N-infusion at KEK/J-PARC

TTC meeting@Milano WG4

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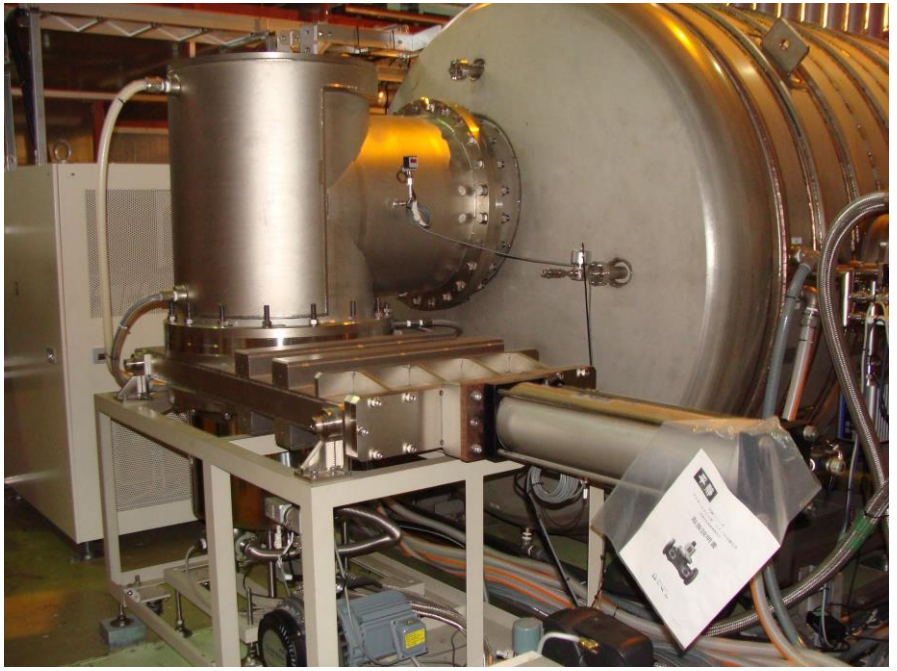
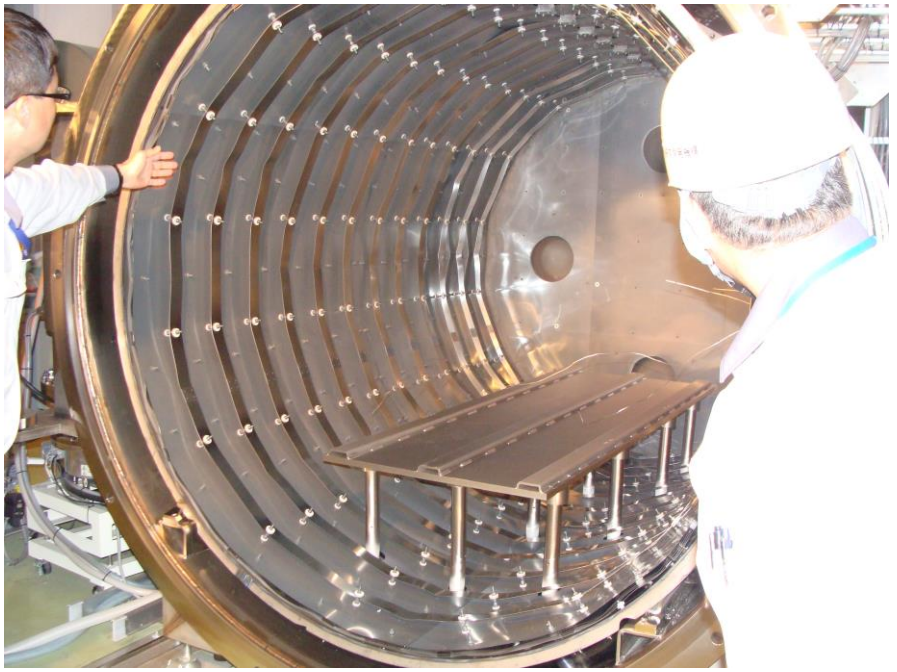
Outline

- J-PARC furnace
- First trial of N-infusion
- Latest results of N-infusion with improved vacuum system
- Summary

N-dope/N-infusion trial using J-PARC furnace

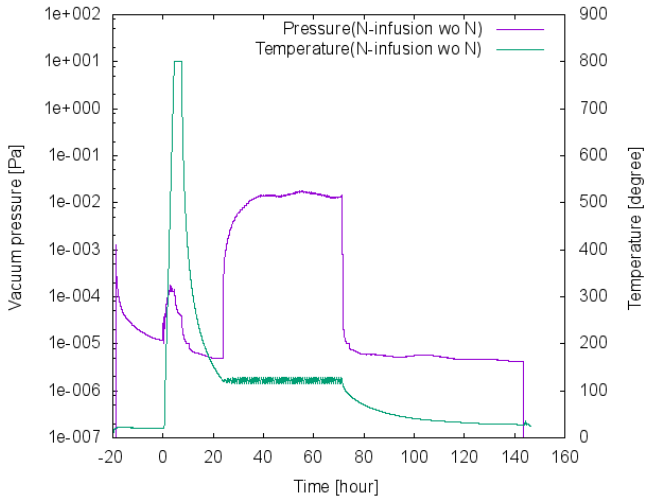


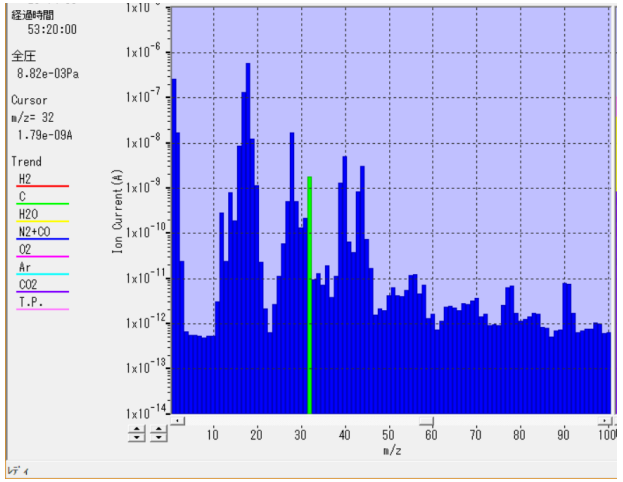


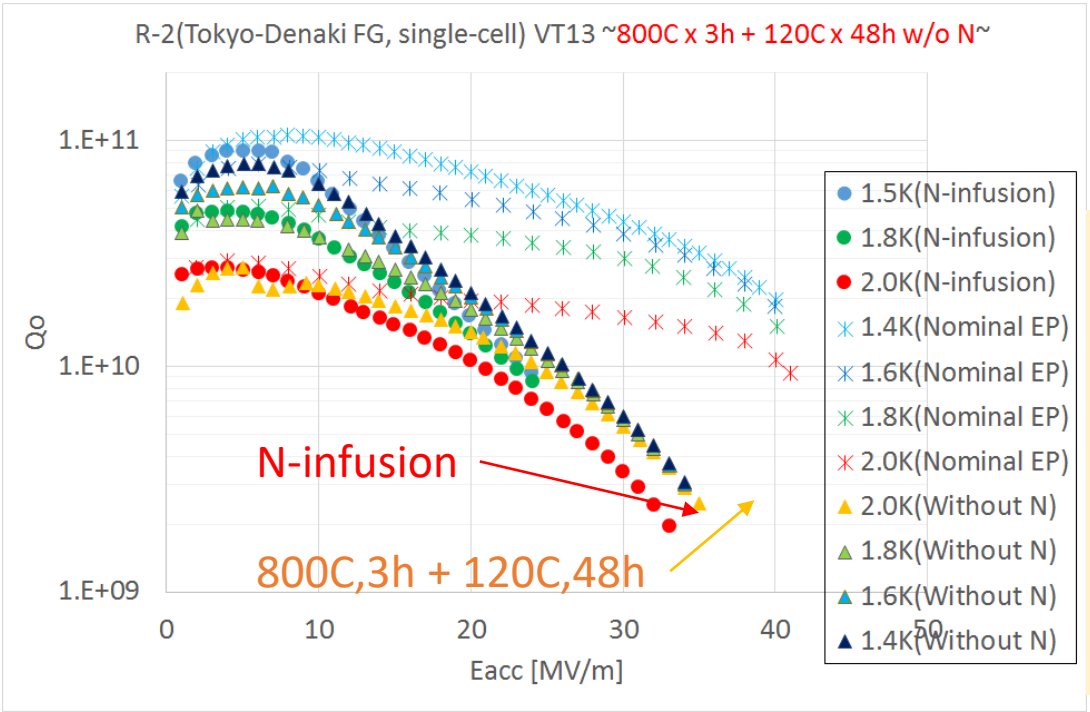
- J-PARC has oil-free furnace with cryo-pump(10,000 litter/sec) and three TMPs(3,000 litter/sec x 3).
- Vacuum level reached to ~1e-6 Pa.
- Normally used for degassing of beam-duct and components.

First trial of N-infusion

①800℃, 3hours + 120℃, 48 hours w/ Nitrogen &
②800℃, 3hours + 120℃, 48 hours w/o Nitrogen





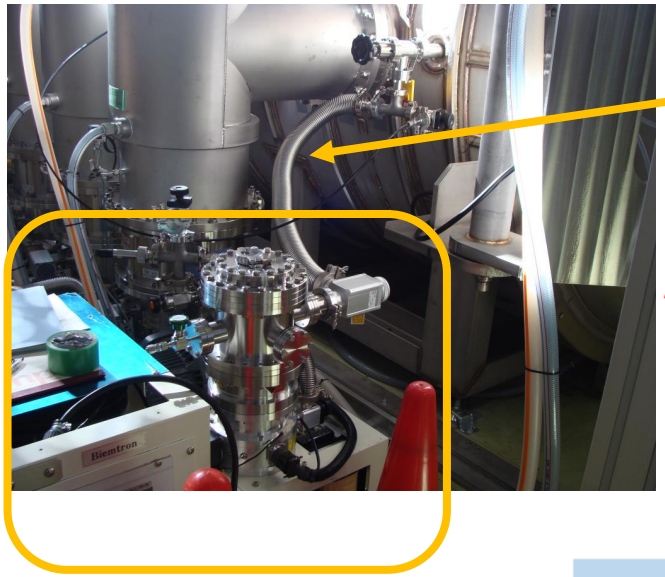


- Vacuum level worthened to 1.7e-2 Pa (Around 0.5% of Nitrogen level)

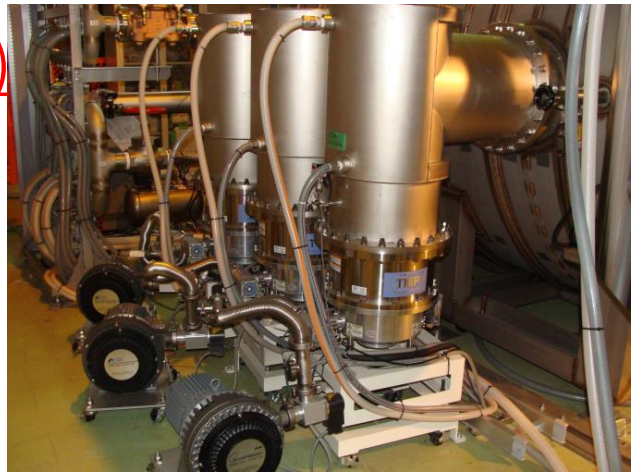
- Degradation above 5MV/m
- Almost same performance between w and w/o Nitrogen
- No degradation for 800C, 3h

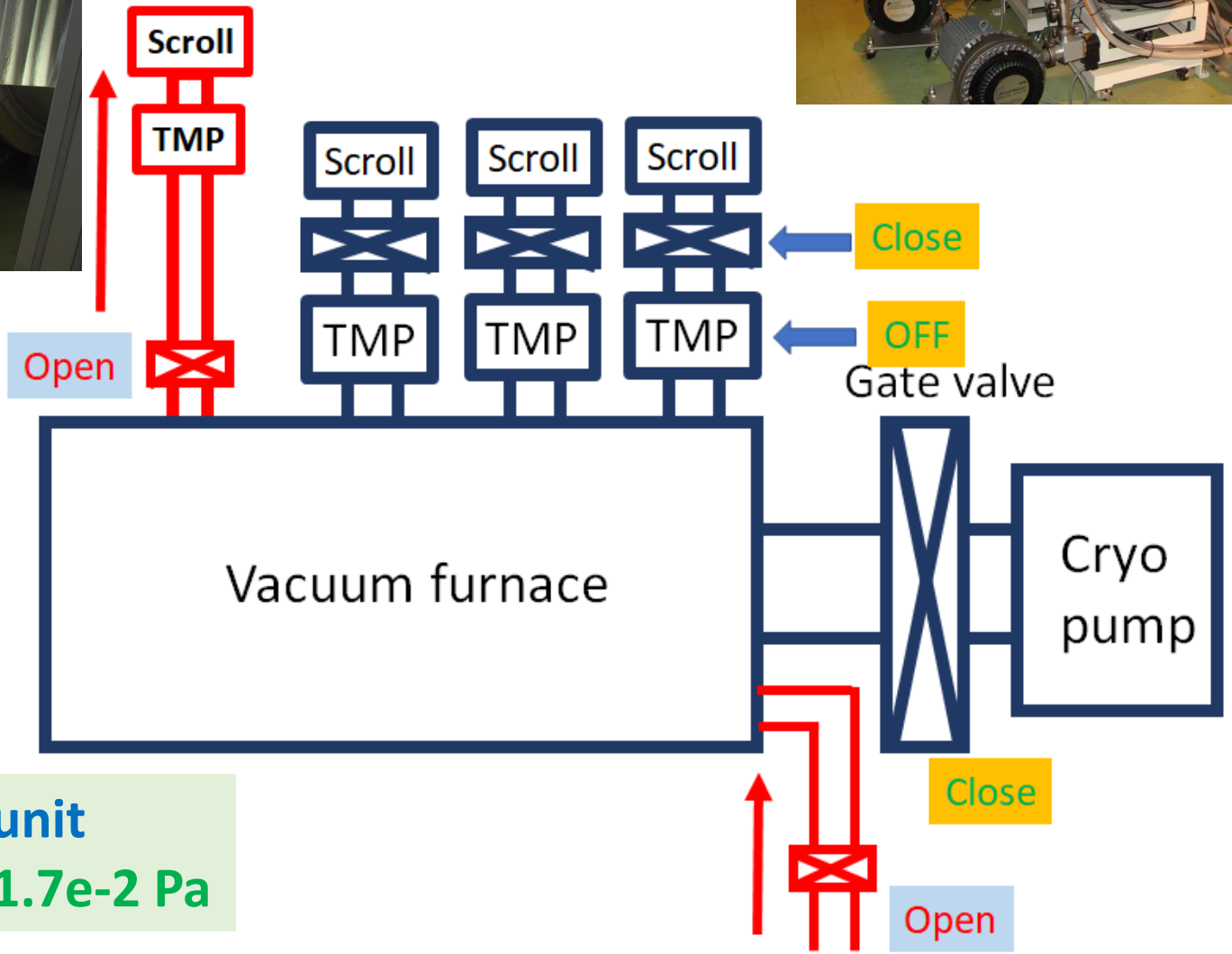
  ⇒ **contamination from furnace during 120C was suspected**

Pumping system during 120 C N-injection (previous)



Bellows limit conductance
~10 litter/sec





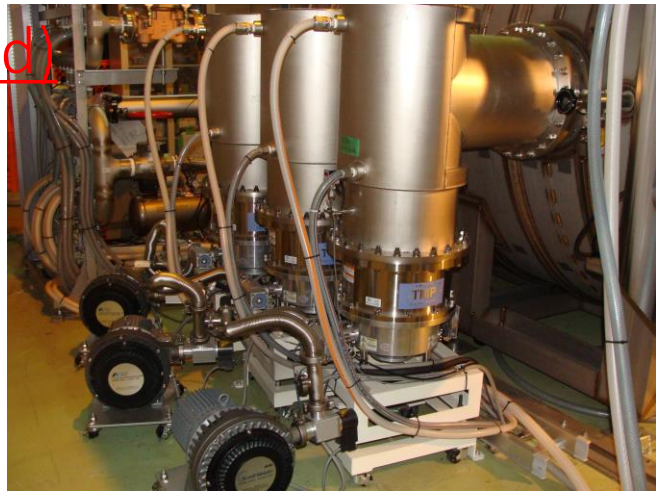
Active pumping
during N injection

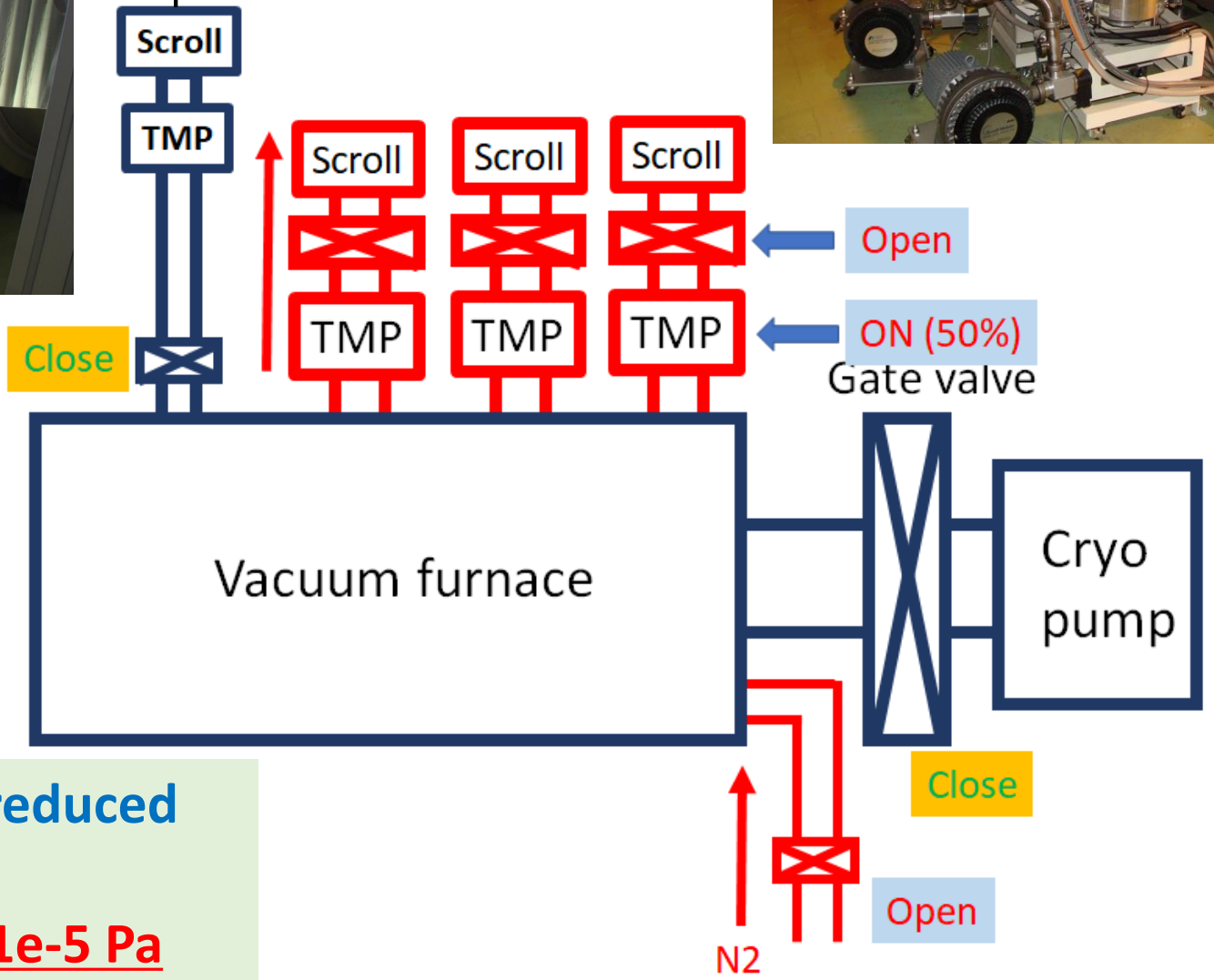
Use **small pumping unit**
Background level **~ 1.7e-2 Pa**

Latest results of N-infusion with improved vacuum condition

Pumping system during 120 C N-injection (improved)

- Use TMP with reduced rotation speed.
- Scroll pumps limit rotation speed.





Background vacuum was improved three orders.

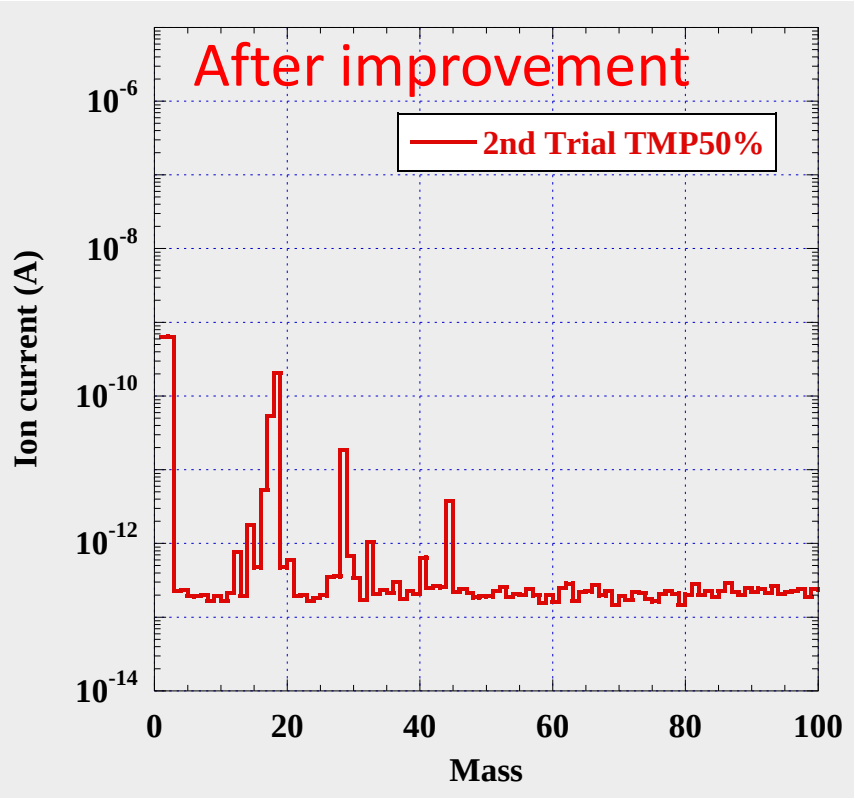
Use **large TMP with reduced rotation speed**

Background level **~ 1e-5 Pa**

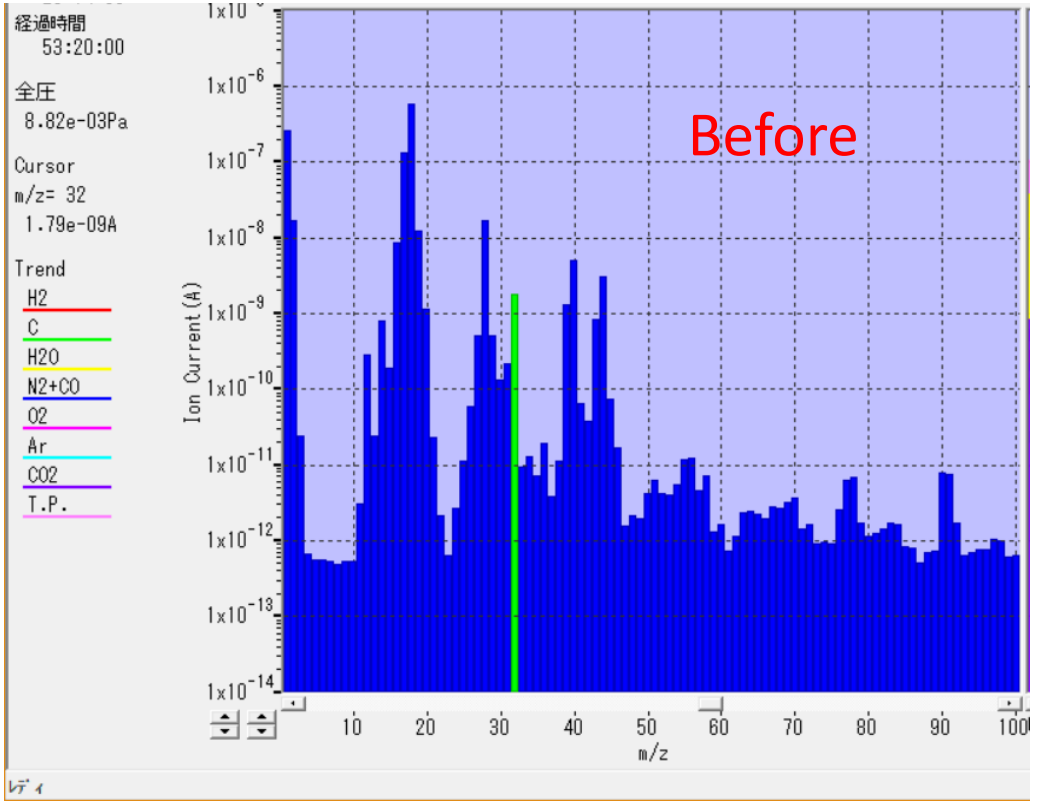
RGA spectrum

Measurements were carried out w/o Nitrogen.
Load to pump was different with 3Pa Nitrogen.

Use **large TMP with reduced rotation speed**
Background level **~ 1e-5 Pa**

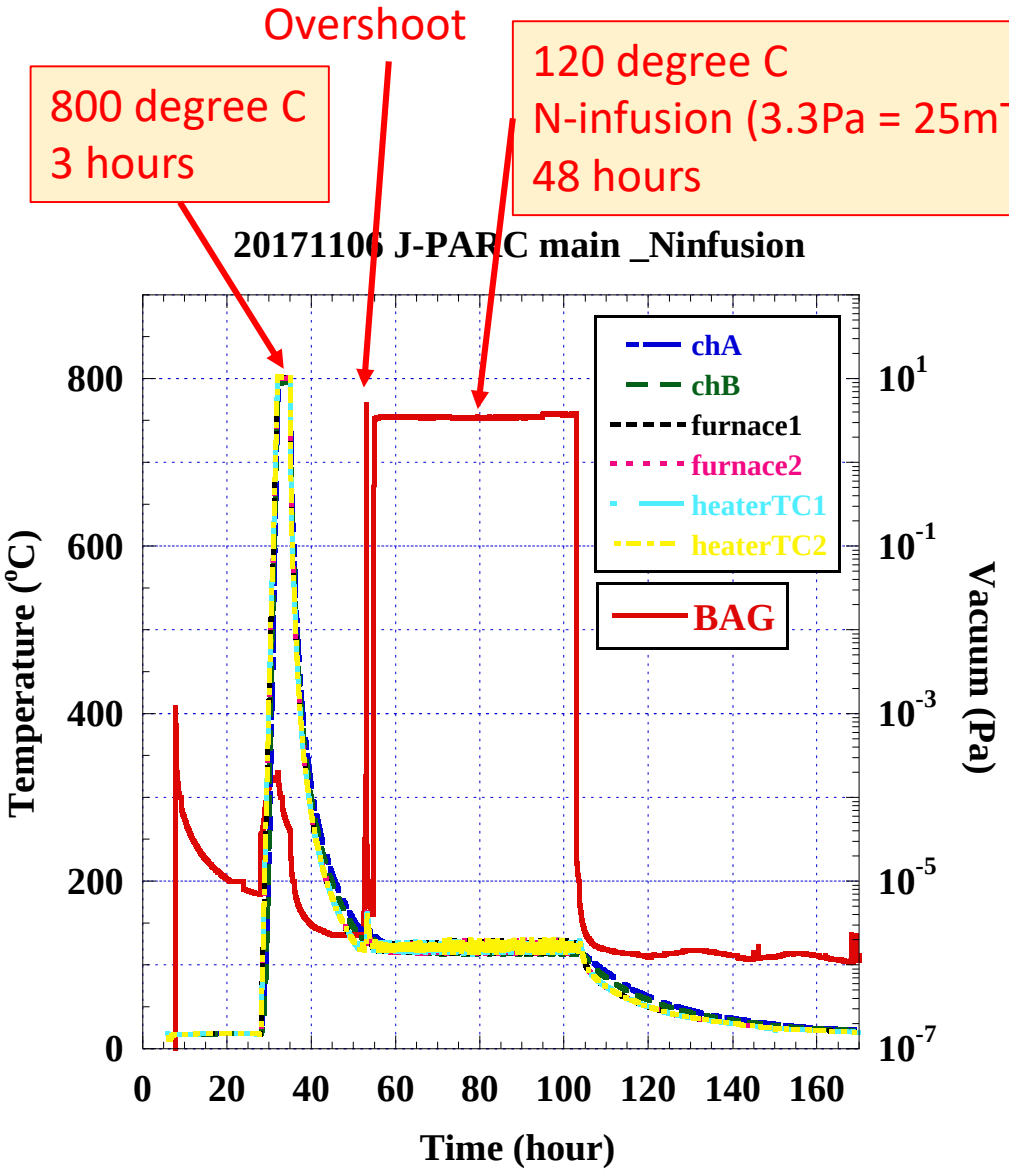


Use **small pumping unit**
Background level **~ 1.7e-2 Pa**



Vacuum background level improved much and showed relatively clean RGA spectrum.

N-infusion at J-PARC furnace



N-infusion applied to two single-cell cavities.

[Reference measurements]

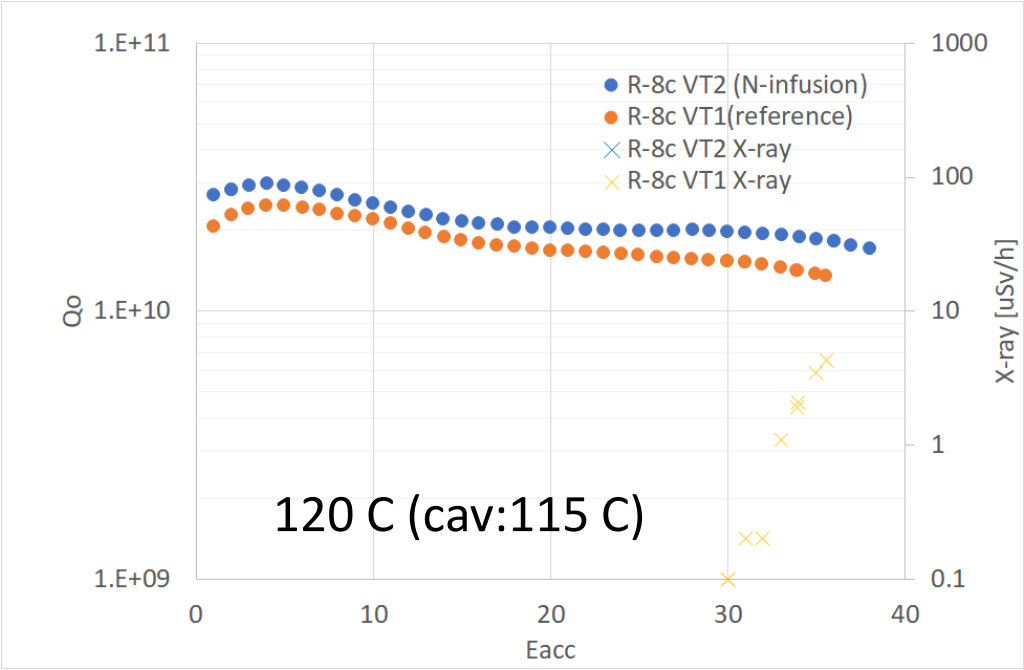
- 100um EP
- 800 or 850 C, 3h
- 20um EP
- HPR, Assembly, 120C baking
- VT

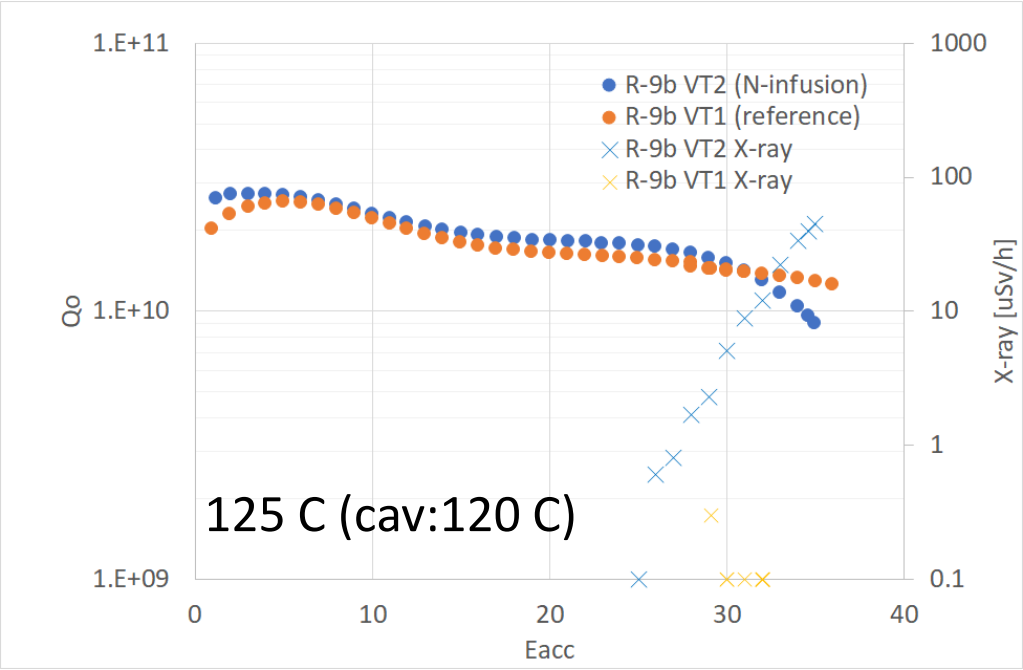
[N-infusion]

- 800 C, 3h + 120 (125)C, 48h with N2 3.3Pa
  (cavity temp. is lower by 5deg)
- HPR, Assembly
- VT

Results of N-infusion at 2.0K

N-infusion successful!





- Q values improved.
- Gradient is also improved.

  36MV/m → 38 MV/m
- No sign of contamination
- No high field Q-slope

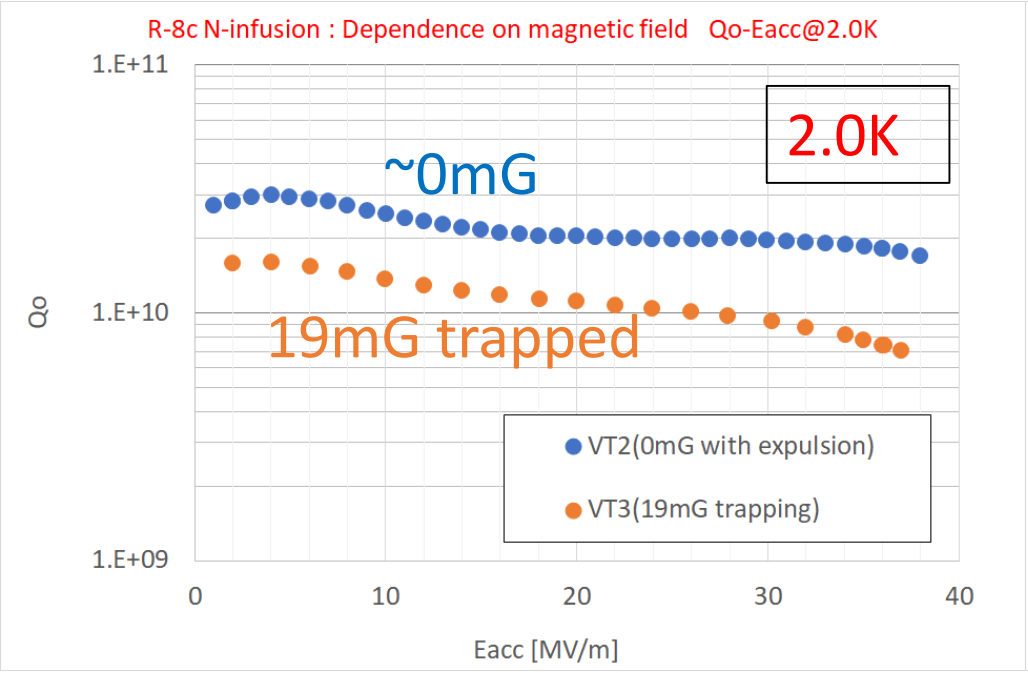
- Q values little bit improved.
- High field was degraded by F.E.
- Gradient slightly decreased

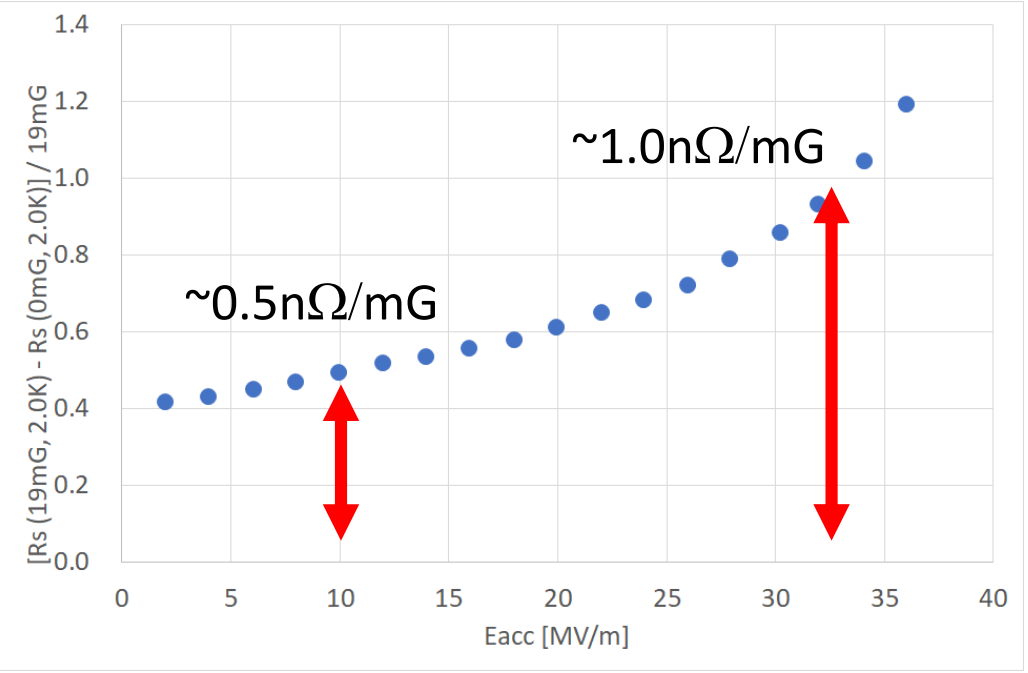
  36MV/m → 35 MV/m
- No sign of contamination
- No high field Q-slope

Sensitivity to flux trapping

VT2: 0mG with expulsion condition ⇒ ~0mG

VT3: 20mG was applied and almost trapped ⇒ 19mG trapped





[Rs (19mG, 2.0K) – Rs (~0mG, 2.0K)] / 19mG

Sensitivity of N-infusion cavity is rather large at high gradient?

Summary and Questions

- N-infusion studies continue at KEK/J-PARC.
- N-infusion was successfully carried out.
- Improvement of pumping ability during 120 C N-injection is effective to avoid degradation due to furnace contamination.

  ⇒ What is procedures for other labs?

  ⇒ What is ideal pumping system?
- Sensitivity to flux trapping is rather high at higher gradient.

  ⇒ How is the results for FNAL N-infusion?

History of 1.3GHz single cell cavities

- TESLA-like single cell cavity made of Tokyo Denkai FG Nb sheet.

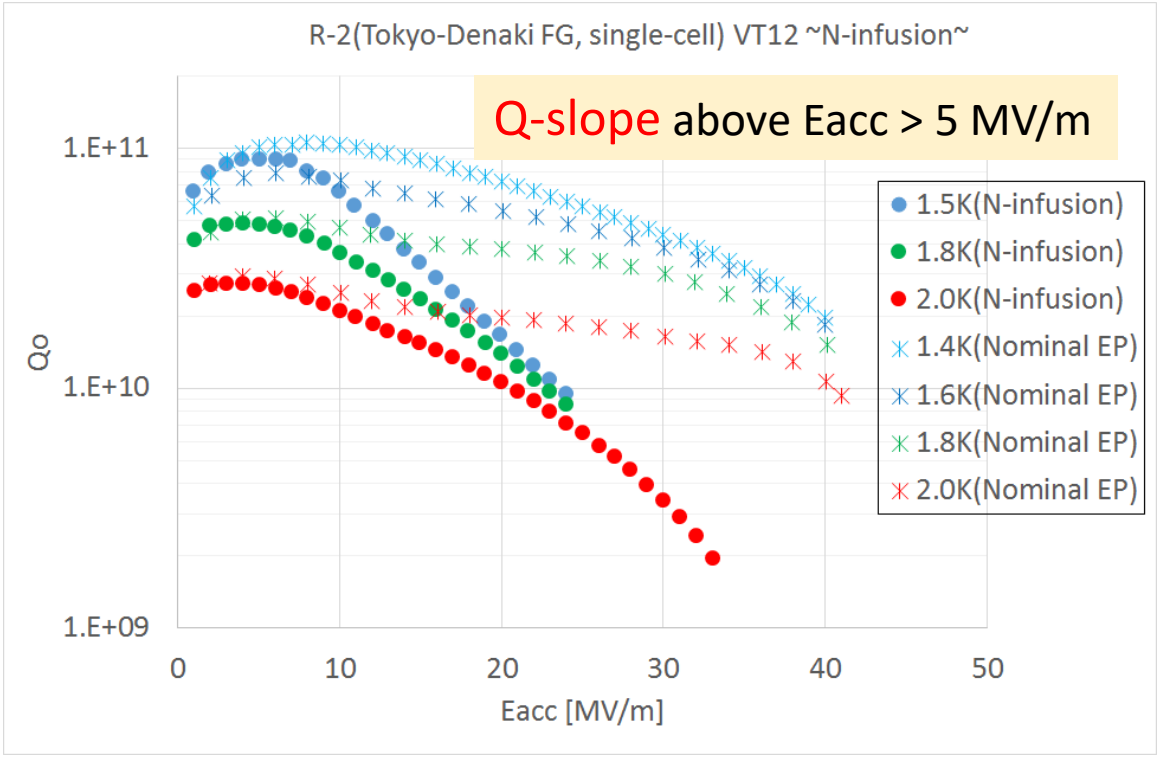
R-8c	R-9b
Pre-EP (5um) & EP-1 (100um)	Pre-EP (5um) & EP-1 (100um)
Heat treatment (800 C x 3hours)	Heat treatment (800 C x 3hours)
EP-2 (20um)	EP-2 (20um)
HPR (3 hours), Assembly, Baking (120 C x 48 hours)	HPR (3 hours), Assembly, Baking (120 C x 48 hours)
1st vertical test (Reference VT)	1st vertical test (Reference VT)
N-infusion at J-PARC (800C x 3h + 120C x 48h, 3Pa N2)	N-infusion at J-PARC (800C x 3h + 125C x 48h, 3Pa N2)
HPR (3 hours), Assembly	HPR (3 hours), Assembly
2nd vertical test (N-infusion)	2nd vertical test (N-infusion)
3rd vertical test with 20mG	

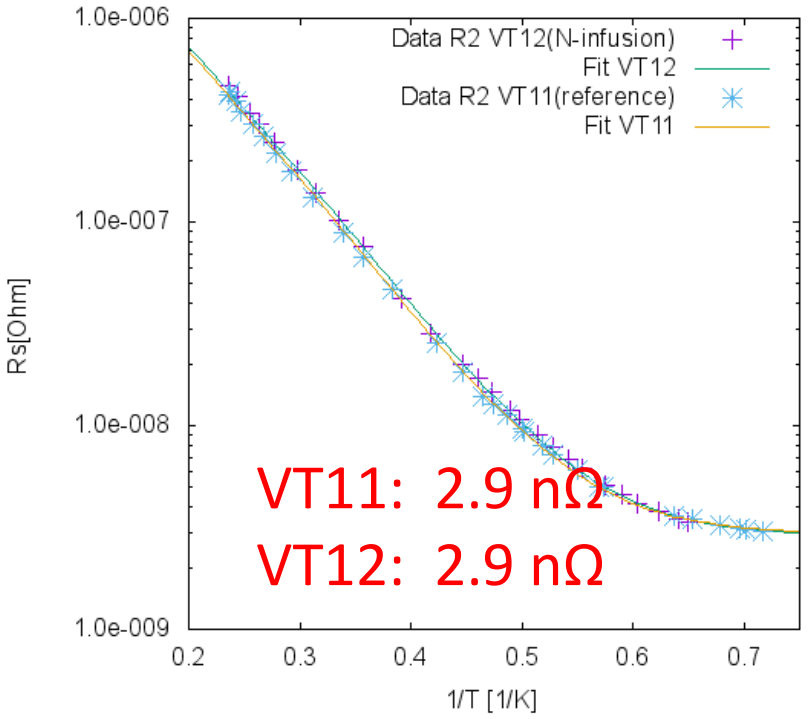
Backup slide

VT results for N-infusion

- Transfer to KEK
- HPR (No EP applied)
- Assembly

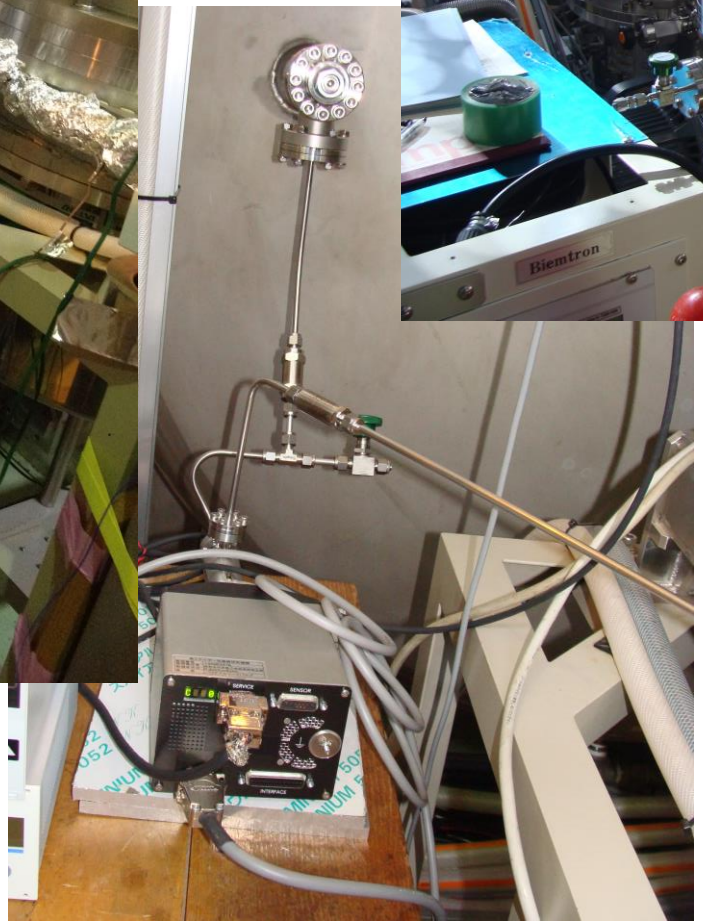
- Magnetic field canceled. (< 1mG)
- Cooled down with thermal gradient





- Degradation was observed for > 5 MV/m
- Eacc was limited at 33MV/m by quench at 225 degree equator
- No field emission

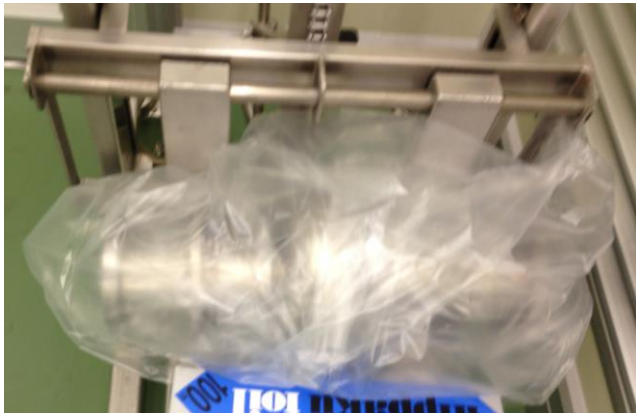
N-injection system

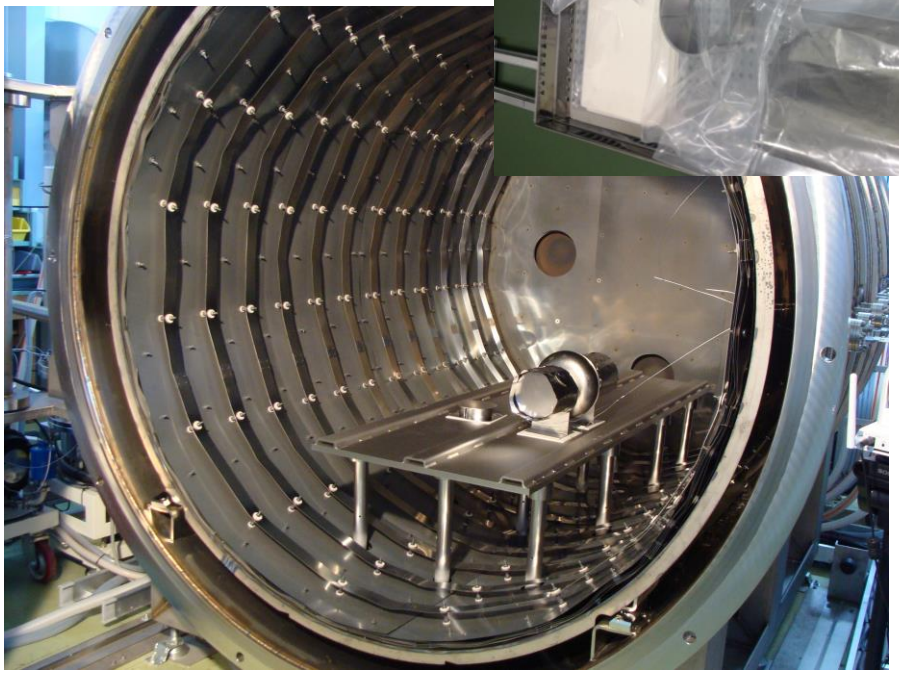


- Nitrogen pressure is controlled by variable leak valve
- Cryo-pump is closed and TMPs are off during N-injection. Small pump set, TMP and scroll, pump the furnace.

Cavity preparation for heat treatment

- HPR (flange open) 2 hours, drying one night
- Cavity was double-packed inside class-1000
- Nb cap & foil was ultrasonic cleaned with degreasing, drying inside class-10, packed inside class-1000
- Transport to J-PARC
- Setup into J-PARC furnace

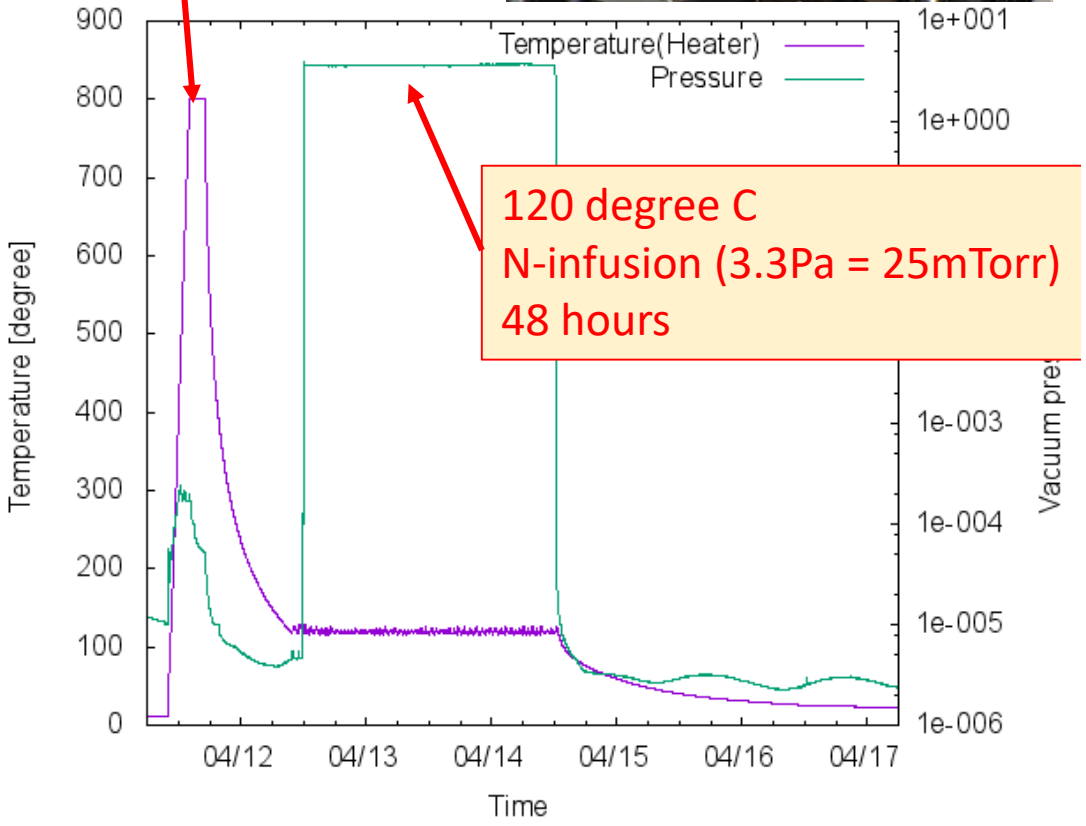




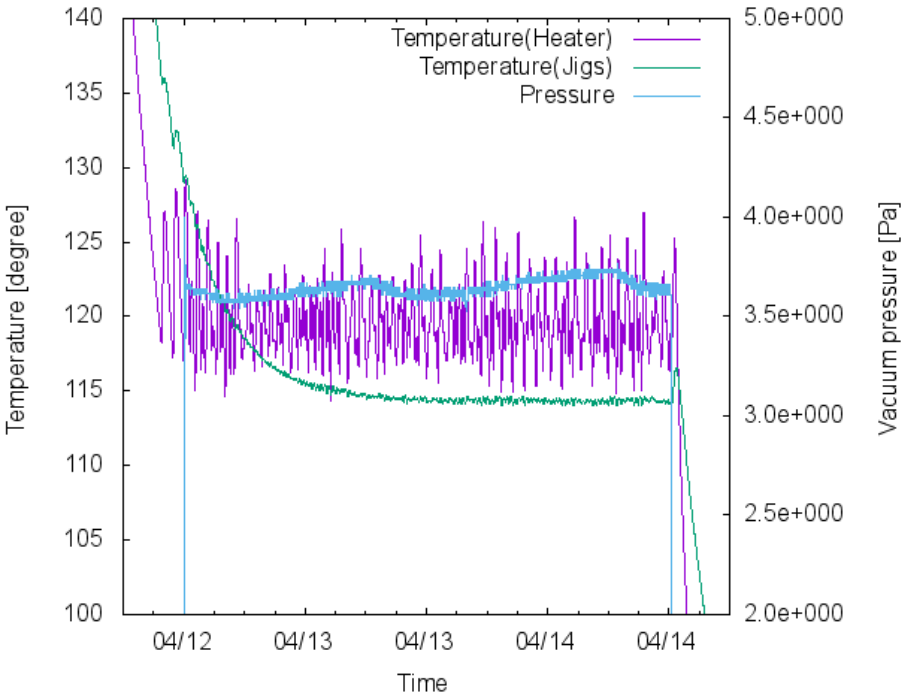
1st N-infusion(FNAL parameter)

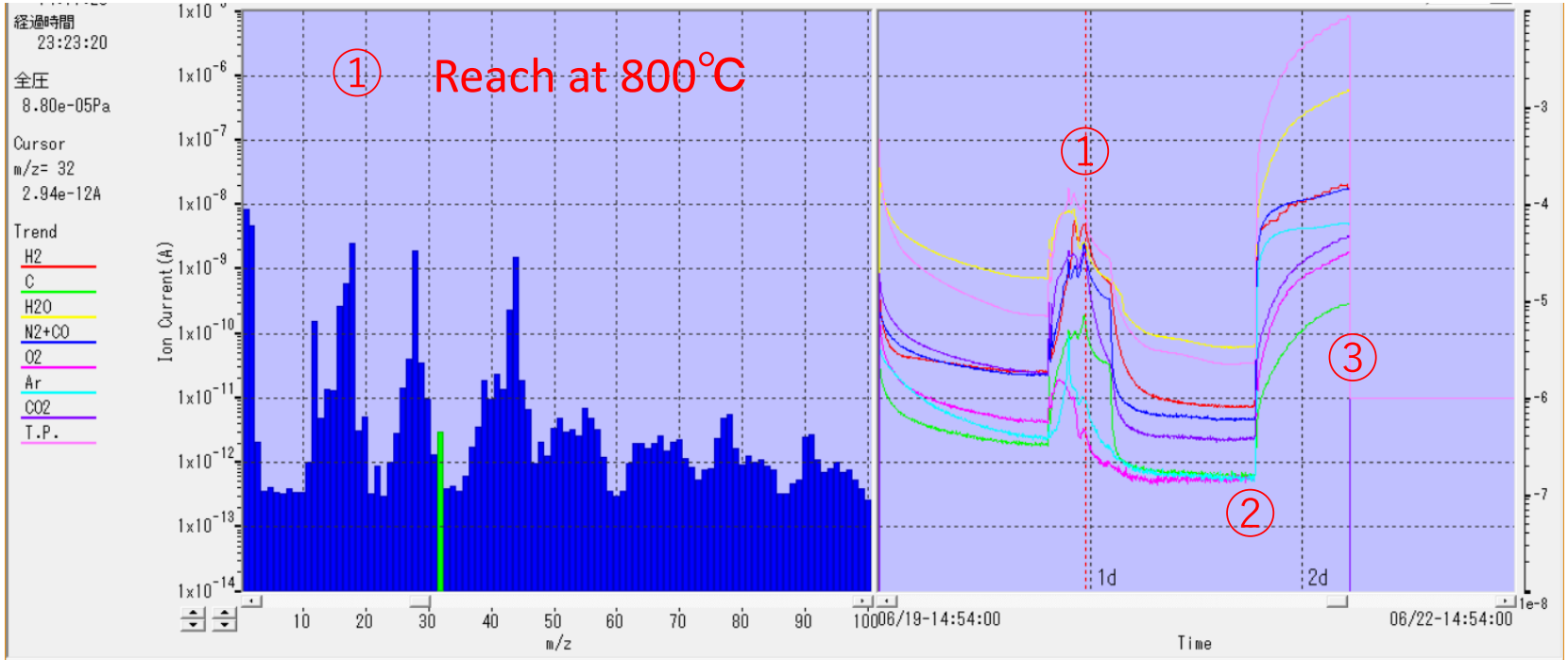
800 degree C
3 hours

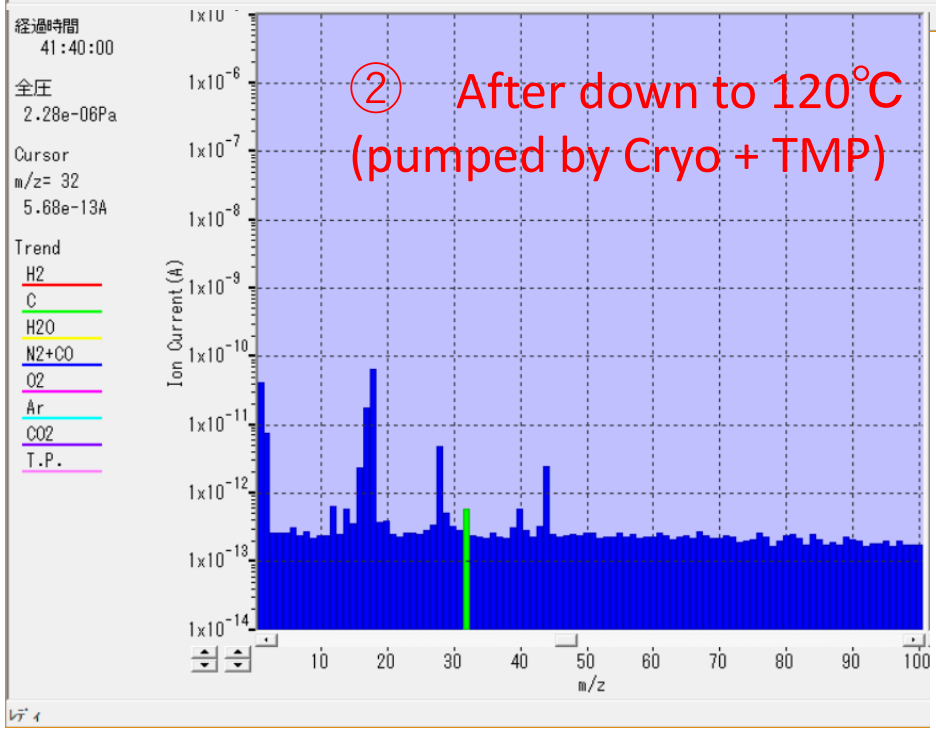
120 degree C
N-infusion (3.3Pa = 25mTorr)
48 hours

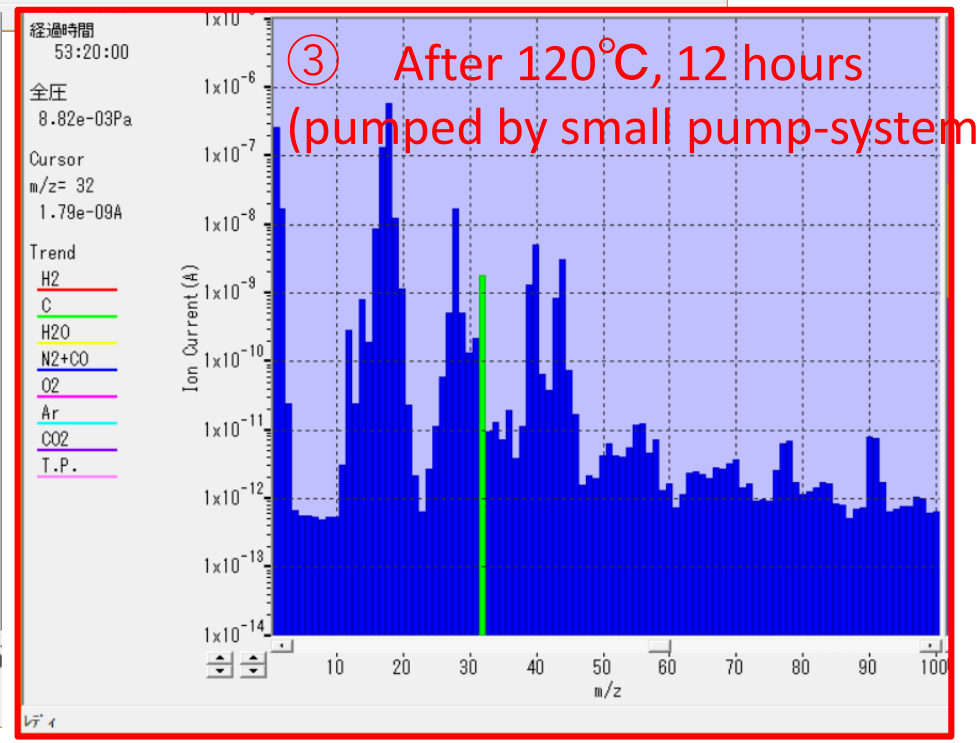


- Pressure is stabilized less than 0.1Pa
- Different vacuum gauges at different positions show around 0.3 Pa offset.
- Temperature is stabilized with +/- 5 degree.
- Temp. offset ~ 5 degree between furnace and jigs.



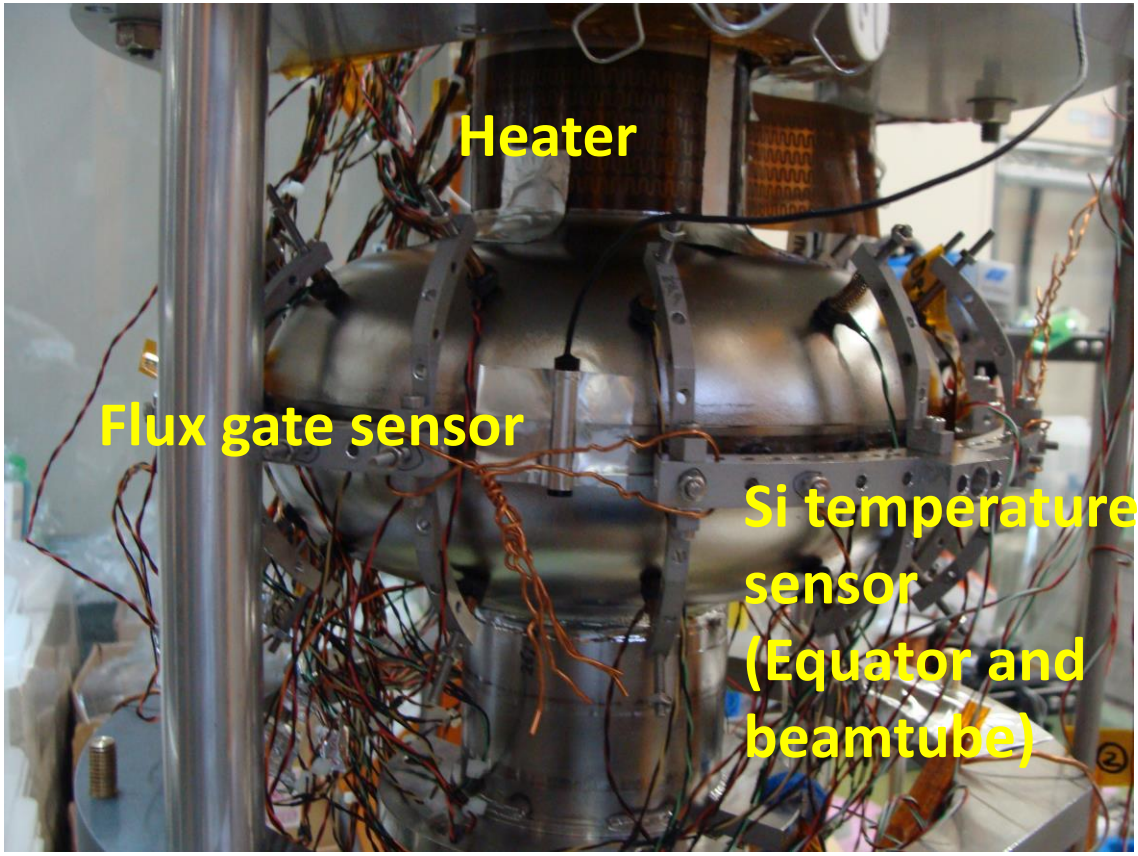

経過時間
23:23:20
全圧
8.80e-05Pa
Cursor
m/z= 32
2.94e-12A
Trend
H2
C
H2O
N2+CO
O2
Ar
CO2
T.P.
① Reach at 800℃
Ion Current(A)
m/z
Time
1d
2d
06/19-14:54:00
06/22-14:54:00


経過時間
41:40:00
全圧
2.28e-06Pa
Cursor
m/z= 32
5.68e-13A
Trend
H2
C
H2O
N2+CO
O2
Ar
CO2
T.P.
② After down to 120℃
(pumped by Cryo + TMP)
Ion Current(A)
m/z


経過時間
53:20:00
全圧
8.82e-03Pa
Cursor
m/z= 32
1.79e-09A
Trend
H2
C
H2O
N2+CO
O2
Ar
CO2
T.P.
③ After 120℃, 12 hours
(pumped by small pump-system)
Ion Current(A)
m/z

Typical vertical test setup

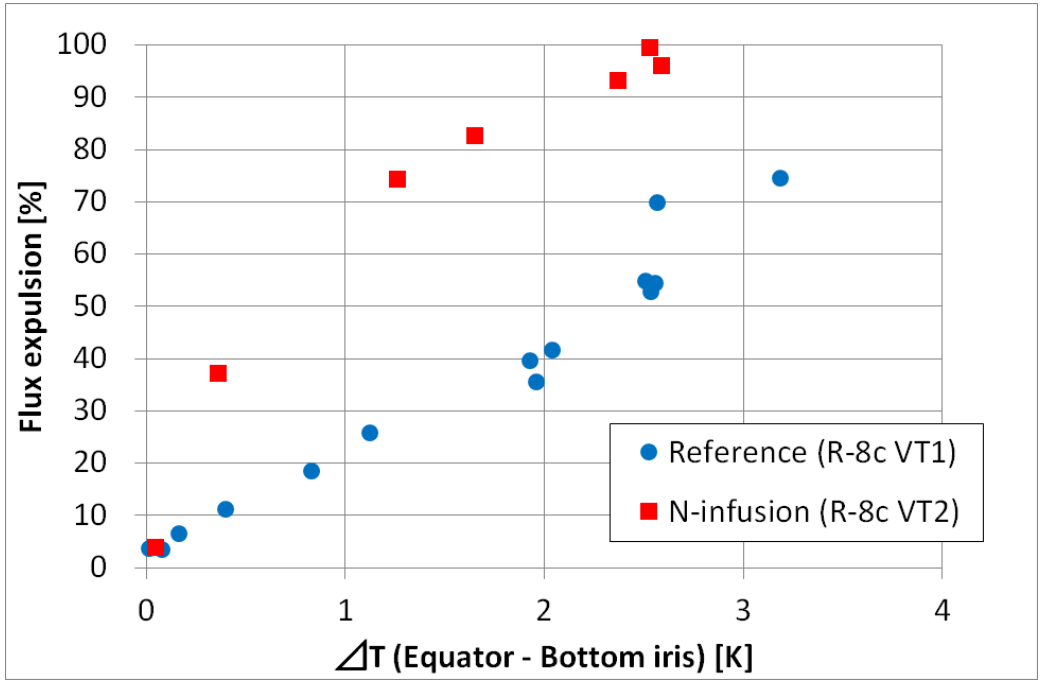
※ Pictures are for different measurement.
※ But setup of sensors and coil are same.

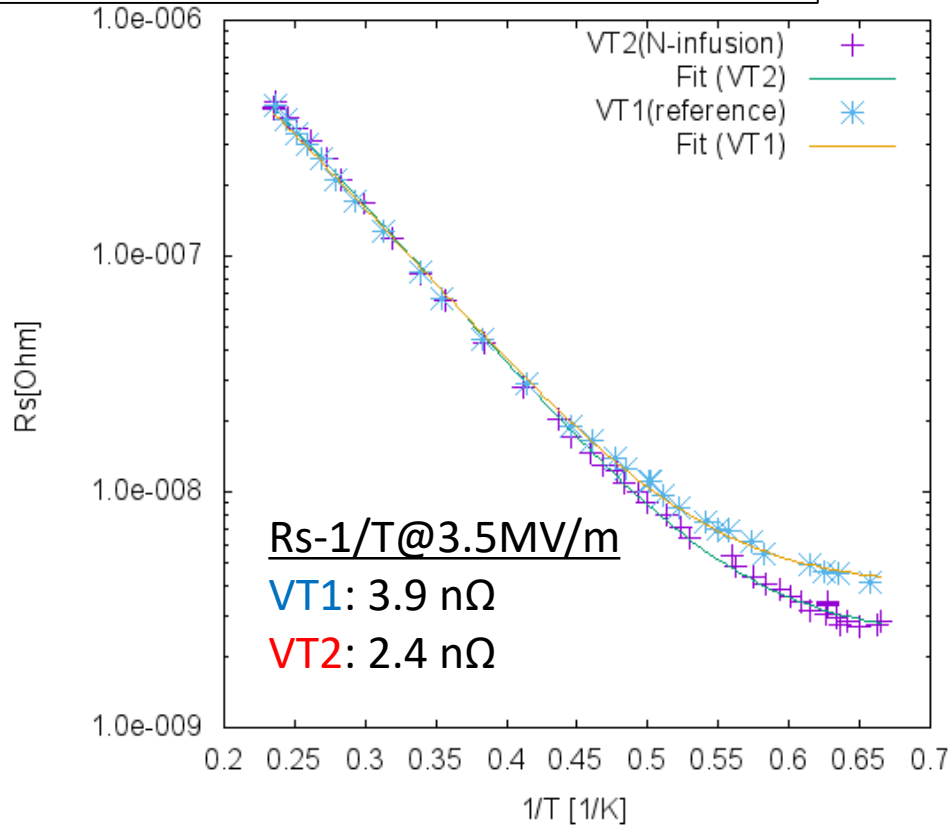


Flux gate sensor, Si temperature sensor, heater and solenoid coil were used.

Flux expulsion & Rs-1/T

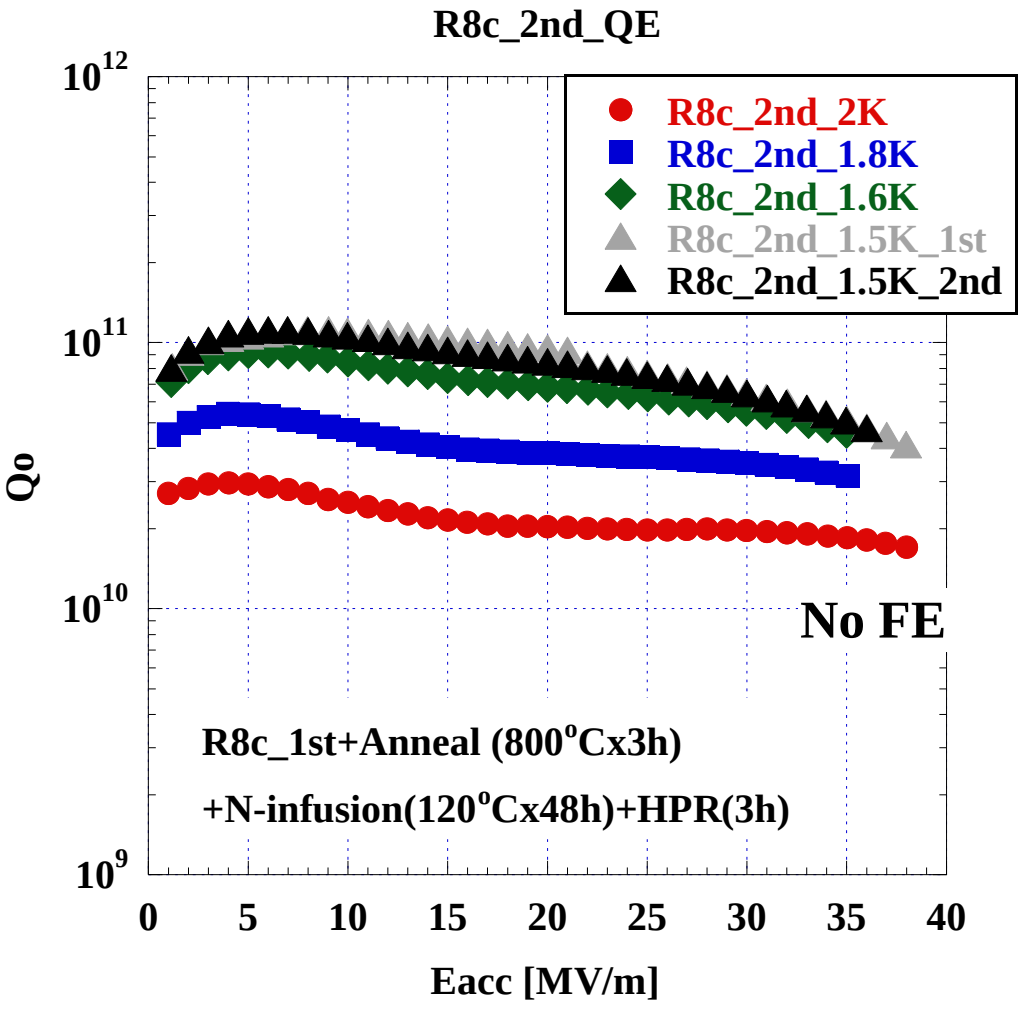
VT1: 800C x 3h heat treatment, EP2, 120C x 48h baking
VT2: 800C x 3h heat treatment, EP2, 120C x 48h baking + N-infusion (800C x 3h + 120 C x 48h, N2)

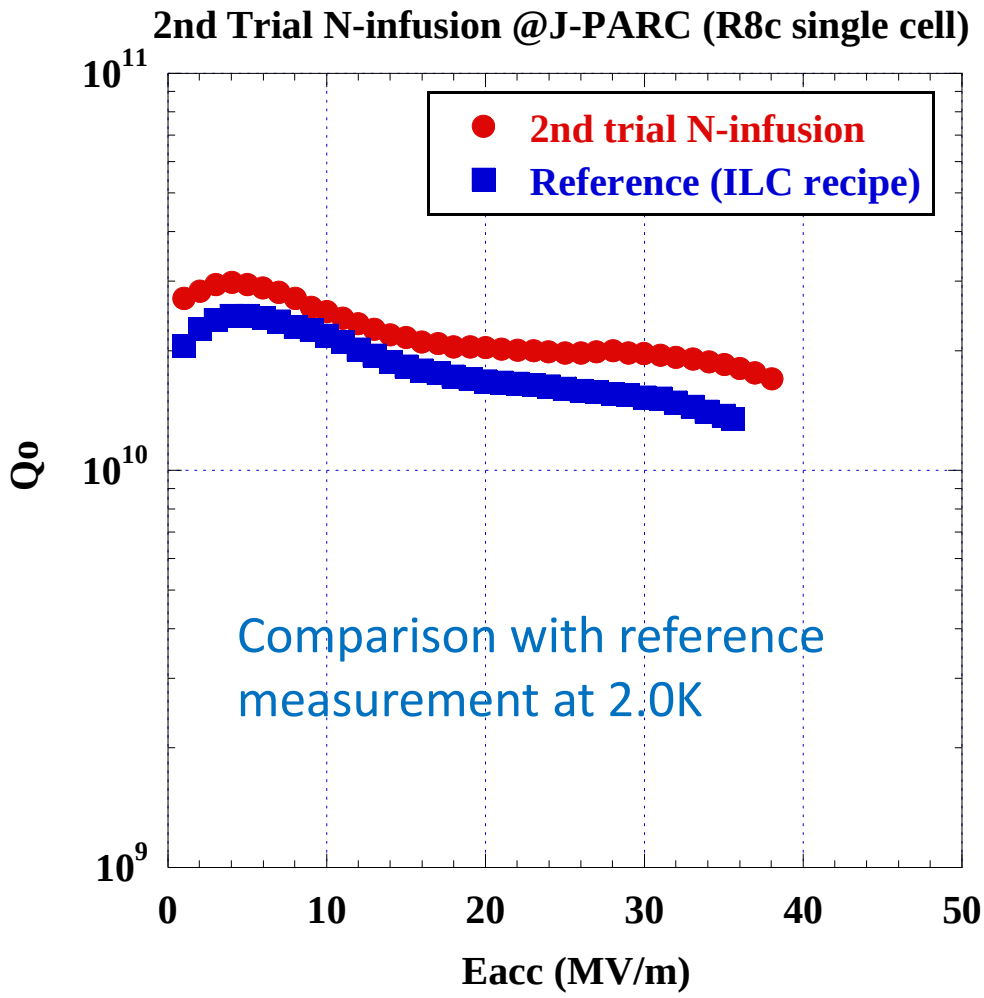




- Additional N-infusion process improved flux expulsion much.
- Residual resistance (@3.5MV/m) is also reduced.

Q-Eacc measurement



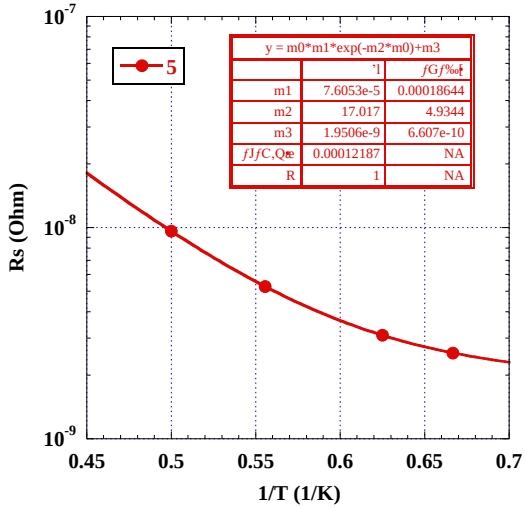


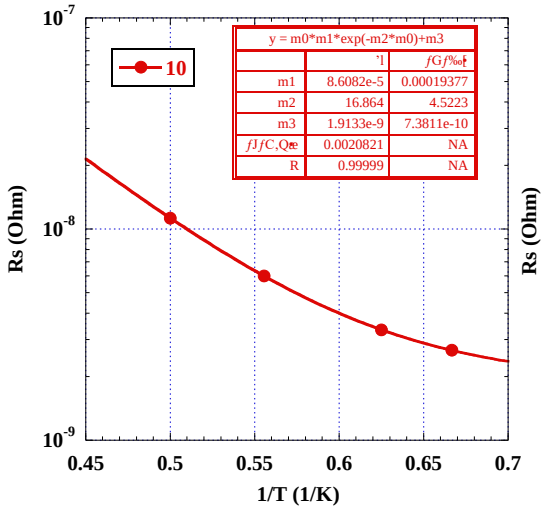
- Q-value improved for all Eacc region.
- Eacc is also improved from 36 to 38 MV/m

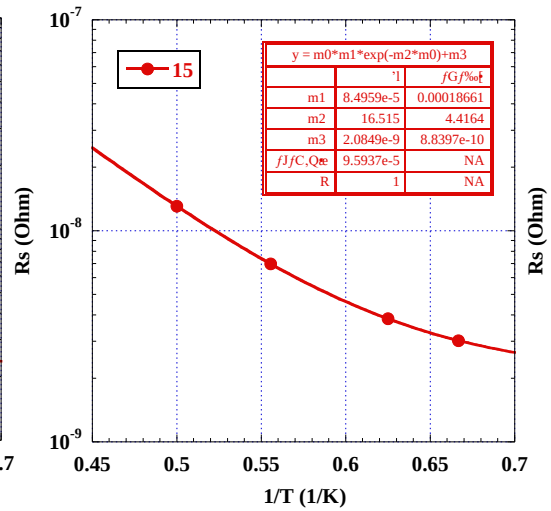
Deconvolution of R(BCS) & R_res

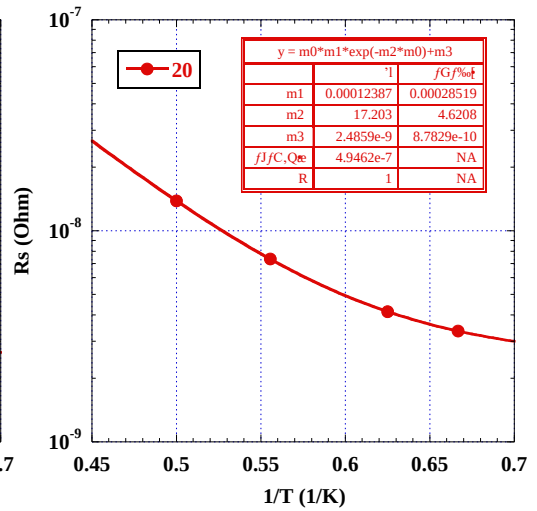
- Rs-1/T curve from each Eacc were fitted by using 2.0, 1.8, 1.6, 1.5 K data points.
- Around 10% error is assumed.

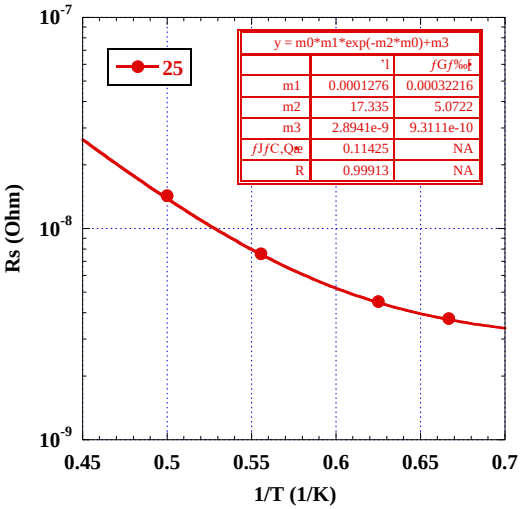
$$R_s = R_{BCS} + R_{res} = \frac{A}{T}\exp\left(-\frac{B}{T}\right) + R_{res}$$

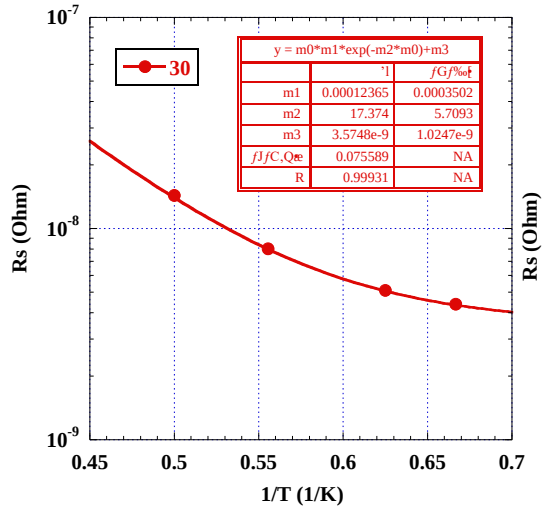


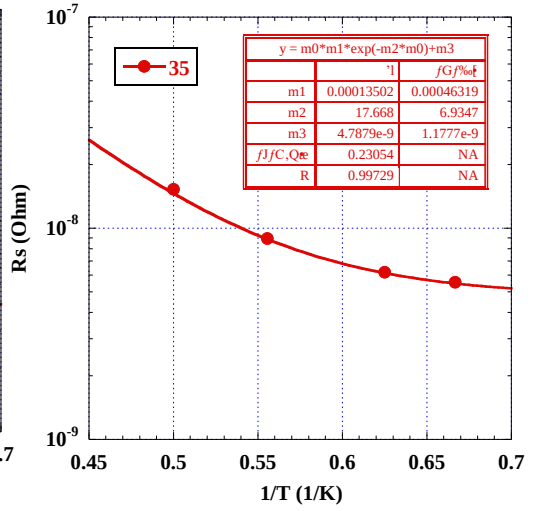




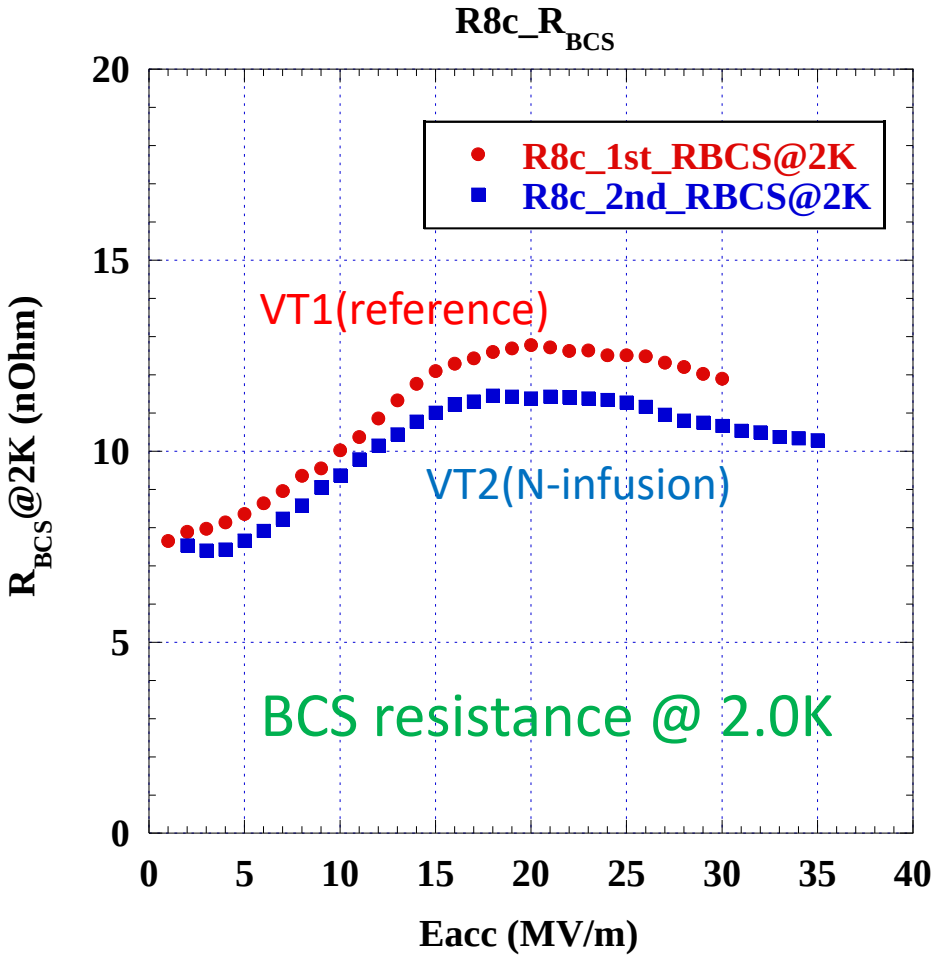


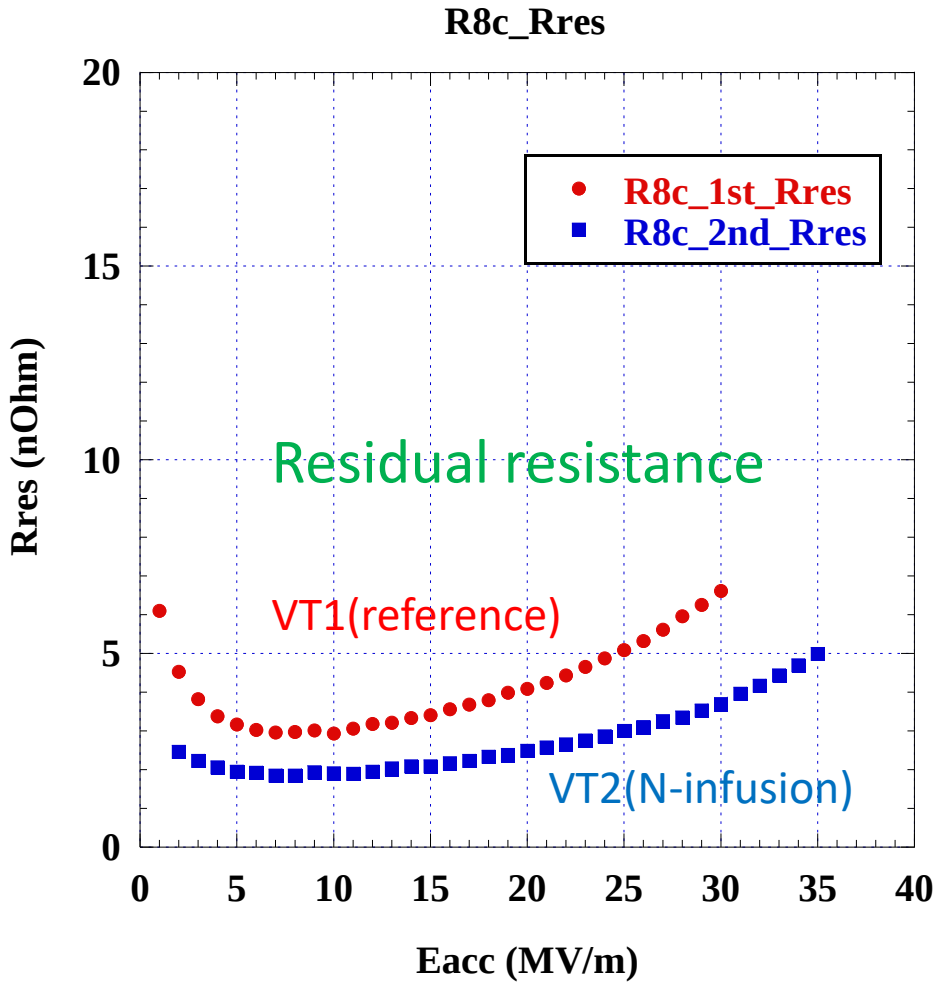






Deconvolution of R(BCS) & R_res





- BCS resistance tends to be reduced for N-infusion.
- Residual resistance was reduced to roughly half.