The S-Band 80MW Multibeam Klystron for KEK e^-/e^+ Injector Linac

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A brief introduction to KEK e^-/e^+ Injector Linac

- Operating with 60 S-band 50 MW klystrons at an efficiency of 45%.

- An MBK (Multi-Beam Klystron) with an output power of 80 MW and an efficiency of 70%, named **KMS80**, is under development to replace the existing klystrons, aiming to:
  - Increasing the RF power capability for the injector
  - Saving energy during injector operation

> For the stable operation of SuperKEKB, the RF power margin of the injector linac is expected to be increased.
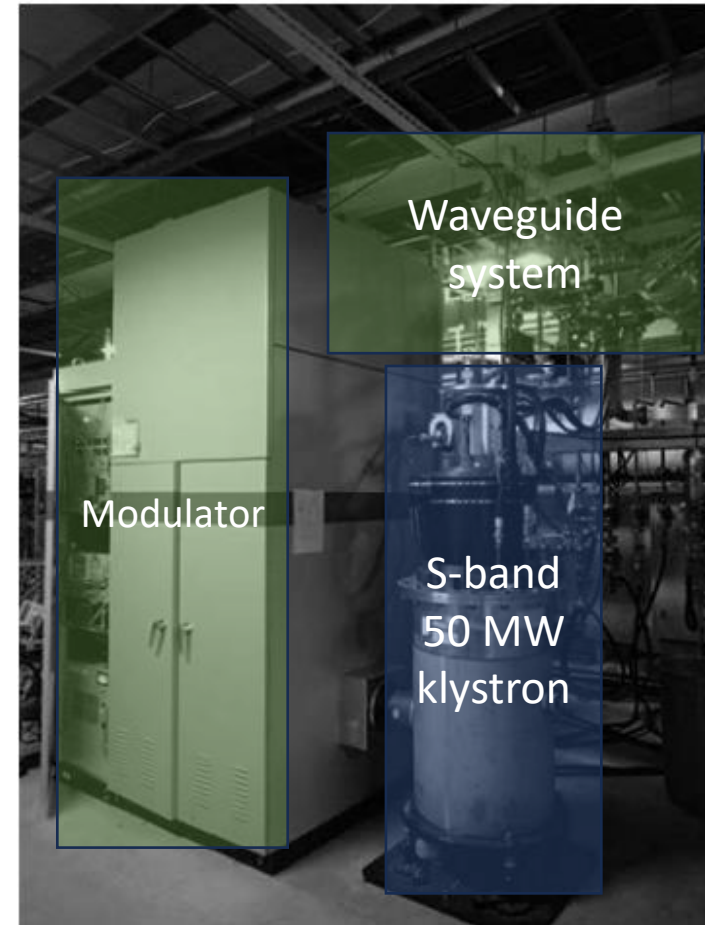

[Ref. *https://www-linac.kek.jp/]

A brief introduction to KEK e^-/e^+ Injector Linac

klystron gallery of KEK e^-/e^+ Injector Linac

[https://www-linac.kek.jp/linacphoto/]

- The modulators and waveguide systems are kept.
- 80MW MBKs will replace the S-band 50MW klystrons.

The overall parameters of S band MBK

- The overall parameters of KMS80

| Parameters(unit)	value
Frequency(MHz)	2856
Gun voltage(kV)	300
Total gun current(A)	366.4
Beam No.	8
Output power(MW)	80
Expected efficiency	73%

(Courtesy of Takuya Natsui)

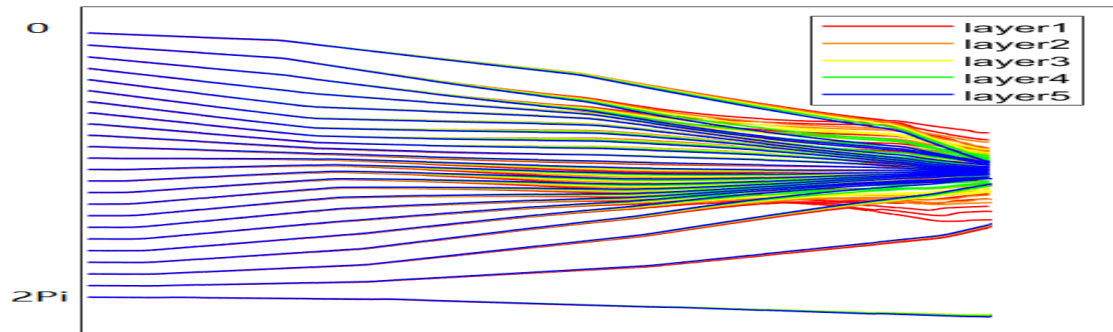- For dual records in both efficiency and output power in the field of S-band MBKs
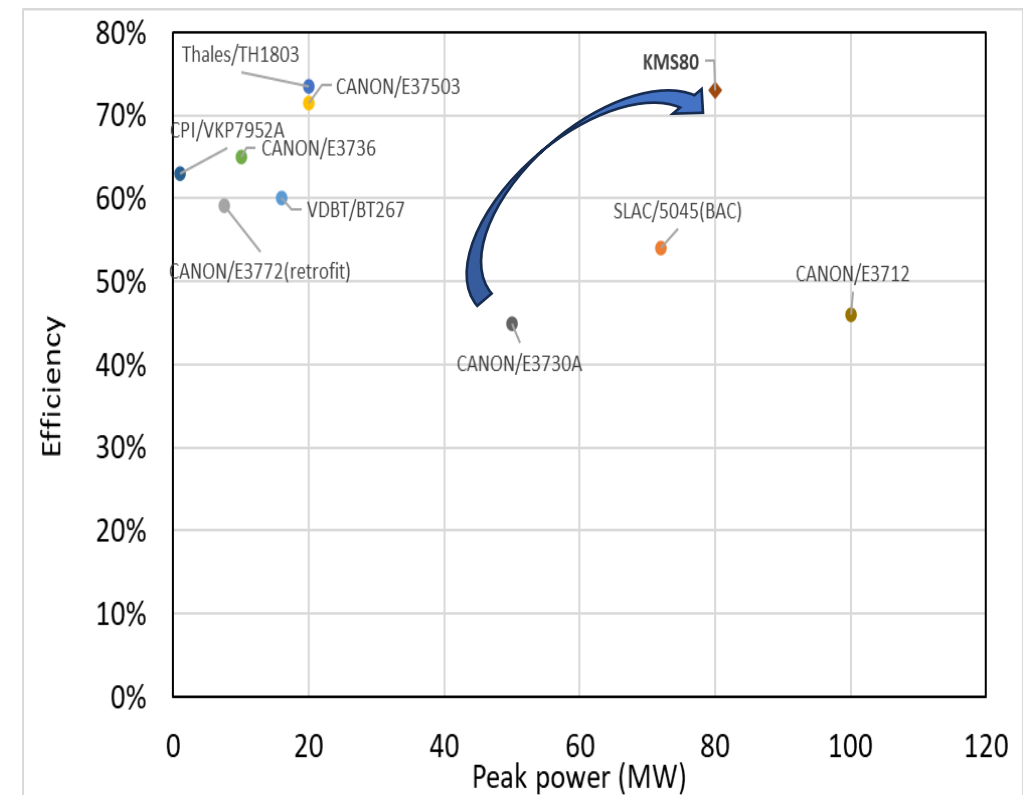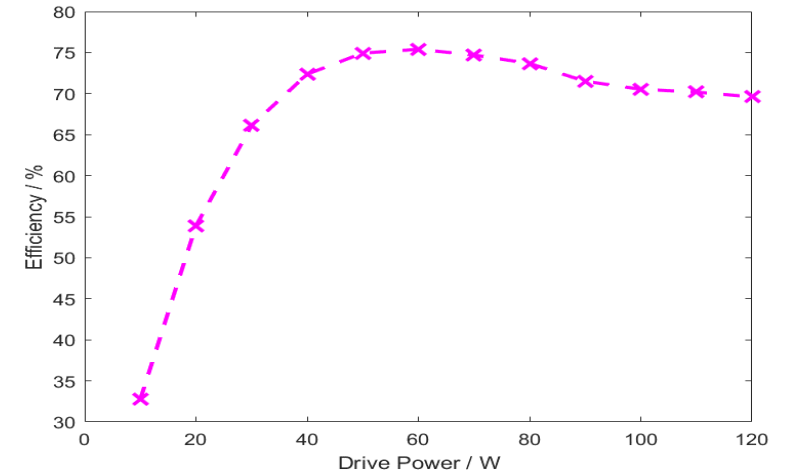
Result of 2-D simulation

- Using EMSYS and a genetic algorithm to automatically optimize the layout parameters.

- Result of the optimization (a total of 6 cavities):
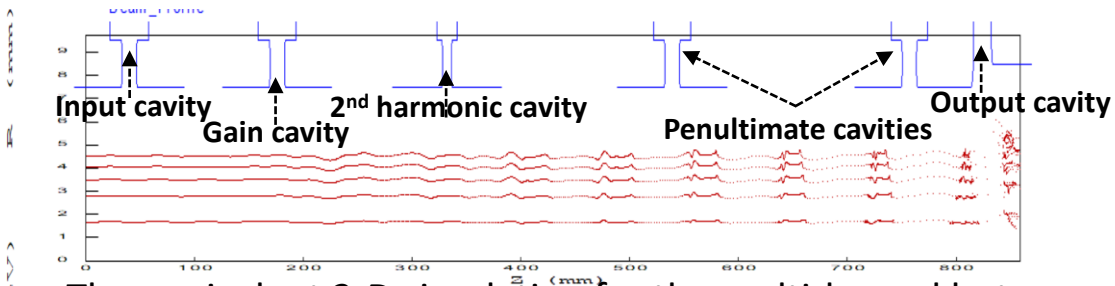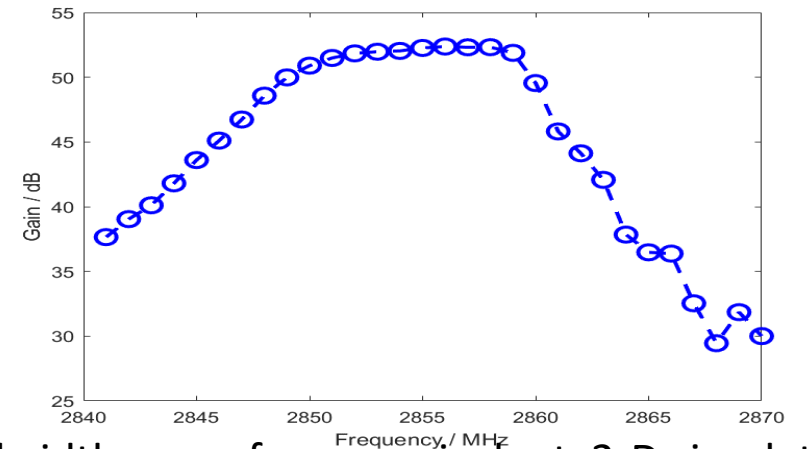

The equivalent 2-D simulation for the multi-beam klystron
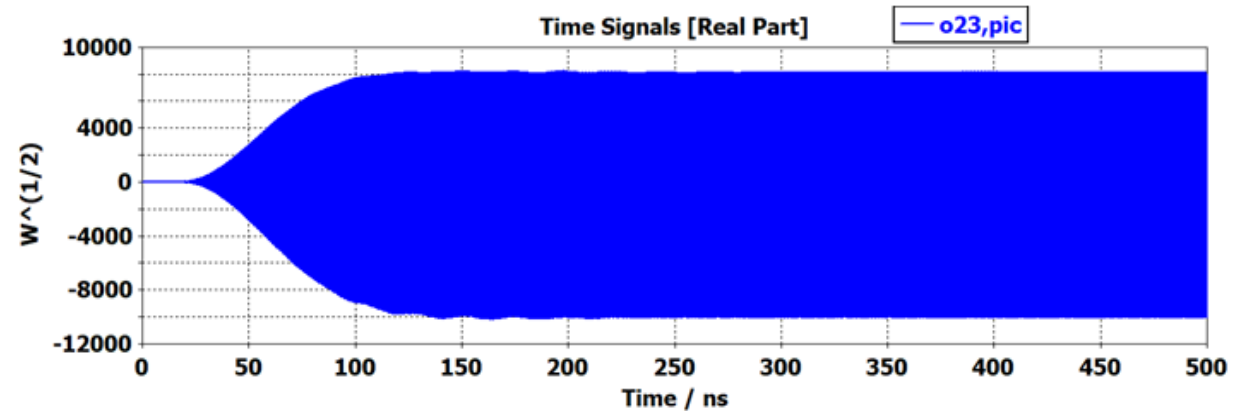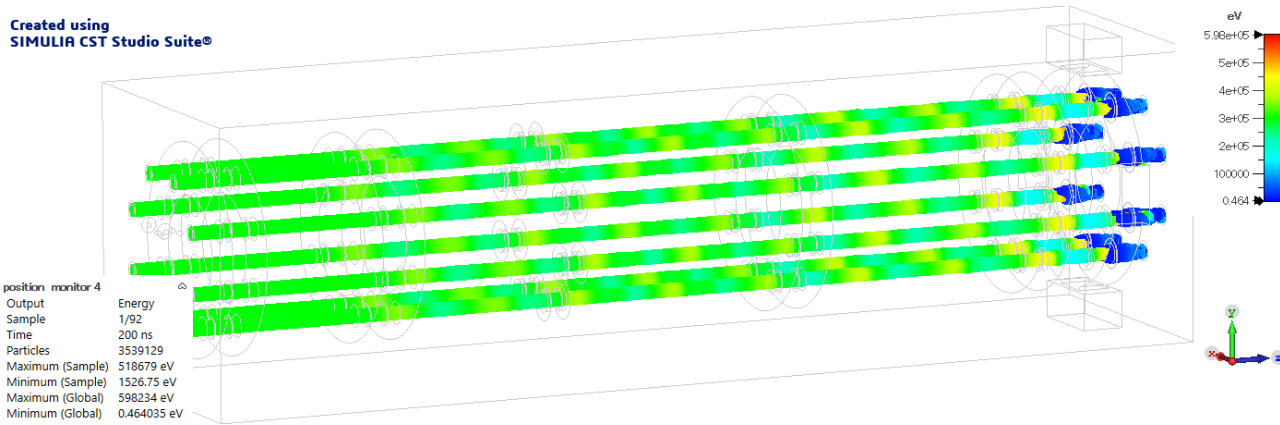

The 2-D phase-space diagram

Transfer curve from equivalent 2-D simulation

Bandwidth curve from equivalent 2-D simulation

Results of 3-D simulation
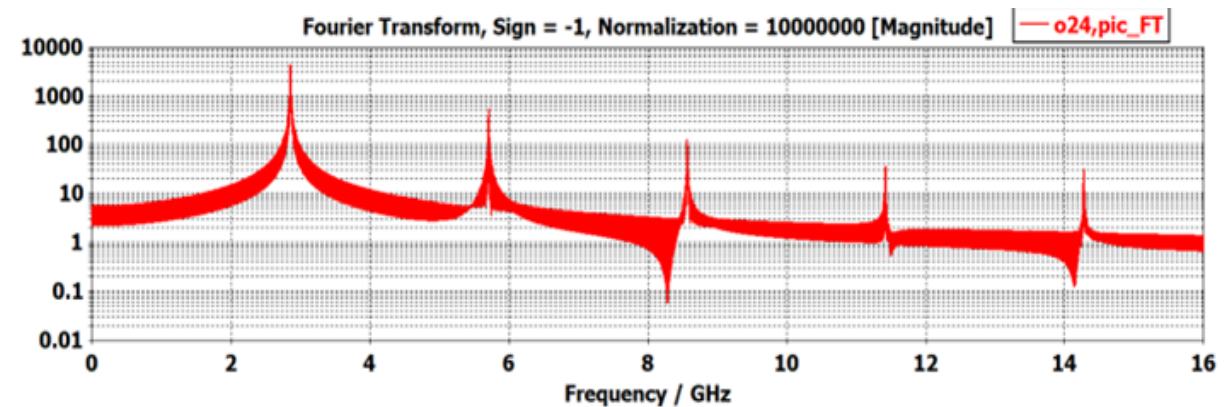

CST: 3-D PIC simulation

The output signal from one of the waveguide ports

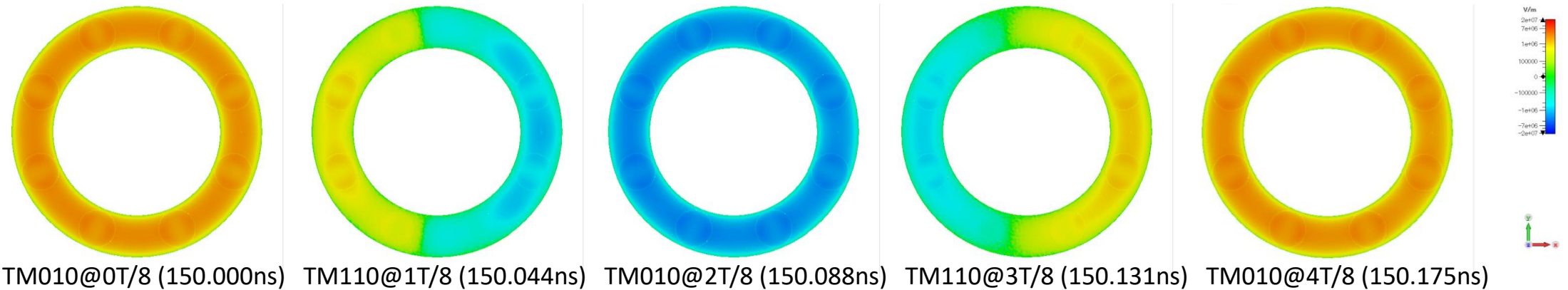Electric efficiency: 73.3%

Circuit Efficiency: 99%

Total efficiency: 72.5%

The frequency spectrum of the output signal

HOM instability

- The electric field in the second harmonic cavity during the PIC simulation indicates that it is operating in a mixed state of the TM010 and TM110 modes.

TM010@0T/8 (150.000ns)   TM110@1T/8 (150.044ns)   TM010@2T/8 (150.088ns)   TM110@3T/8 (150.131ns)   TM010@4T/8 (150.175ns)

- The TM710 mode is induced in the **penultimate cavity** due to the unbalanced beams. This results in a transverse movement of the beam downstream of the **penultimate cavity**.
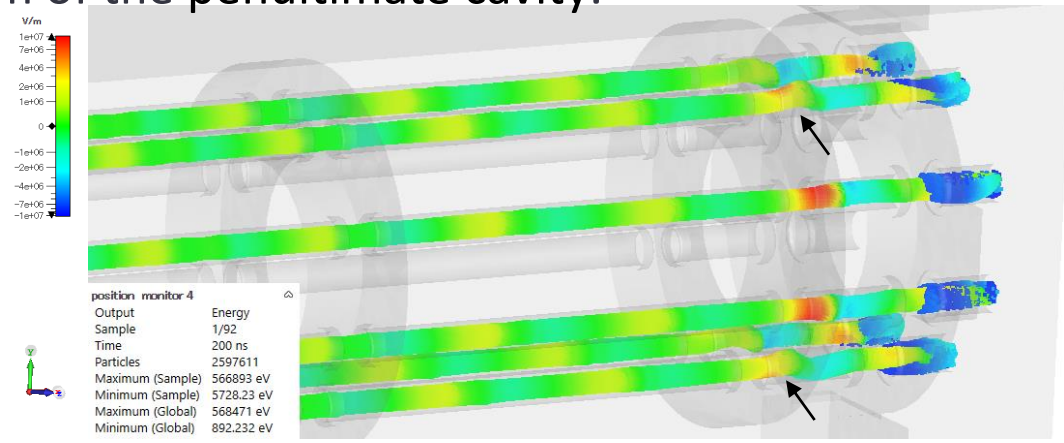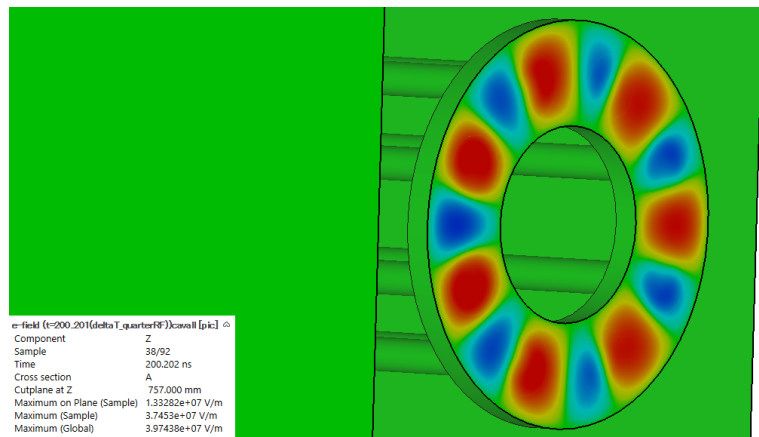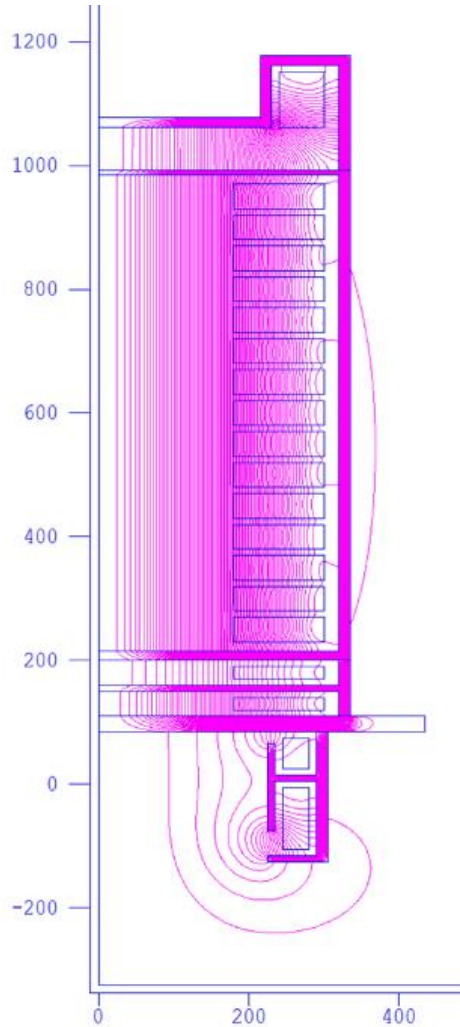
Tolerance analysis
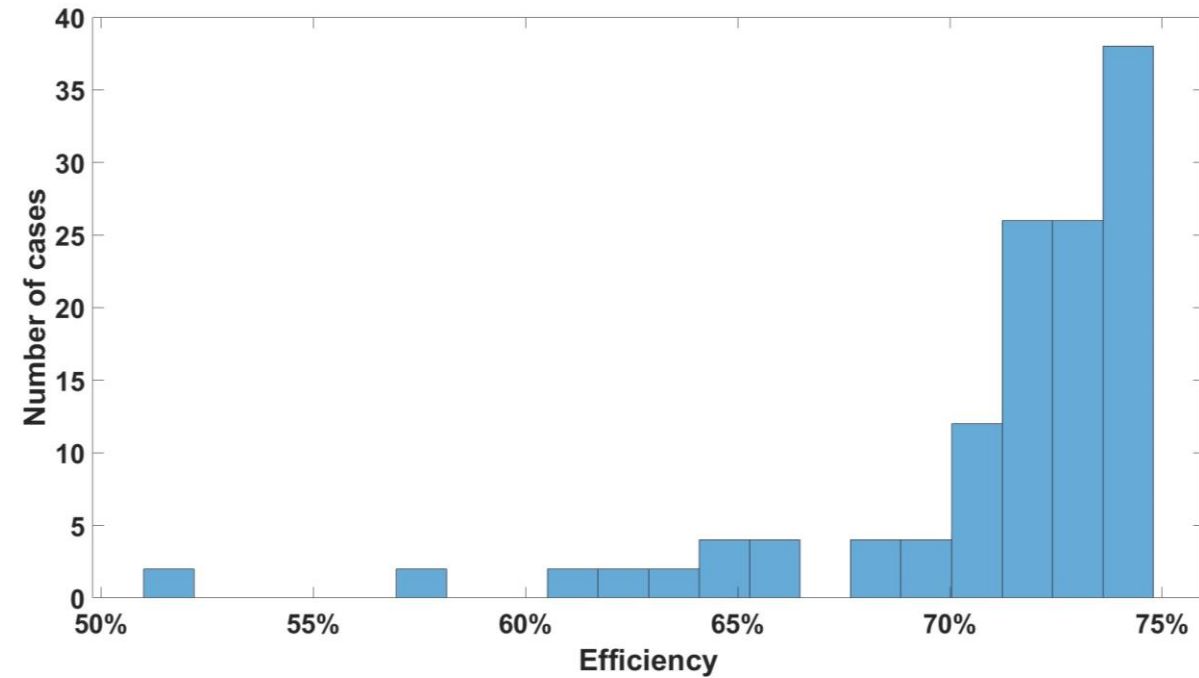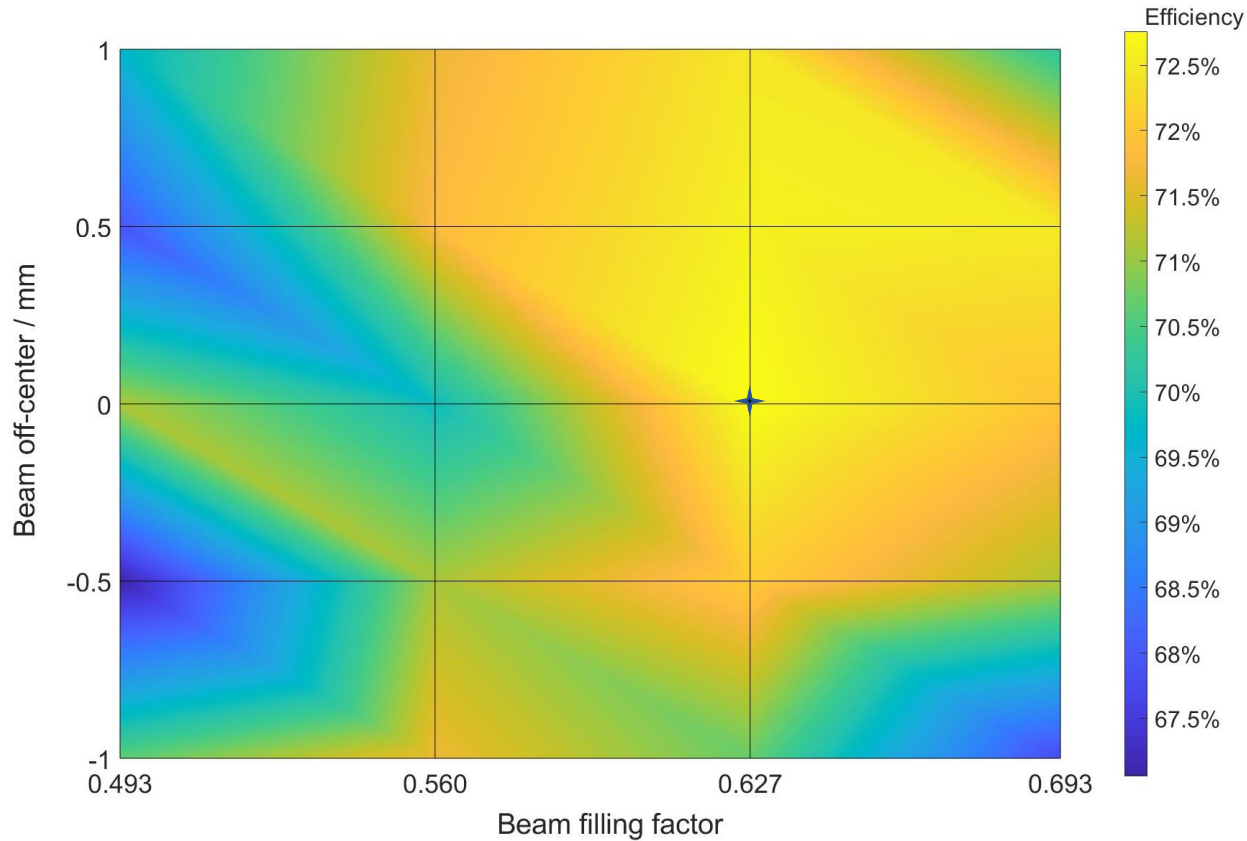
- CST
- Error of the Beam off-center and beam filling factor

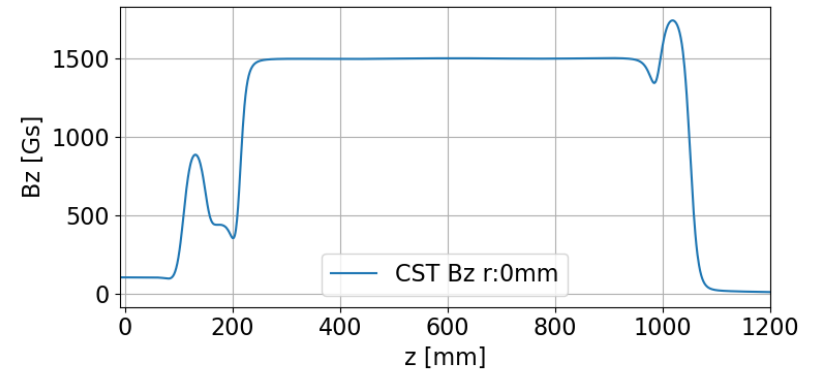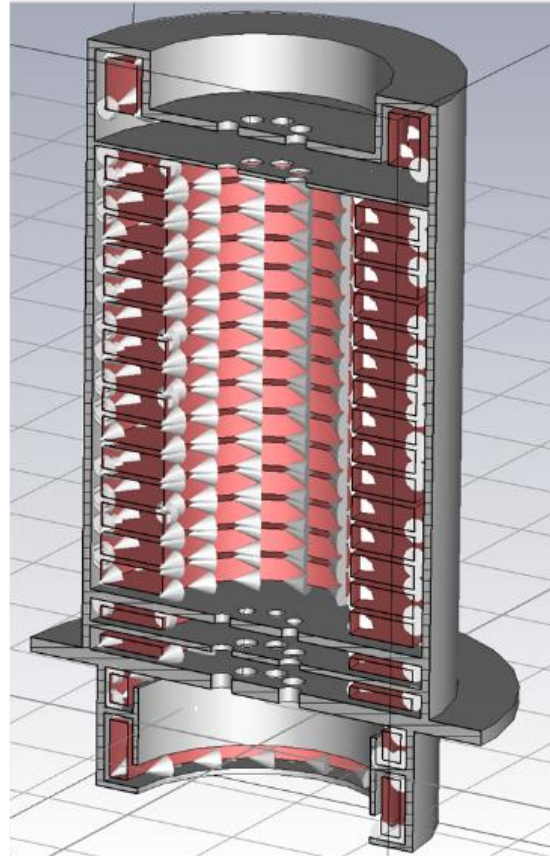o There is a region where the efficiency remains above 70%.

- EMSYS
- Random frequency errors within the tuning error ranges

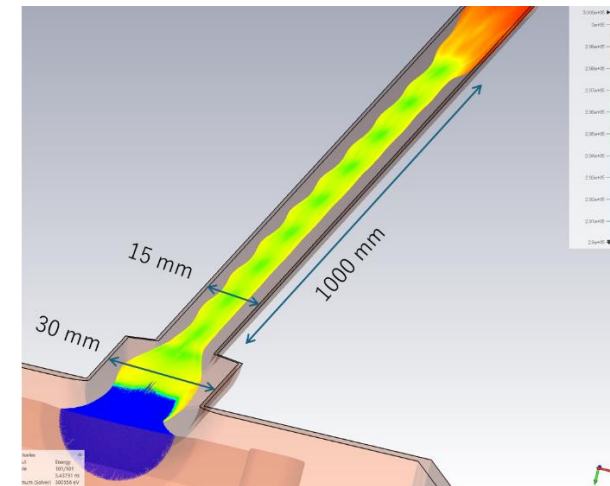o For most scenarios, the efficiency remains above 72%.

Electron gun and magnet

(Courtesy of Takuya Natsui)

The longitudinal magnetic field along the beam axis

The magnet

3D TRK simulation result

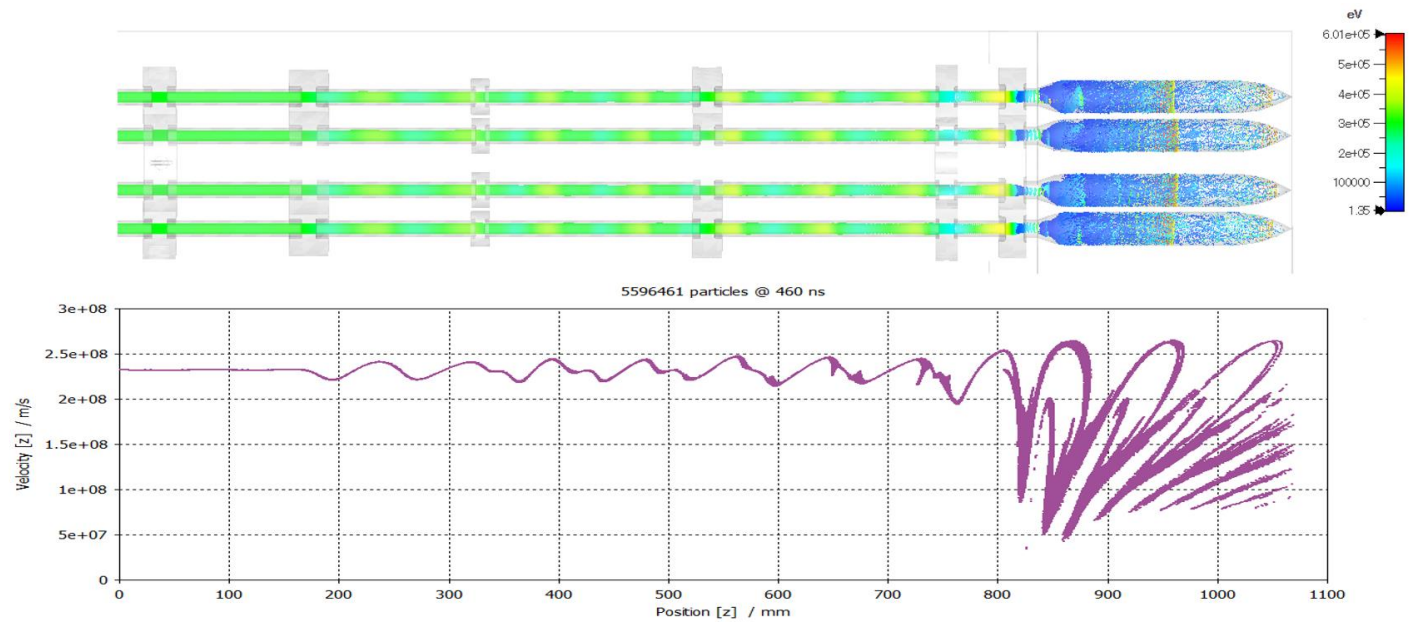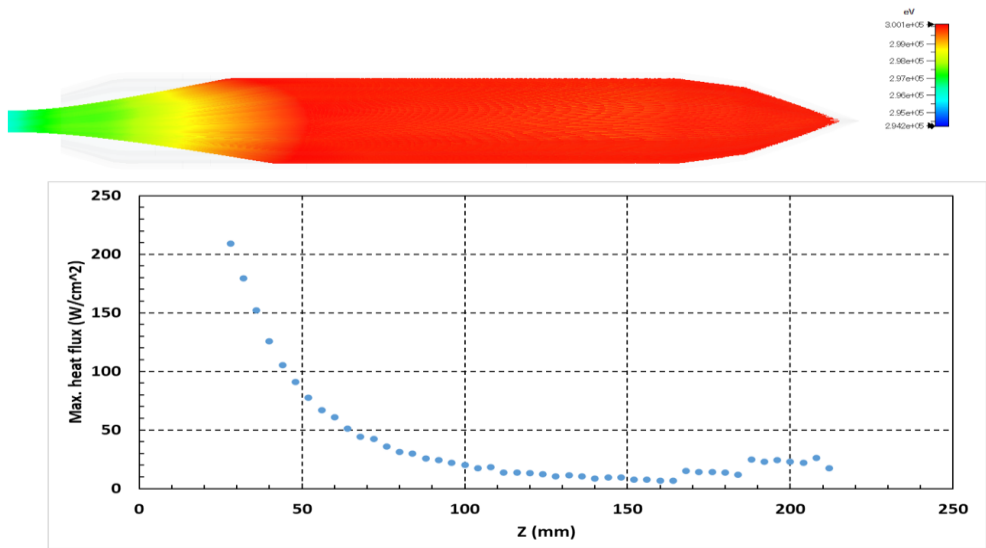# Interaction simulation with electron gun interface and magnetic field

1) Import focusing magnetic field
2) Import beam with an electron gun interface

Efficiency: 72.3%

Collector

- Individual collectors
- The maximum heat flux is 210 W/cm^2
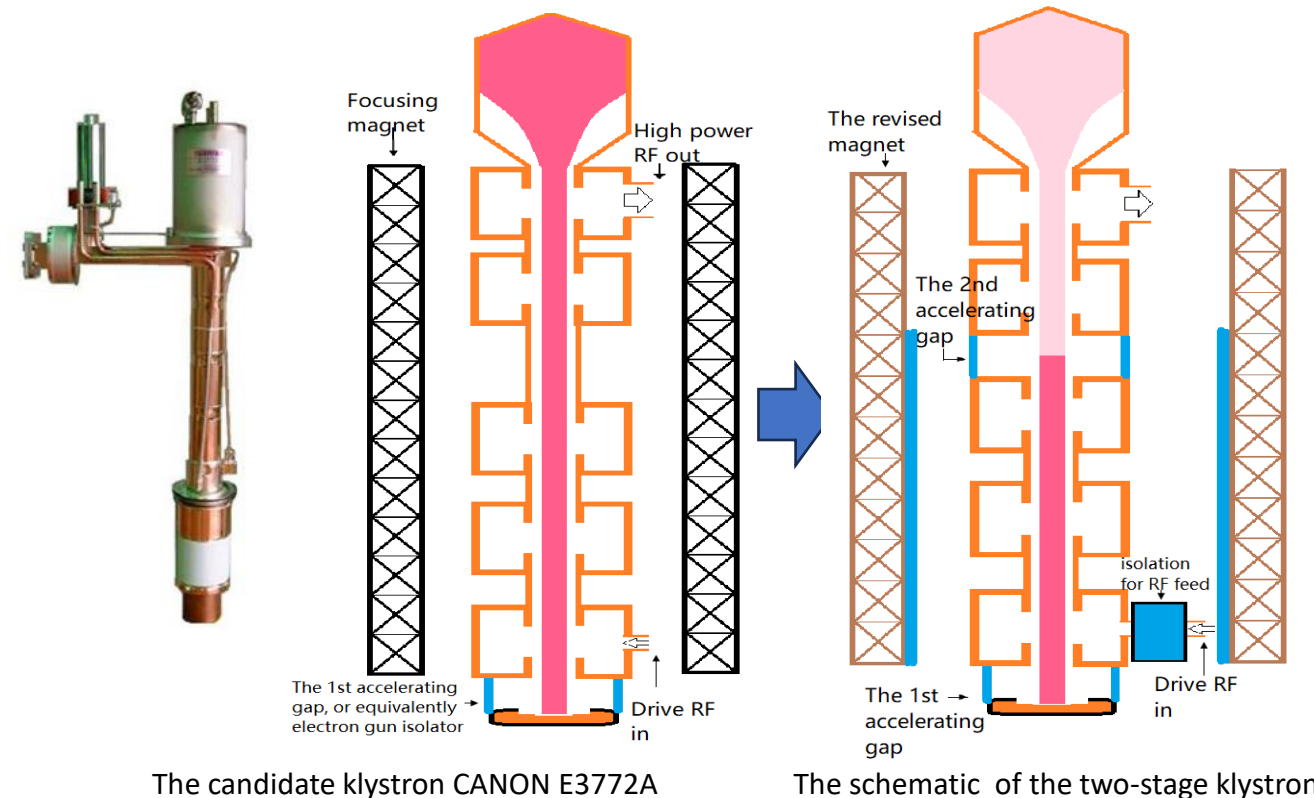- No back-electrons

Design of a S-band two-stage klystron

	E3772A	Two-stage klystron (design)
Efficiency	45%	72%
Beam voltage	150 kV(gun)	80 kV(gun)+170 kV(post accel. gap)
Beam current	110 A	41 A
Output power	7.5 MW	7.3 MW
Cavity number	5	6
Length	1 m	1 m

- Two-stage method [*Vladimir E. Teryaev*]

- Increase the efficiency of the existing S-band klystron from 45% to 72%, while maintaining the same output power and klystron length

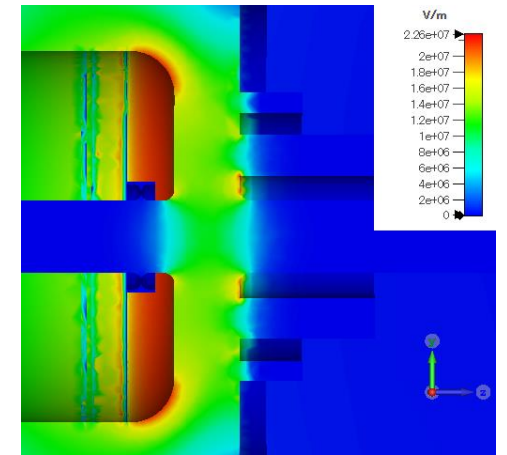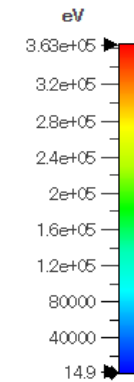- Electron gun and collector are kept as same as the CANON E3772A

This project belongs to the **Early Career Research Program on Accelerator Technology R&D** of KEK

The candidate klystron CANON E3772A

The schematic of the two-stage klystron

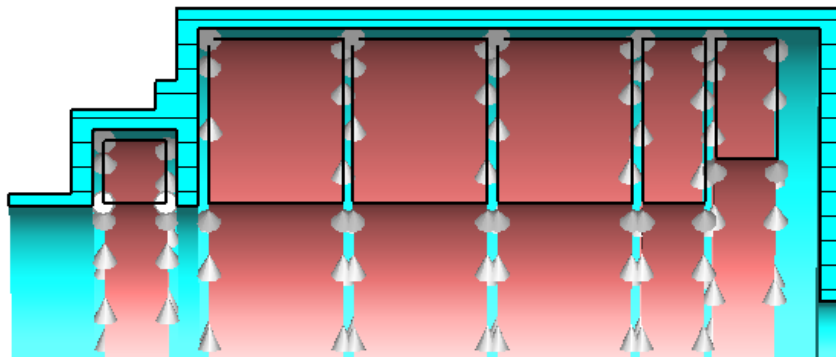[https://etd.canon/en/product/category/microwave/klystron.html]

Design of a S-band two-stage klystron
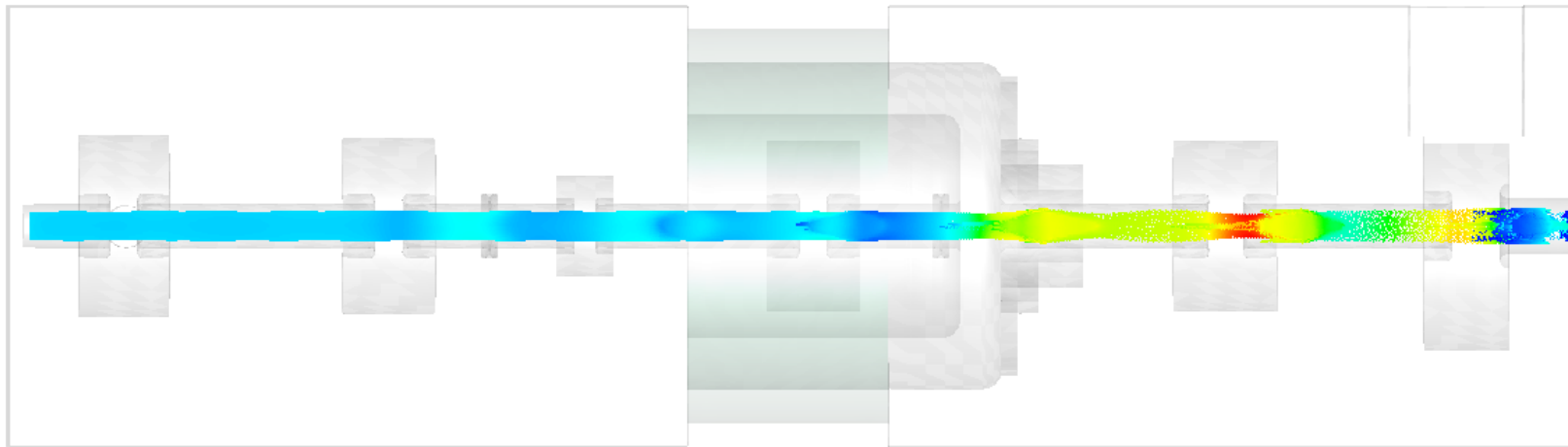
PIC simulation by CST

22.7 MV/m for the post gap voltage of 170 kV

The existing magnet of the S-band 50 MW klystron

- Output power: 7.3 MW, Efficiency: 72%
- Max E-field at the post gap: 22.7 MV/m
- Attenuation of the leaked RF: -40 dB
- The existing magnet of the S-band 50 MW klystron is reused and slightly modified to accommodate the newly designed two-stage klystron, for a lower R&D budget.