Positron source

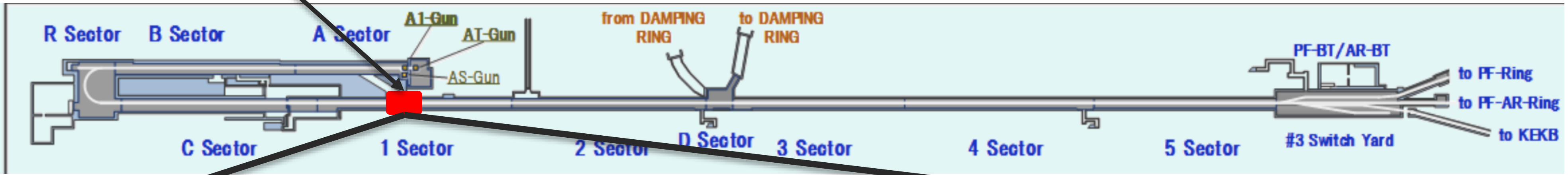
Yoshinori Enomoto

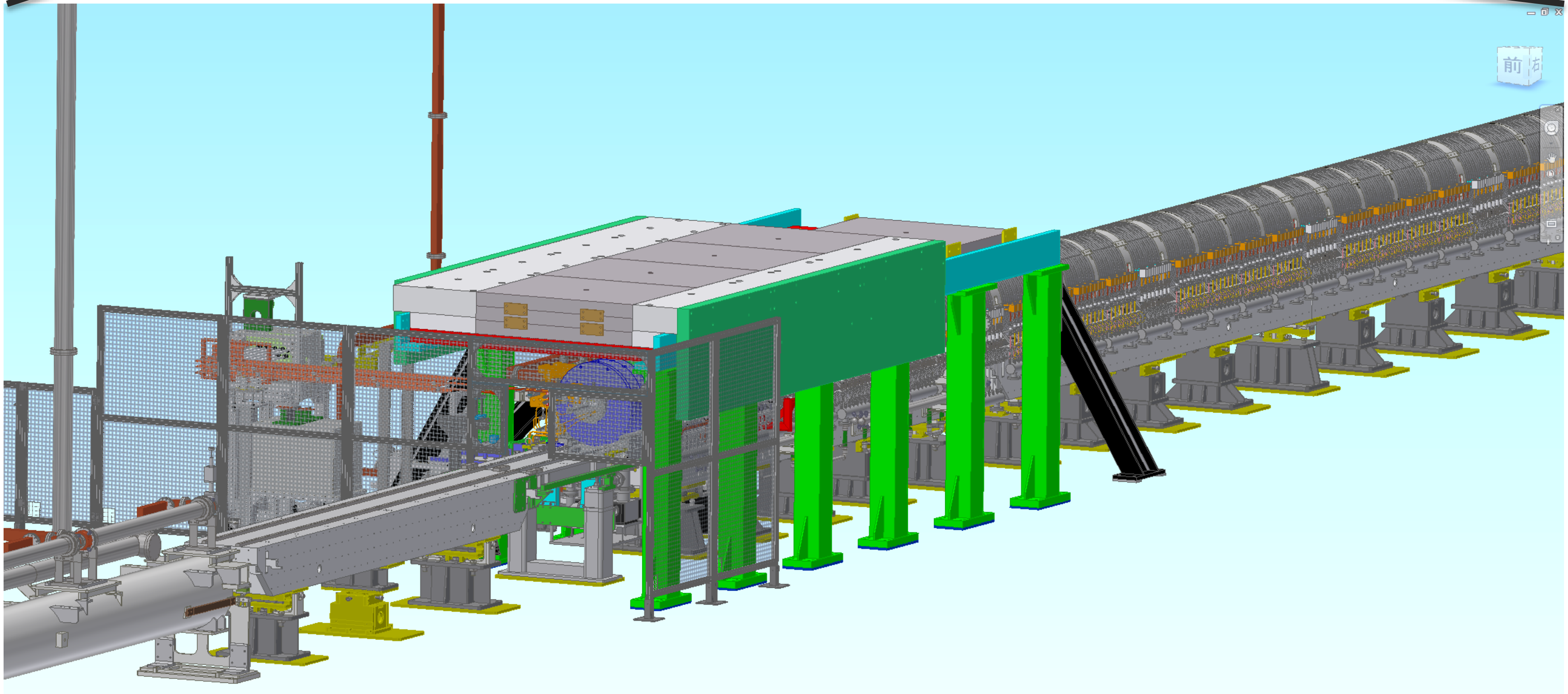
Outline

- Operation in phase 3
  - Positron source setup
  - Requirement and achievement
- Present status and development
  - Magnetic filed in solenoid section
  - Discharge of FC
  - Upgrade plan
  - Collaboration
- Summary
- Answer to the previous review comments

Positron source setup 1

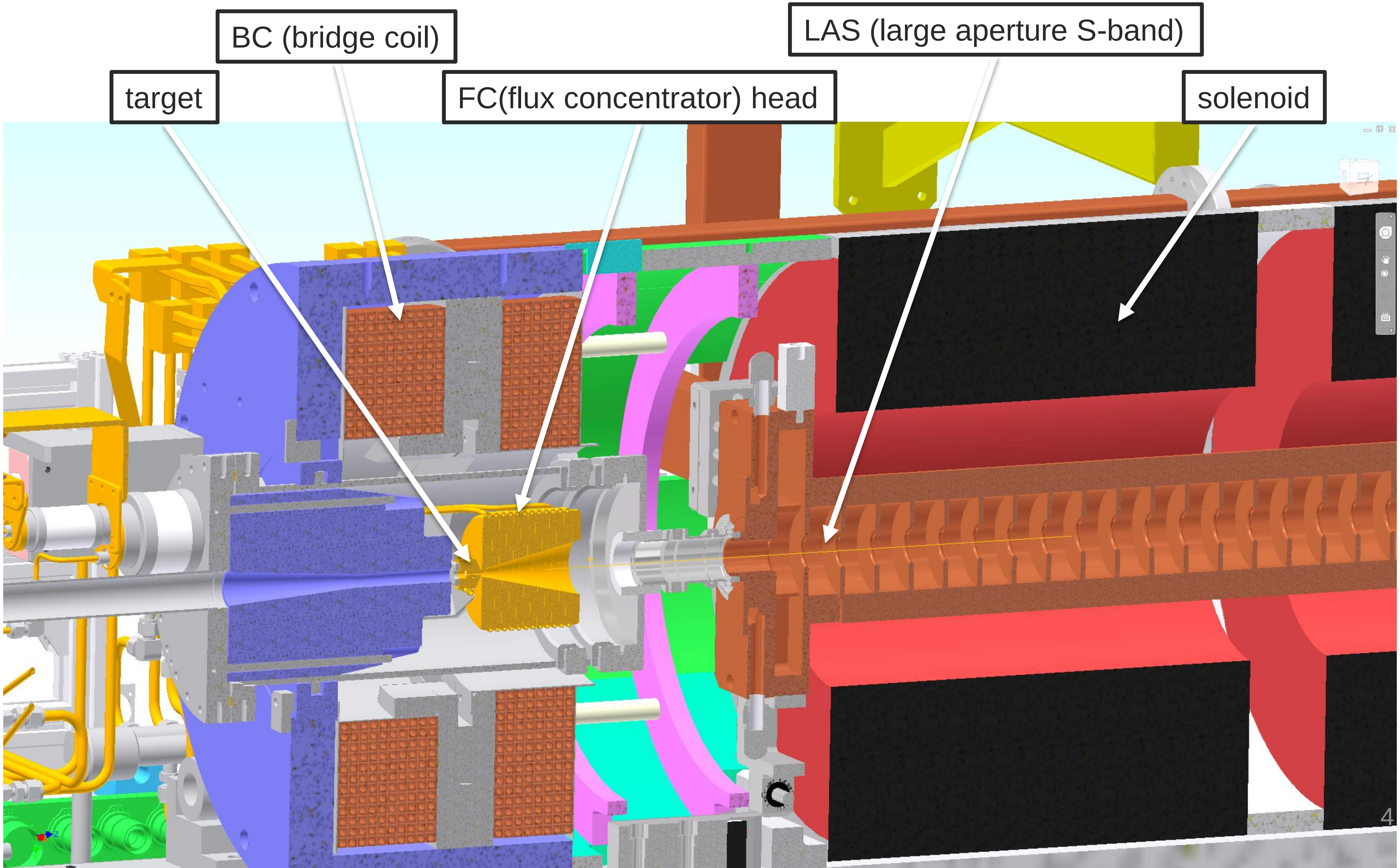
Positron target and capture section



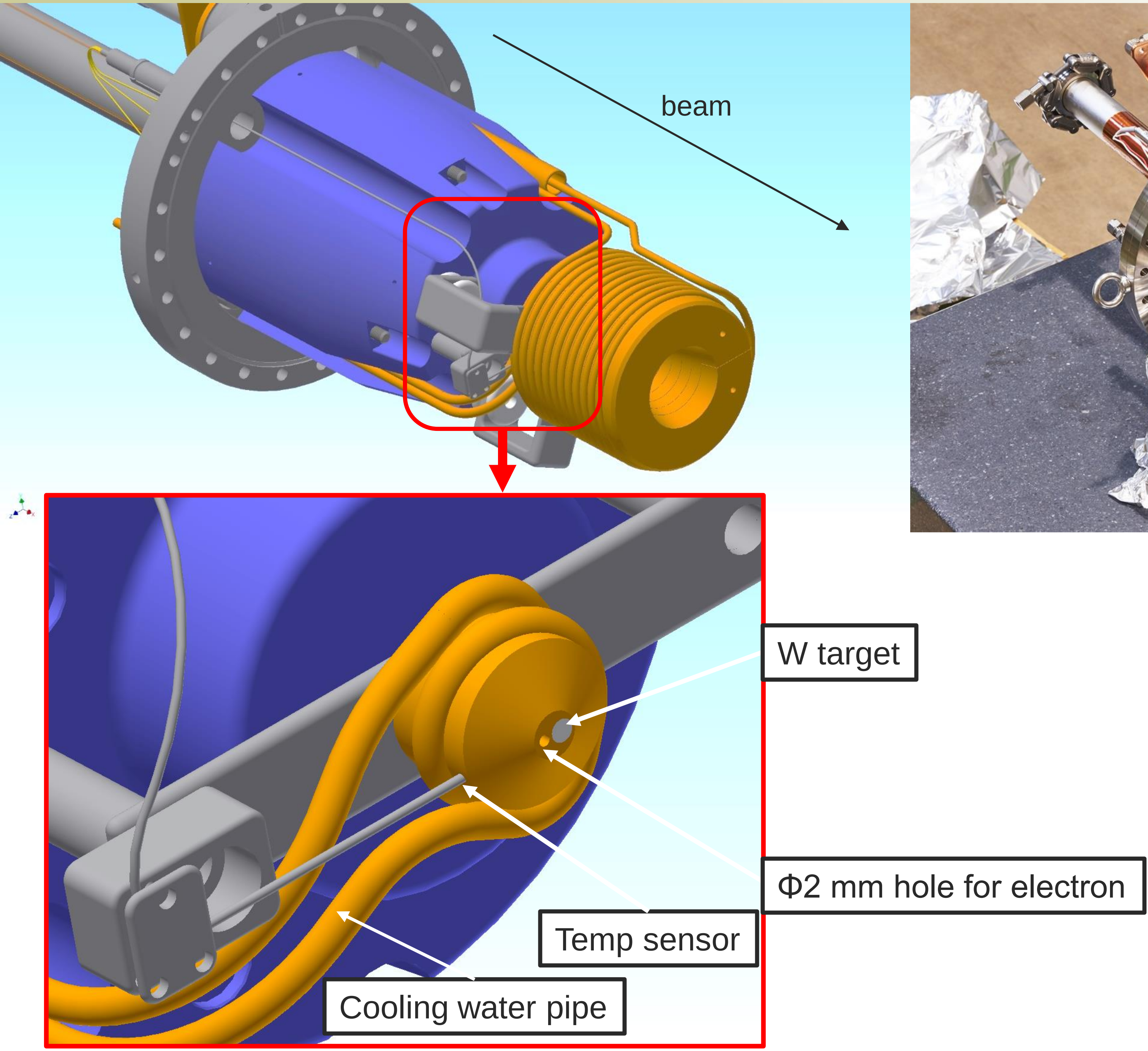


Positron source setup 2

FC head + BC + target = FC assembly



Positron source setup 3



Required injector beam parameters

Stage	KEKB (final)		Phase-I		Phase-II		SuperKEKB (final)	
Beam	e+	e–	e+	e–	e+	e–	e+	e–
Energy	3.5 GeV	8.0 GeV	4.0 G	x2.25 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV
Stored current	1.6 A	1.1 A	1 A	1 A	1.5 A	1.2 A	3.6 A	2.6 A
Life time (min.)	150	200	100	100	–	–	6	6
Bunch charge (nC)	primary e- 10 → 1	1	primary e- → 0.4	1/25 1	0.5	1	primary e- 10 → 4	4
Norm. Emittance (γβε) (μrad)	1400	310	1000	130	200/40 (Hor./Ver.)	150	100/15 (Hor./Ver.)	40/20 (Hor./Ver.)
Energy spread	0.125%	0.125%	0.5%	0.5%	0.16%	0.1%	0.16%	0.07%
Bunch / Pulse	2	2	2	2	2	2	2	2
Repetition rate	50 Hz		25 / 50 Hz		25 / 50 Hz		50 Hz	
Simultaneous top-up injection (PPM)	3 rings (LER, HER, PF)		No top-up		Eventually		4+1 rings (LER, HER, DR, PF, PF-AR)	

Injection requirement

Present working assumption (final)

Life	360 s
Current	3.6 A
Injection bunch charge	4 nC
Injection rate	25* Hz x 2 bunch
Injection efficiency	50 %
Circulation frequency	10^5

$$\frac{dI}{dt} = \frac{3.6\ [\mathrm{A}]}{360\ [s]} = 10\ [mA/s]$$

$$4\ [\mathrm{nC}] \times 25\ [\mathrm{Hz}] \times 2\ [\mathrm{bunch}] \times 50[\%] \times 10^5[\mathrm{Hz}] \\ = 10\ [mA/s]$$

Injection requirement

Present working assumption (final)

Life	360 s
Current	3.6 A
Injection bunch charge	4 nC
Injection rate	25* Hz x 2 bunch
Injection efficiency	50 %
Circulation frequency	10^5

$$\frac{dI}{dt} = \frac{3.6\ [\mathrm{A}]}{360\ [\mathrm{s}]} = 10\ [mA/s]$$

$$4\ [\mathrm{nC}] \times 25\ [\mathrm{Hz}] \times 2\ [\mathrm{bunch}] \times 50[\%] \times 10^5 [\mathrm{Hz}] = 10\ [mA/s]$$

Typical Phase 3 operation

Life	2500 s
Current	0.5 A
Injection bunch charge	0.6 nC
Injection rate	6.2 Hz x 1 bunch
Injection efficiency	50 %
Circulation frequency	10^5

$$\frac{dI}{dt} = \frac{0.5\ [\mathrm{A}]}{2500\ [\mathrm{s}]} = 0.2\ [mA/s]$$

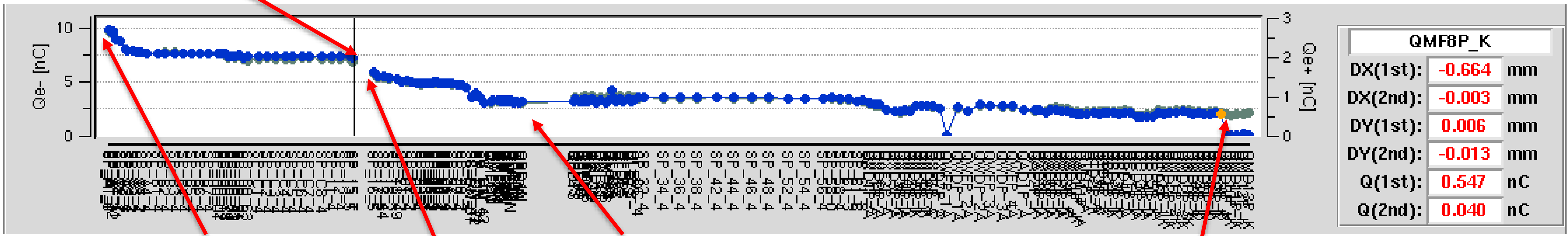
$$0.6\ [\mathrm{nC}] \times 6.25\ [\mathrm{Hz}] \times 1\ [\mathrm{bunch}] \times 50[\%] \times 10^5 [\mathrm{Hz}] = 0.2\ [mA/s]$$

*total rep. rate is 50 Hz
The other 25 Hz will be used electron injection

Due to limitation by Belle2 detector and SuperKEKB ring
Required injection amount is still low.

Positron charge and injection efficiency

Primary e- 7 nC@target



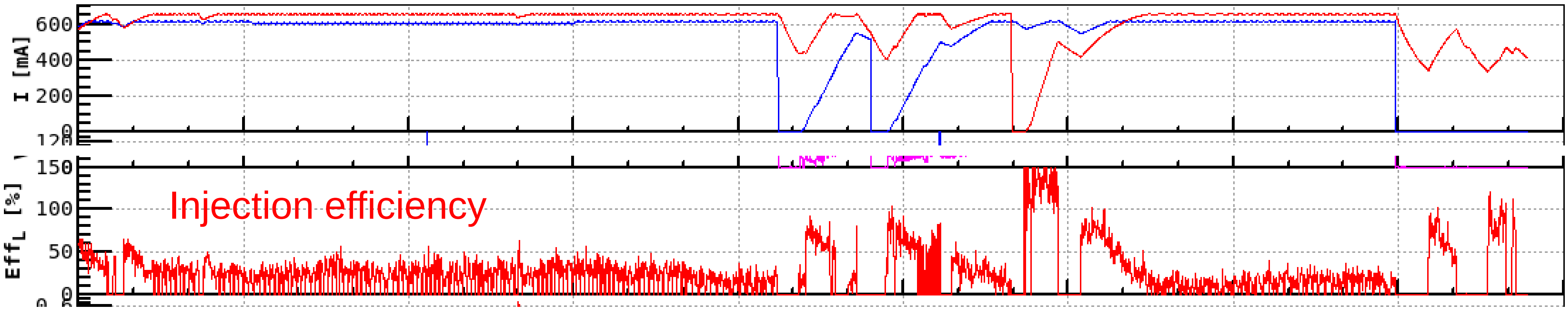
Primary e- 10 nC@e-gun

Positron 1 nC@DR

Positron 0.55 nC@BT end dump

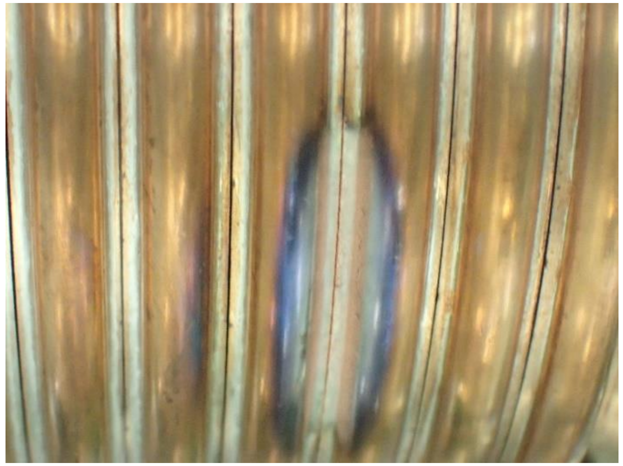
Positron 1.5 nC@first BPM

Positron current in the ring (LER)



9 hours

Operation in phase 3



- FC used in phase 2 was removed in Sept. 2018
  - With work hardened
  - Tested up to 12 kA at test bench
  - Damaged by discharge after installation in tunnel
  - Maximum current was limited to 6 kA in phase 2 operation
  - New exchange jig works well
- New FC was installed in Jan. 2019
  - Without work hardened (old one)
  - Tested up to 12 kA at test bench
  - Operated 3.5 kA in tunnel
  - Not damaged till now

Safe and stable operation in phase 3
→play for time
→push R & D at test bench

Outline

- Operation in phase 3
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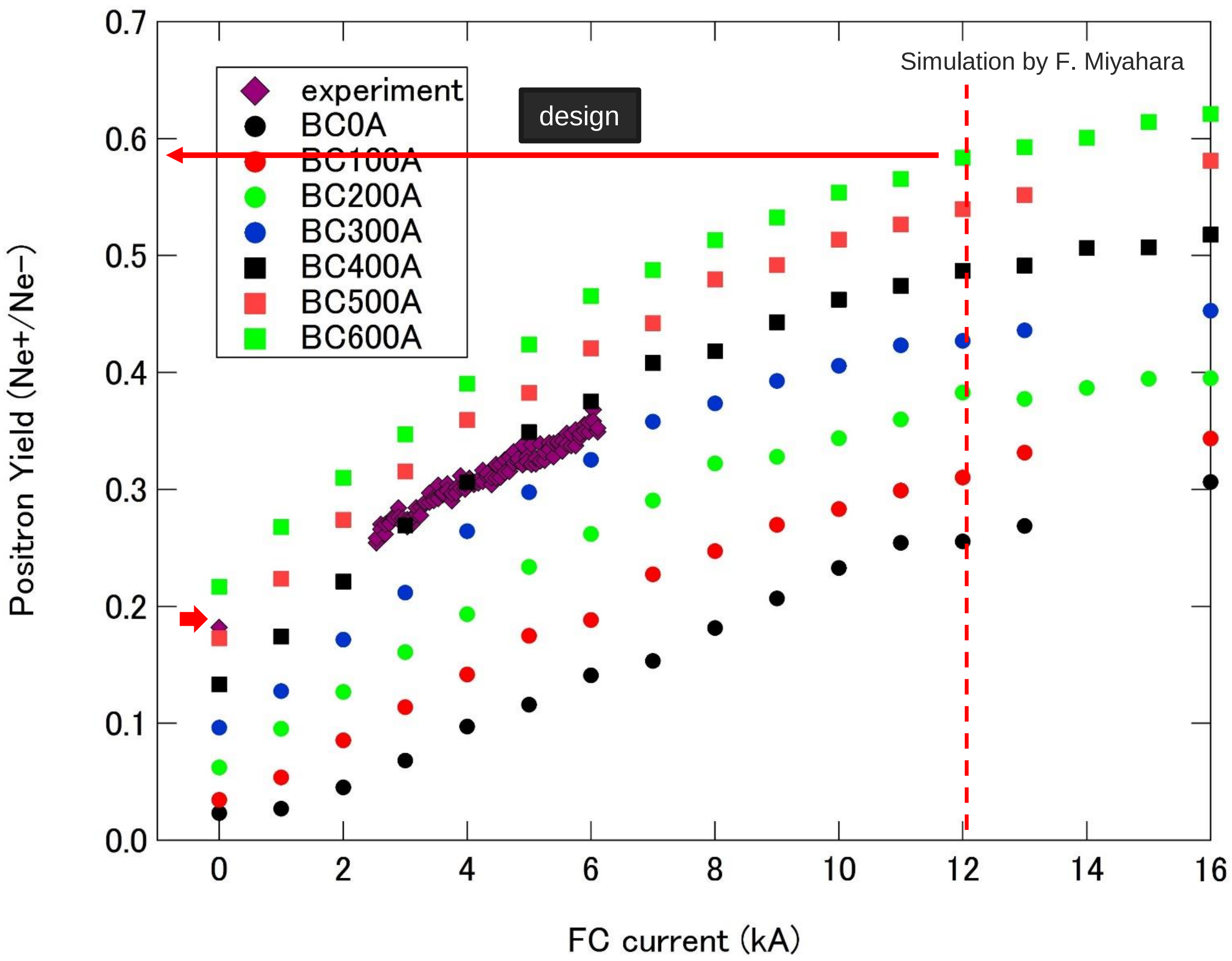
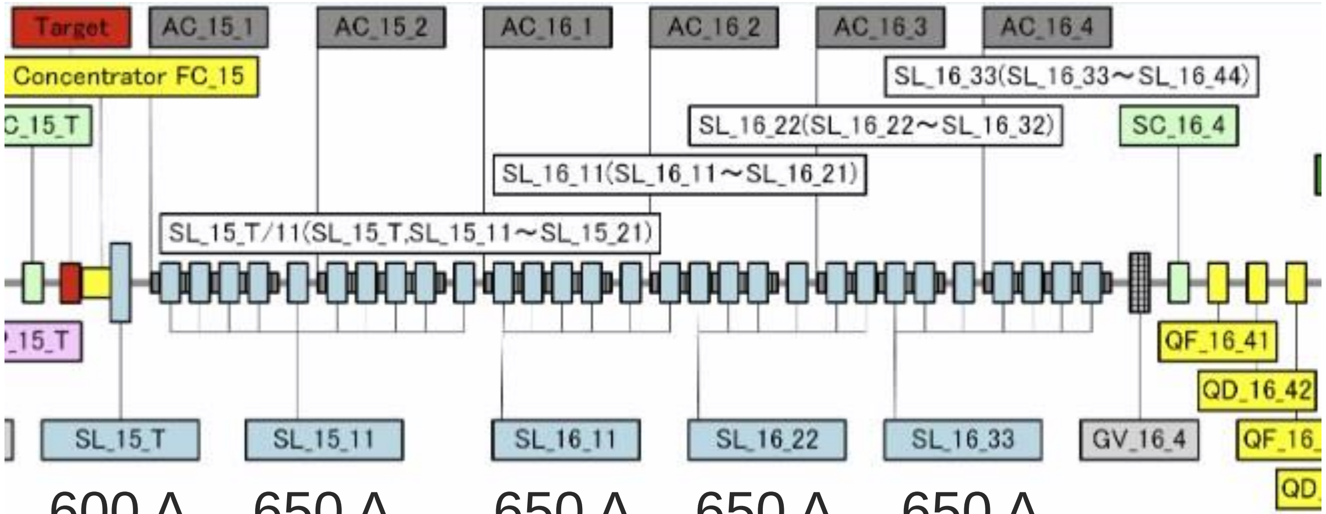
Design and present status



Parameter	simulation	Experiment
BC	600 A	600 A
SL_15_11	650 A	600 A
SL_16_11	650 A	400 A
SL_16_22	650 A	400 A
SL_16_33	650 A	650 A
ACC_15_1/2	10 MV/m	8.5 MV/m
ACC_16_1/2/3/4	12 MV/m	12 MV/m

Why yield is low compared to the design value?
How to increase the FC current?

Solenoid field issue

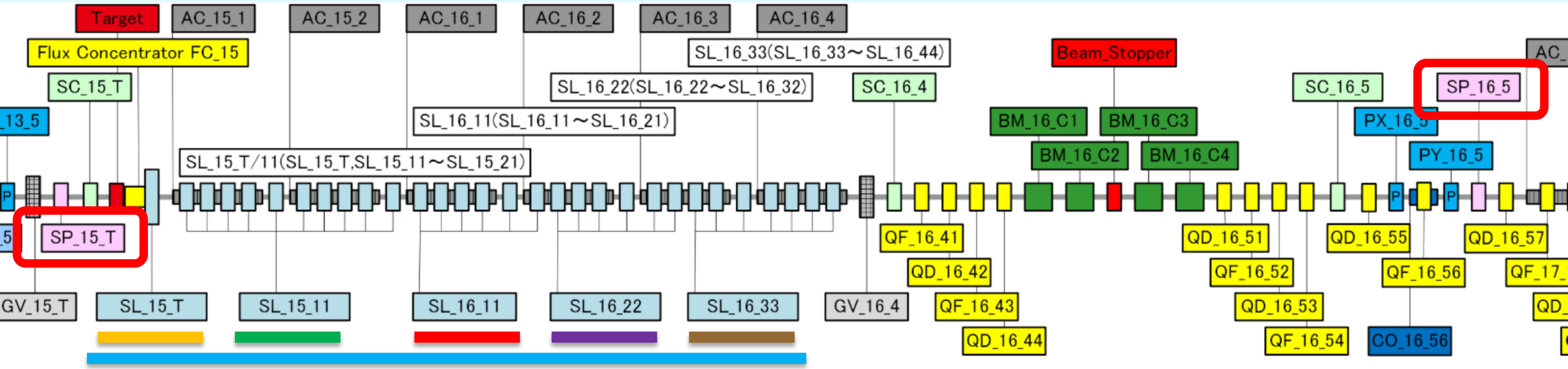


	SL_15_T	SL_15_11	SL_16_11	SL_16_22	SL_16_33
Design	600 A	650 A	650 A	650 A	650 A
present	600 A	600 A	400 A	400 A	650 A

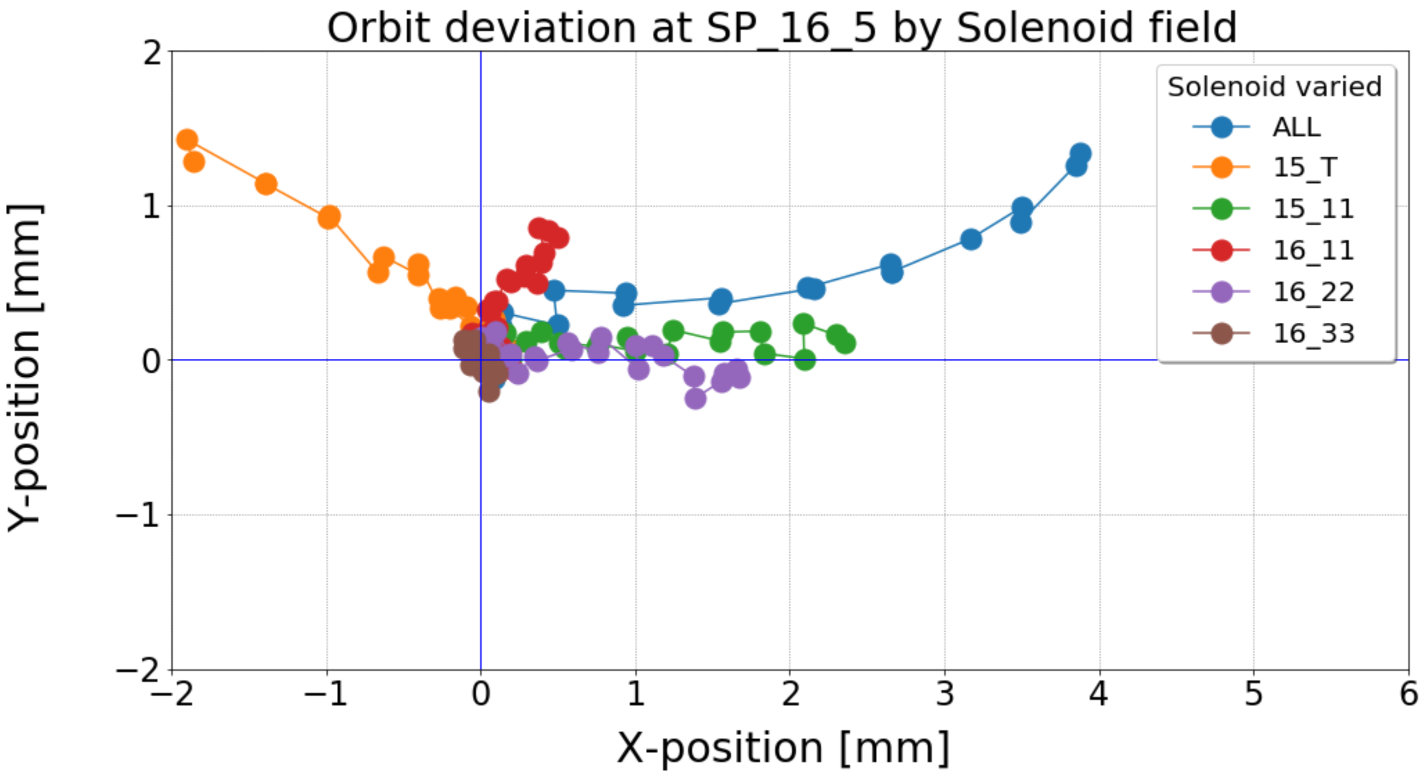
Solenoid section consists of 30 solenoid coils.
They are connected in 5 groups.
Each group is energized by independent power supply.

Design value and present value tuned to maximize positron yield is different

Solenoid field issue



Measured by T. Kamitani



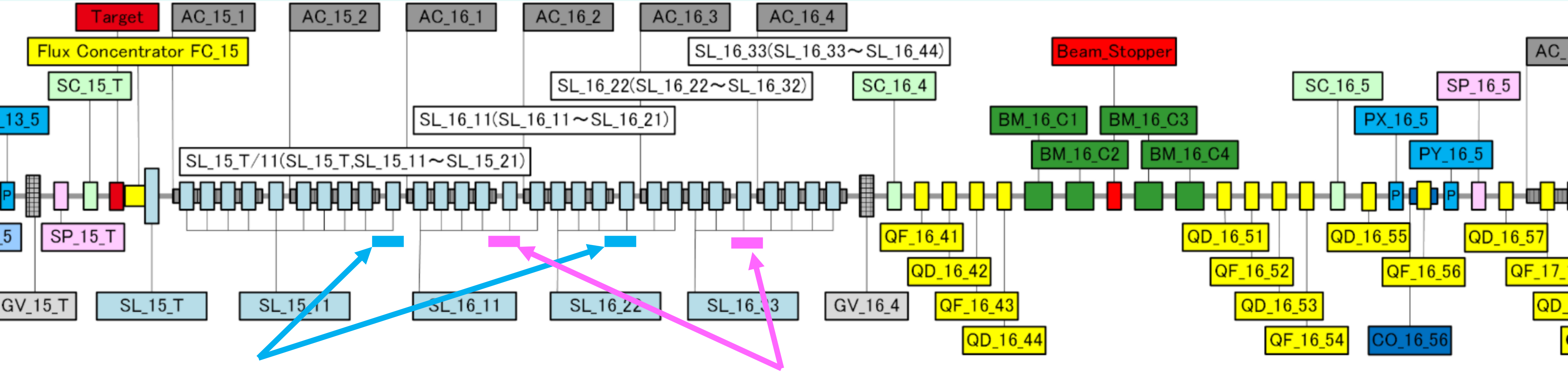
Measurement of deflection amount of 3 GeV electron beam by asymmetric field in solenoid section

1,Prepare ballistic beam between SP_15_T and SP_16_5

2,Energize a part of solenoid by 1/10* max. value step.

3, Monitor beam position at SP_16_5

Solenoid field issue



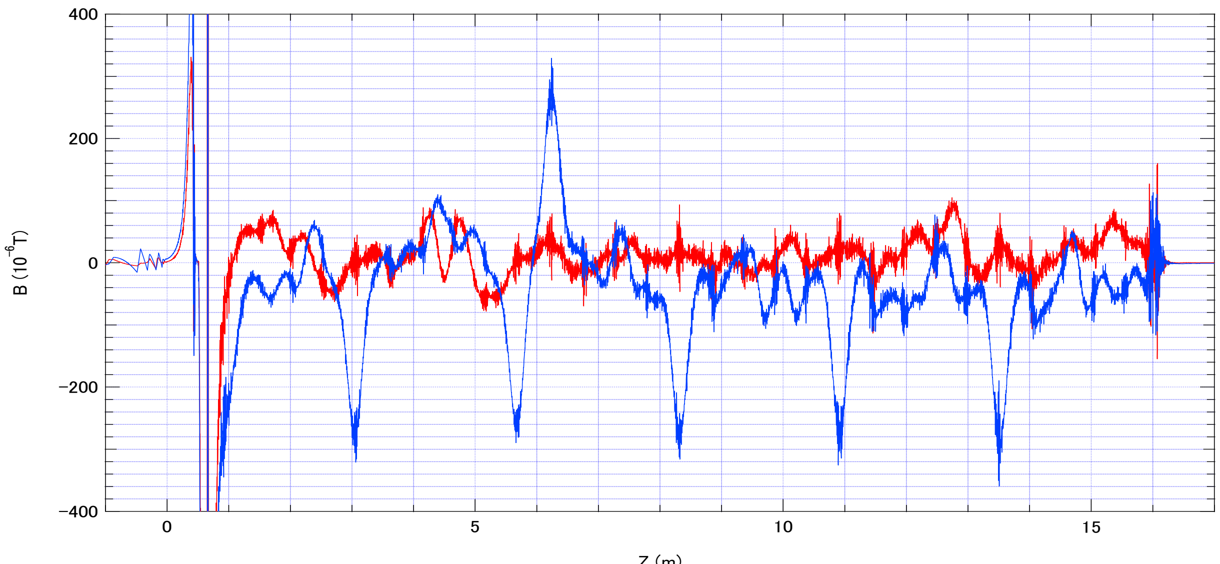
Steering coils

BPM

Install steering coils and BPM in solenoid section.

Measure magnetic field in the solenoid section using electron beam.

Detailed simulation of magnetic field by CST is also in progress

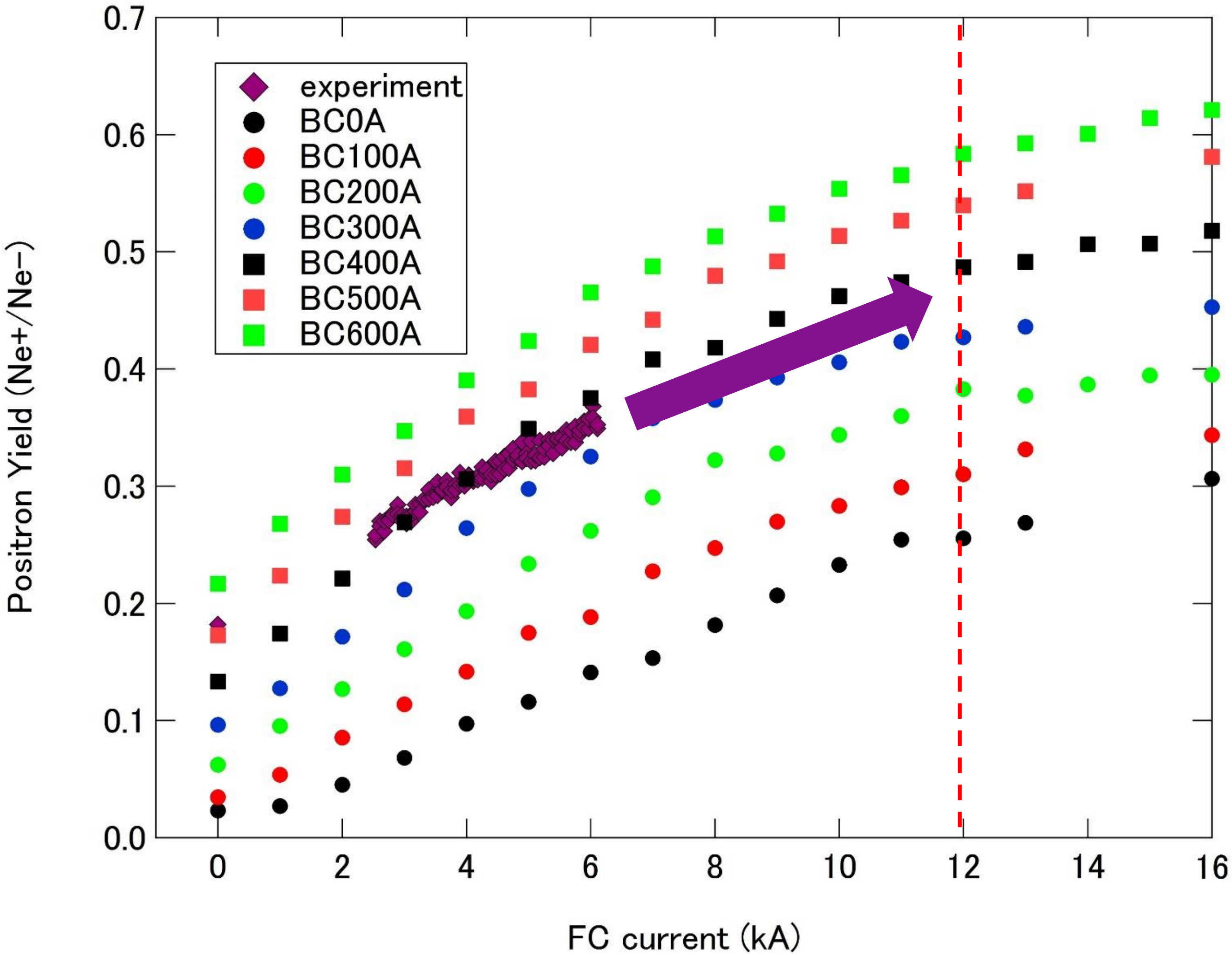


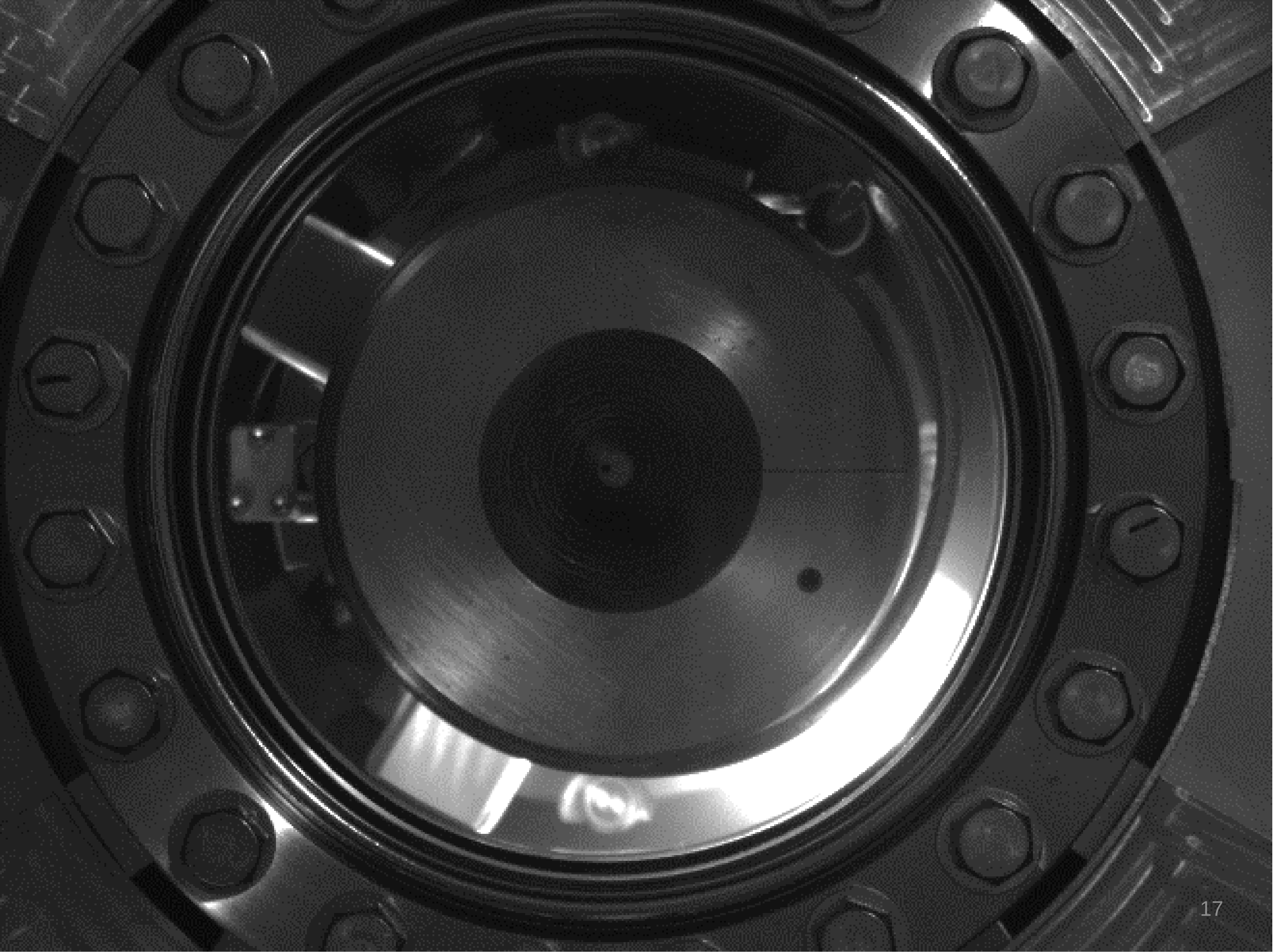
Bx

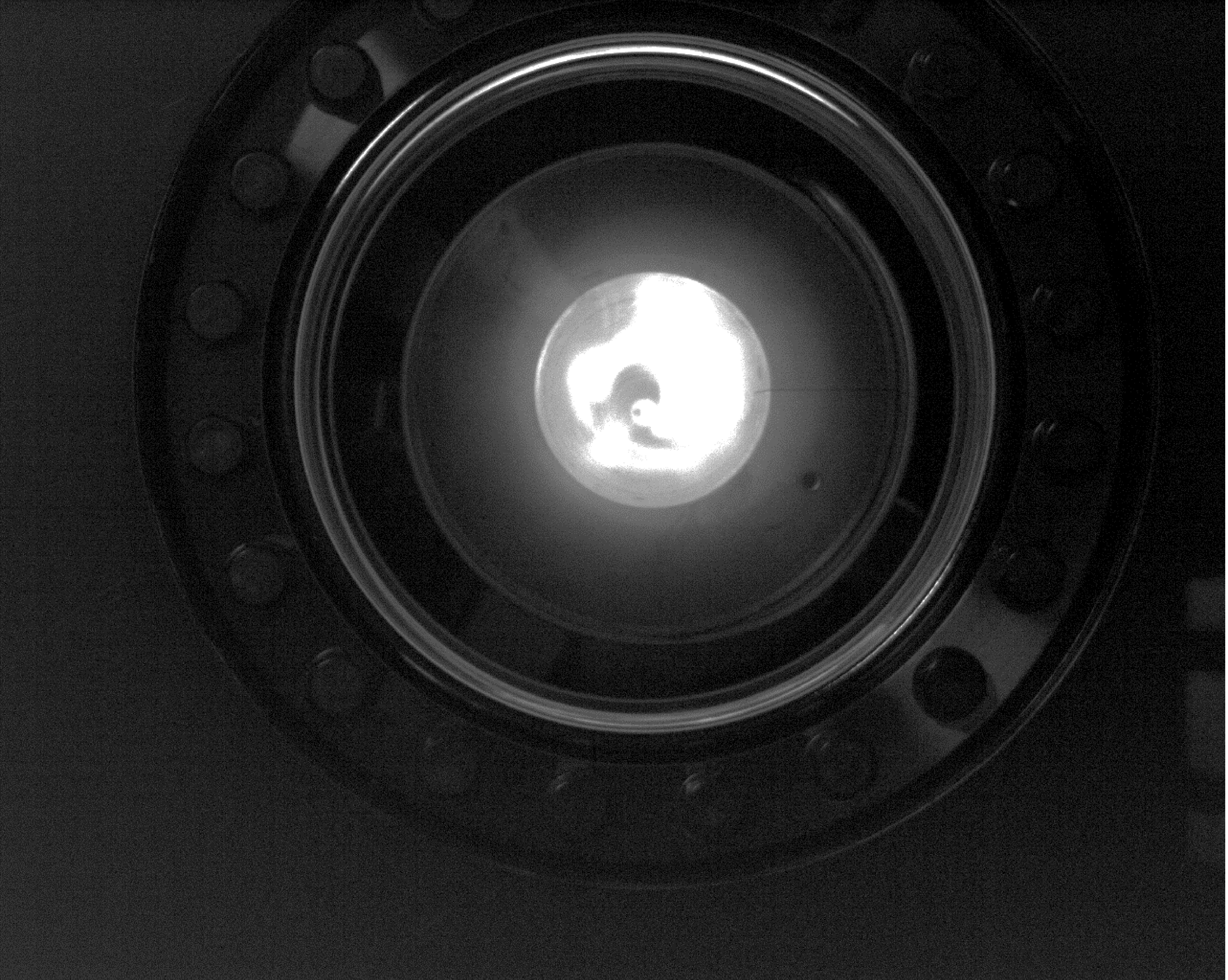
By

Fight against discharge

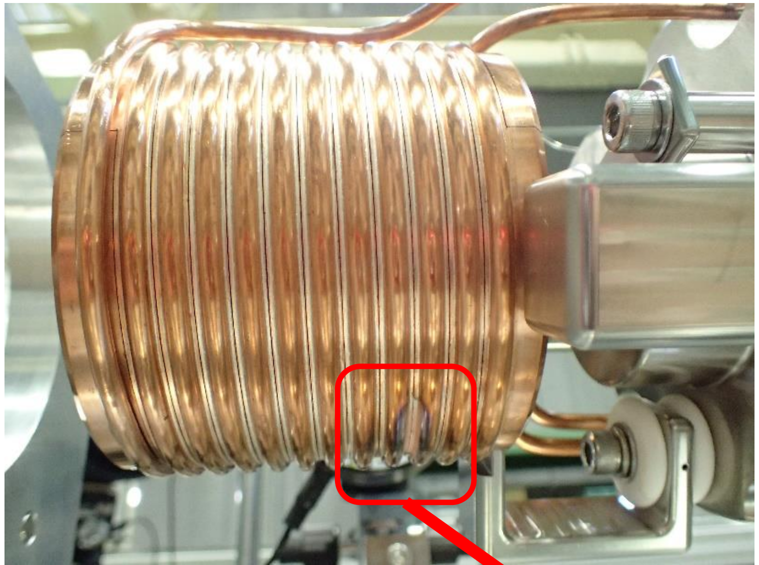
- Why we can not apply 12 kA to the FC?
- Because it discharges!



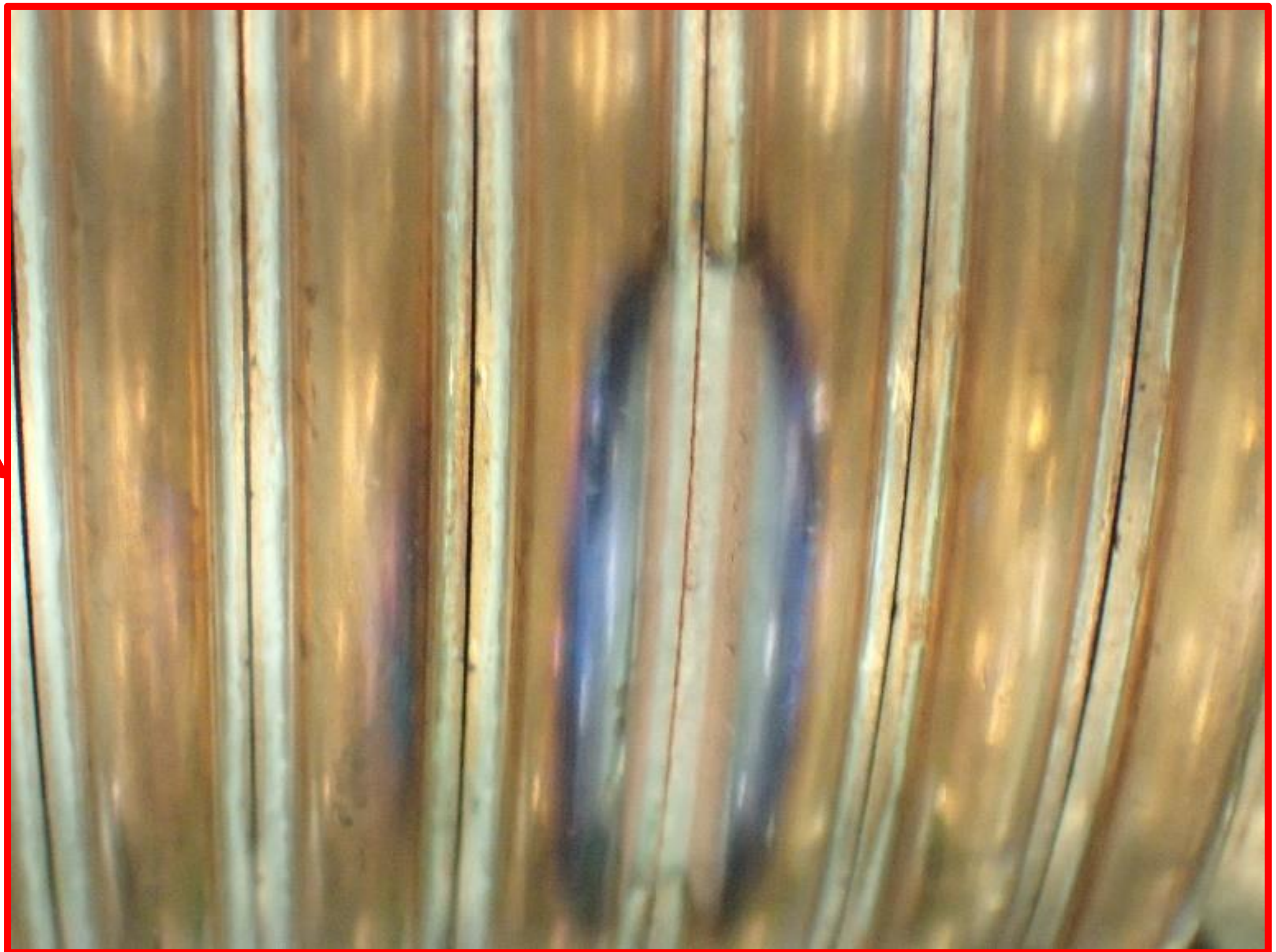




After large discharge…



After large discharge



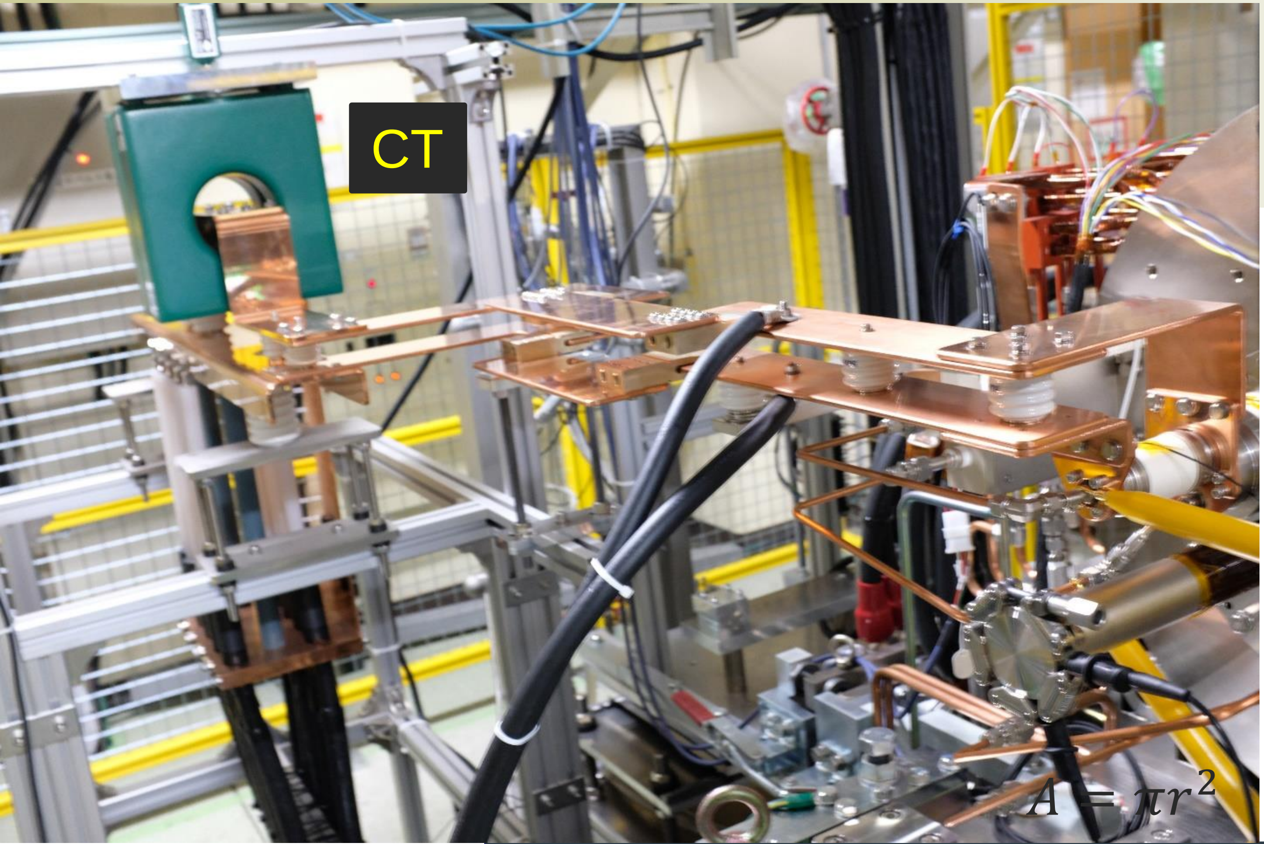
Slit gap got narrow.
Not possible to apply high voltage unless the gap will be expanded.

Fight against discharge

- Why we can not apply 12 kA to the FC?
- Because it discharges!

To suppress discharge

- Reduce voltage by snubber circuit
- Cu-alloy material for FC head
- Insertion of insulators in the slit
- Optimization of gap width

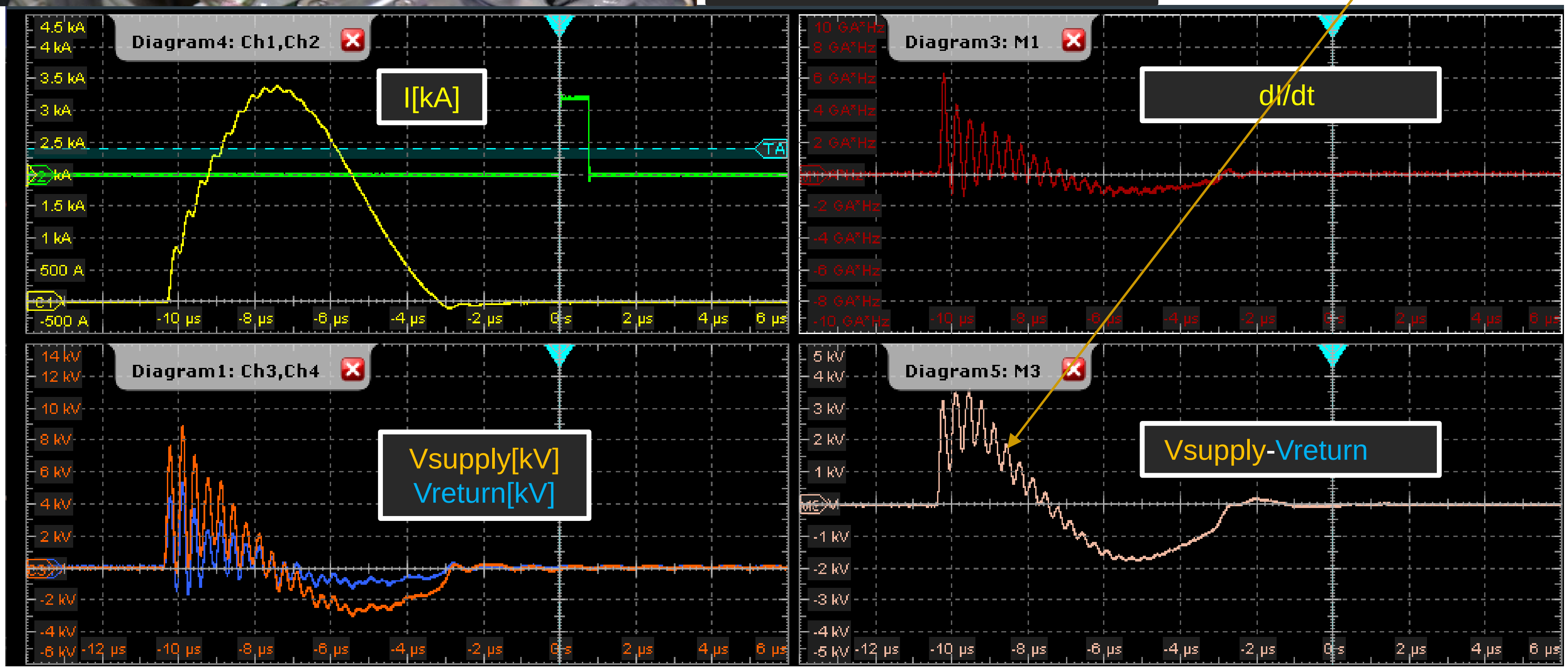


$$V \sim L \frac{dI}{dt}$$

High voltage probe

High voltage probe

～3MHz
Due to resonance by capacitance of the cable and inductance of the load



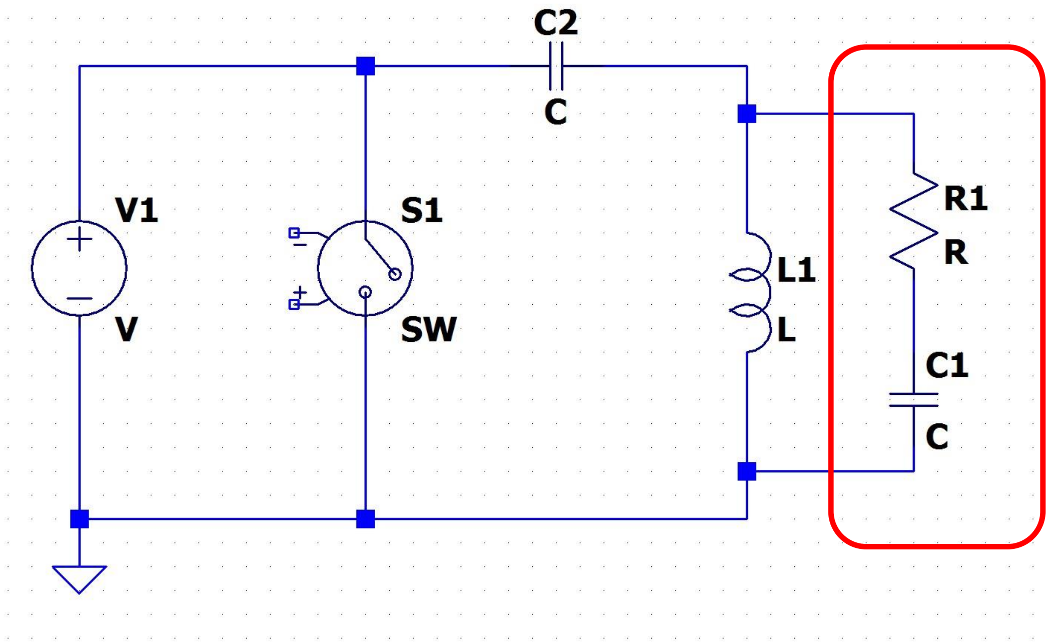
Snubber circuit

Avoid discharge
→Reduce electric field between gap
→Reduce voltage keeping current
→suppress rapid current change

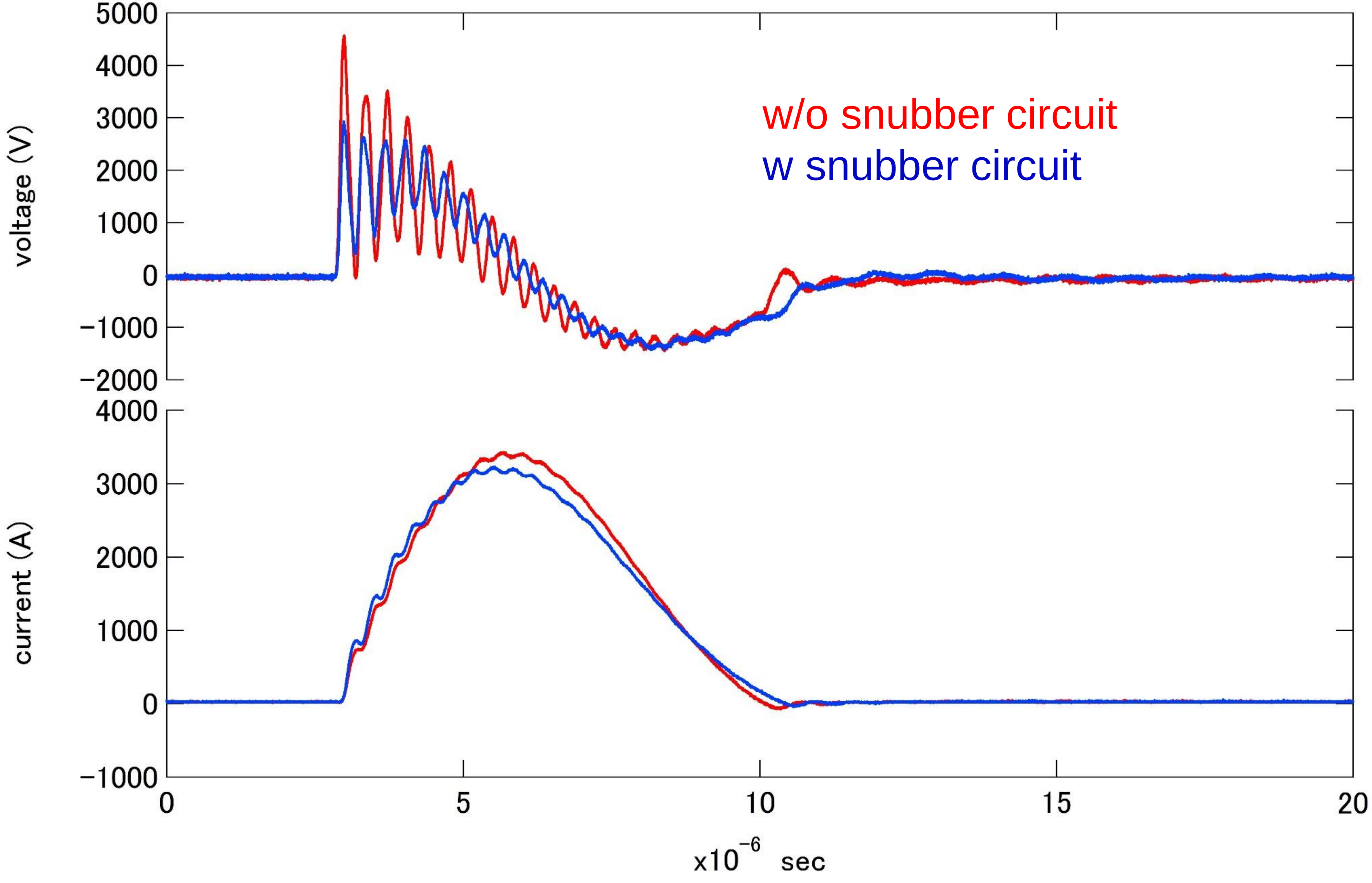
$$V \sim L\frac{dI}{dt}$$

Resister 3 Ω

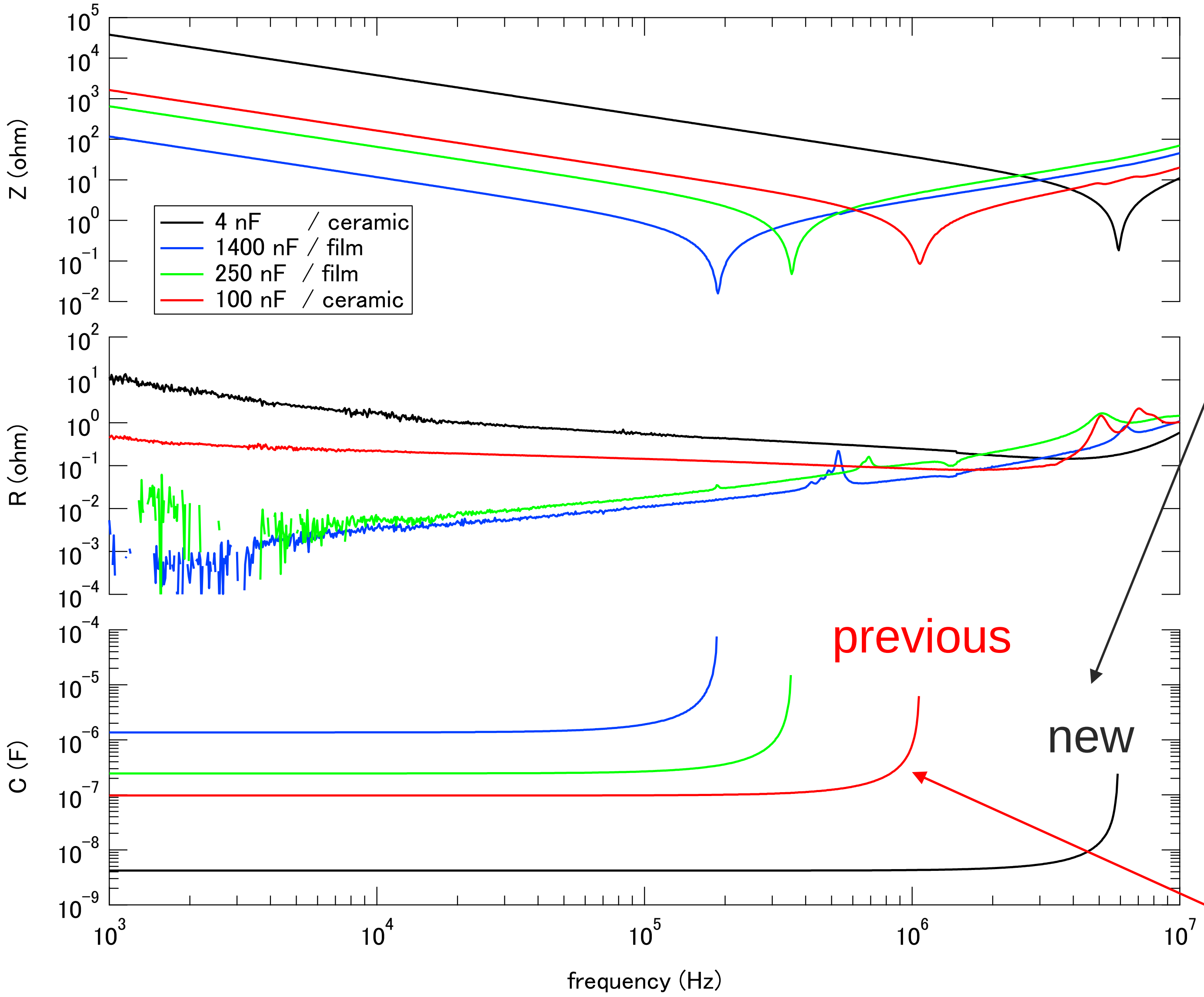
Capacitor 100 x 4 nF



Current and voltage waveform w or w/o snubber circuit

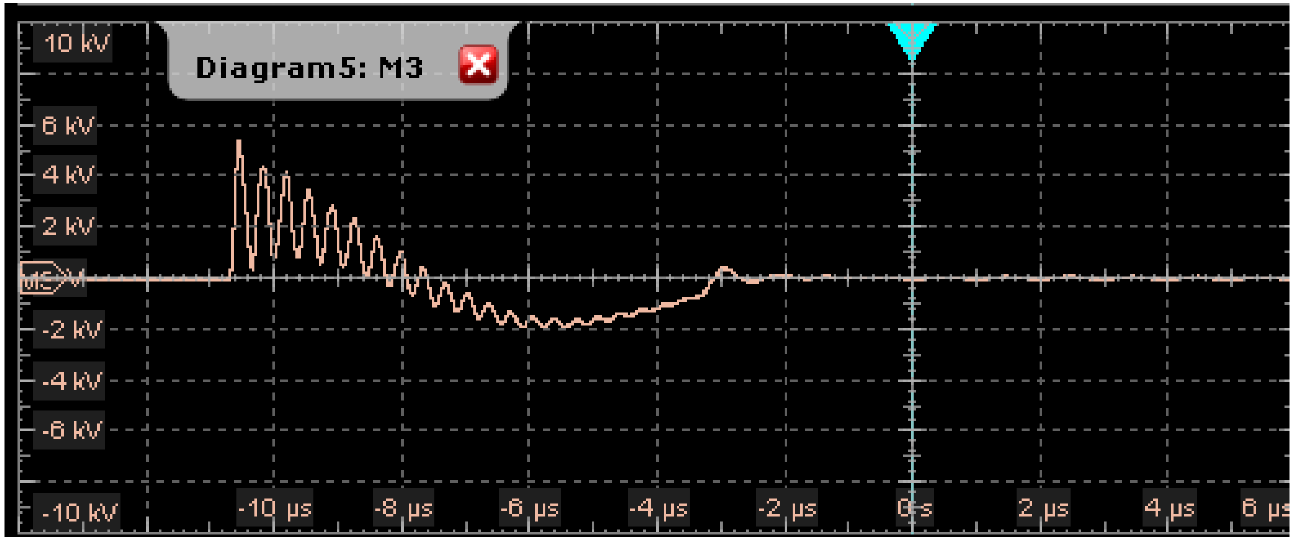


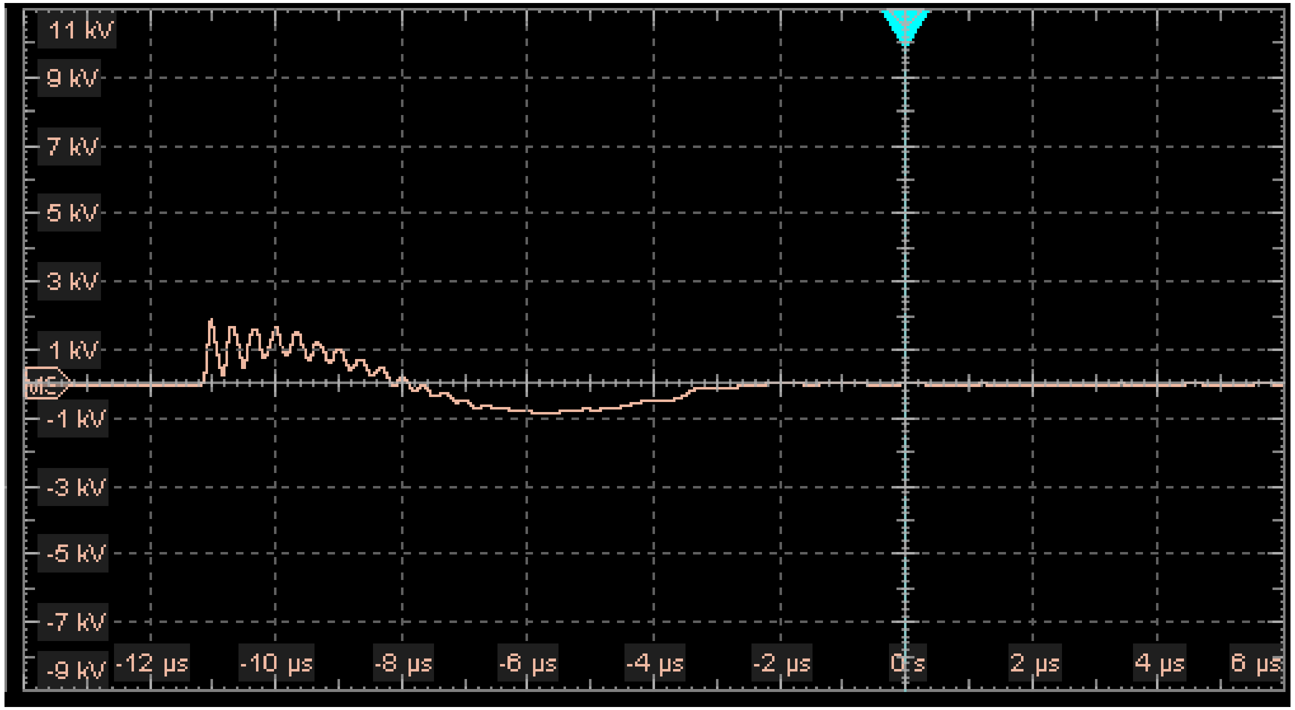
Frequency response of capacitors



Optimization of the snubber circuit

Es = 5 kV
IFC = 3.5 kA

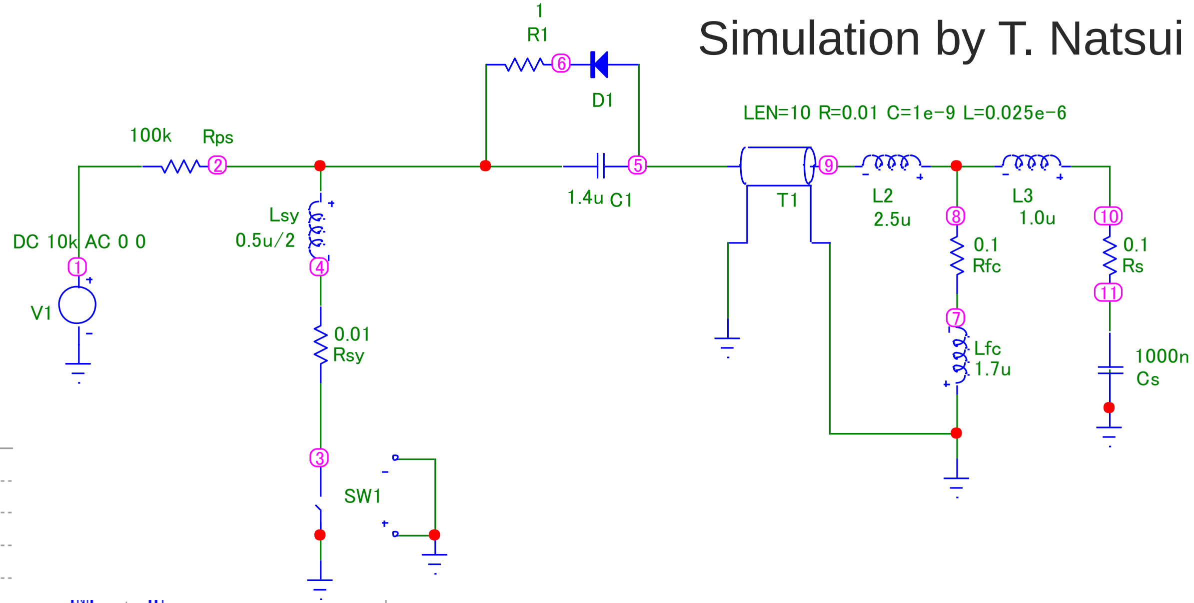


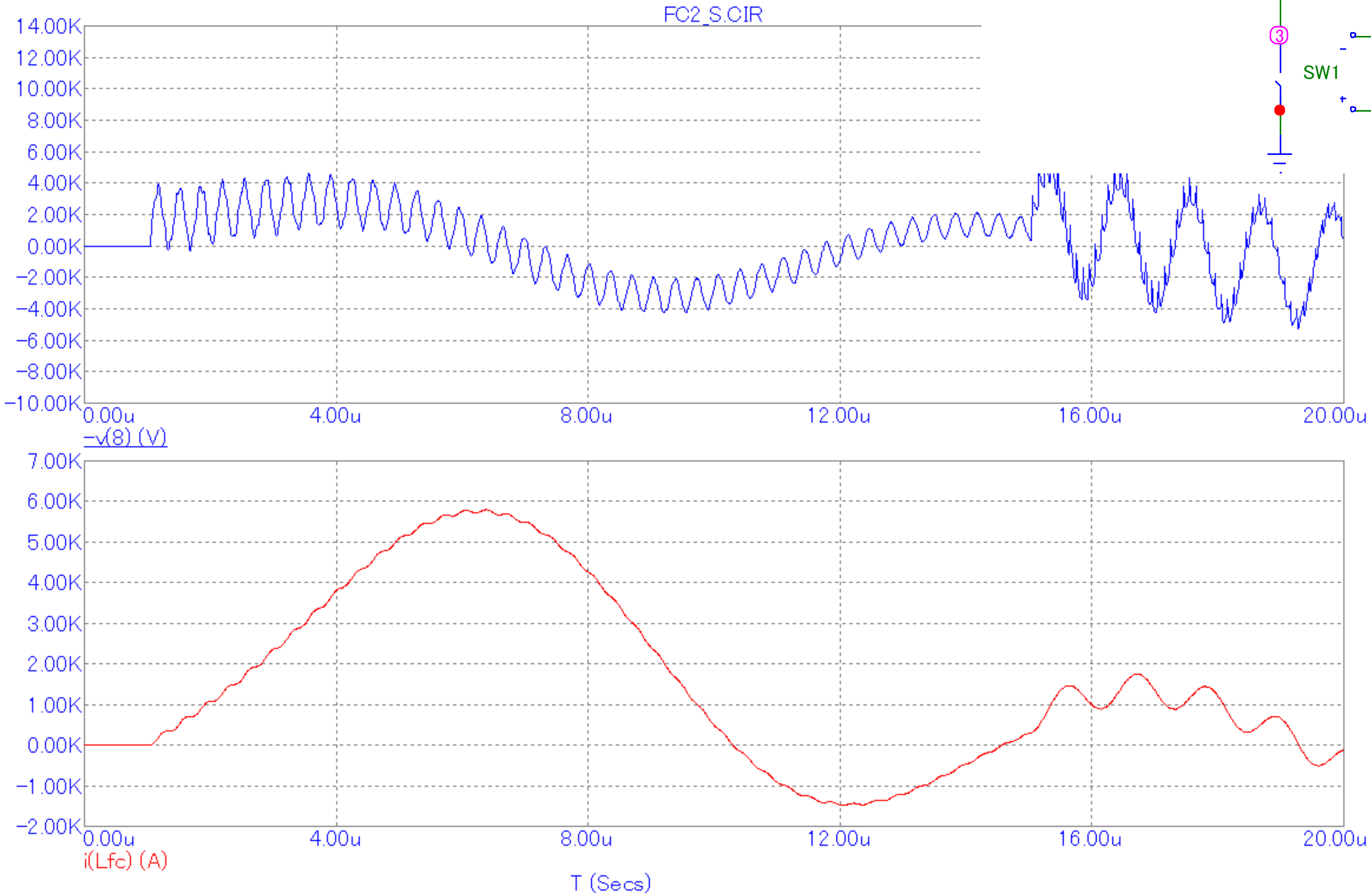


Optimization of the snubber circuit

Circuit simulation

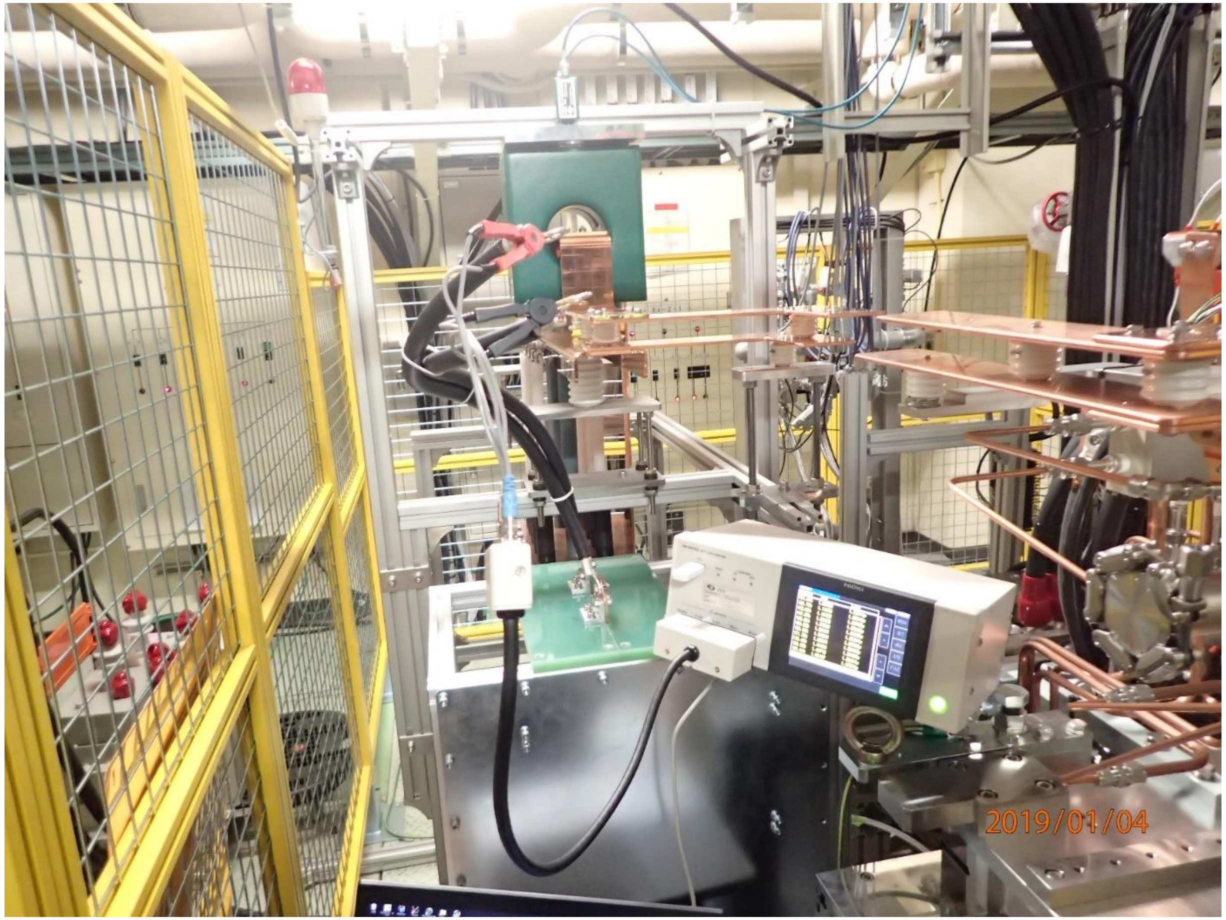
Simulation by T. Natsui

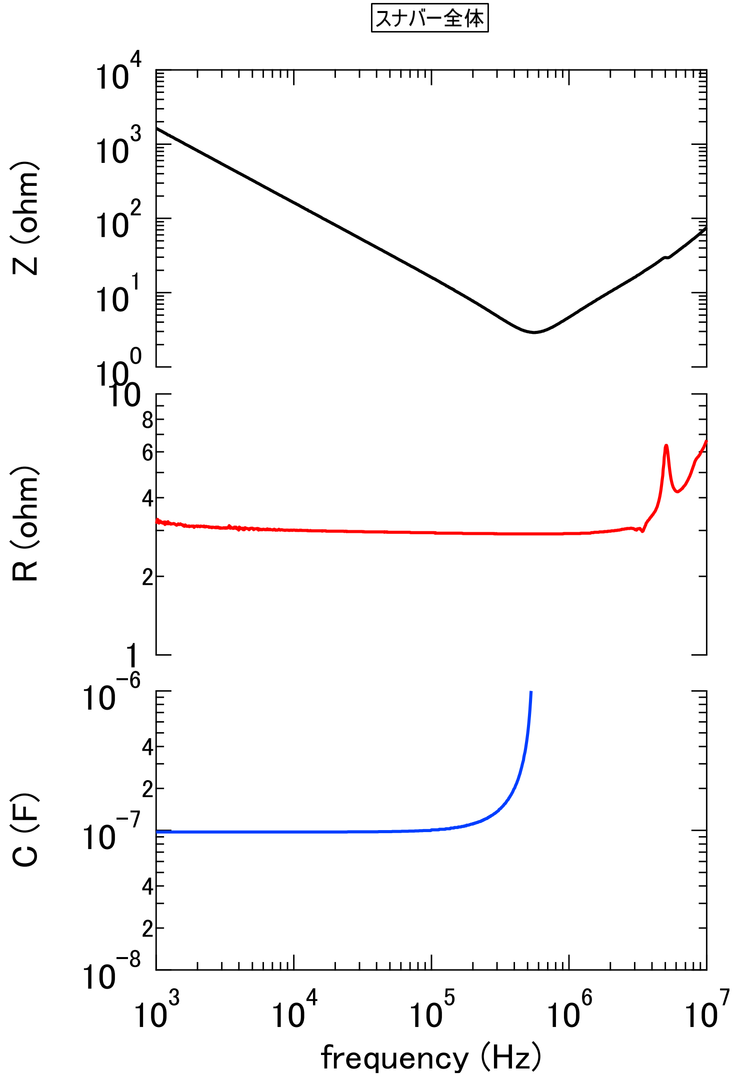




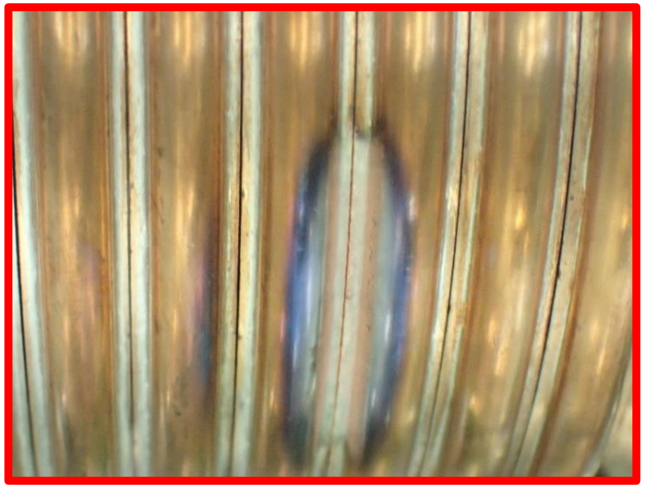
Optimization of the snubber circuit

LCR measurement





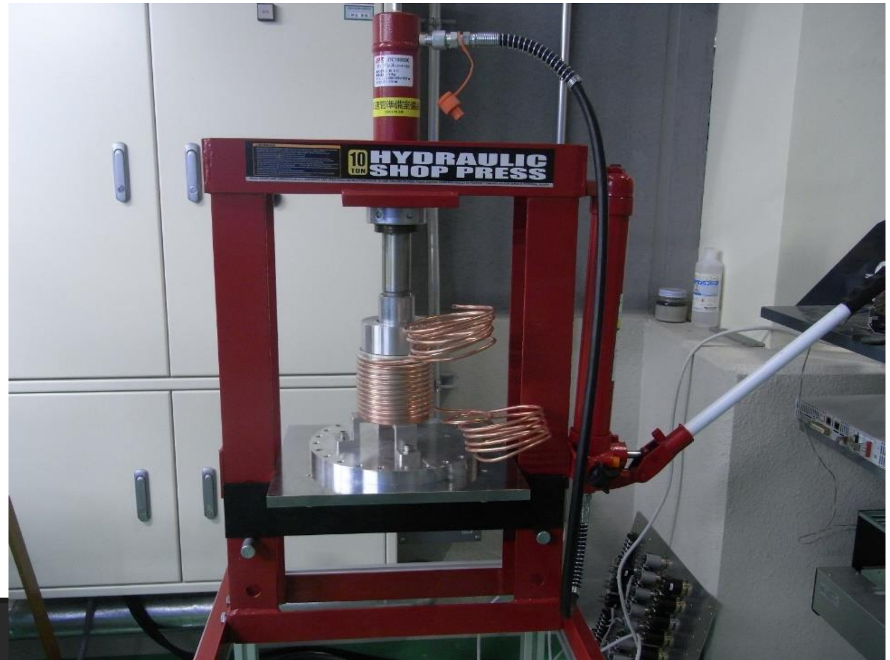
New material for FC head



Avoid discharge
→Reduce electric field between gap
→manage slit distance
→avoid deformation

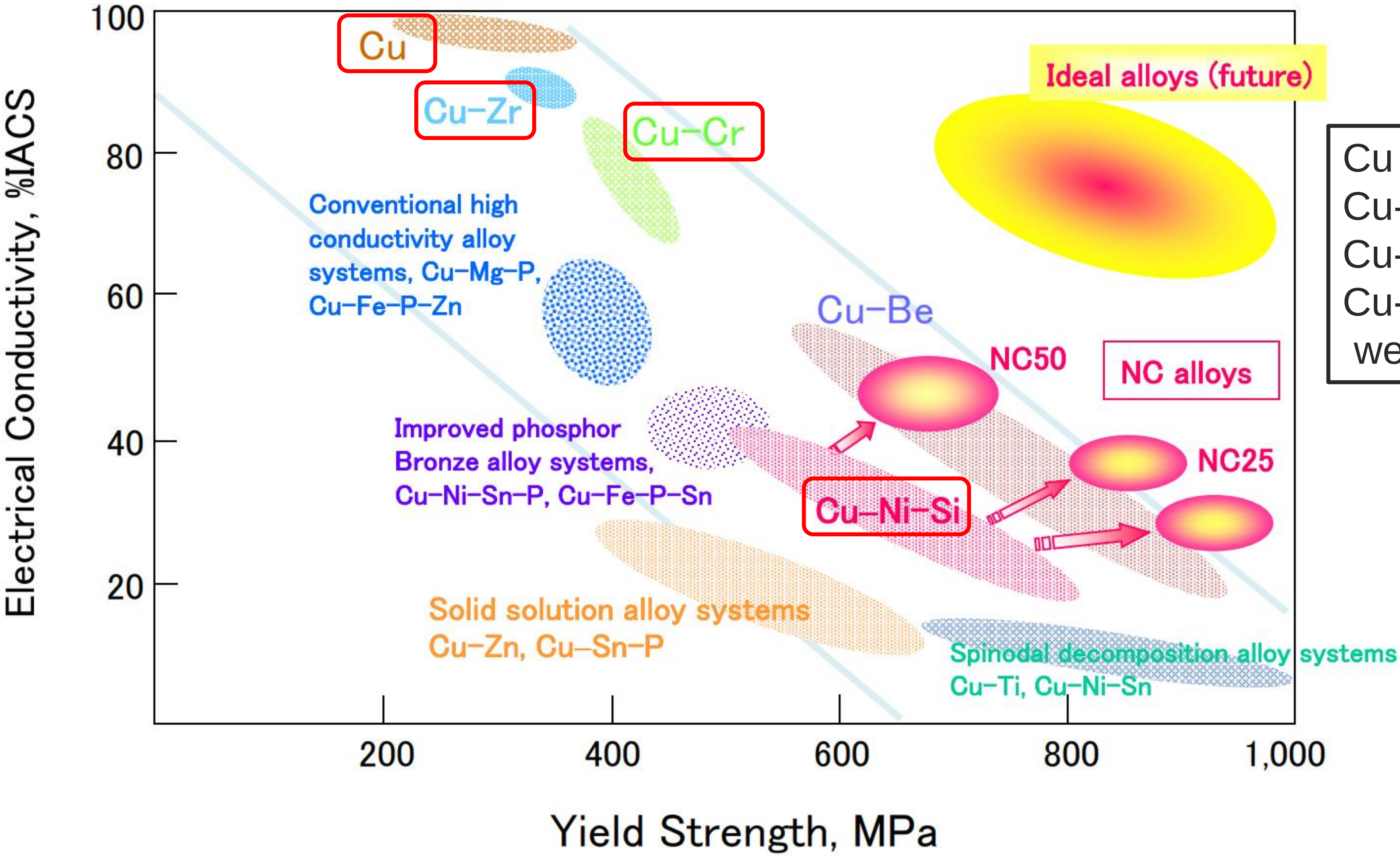
$$E \sim \frac{dV}{dx}$$

- Increase yield strength of the material
- Work hardening process was tested
  - Result was not clear
- Another approach using Cu-alloy



Requirements for material of the FC head are
- Good brazing characteristic
- High yield strength even after brazing
- High electric and thermal conductivity

Cu alloys



Positions of various copper alloy systems in conductivity–strength map

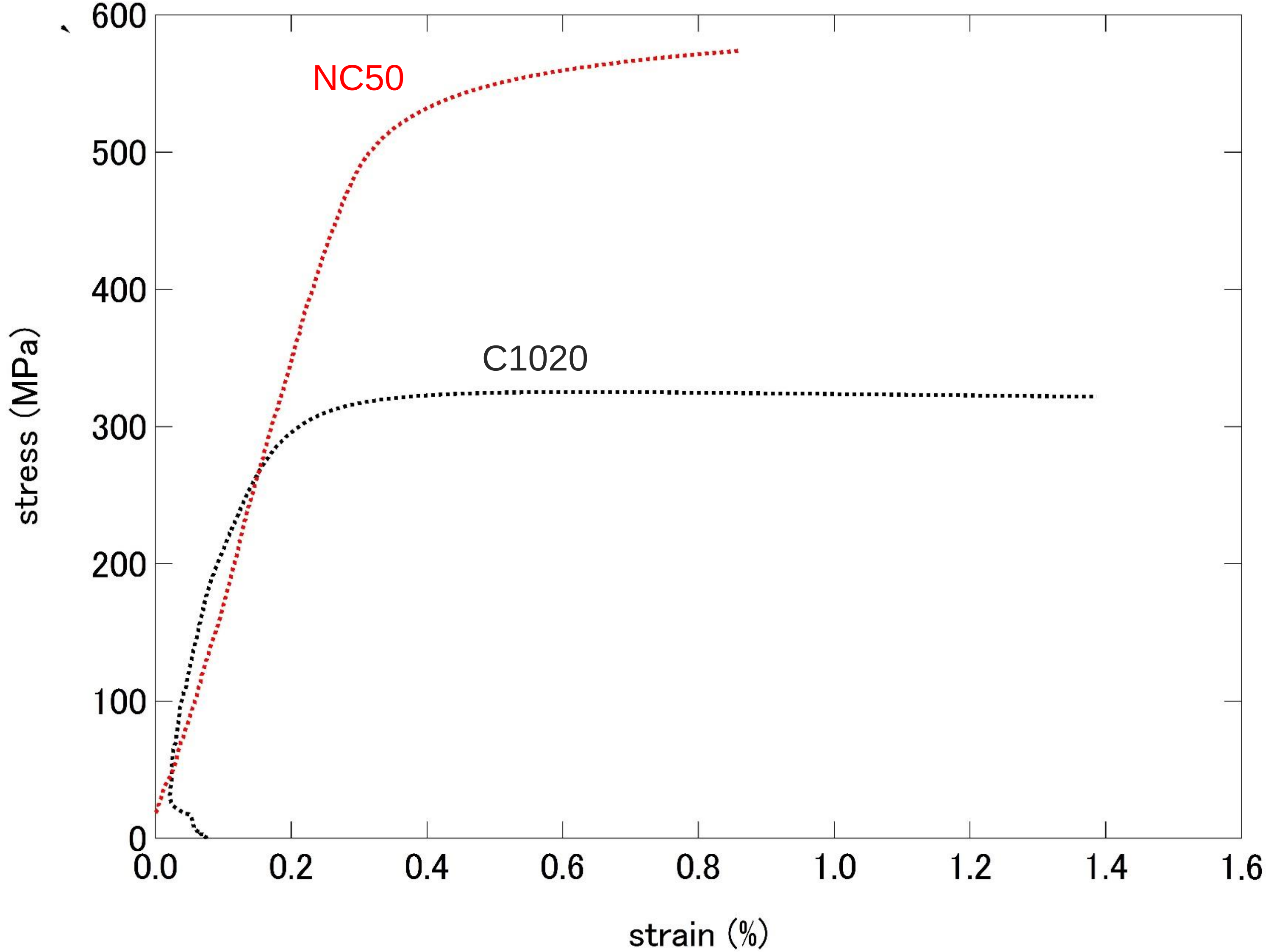
Cu
Cu-Zr
Cu-Cr
Cu-Ni-Si
were tested

Evaluation of brazing characteristic

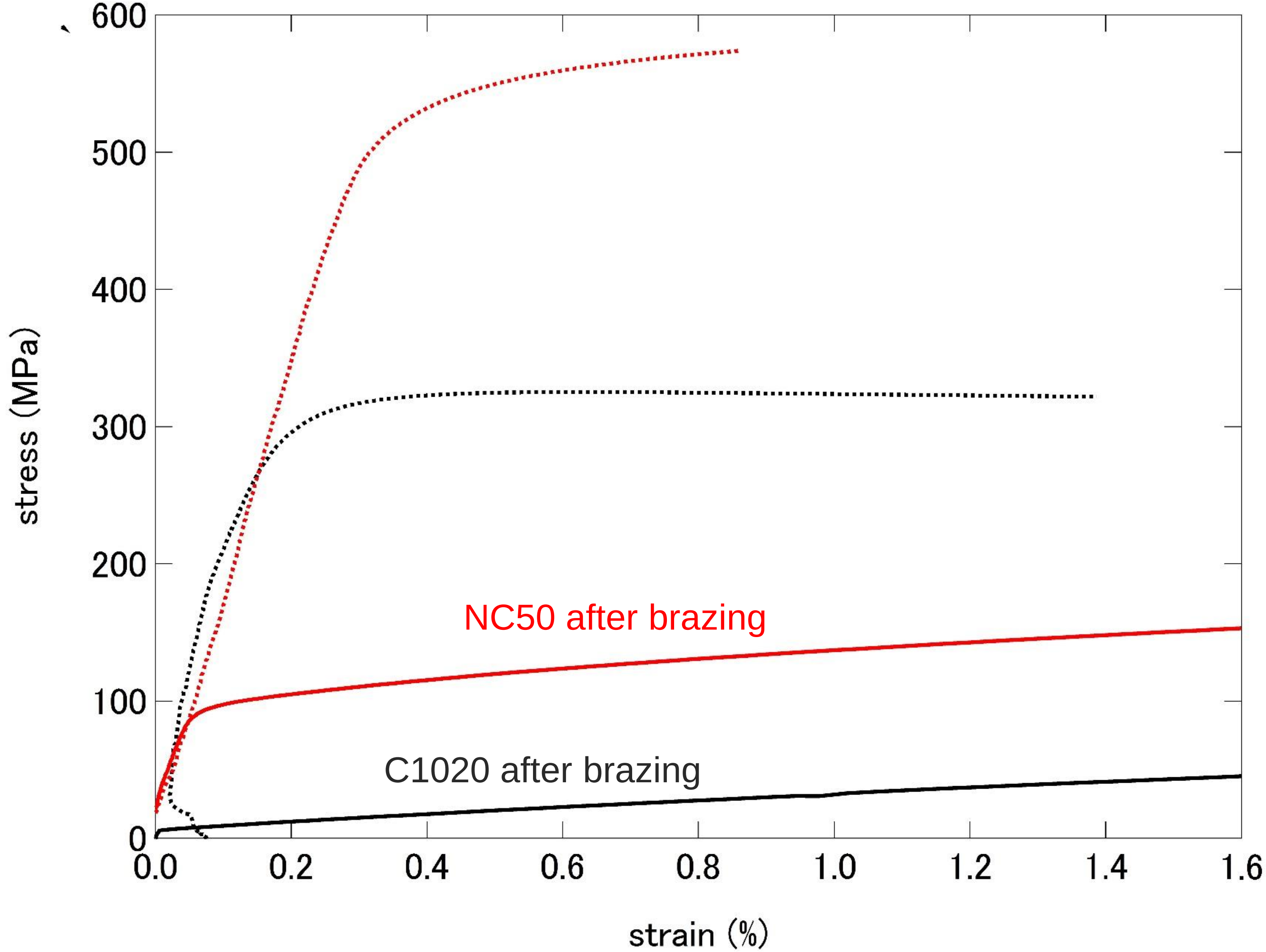
Measured properties of materials

Material	Cu (C1020)		Cu-Cr (SH-1)		Cu-Zr (SH-2)		Cu-Si-Ni (NC50)		
Thermal cycle		After brazing		After blazing		After blazing		After blazing	After aging
conductivity %IACS	102.2	102.1	90.8	76.0	81.1	68.5	50.3	25.1	48.8
Hardness	87.4	30.4	71.6	60.0	45.9	55.8	95.3	61.2	95.4
Tensile strength Mpa	327.4	232.1	402.6	237.2	443.1	238.3	648.7	323.7	658.8
Elongation %	21.6	54.4	36.8	56.8	32.6	51.4	14.8	46.6	10.6
Yield strength Mpa	322.3	12.9	293.6	57.9	348.2	40.8	551.8	109.7	513.1

Strain-stress curve for C1020 and NC50



Strain-stress curve for C1020 and NC50



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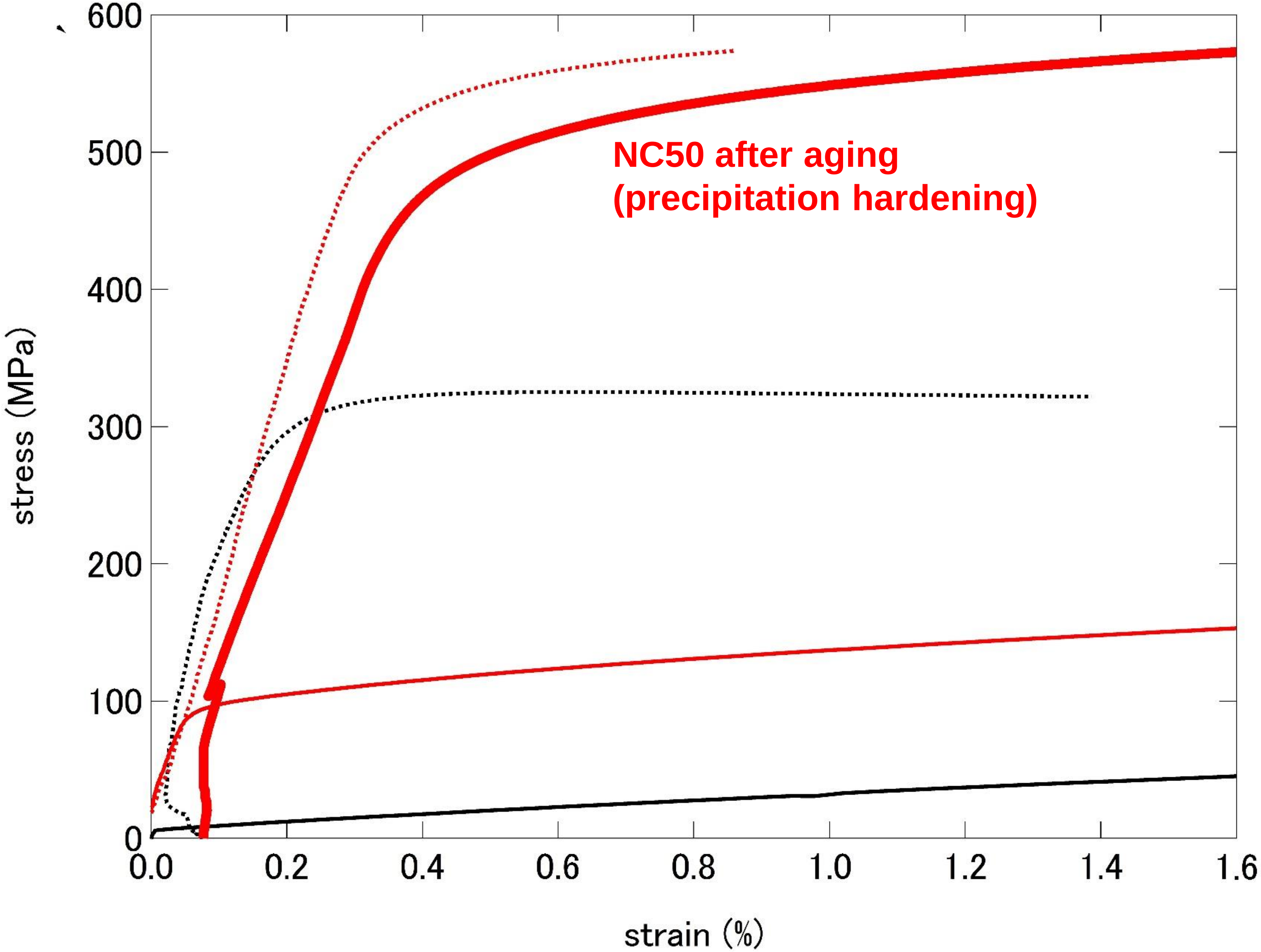
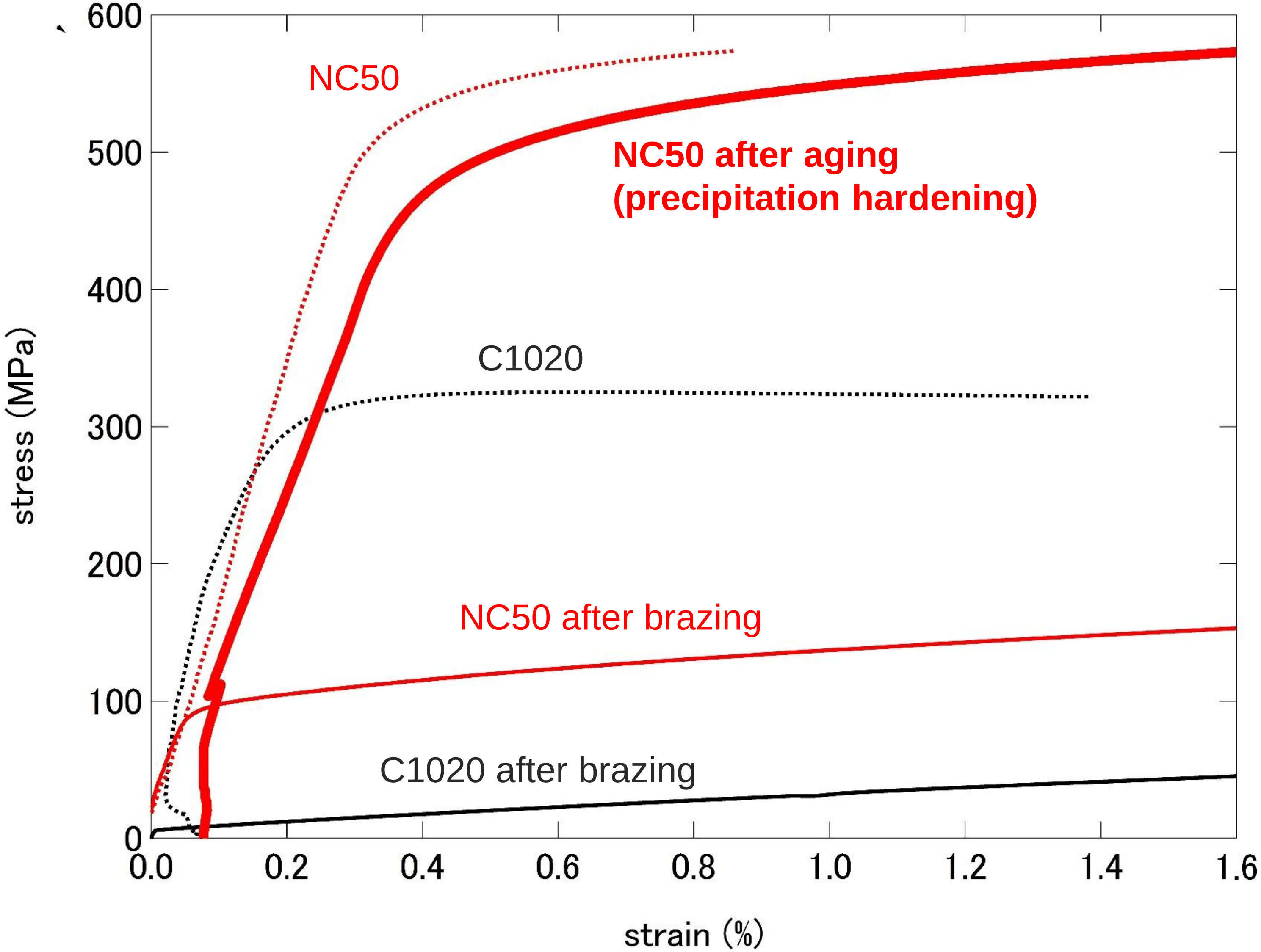
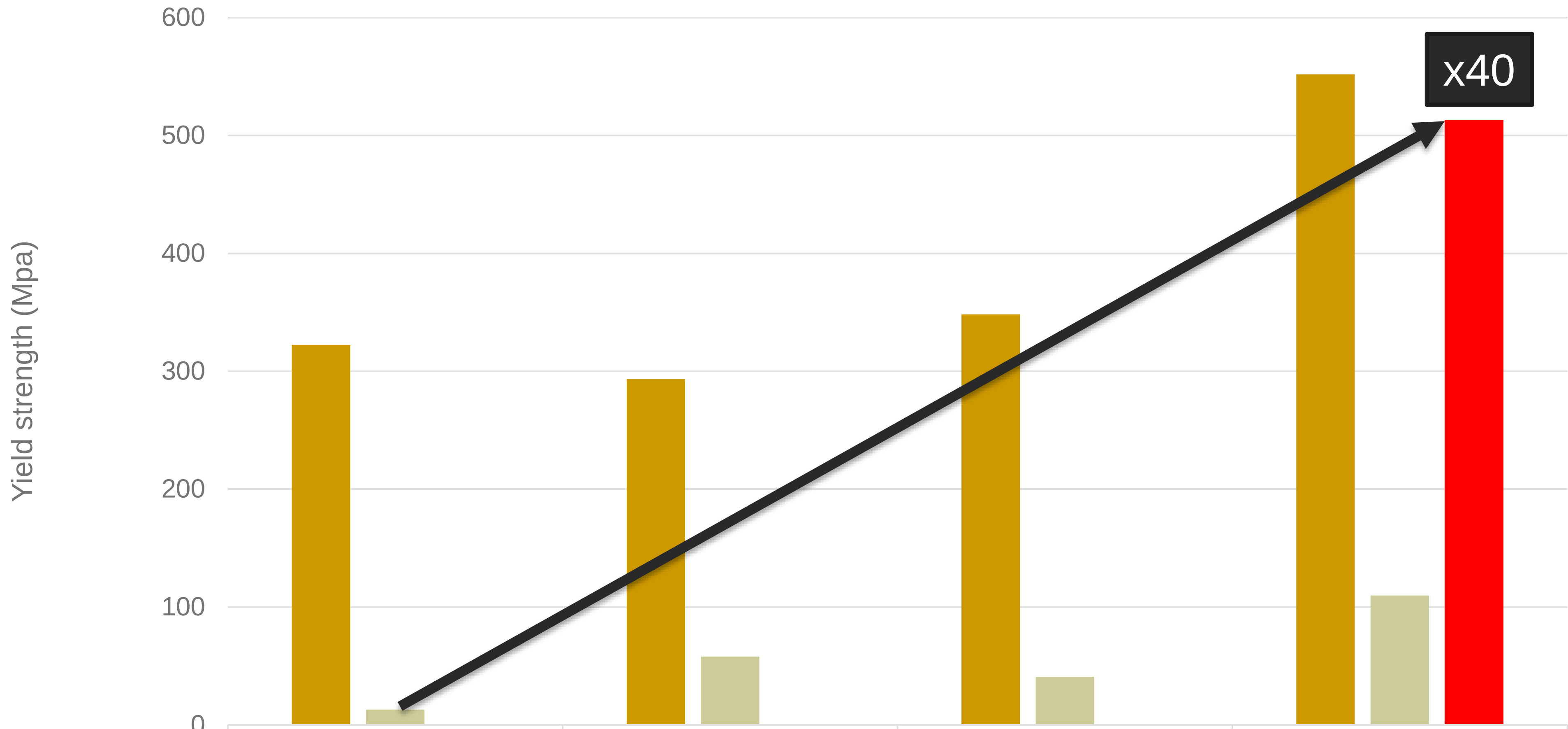


Strain-stress curve for C1020 and NC50



Yield strength

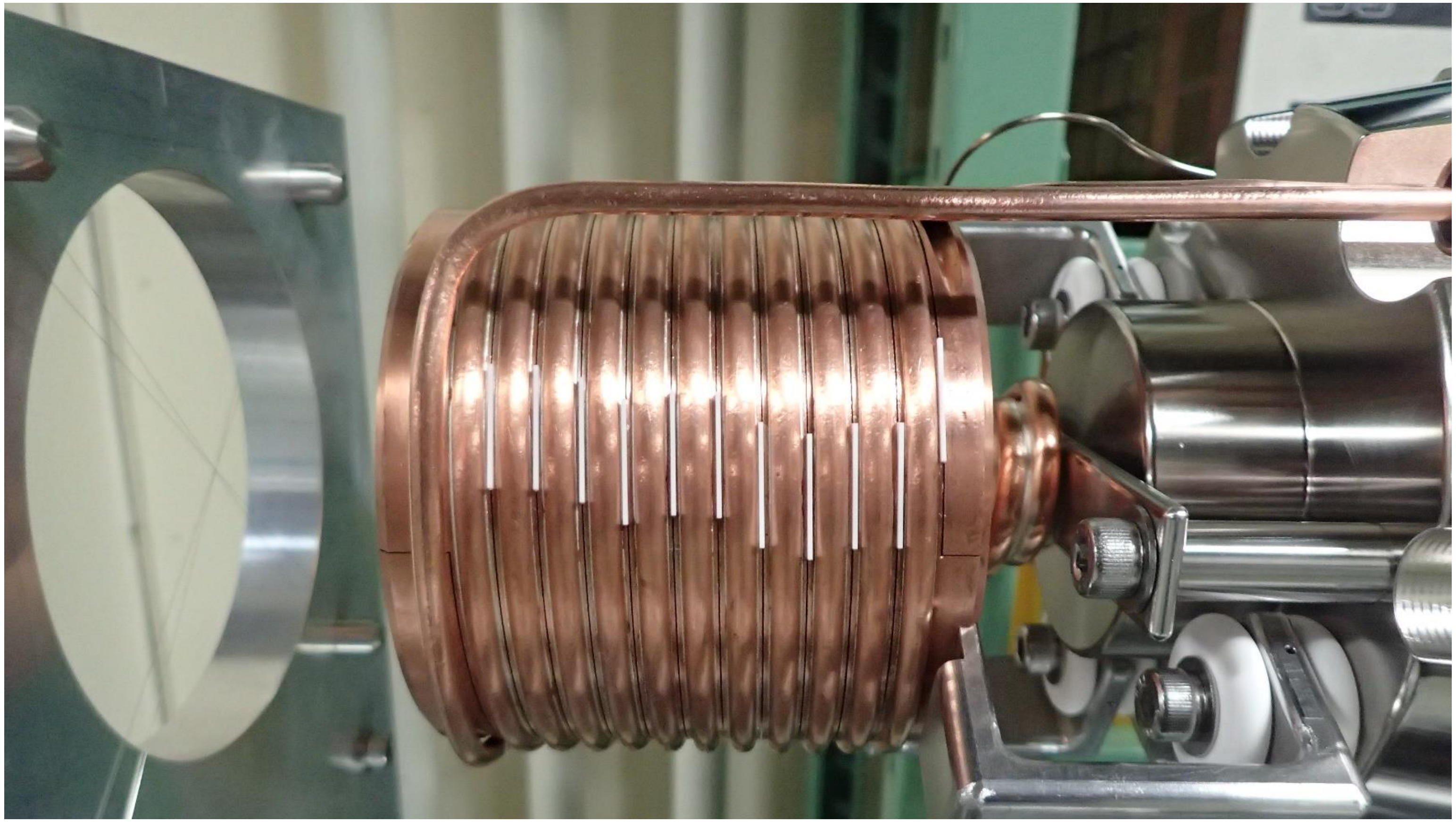


	C1020	SH-1	SH-2	NC50
before brazing	322.3	293.6	348.2	551.8
after brazing	12.9	57.9	40.8	109.7
brazing + aging				513.1

Production and simulation

- New FC head is in production using NC50.
  - Assembly will be delivered in Oct.
- To evaluate mechanical stress, combined electromagnetic and mechanical simulation by ANSYS-Maxwell has just started.

Insertion of insulator plates in the slits



20mm x 25mm x 0.2mm Zirconia (ZrO_2) plates are inserted from 3 direction

It works but not perfect
→discharge decreased but happened
→further investigation is needed

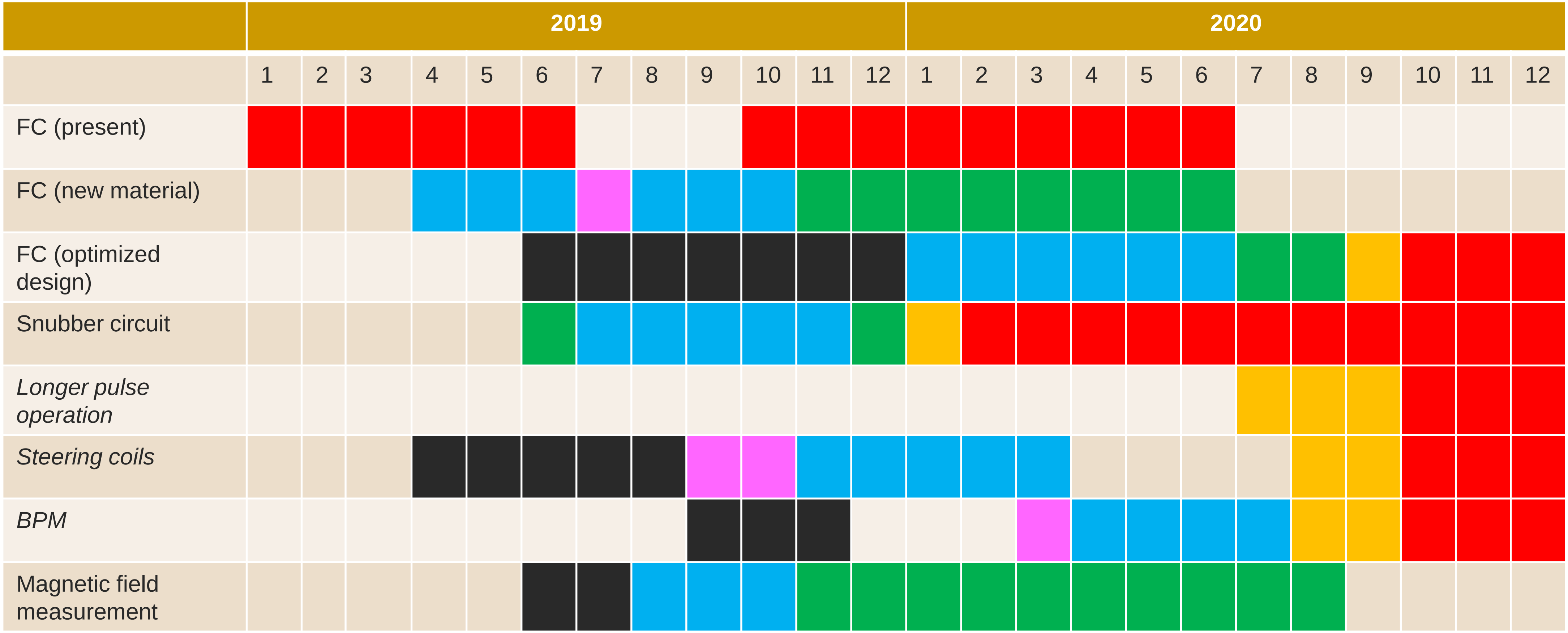
Optimization of slit gap

- Presently 0.2 mm (same value as the one used in SLAC)
- Simulation suggest wider gap makes stronger Bx and By
- To confirm simulation, magnetic field measurement using pick-up coil is under preparation
- It is easy to change the gap by inserting insulator plates
  - 0.3 mm thickness plates will be delivered soon

Upgrade plan - items

- FC
  - New one made of Cu-alloy (NC50)
  - Insertion of insulator plates?
  - Optimization of slit gap?
- Pulsed power supply
  - Optimization of snubber circuit
  - Longer pulse operation?
- Beam tuning in solenoid section
  - Steering magnet
  - BPM

Upgrade plan - schedule



Operation
Design
Test
Biding
Manufacturing
Installation

We are planning big upgrade of positron source in 2020 summer shutdown.
budget is one of the concern…..

collaboration

Most important problem is lack of manpower (less than 1 now…)

collaboration with people in charge of future positron source is expanding

- ILC
  - KEK
    - Attend weekly meeting
    - Start working together
- FCC-ee
  - LAL and BINP
    - Collaboration in the frame work of FJPPL
    - Share 3D model for simulation
    - Visit us in Feb. 2019
- CEPC
  - IHEP
    - Provided FC head last year
    - Visit us in Jan. 2019, joined installation of the FC
- CLIC
  - CERN
    - Share 3D model for simulation

summary

- Phase 3 operation of positron source was stable
  - Very low current (3.5 kA)
  - FC is not damaged now
- Beam study with 3 GeV electron beam in solenoid section was done to investigate low positron yield
  - Confirm electron beam was deflected
  - Steering coils and BPMs will be installed for compensation and monitor
- To avoid discharge of FC
  - Optimization of the snubber circuit is in progress
  - New FC made of Cu-alloy is in production
  - Insertion of insulator plates are tested
  - Optimization of Slit gap distance is under consideration
- Major upgrade is planed in summer shutdown 2020
- Collaboration with other projects is rapidly expanding

Answer to previous review 1

- R7.1: Continue to build-up of a realistic simulation of the positron production and collection. This is needed for a realistic prediction of the gain available from any FC improvements.

  Simulation is in progress but man power is limited.
  Collaboration with people in charge of future positron source is expanding.

- R7.2: The Committee suggests to study whether an increase of the coil gaps, to, say, about 250 microns or so, can significantly increase the break down voltage. The resulting central magnetic field will likely be lowered by about 20% for the same current, but with the increased voltage limit the overall magnetic field may go up significantly.

  Gap management with insulator plates was tested and worked well.
  Magnetic field measurement is in preparation.

- R7.3: Perform a new study to improve the work hardening process of the copper FC coils. Compare with the experience at other laboratories, e.g. at SLAC and BINP.

  Mechanical properties of the material for the FC were evaluated.
  Promising Cu-alloy was found. New FC is in production.

Answer to previous review 2

- The Committee would also like to draw attention to the findings and recommendation of the last Domestic Review as of September, 8, 2017, concerning the Positron Source (see Appendix C).
  - The exchange of the flux concentrator(FC) should be done regularly even without damage to reduce the radiation exposure.

    The exchange jig works well. It is possible from the technical point of view. Residual radioactivity is monitored. There is no need to do that presently. There is not enough budget.

  - Reconsidering the material of the FC can be necessary. Review the material choice by reevaluating the data in the past.

    Mechanical properties of the material for the FC were evaluated. Promising Cu-alloy was found. New FC is in production.

  - A coil with a larger gap width may be possible.

    Gap management with insulator plates was tested and worked well. Magnetic field measurement is in preparation.

Answer to previous review 3

- This time the FC caused discharging after installing into the tunnel, despite the success in the tests on surface. The actual pulse form could differ between them.

In addition to current, voltage pulse shape evaluation was established. We will try to compare the pulse shape at test bench with that in tunnel in detail.

- The conditioning should be performed at a voltage higher than the spec by 20%.

Preparation of the power supply at test bench is in progress.

- It is important to know whether the discharge at the large aperture S band (LAS) structure was due to the placement nearby the positron source.

Dummy load and contact of the wave guide flanges were suspicious.

Answer to previous review 4

- The validness of “hardening” needs more investigation including on the diagnostics.
- Did it really improved the entire elasticity or just for the surface?

Mechanical properties of the material for the FC were evaluated.
Promising Cu-alloy was found. New FC is in production.

- The estimated improvement on the amount of charge is 20% by increasing the voltage from 6kV to 12 kV. Consider the priority of the higher voltage plan taking the necessary resources and the effect.

Beam transport in the solenoid section was evaluated.
Total upgrade work is scheduled in 2020.

- Even a non-FC scheme such as at the previous KEKB is thinkable.

Presently, no man power.

- Establish an interlock system against discharging to stop operation in a single pulse to prevent a fatal damage.

Done.

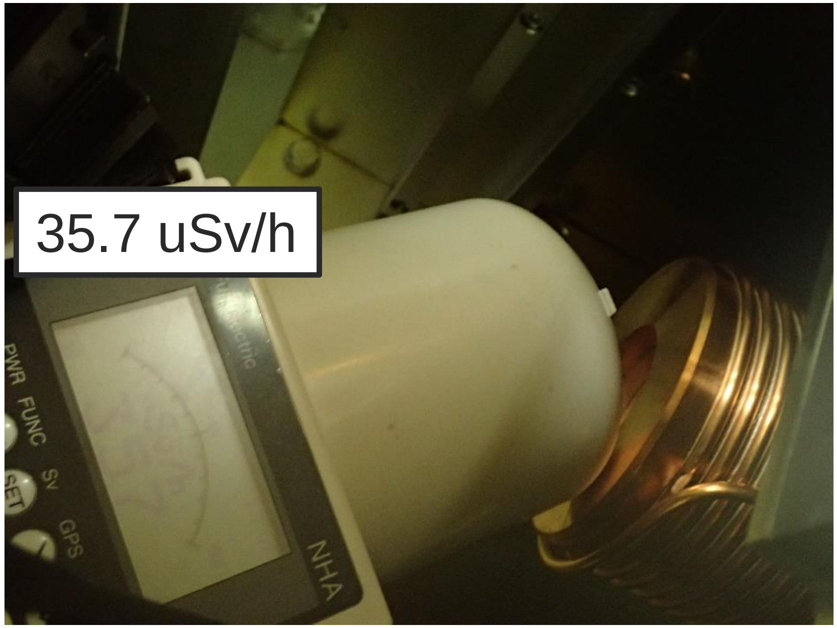
Assembly, base management

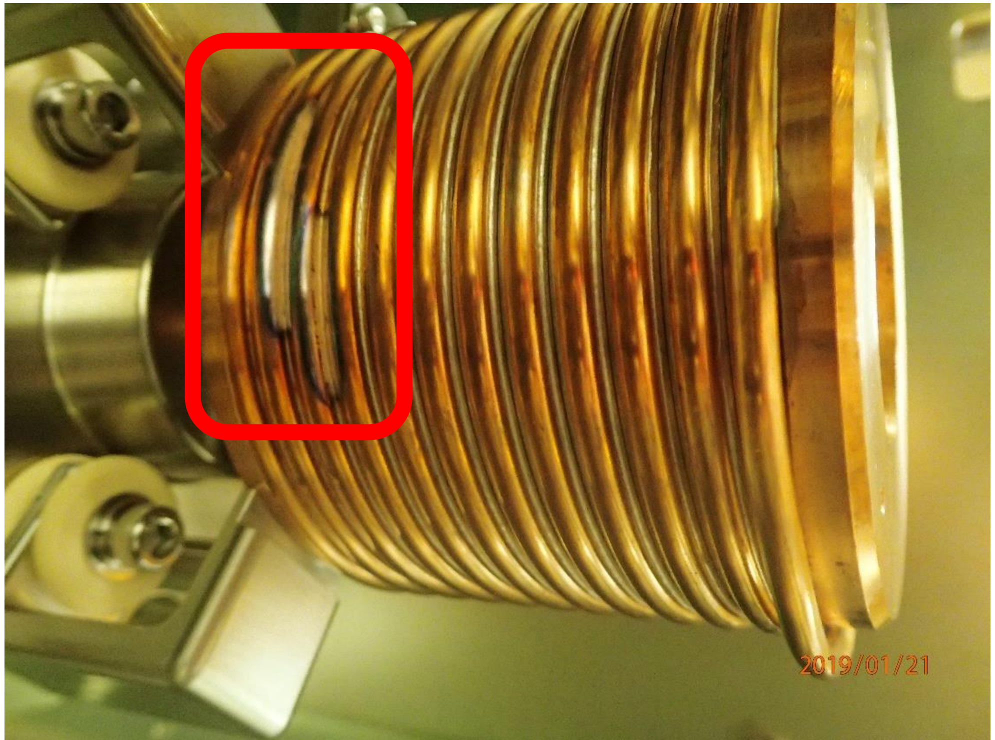
	Phase 1	Phase 2	Phase 3	2019 Q4	2020 Q1, Q2	2020 Q4	delivered	removed	presen	Note
Assembly 1							<2015	2017/3	In tunnel	
Assembly 2							2016/3		In operation	
Assembly 3							2017/11		Test bench	
FC base 1							<2015			Test
FC base 2							<2015			Test
FC base 3							<2015	2017/3	With Assembly 1	
FC base 4								2018/9	In tunnel	
FC base 5							2016/7		In operation	
FC base 6							2017/11		Test bench	
FC base 7							2019/10			In production
FC base 8							2020/7			Final version In design
FC base 9							2020/10			Saper for Final version

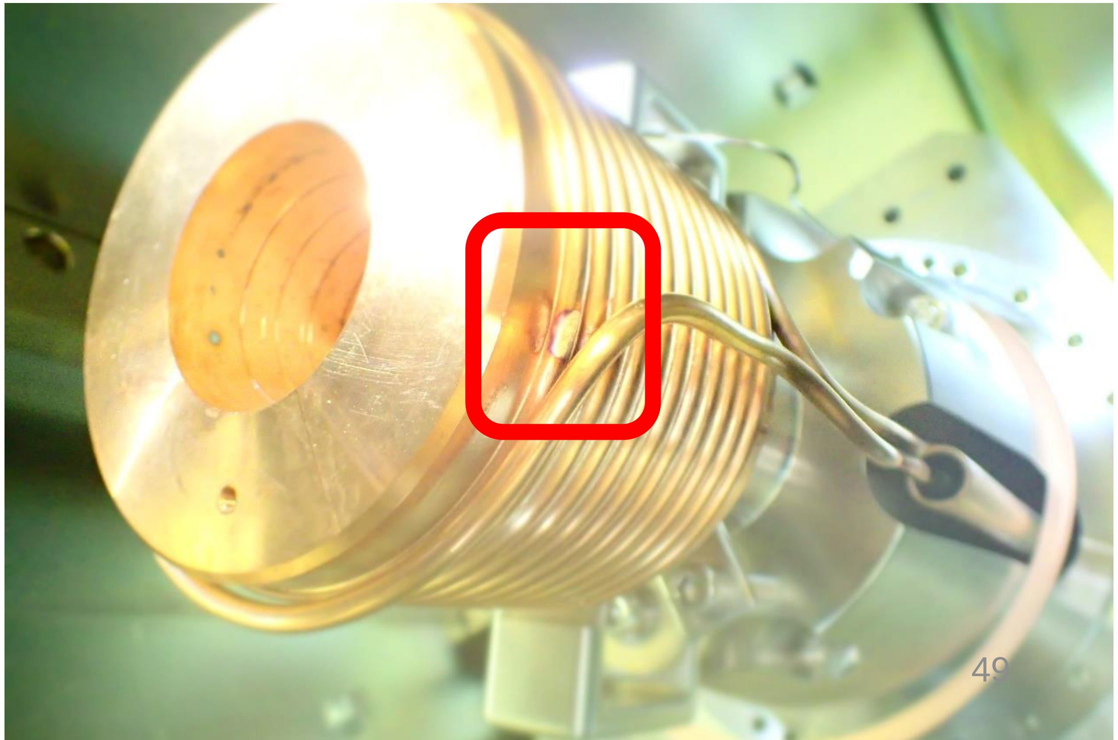
in operation
spare
test bench

Observation of FC used in phase 1

FC used in phase 1 operation, which is stored in the shield case was extracted for investigation since radiation level got low.

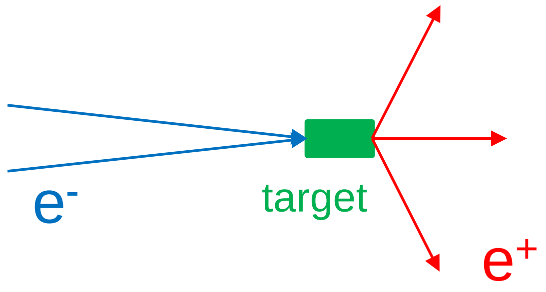




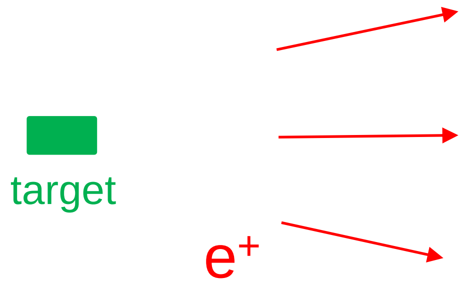


Positron source setup 4

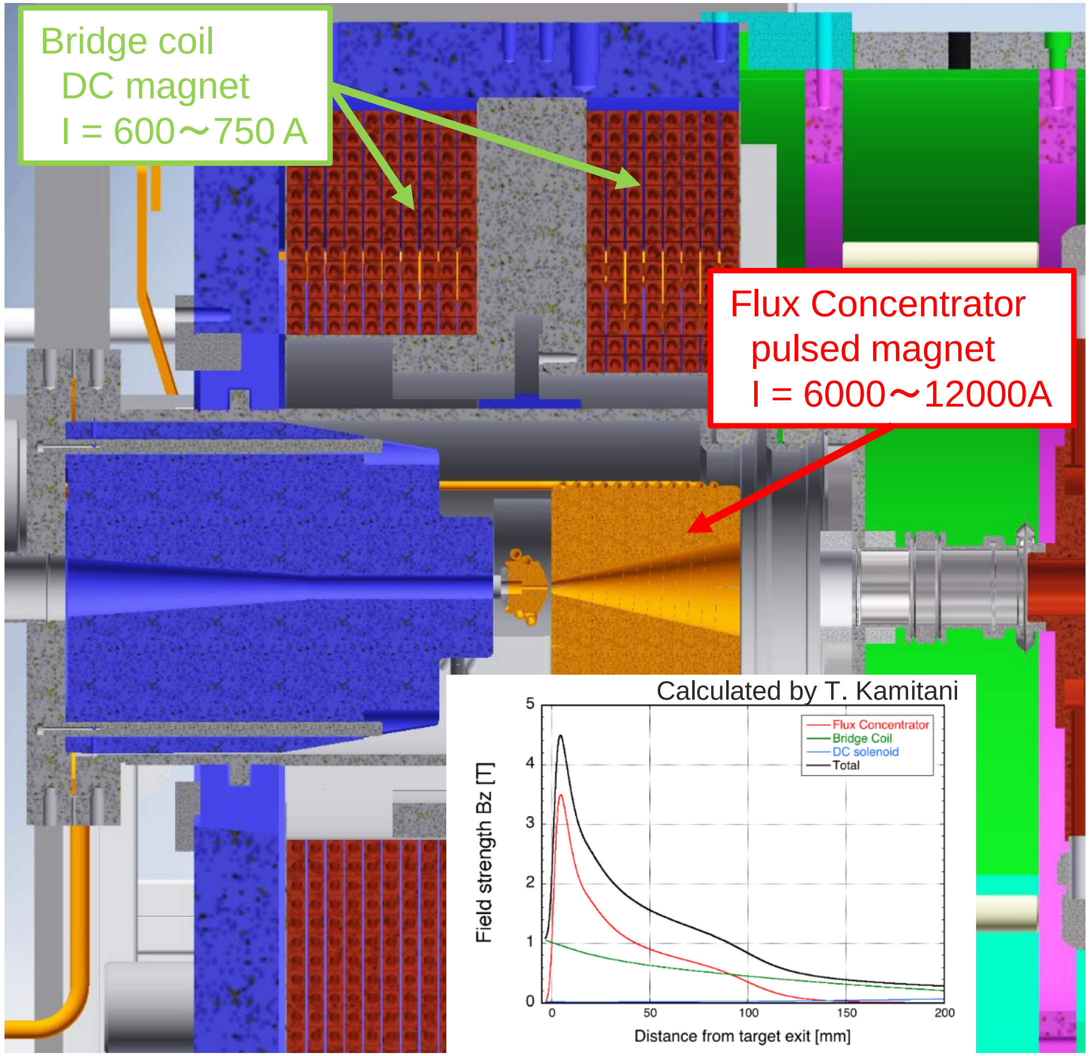
How the FC works?



- Electron hit small point of the target.
- Positron comes from small spot.
- Angle distribution is large.



- Adiabatically expand position distribution.
- Angle distribution decrease.
- Matched to the aperture of the following LAS.



Ratio B @ target / B @ entrance of the LAS is important
stronger field is preferred in the following solenoid section
much stronger field is required @ target