LIPAc RFカプラにおける電子マルチパクタおよびそれに対する磁気バイアスの効果についてのシミュレーション

Electron simulation about multipactor and effect of magnetic bias in LIPAc RF couplers

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22-th PASJ annual meeting (2025)
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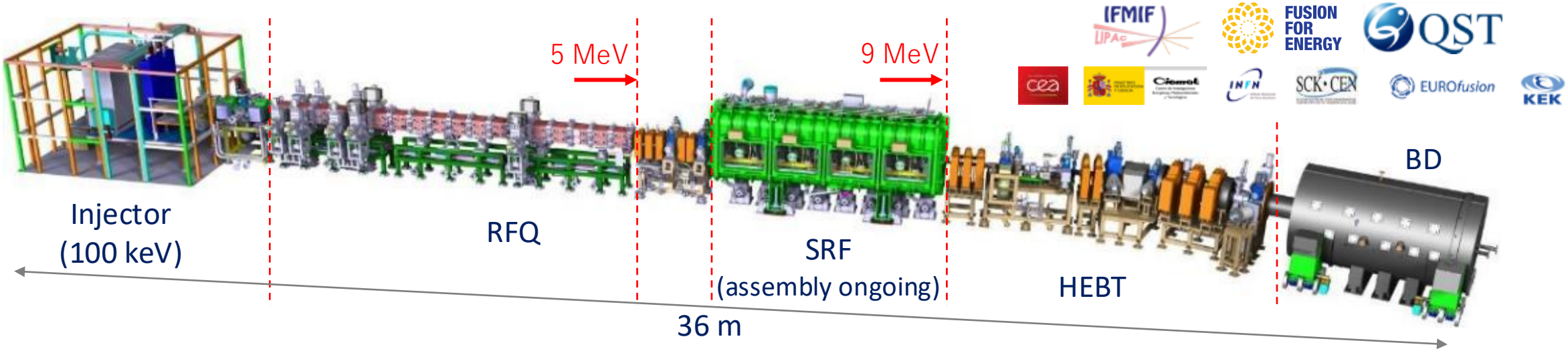
IFMIF-LIPAc



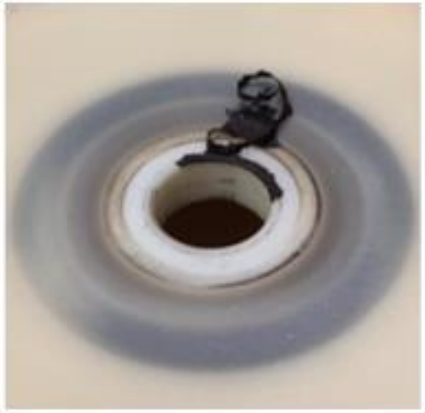
IFMIF: International Fusion Materials Irradiation Facility

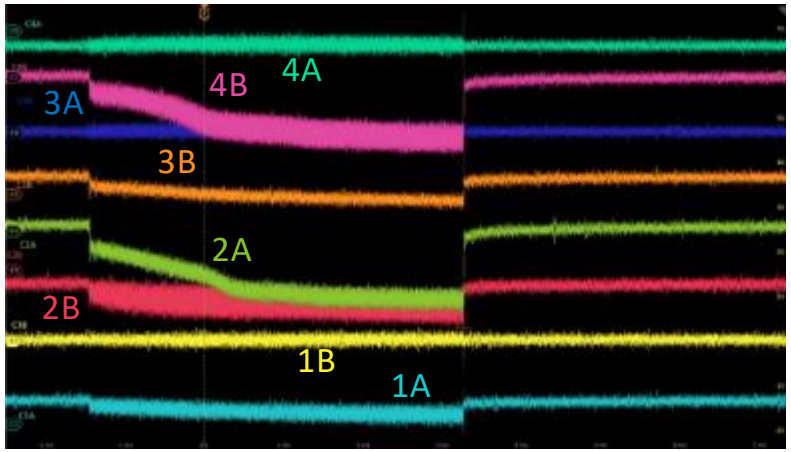
LIPAc: Linear IFMIF Prototype Accelerator

	IFMIF	LIPAc
Current	125 mA × 2 lines	125 mA × 1 line
Energy	40 MeV	9 MeV
Acceleration Line	RFQ + 4 SRF	RFQ + 1 SRF
Target	Li	Cu

RF coupler for LIPAc-RFQ, and its problem

Current RF coupler (O-ring coupler)


Damaged O-ring
at the RF window



Observed light emission

8 couplers,
160-180 kW for
each in nominal

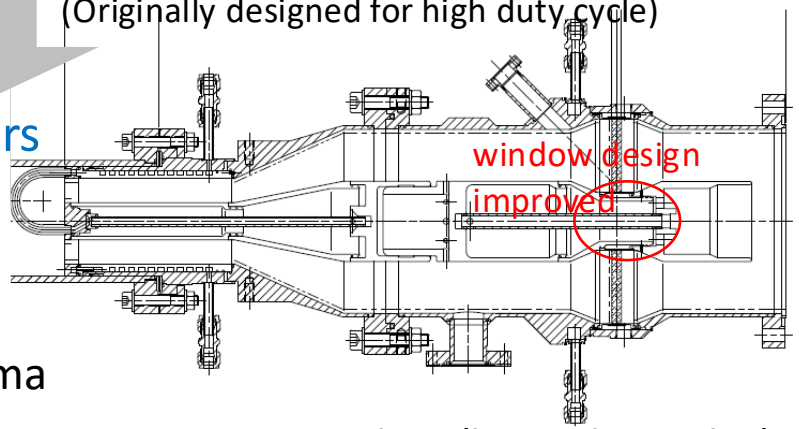
Overheating, damage of O-rings, and light emissions observed

- Duty cycle limited < 10%
- Multi-pactoring (MP) is suspected as a major cause.

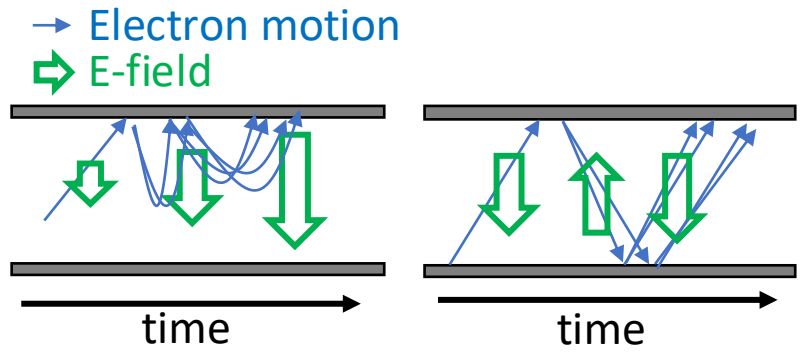
Test of a set of new RF couplers (brazed coupler) is ongoing

- Reduce axial field around the window to relax MP
- Improve its durability to plasma expose and thermal stress

(Originally designed for high duty cycle)



Testing new couplers (brazed coupler)

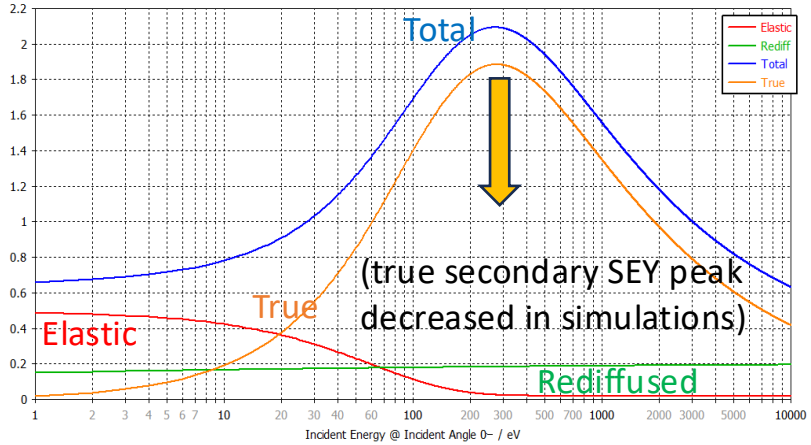


Principle of multi-pactoring (MP)

Simulation study of MP

Purpose

- Analyze the MP conditions in both old and new couplers to support testing of the new coupler
- Establish an alternative countermeasure to control MP



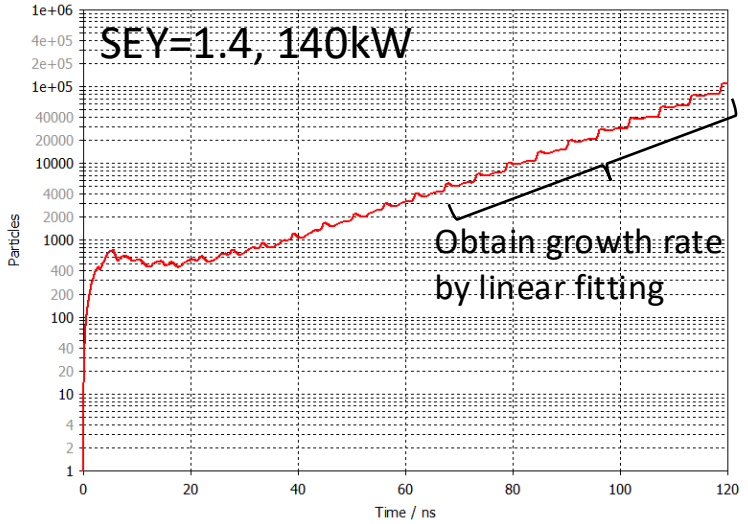
Energy dependency of 2ndary emission of Cu*
(also using same one for ceramic window)

*M.A. Furman and M. T. F. Pivi, LBNL-52807, SLAC-PUB-9912

Method

MP simulation with electromagnetic particle simulations using the CST-Studio suite® (Charged Particle Dynamics solver)

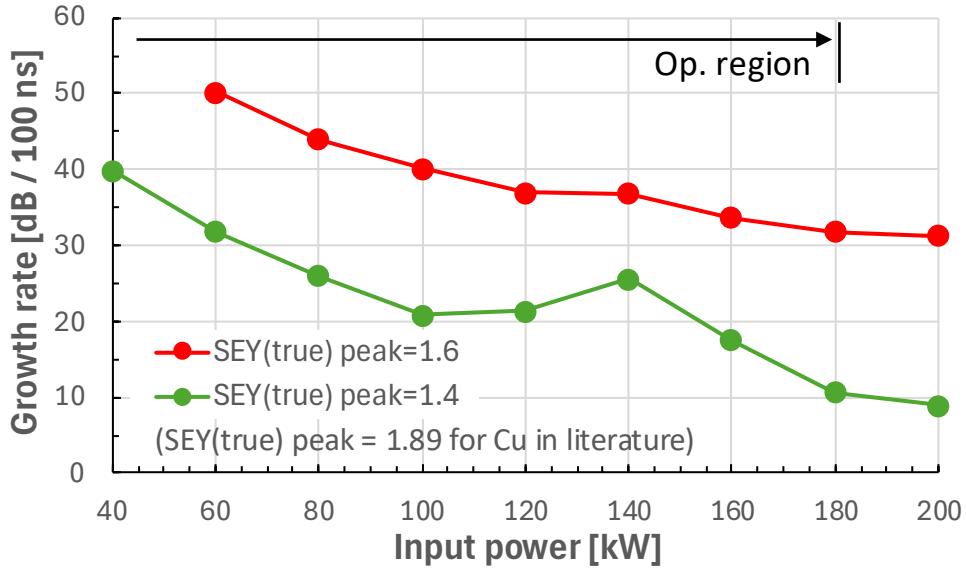
- Comparison of MP between O-ring and brazed couplers
- MP control by the axial B-field bias



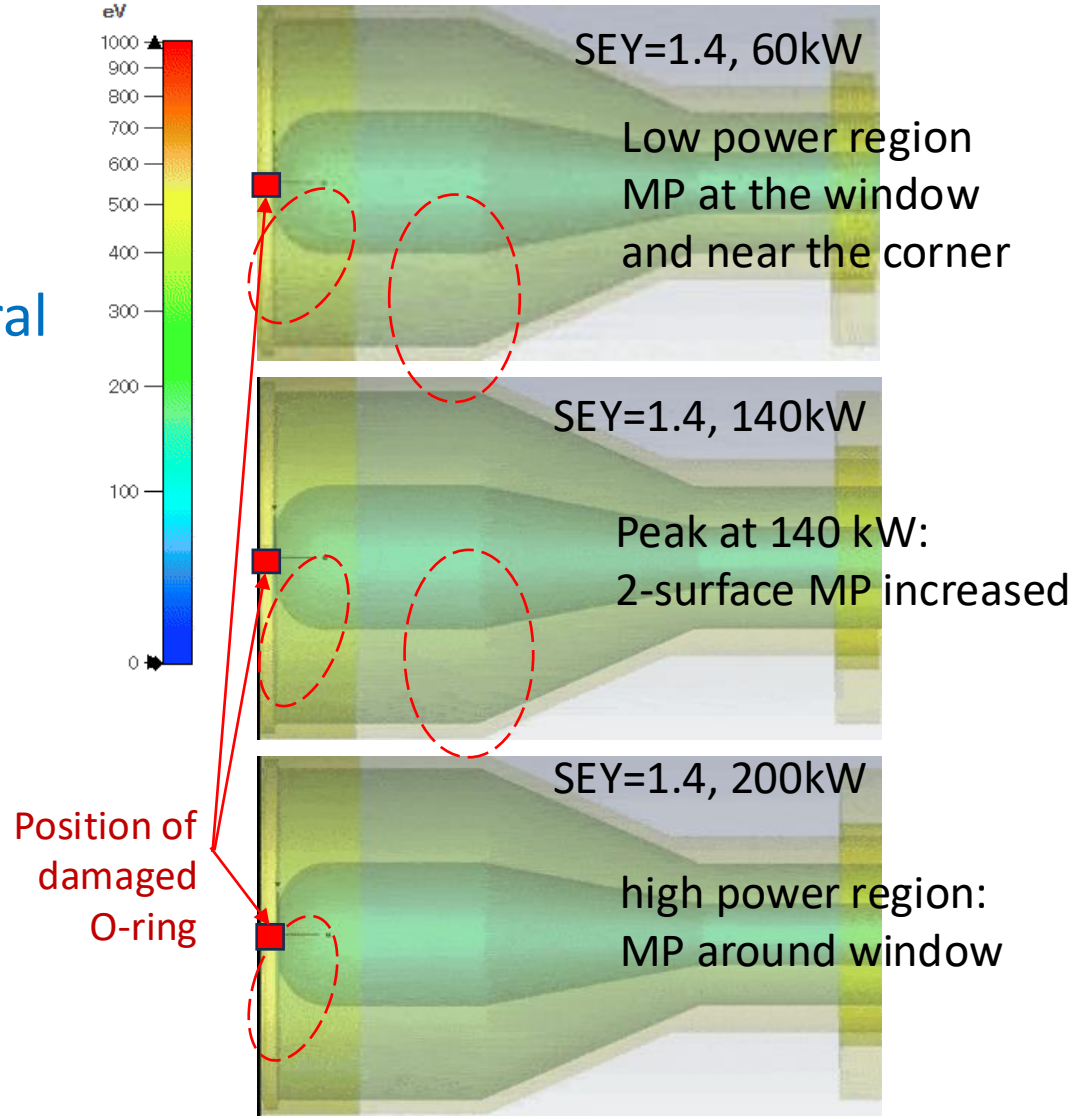
Typical case of electron number growth

MP simulation of the O-ring coupler

- MP caused around the ceramic window on the entire power level until 200 kW
  - Near the damaged O-ring
- MP is likely to be strong in the areas of structural changes.
  - Around the window and a corner in this case



Growth rate of the electron number by MP

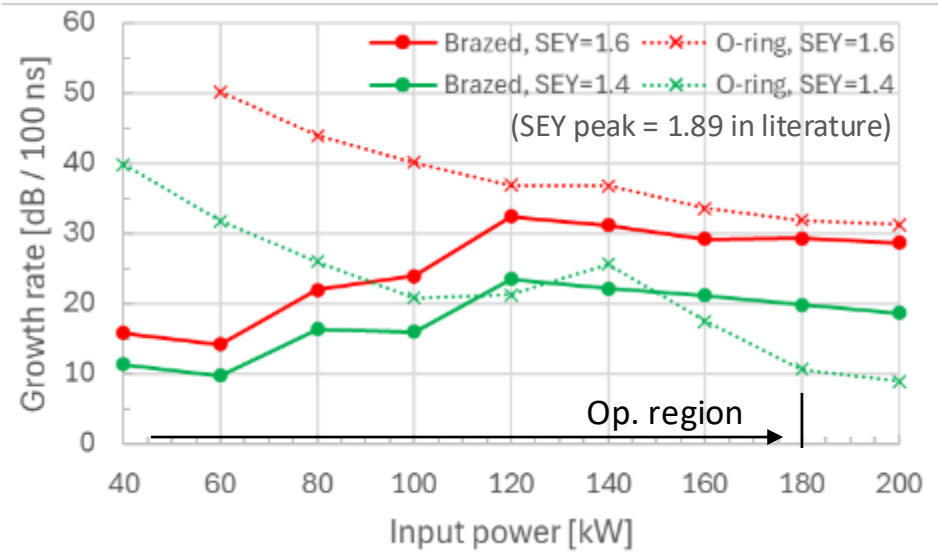


Electron motion and
MP significant regions

MP simulation of the brazed coupler

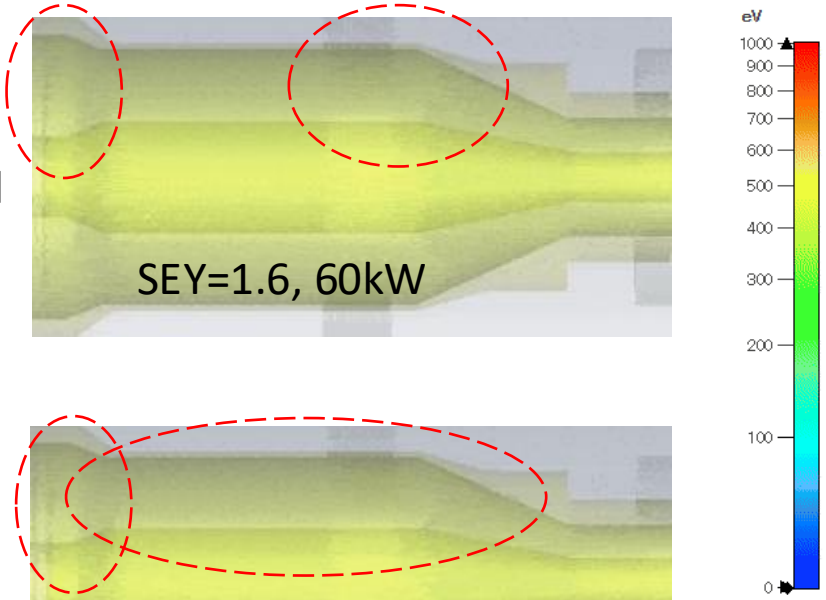
The electron number growth rate notably decreases compared with that in the O-ring coupler.

- Improved especially in the lower-power side while not so remarkable in high power region.
- Improved in the entire region of input power with high (but still lower than literal) SEY
- Still the MP-free (growth rate < 0) not achieved
- MP associated with the motion of electrons like rubbing on the window surface still exists



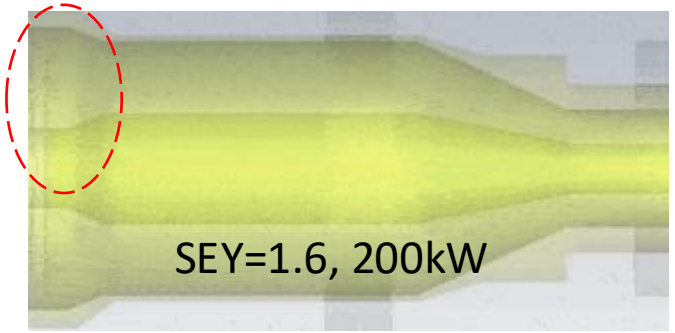
Comparison of growth rate

Low power region
MP at window and edge of cone



Peak at 120 kW:
2-surface MP increased

high power region:
MP around window



Electron motion and MP regions

Axial B-field bias to control MP

Control of the MP by the axial B-fields

- Suppress the energy gain of electrons from potential change until re-injection to the wall surface.

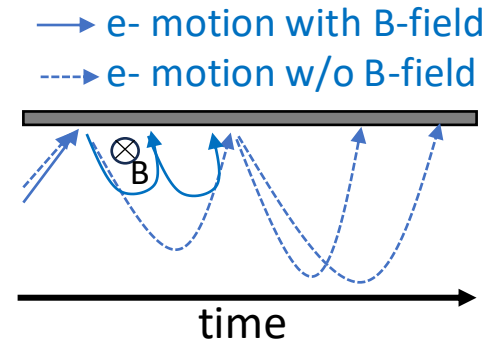
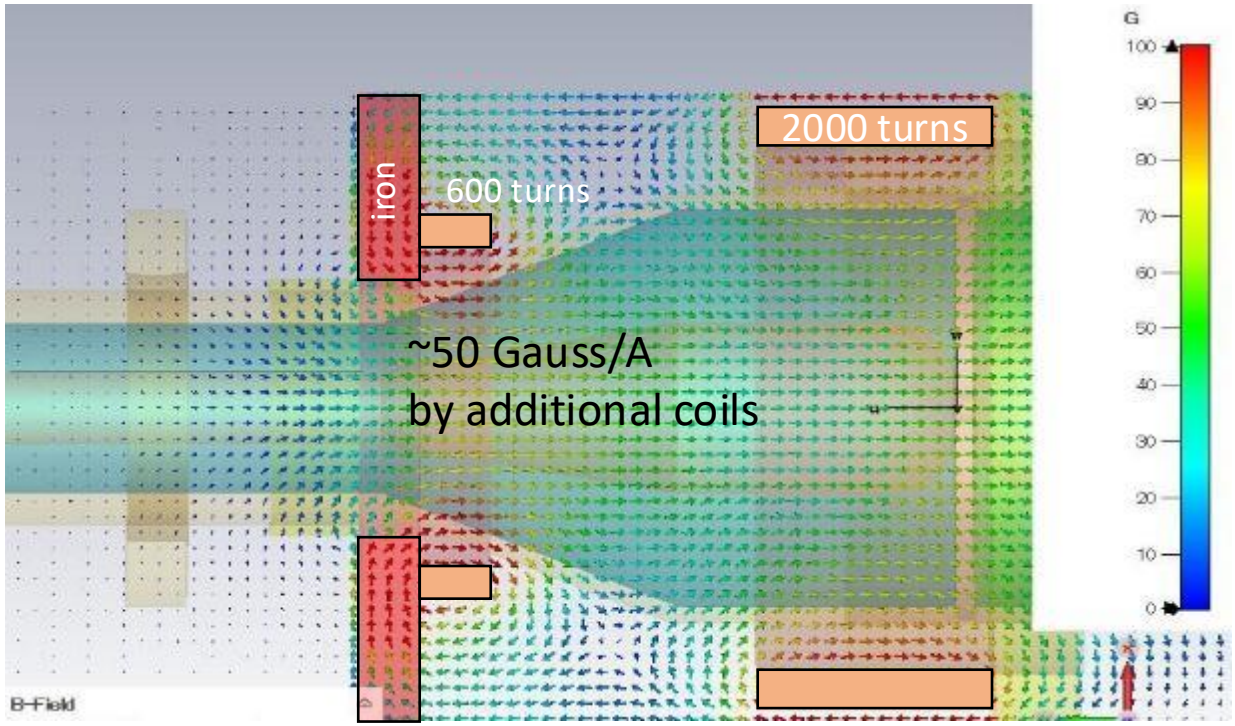
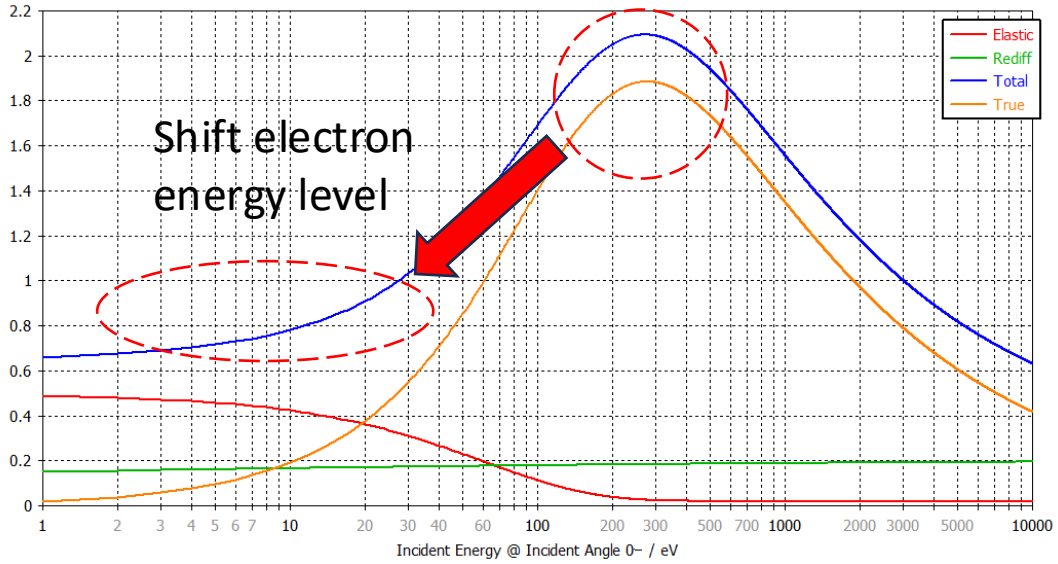


Image of electron motion
with and without bias B-field



Optimized bias field configuration for the O-ring coupler

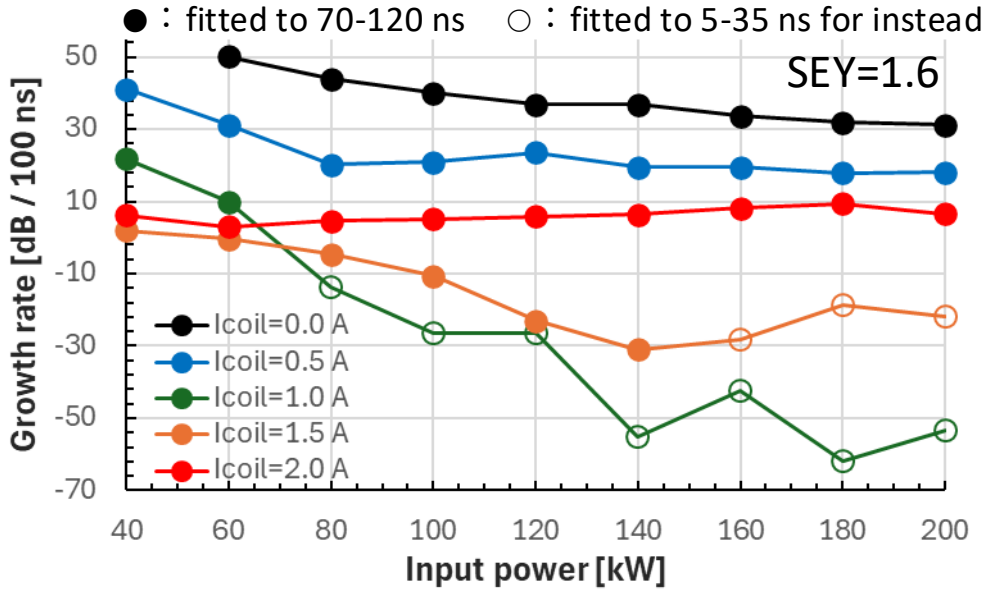


Using energy dependency of secondary yield

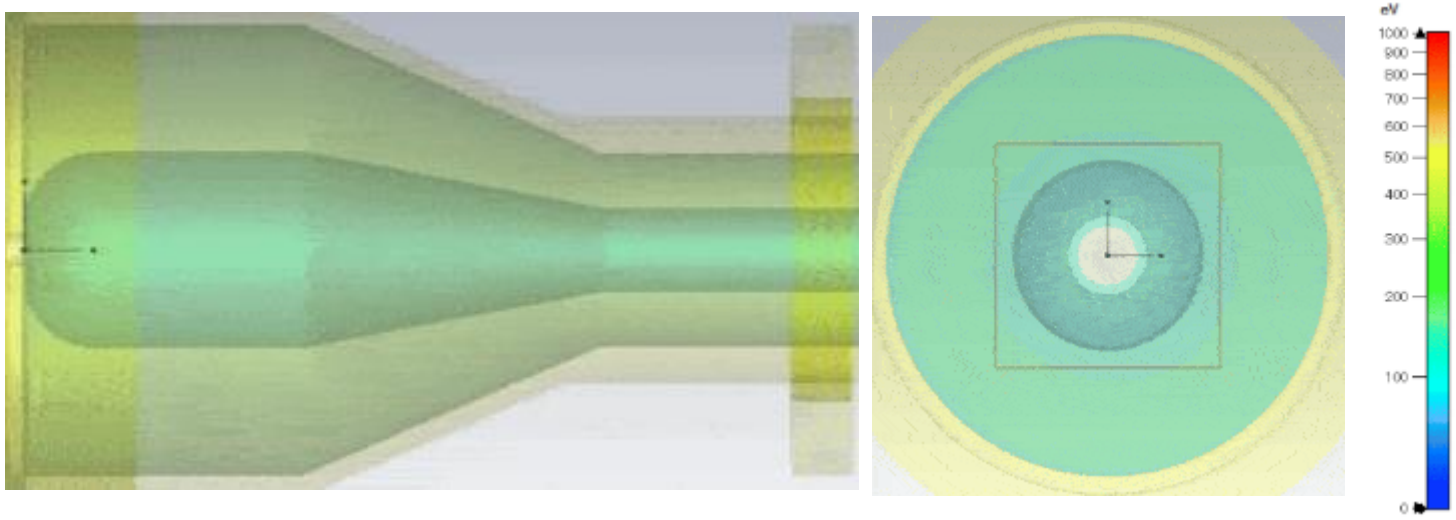
MP characteristics under the bias field

Optimized bias Bz field can suppress MP up to MP-free region(Growth rate < 0)

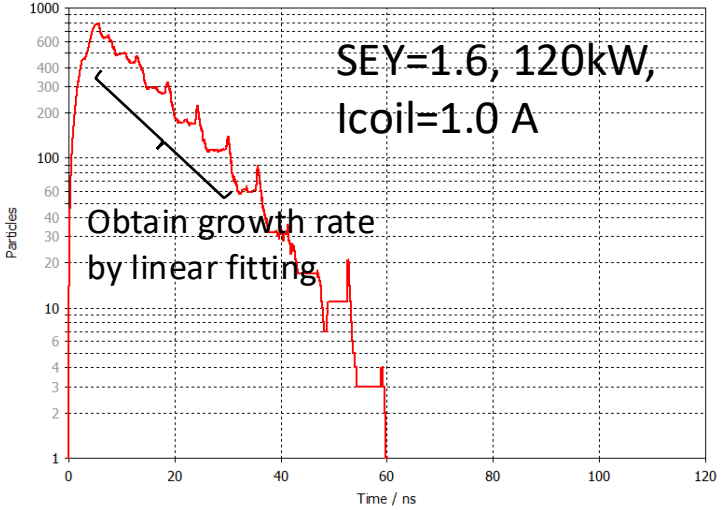
- In this case, around 50-75 Gauss of bias B field can achieve MP-free for almost the entire region of input power.



Growth rate with bias field for the O-ring coupler



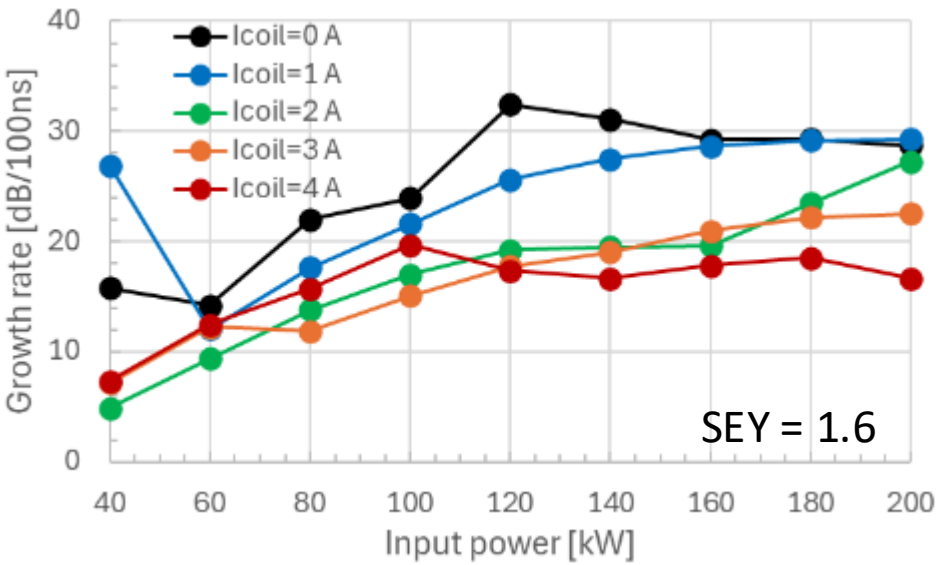
Electron motion; SEY=1.6, 140kW, Icoil = 1.0 A (Bz ~ 50 Gauss)



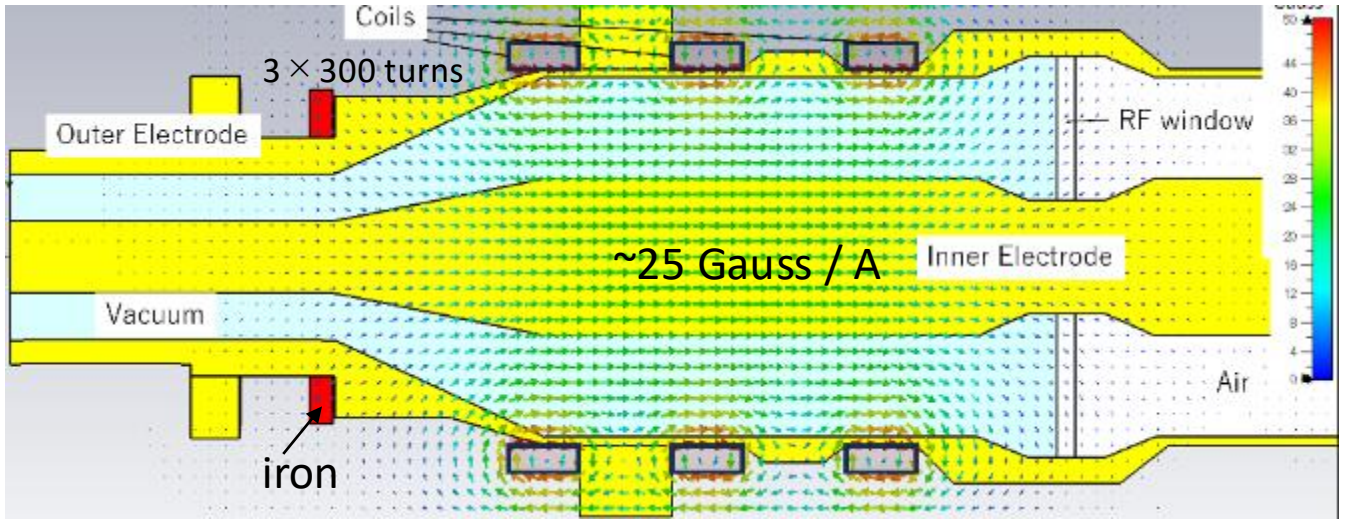
Particle decrease of a MP free case

Effects of the bias fields in the brazed coupler

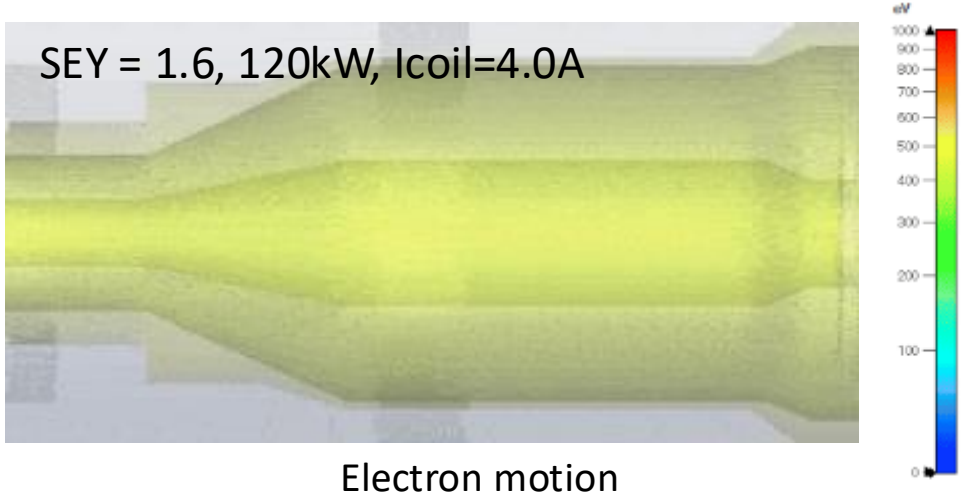
- With enough field more than 2A of coil current (50 Gauss) at the straight pipe, it can effectively decrease the growth rate.
- The currently considered bias fields could not achieve MP-free (growth rate <0), as the coil configuration still not well optimized.
  - There is some difficulty in coil setting since the brazed coupler has a bit more complicated structure than the O-ring couplers.
  - The field configuration is specified so as to generate Bz fields in the straight pipe region of the coupler



Growth rate with bias field for brazed coupler (the field configuration is still not well optimized)



Bias field configuration

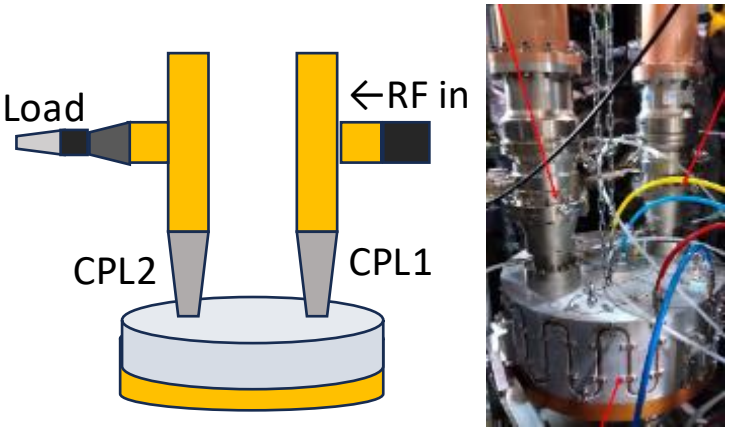


Electron motion

Tests of couplers are ongoing

- Testing of the brazed couplers are ongoing and going better than the simulations.
  (details will be reported by others)
  - CW run in 4 hours with 180 kW(nominal input) has been demonstrated.
  - MP region is limited to several input power bands → e.g. 60-80 kW and 120-150kW
  - Not all couplers have the same behavior (some present more pronounced MP than others)

  → Fitting secondary yield distribution is needed, since they seems to have lower secondary yield than that in a literature due to surface procession or conditioning.



High power test bench (HPTB): test of new couplers is ongoing

- Preparation of bias field test with using the O-ring couplers is also ongoing.

Simulation study of MP (with and without bias)

Feedback knowledge

Brazed coupler HPTB test

MP control test by bias field using O-ring coupler

Test of bias field effect with using the O-ring coupler is prepared

Summary and future tasks

Summary

- Simulations of O-ring/brazed RF coupler have done.
  - Brazed coupler shows better characteristics especially in low power region
  - MP around the RF window is important for the both designs, especially in high power region.
  - MP around taper end is important for low power region
  - 2-surface MP at the 120-140 kW
- Tests of brazed couplers are ongoing, with better behavior than the simulations
  - MP region is limited to several power bands in the tests.
  - It seems to have lower secondary yield than a literature by surface processing or conditioning.
- MP control by external B-field bias simulations
  - It showed promising result especially for the O-ring coupler
  - Preparation for test of the bias is ongoing

Future task

- Secondary emission parameter fitting to the brazed-coupler test results.
- Optimization of bias B-field for the brazed-couplers.
- Validation of the couplers with the RFQ

Thank you!