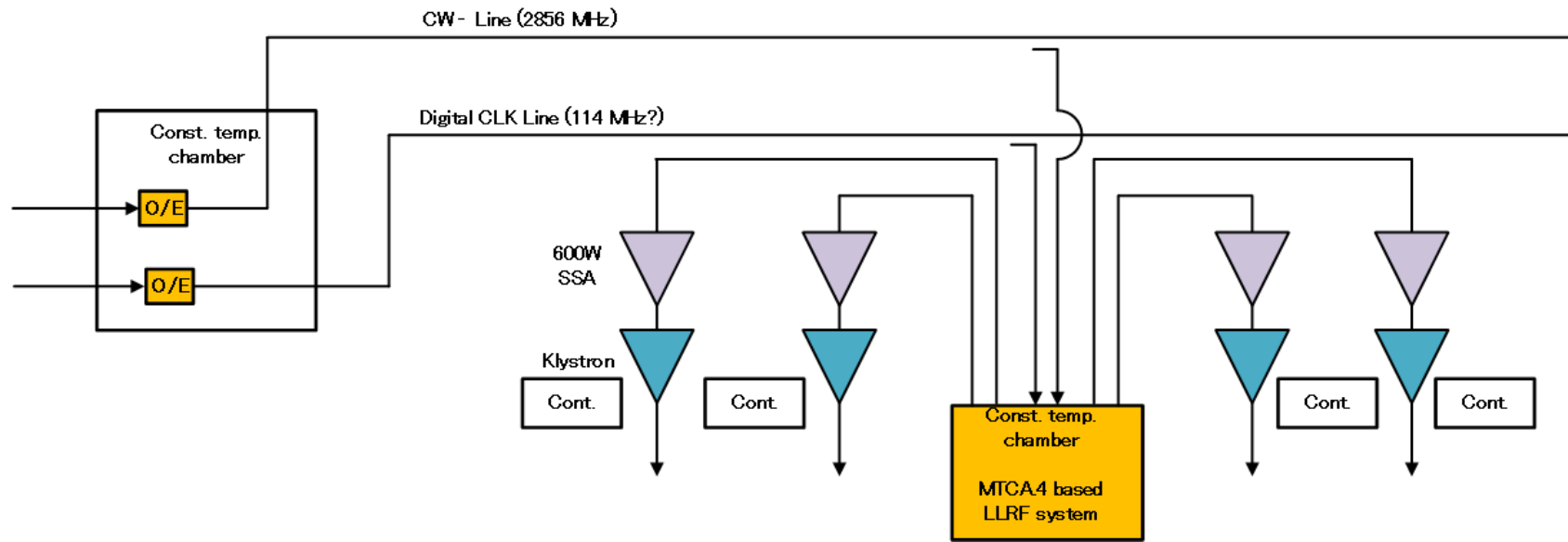
- Essential Parts for MTCA.4 System
- Crate with Backplane
  - Power Supply Module (PM)
  - Cooling Unit (CU)
  - MicroTCA Carrier Hub (MCH)
  - Advanced Mezzanine Card (AMC)
  - Rear Transition Module (RTM)



- The MTCA-based LLRF system was adopted for the XFEL's LLRF control system and commenced operation in 2017.
- Recently, it has been adopted in the LLRF control systems of various accelerators and has also been introduced in the LLRF systems of Spring-8, J-PARC, and PF-ring in Japan.

# ○ Plan of LINAC LLRF Upgrade -3-

- Sketch of Digital LLRF system for KEK LINAC



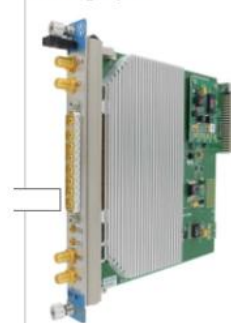
platform:  $\mu$ TCA.4 AMC  
 FPGA: Zynq XC7Z045-1FFG900C,  
 QSPI FLASH-ROM 16 MB,  
 SD-card Remote Update  
 RAM: DDR3-SDRAM 1 GB $\times$ 2 (PL, PS)  
 OS: Xilinx Linux (EPICS-IOC)  
 ADC: 8ch 16bit 370MSPS(max.), BW: 800 MHz  
 DAC: 2ch 16bit 500MSPS  
 SFP: 2ports

## DWC8VM1 MTCA.4 DOWNCONVERTER/VECTOR MODULATOR RTM

The DWC8VM1 is an eight channel downconverter/one channel vector modulator MTCA.4 RTM that was developed at DESY and is build by Struck under license of DESY.

The frequency range of the DWC8VM1 standard unit is complemented on the lower side by the DWC8VM1LF and on the higher end by the DWC8VM1HF (see parameter table below).

### Photograph



### Central Design Parameters

- MTCA.4 ( $\mu$ TCA for Physics) RTM Implementation
- Class A1.1 compatible
- 8 channels downconverter
- One channel vector modulator
- 8 Channel FBM multi coax. connector (CH1 to CH8)
- SMA vector modulator output
- 350 MHz - 500 MHz (DWC8VM1LF)
- 500 MHz - 3500 MHz (DWC8VM1)
- 3500 MHz - 6000 MHz (DWC8VM1HF)
- Various intermediate frequencies
- Switchable front end attenuators
- LO clock from front panel or RF backplane
- LO power level monitor
- I2C support

- The candidates for the AMC and RTM boards have been selected, but the details of the LLRF systems are still under consideration.
- Unlike previous designs, the amplitude and phase for each individual klystron can be adjusted independently.

# Summary

- High-efficiency and high-power multi-beam klystron is developing.
- The prototype MBK is under construction.
- Performance testing of the MBK is scheduled for next fiscal year.
- Next fiscal year, we plan to purchase two or three sets of new modulators and MBKs.
- The new RF units are scheduled to be installed on the beamline in the summer of 2027.
- We would like to update the RF unit, including LLRF, to increase acceleration gain and stability.