Recent activity toward high-Q at KEK

2016/11/3

TTC High-Q meeting

KEK Kensei Umemori

Contents

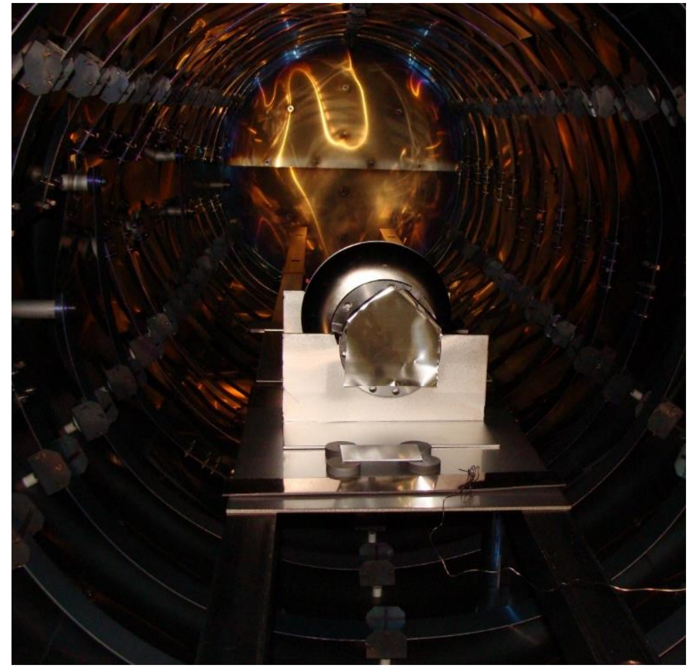
- N-doping
  - ➢N-doping @ KEK
  - ➢Results of VT @KEK
  - ➢Results of VT @FNAL
  - ➢N-doping @FNAL and VT@FNAL for KEK cavity
- Measure against magnetic field
  - ➢Study on magnetization
  - ➢Cancelling coil
- R&D plan of KEK
  - ➢High-Q and high-gradient study for ILC
- Summary

(N-doping @ KEK and Results of VT @KEK: Shown at TTC meeting@SLAC)

(Results of VT @FNAL: Shown at IPAC16)

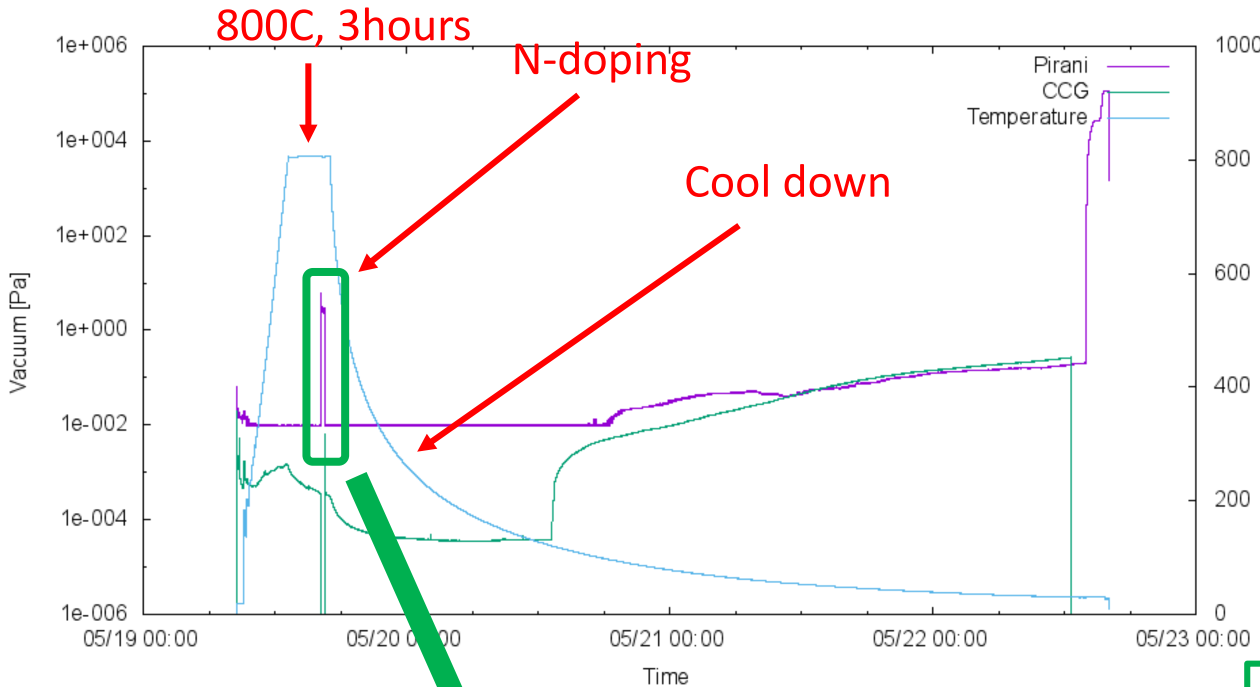
N-doping (800 C)

N-doping system at large furnace

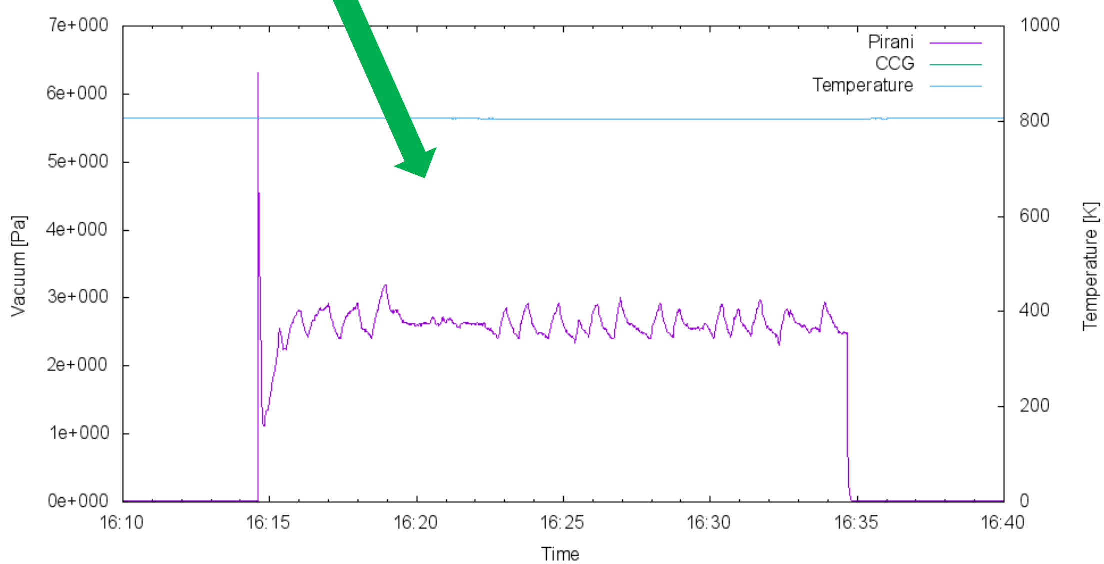


- N-doping system was constructed on large furnace which was for 9-cell cavity annealing.
- Nitrogen pressure is controlled by variable leak valve.
- Nitrogen pressure is monitored by pirani gauge.
- No cryopump. Diffusion pump works.

N-doping at KEK



- Upto 800C with 3hours
- Keep 800C, 3hours
- N-doping
  - -- Stable state within 1min.
  - -- Keep 2.7Pa, 20min.
  - -- After valve close, vacuum recover quickly
- Keep 800C, 30min
- Heater OFF ⇒ cool down



We tried three N-doping parameter

(1) 800deg, 3h + 3.3Pa N-dope, 2min + 800deg, 6min

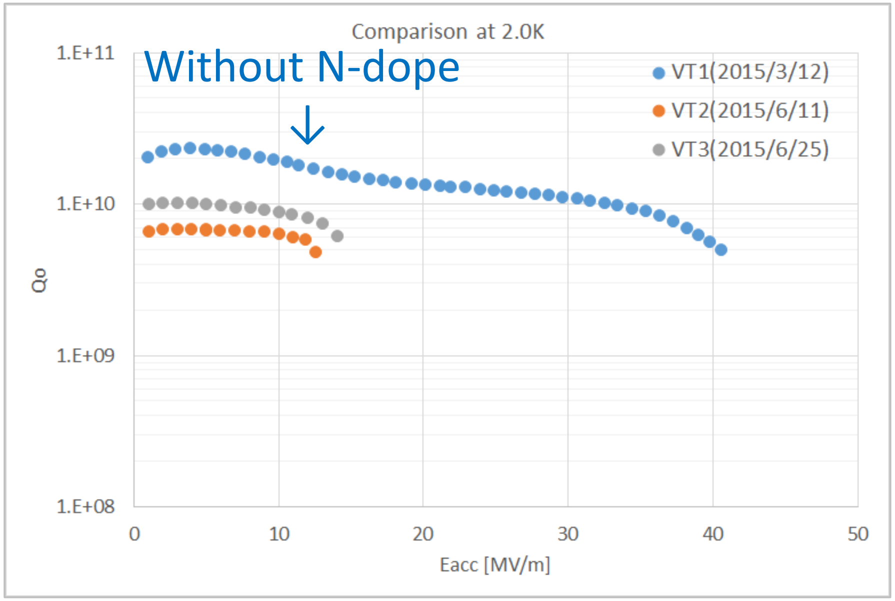
(2) 800deg, 3h + 5.5Pa N-dope, 20min + 800deg, 30min

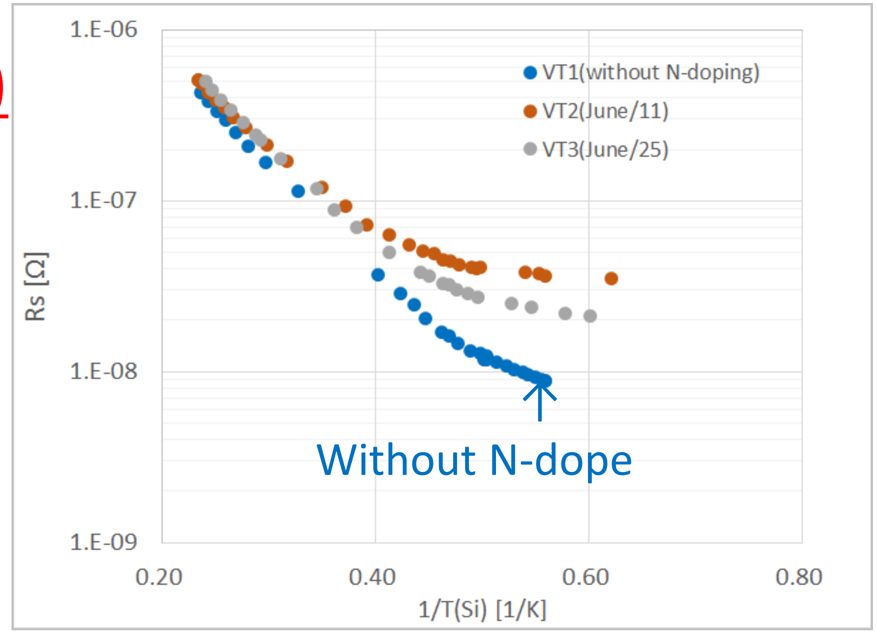
(3) 800deg, 3h + 2.7Pa N-dope, 20min + 800deg, 30min

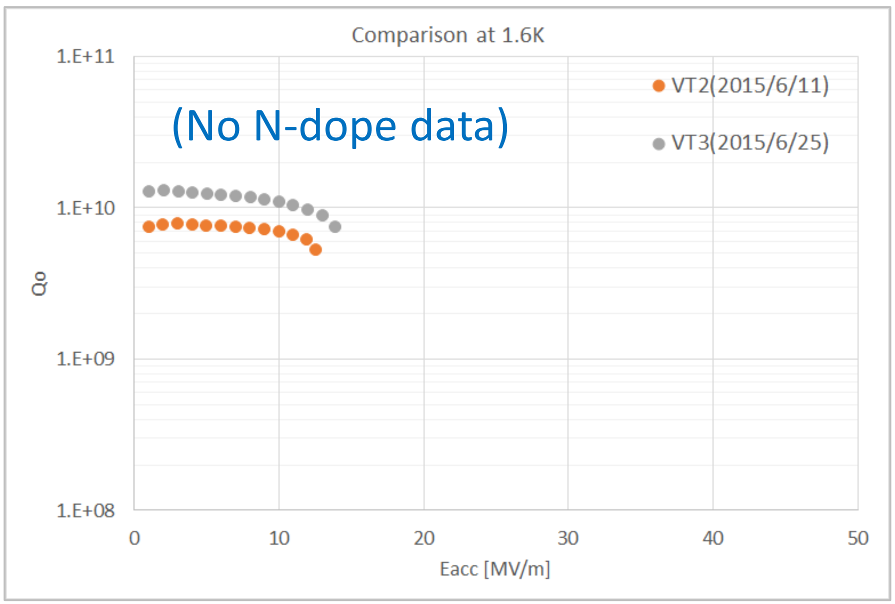
History of Fine grain(ULVAC) single-cell cavity

Date	Process	Details
2015/2/12	EP-1	100um
2015/2	Anneal	750deg, 3h
2015/3/3	EP-2(1)	20um EP-2, HPR, Assembly, Baking(140deg, 48hours)
2015/3/12	**VT(1)**	Confirm Eacc and Qo
2015/5/19	**N-dope(3)**	**800deg, 3h + 2.7Pa N-dope, 20min + 800deg, 6min**
2015/6/2	EP-2(2)	**15um EP-2**, HPR, Assembly, Baking(140deg, 48hours)
2015/6/11	**VT(2)**	
2015/6/16	EP-2(3)	**15um EP-2**, HPR, Assembly, Baking(140deg, 48hours)
2015/6/25	**VT(3)**	
2015/11/24	EP-2(4)	**5um EP-2**, HPR, Assembly, (No baking)
2015/12/21	**VT(4)**	
2016/3/16	**VT(5)@FNAL**	
2016/3/21	HPR	HPR, Assembly, (No baking)
2016/3/25	**VT(6)@FNAL**	

VT results (2.7Pa N-dope, 20min)







- Two times VT after N-doping, with 15um EP and additional 15um EP.
- Q values were drastically degraded.
- Quench field decreased to 13MV/m.
- Q values and quench field recovered little bit after additional EP.

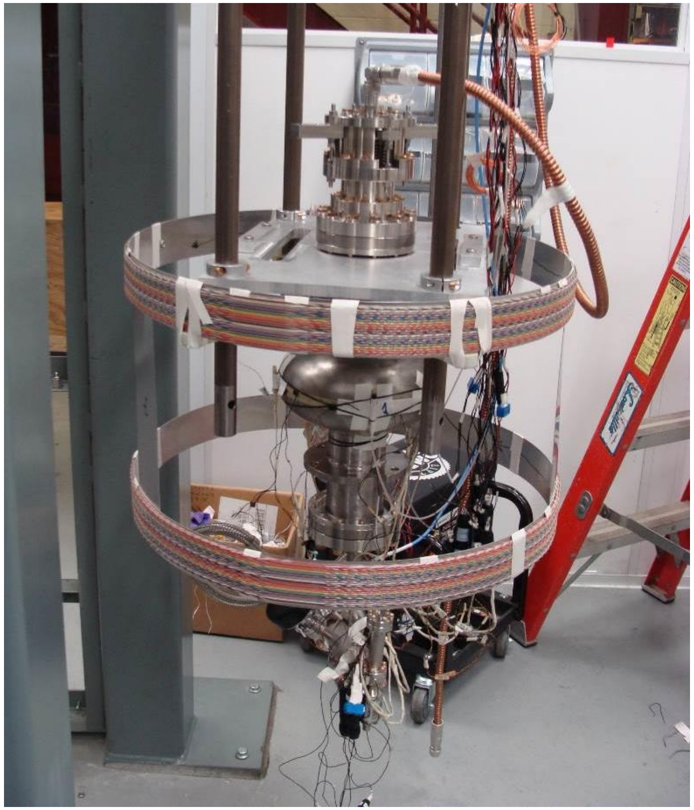
For tried three N-doping parameters, but everytime Rres becomes worse.

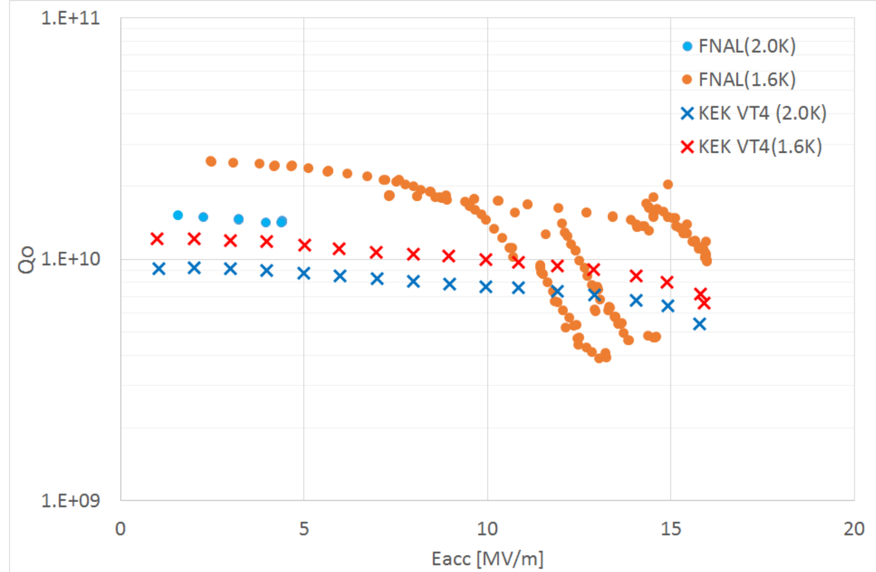
Why N-doping does not work?

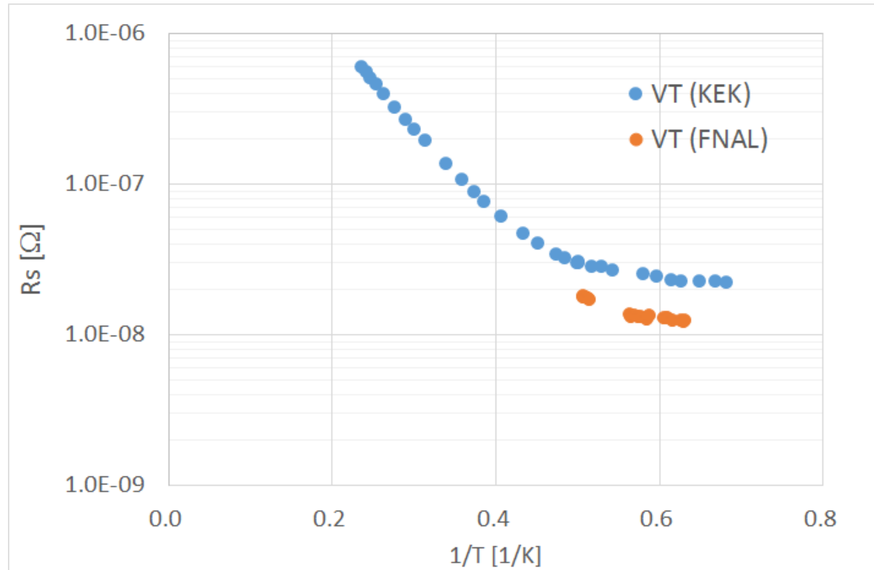
Possible reason of bad results are followings.

1. Nb surface was not N-doped correctly.
   - Something wrong?
   - Difference of vacuum system? (Cryopump or diffusion pump, oil-free?)
   - Difference on N-doping system?
2. Effect due to remnant field on vertical test cryostat. ⇒ VT@FNAL(March)
   - Trapping of magnetic field on N-doped surface is more sensitive to remnant field on vertical test cryostat.(More than a few ～ several times sensitive?)
   - KEK's VT cryostat has more than 10 mG.
   - Also depend on cooling procedure.
3. Cavity or material is wrong?
   - Cavity was made at KEK-CFF.
   - Nb supplier is ULVAC and Tokyo-Denkai.

Vertical test at FNAL (March)







- Vertical test of KEK N-doped cavity was carried out at FNAL, where magnetic field inside VT dewar is very small.
- However, Q-value was not good as nominal N-doping cavity.

Even in zero magnetics field, still Rres was too large.

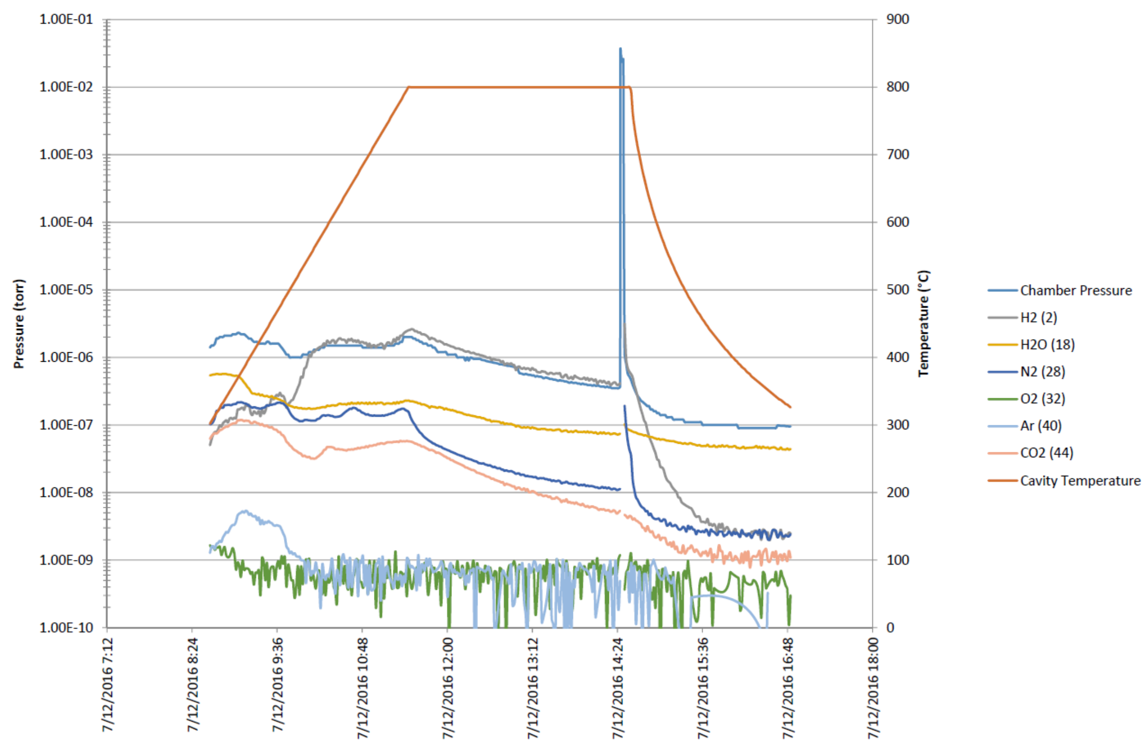
Why N-doping does not work?

Possible reason of bad results are followings.

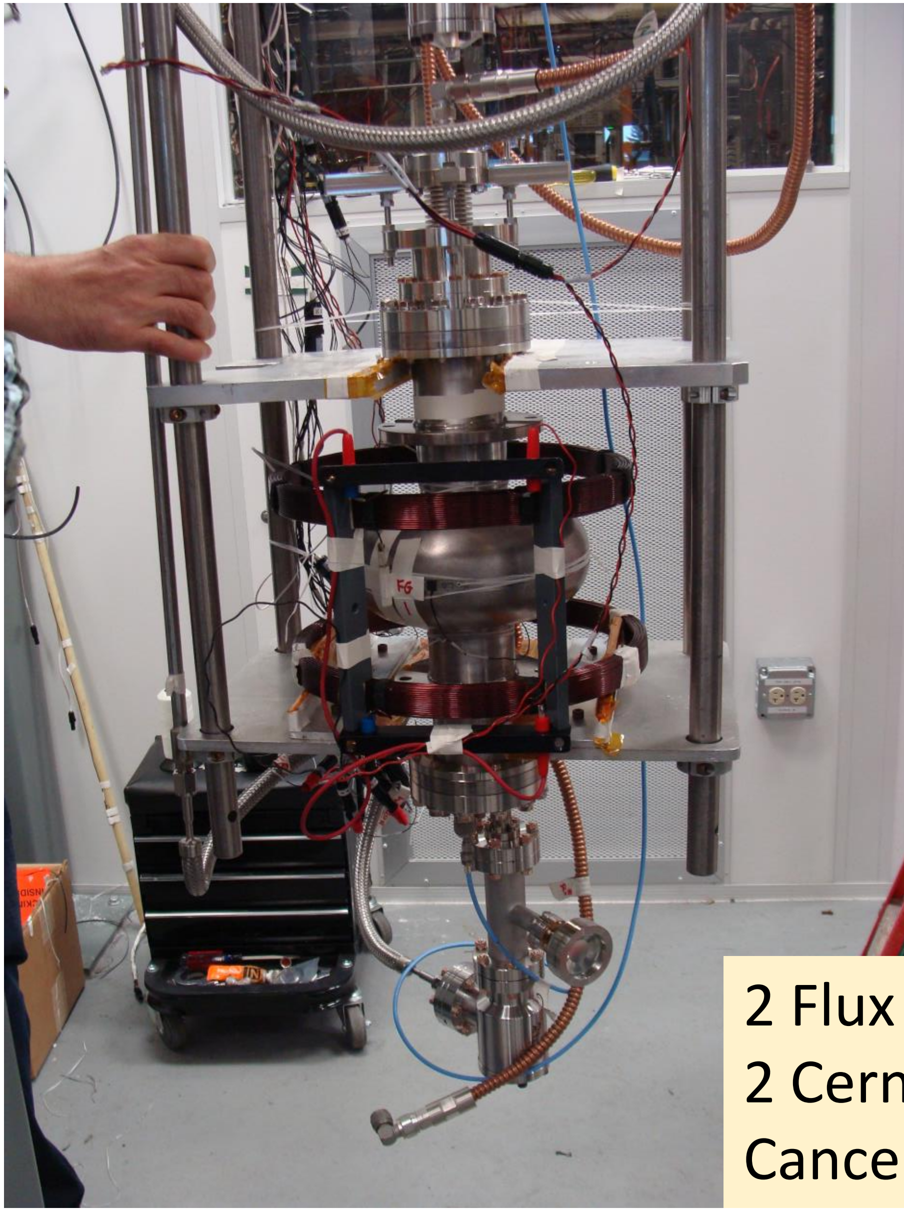
1. Nb surface was not N-doped correctly.
   - Something wrong?
   - Difference of vacuum system? (Cryopump or diffusion pump, oil-free?)
   - Difference on N-doping system?
2. Effect due to remnant field on vertical test cryostat. ⇒ VT@FNAL(March)
   - Trapping of magnetic field on N-doped surface is more sensitive to remnant field on vertical test cryostat.(More than a few ～ several times sensitive?)
   - KEK's VT cryostat has more than 10 mG.
   - Also depend on cooling procedure.
3. Cavity or material is wrong? ⇒ N-dope@FNAL and VT@FNAL(October)
   - Cavity is made at KEK-CFF.
   - Nb supplier is ULVAC and Tokyo-Denkai.

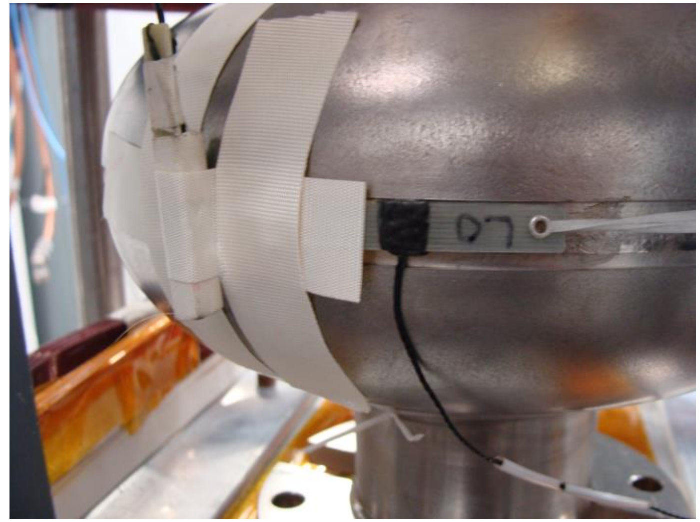
N-dope of KEK cavity @FNAL

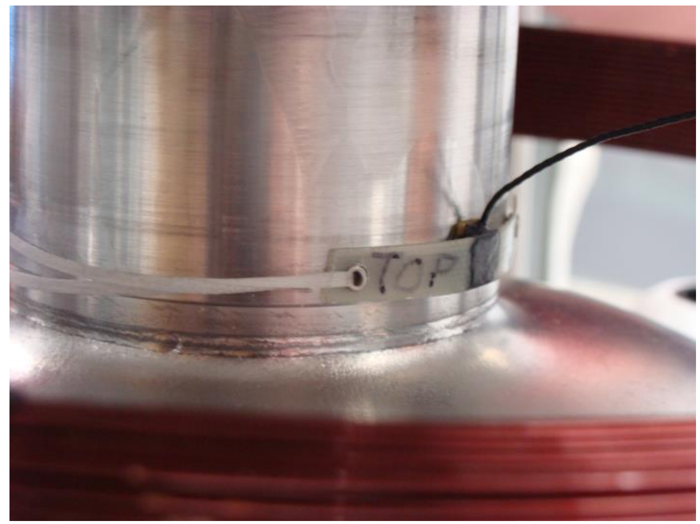
- 2016/7/9 EP 60um
- 2016/7/12 N-doping (FNAL standard recipe 2/6)
  - 800 deg, 3 hours
  - 2min N 25mTorr
  - 800 deg VAC, 6min
  - Cooling down
- 2016/9/13 EP 6um
- 2016/10/25, 26 VT



VT setup





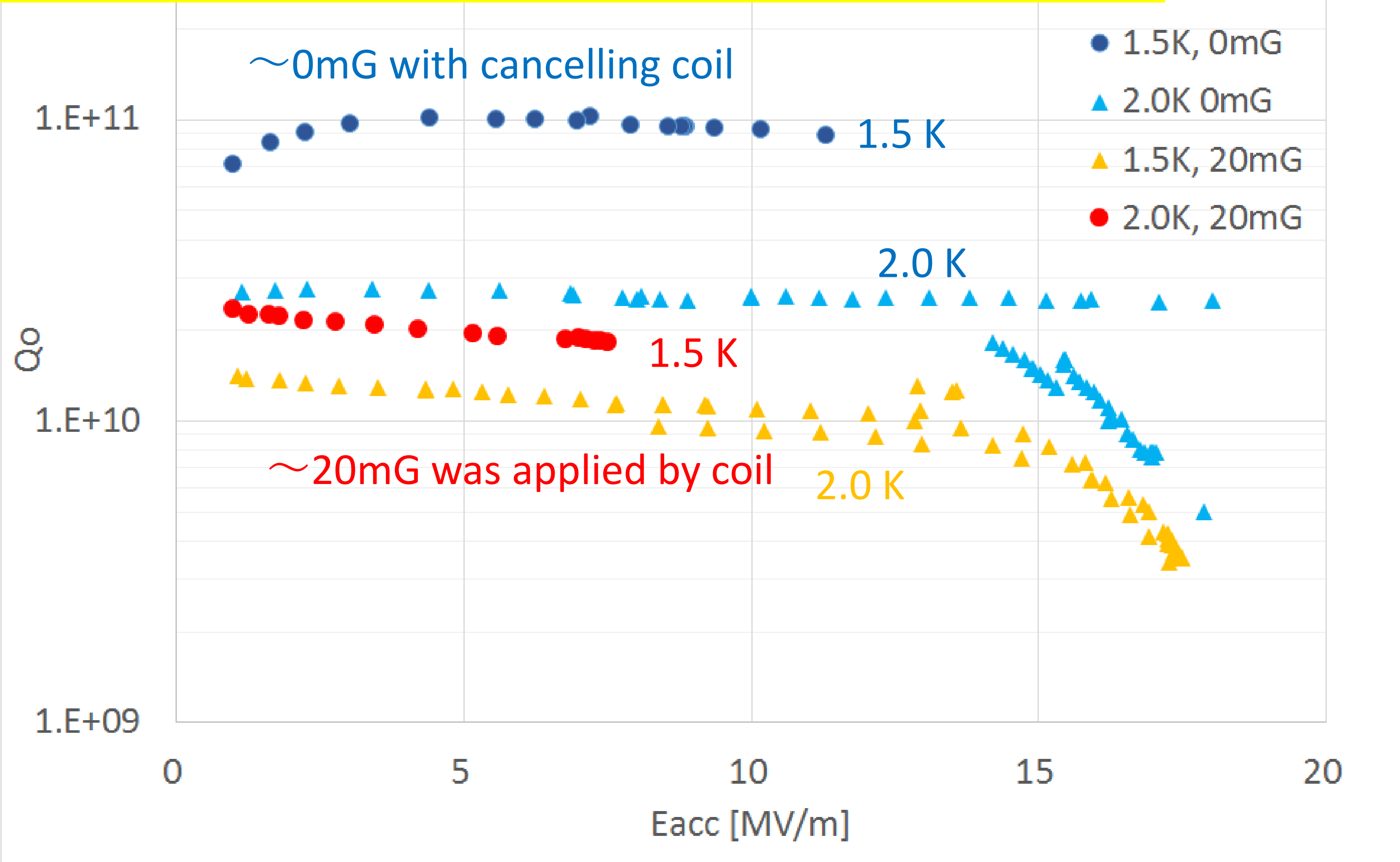


2 Flux gate at equator
2 Cernox at Equator and 2 at both beampipe
Cancelling coil

VT results

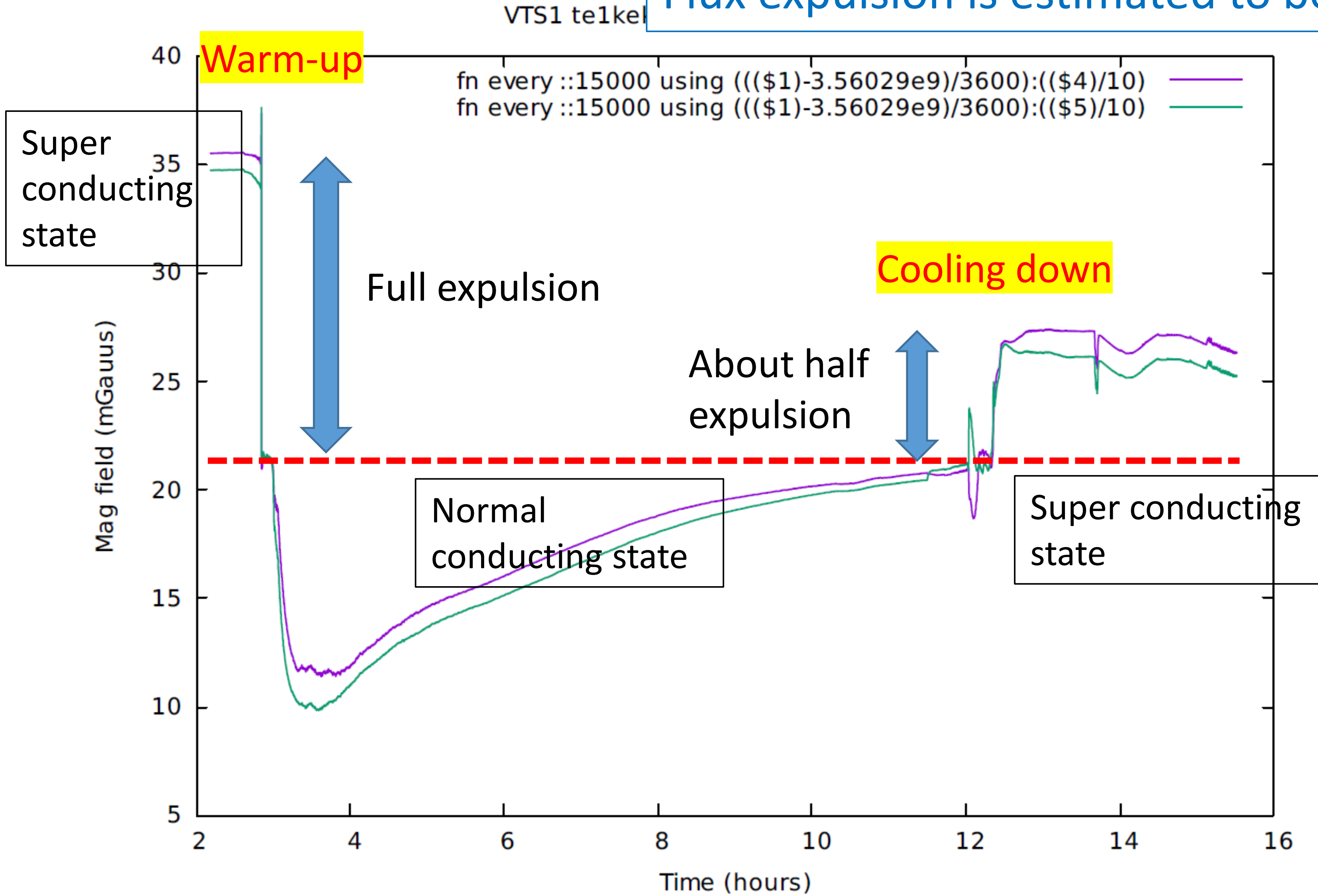
Q = 1e11 at 1.5 K with zero magnetic field
Q = 2.8e10 at 2.0 K with zero field
Q = 2.4e10 at 1.5 K with 20 mG

N-doping successful !! Thanks for FNAL-SRF group!!



Flux expulsion

Test of flux expulsion under 20 mG of magnetic field.
Flux expulsion is estimated to be about half.



Why N-doping does not work?

Possible reason of bad results are followings.

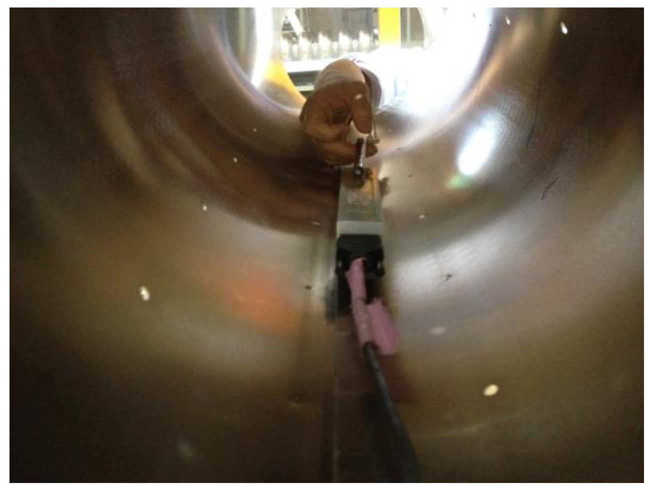
1. Nb surface was not N-doped correctly.
   - Something wrong?
   - Difference of vacuum system? (Cryopump or diffusion pump, oil-free?)
   - Difference on N-doping system?
2. Effect due to remnant field on vertical test cryostat. ⇒ VT@FNAL(March)
   - Trapping of magnetic field on N-doped surface is more sensitive to remnant field on vertical test cryostat (More than a few ～ several times sensitive?)
   - KEK's VT cryostat has more than 10 mG.
   - Also depend on cooling procedure.
3. Cavity or material is wrong? ⇒ N-dope@FNAL and VT@FNAL(October)
   - Cavity is made at KEK-CFF.
   - Nb supplier is ULVAC and Tokyo-Denkai.

Measure against magnetic field

Study on magnetized components (example)

From T. Yanagimachi(9/26)

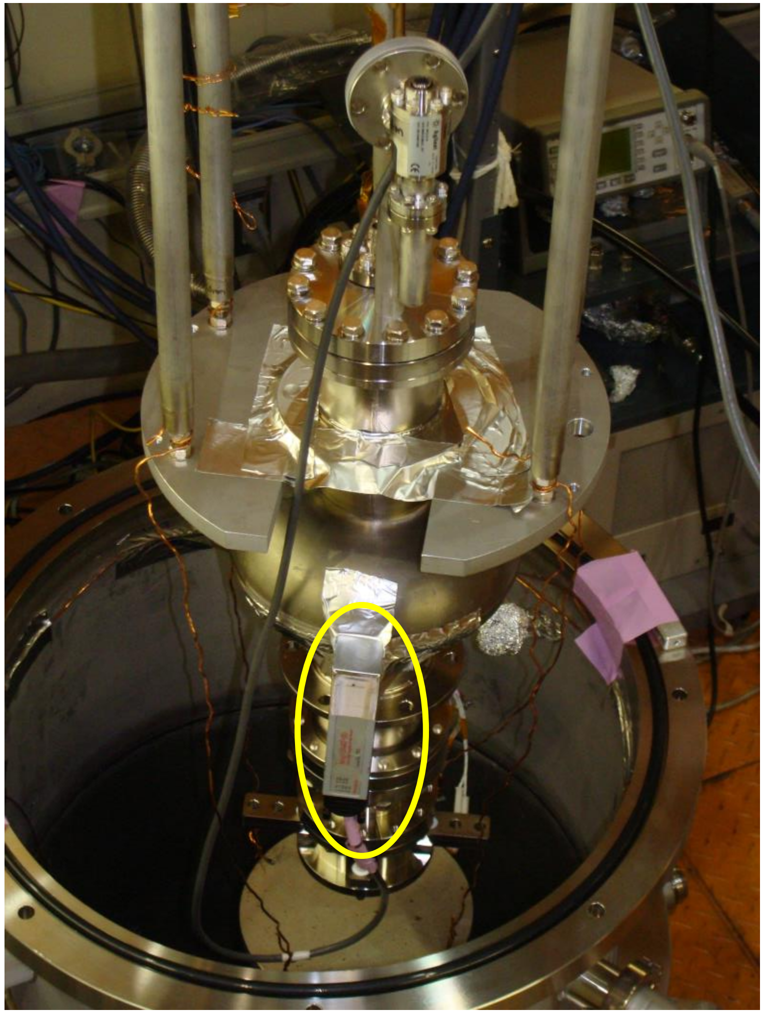
No.	name	Magnetic field [mG]
14	Φ034 metal valve ①	430
15	Φ034 metal valve (which observed vacuum leak)	80
19	Φ034 metal valve ②	59
25	Volts and washers for support of input coupler shaft	140
28	Nuts and washers for hanging cavity	110
29	Stat-volts, nuts and washers for hanging cavity	300



Measure inside magnetic shield by using 3-axis flux gate sensor.

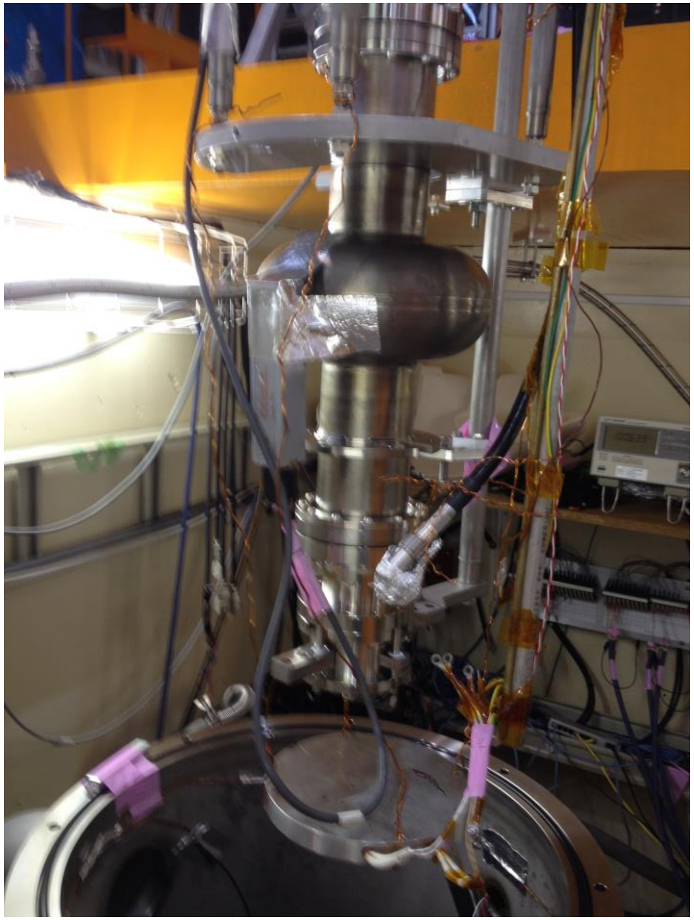
Measurement inside cryostat

- Measure magnetic field around equator of single-cell cavity inside the cryostat by 3-axis flux gate sensor, while changing condition of flanges and jigs.
- Measurements were done at 0, 90, 180 and 270 degree of equator.
- Conditions
  - ① Only cavity; without flanges and minimum jigs.
  - ② Almost full setup with flanges and jigs
  - ③ One tuner shaft for input coupler was removed from ②
  - ④ Both of tuner shafts for input coupler were removed from ②
  - ⑤ Changed Φ034 metal valve with highly magnetized one. Other conditions are same with ④



No	Flange	270 deg Shaft	90 deg Shaft	Metal valve	Angle	Bx [mG]	By[mG]	Bz[mG]	B[mG]
1	No	No	No	No	0	1	0	-1	2
					90	1	1	-1	2
					180	0	0	-1	1
					270	1	0	-2	2
2	Yes	Yes	Yes	Yes (A)	0	-7	-11	-6	15
					90	-6	2	-9	11
					180	6	-11	-7	15
					270	8	130	-49	139
3	Yes	No	Yes	Yes (A)	0	1	0	-2	2
					90	-5	9	-5	12
					180	0	0	-2	2
					270	0	0	-2	2
4	Yes	No	No	Yes (A)	0	1	1	-2	2
					90	0	1	-1	2
					180				
					270				

Remove one shaft from setup



Removed shaft for input coupler tuning

SUS shafts were highly magnetized. More than 1 G!!
Already exchanged with Ti shafts.

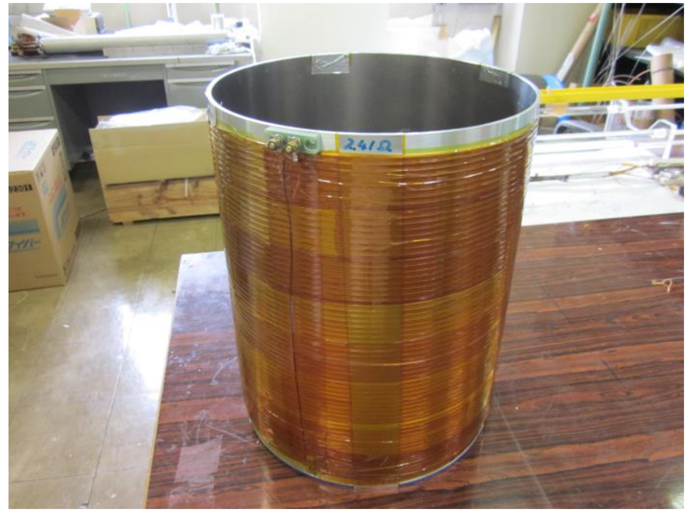
From slide M. Masuzawa(2016/8/26)

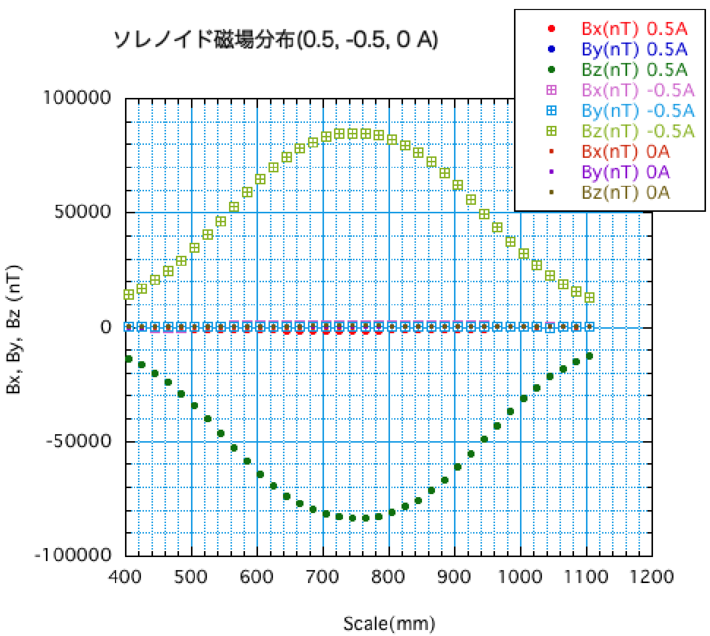
Solenoid coil for control magnetic field

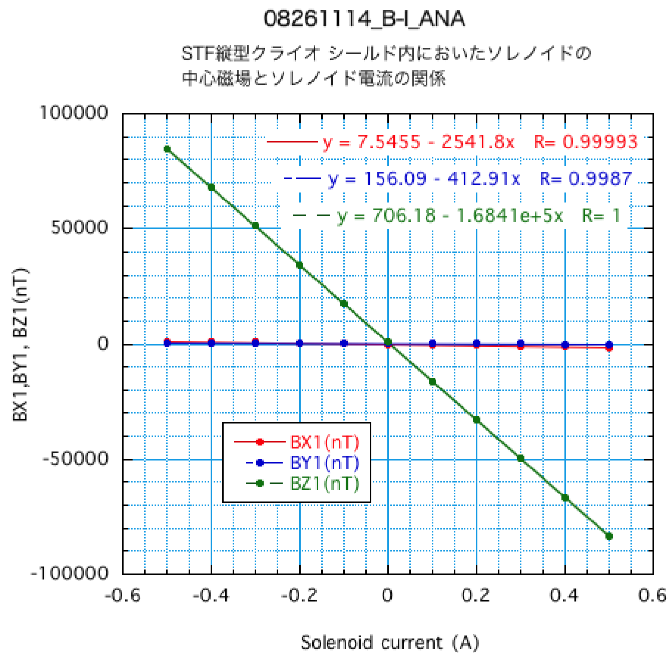
Inner of bobbin：　326 mm
Outer of solenoid：　339 mm
Length of bobbin：　~420 mm
No of turn：　64 Turns

Resistance(RT)：　2.36 Ω

Design value：　B0= 0.7 G @ NI=32 AT

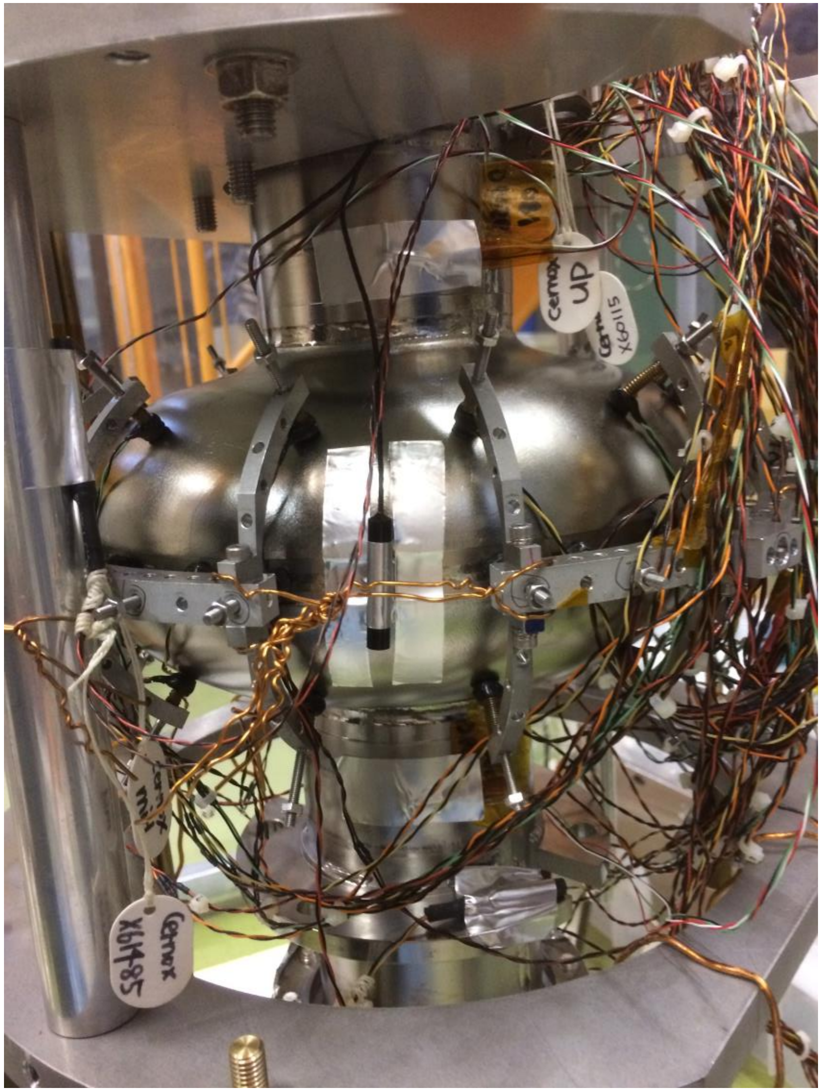






- ~850 mG can be generated by +/- 0.5A of current
- Linearity is fine

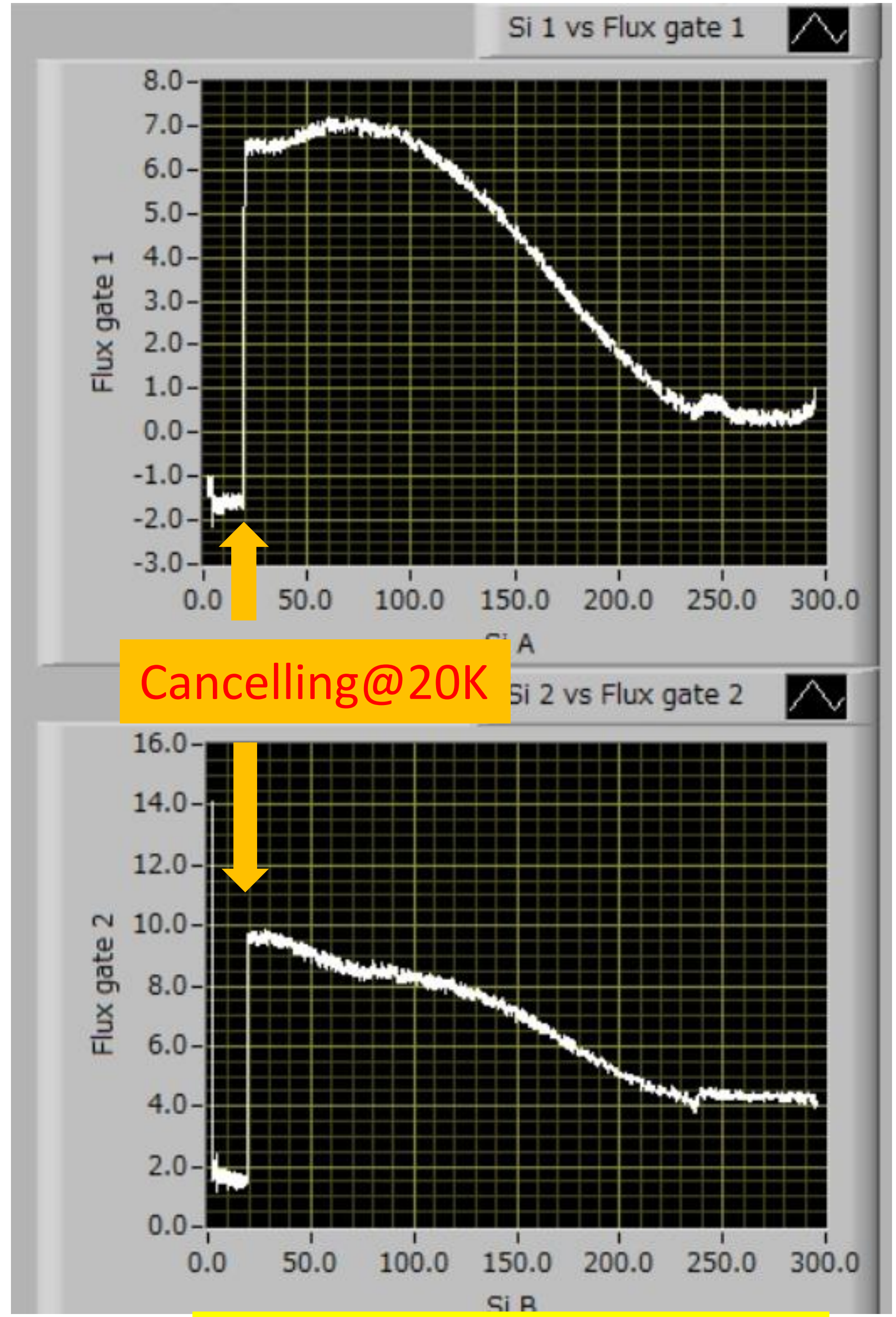
VT setup for R-6 cavity



Carbon sensor, X-ray sensor (PIN diode), flux gate sensor, solenoid coil were used.

Control of mag. field

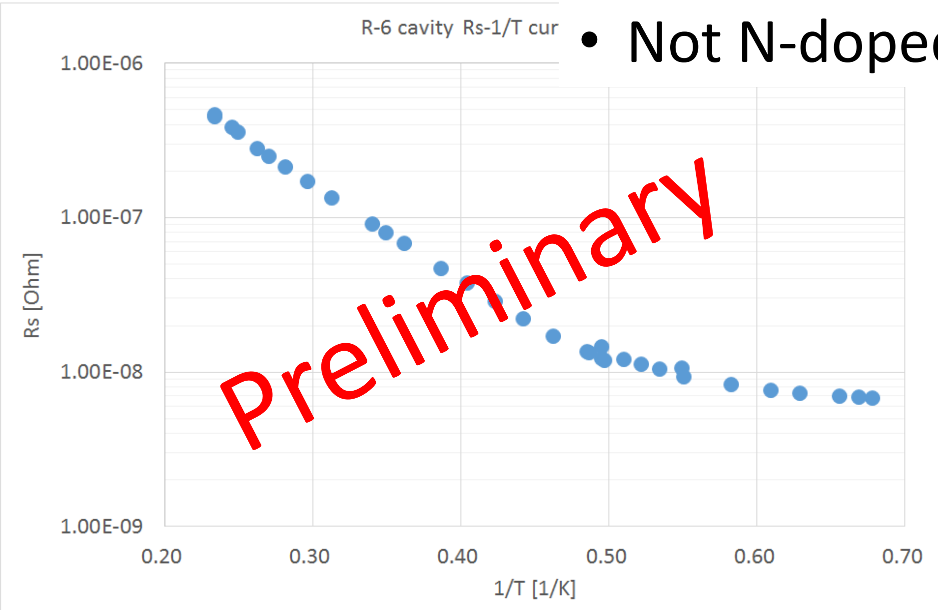
- Flux gate was located at equator 60 deg(FG1) and 240 deg(FG2)
- At RT
  - FG1：～0.5 mG
  - FG2：～4.2 mG (large)
- Low temp(20K)
  - FG1：～6.5 mG
  - FG2：～9.7 mG
- With solenoid (+4.56mA)
  - FG1：～ -1.55 mG
  - FG2：～+1.55mG
- Cancelling was done successfully (at least considering values)

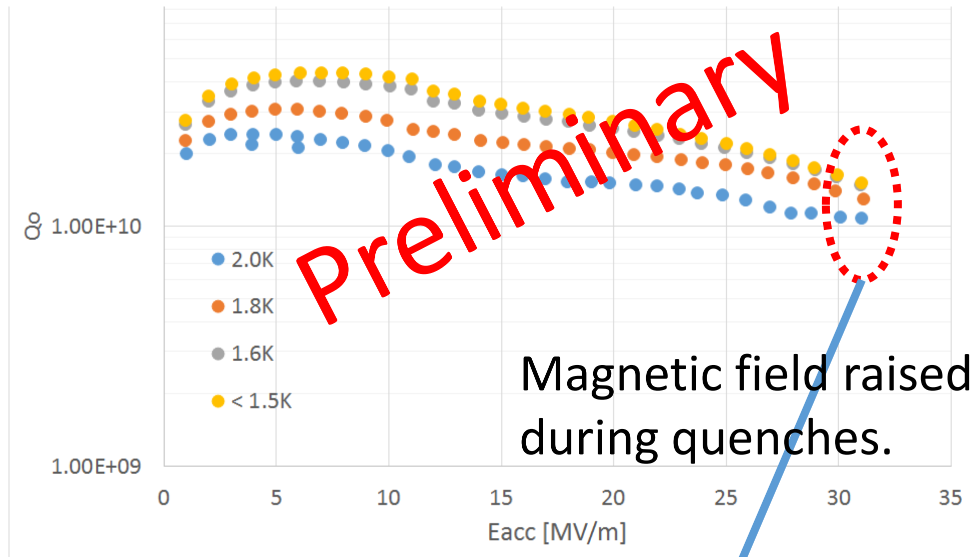


This is first try at KEK !!

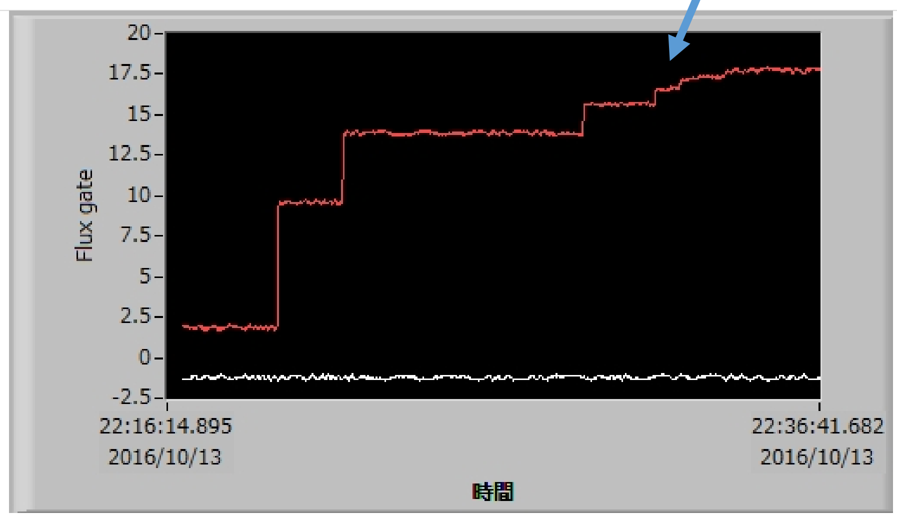
VT resulst

- Rres ～6.6 nΩ
- Almost same or little bit better than nominal results for single cell cavity
- Not N-doped cavity. ILC standard treatment.



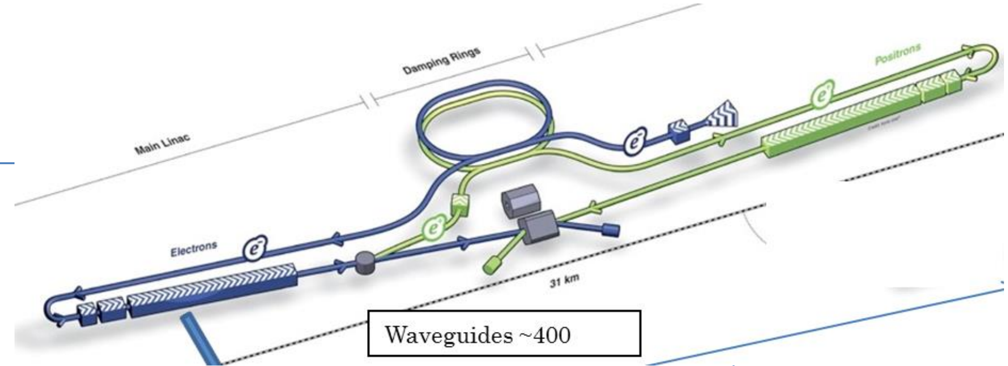


- Quench at Eacc = 31 MV/m
- 10% of Qo droped after 2K self-pulse
- Magnetic field was trapped during quenches? (Heat spot is close to flux gate.)



R&D plan at KEK

R&D for ILC



A. Short-term R&D (2–3 years)

A-1. Niobium material preparation

- with new processing for sheeting and piping

A-2. SRF cavity fabrication for *high gradient and high Q*

- with a new surface process recipe provided by Fermilab

A-3. Power input coupler fabrication

- with new-ceramic window (w/o additional coating)

A-4. Cavity chemical treatment

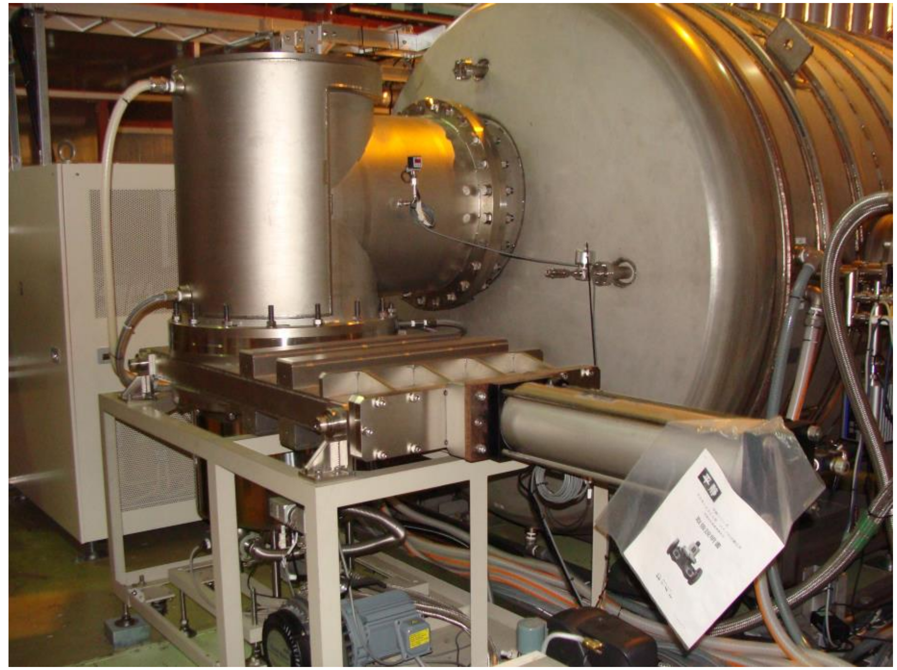
- with vertical configuration and new chemical

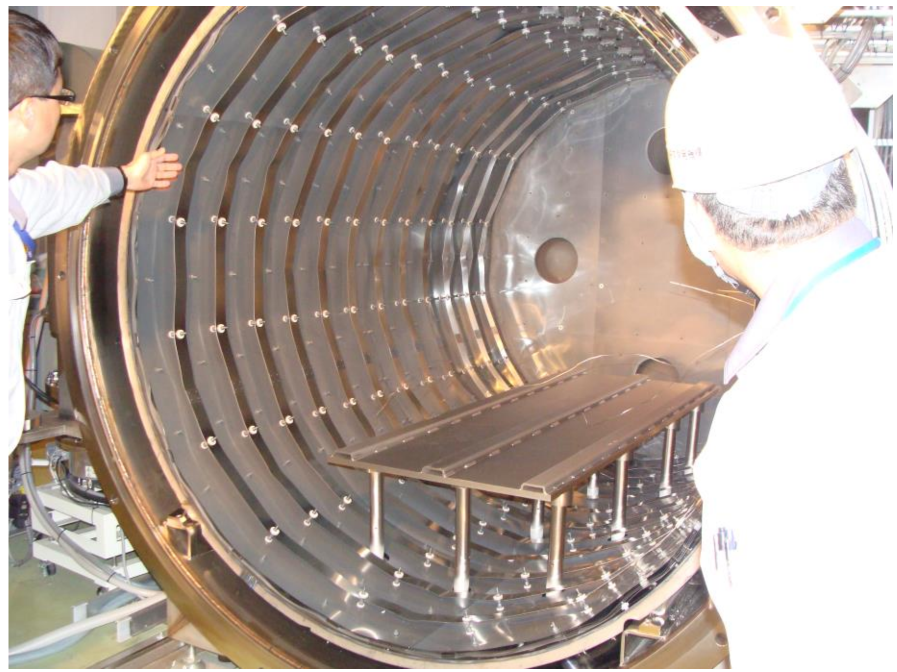
- KEK support high-Q & High-Gradient study for ILC.
- Plan to buy new furnace next year.
- Start from single-cell cavities.
- Hope to obtain reliable results for 9-cell cavities within a few year.

Test with single-cell cavity

	Main pump system	Sub pump system	120 deg N2 (new)	Original N2-doping
FNAL with FNAL cavity	Cryo	Dry roots	○ (Success)	○ (Success)
FNAL with KEK cavity	Cryo	Dry roots	Test in future?	○ (Success)
DESY with DESY cavity	TMP	Dry	Test	----------
KEK with KEK cavity	Diffusion	Mechanical booster + Rotary	Test?	× (Fail)
J-PARC with KEK cavity	Cryo	TMP + scroll	Test	Test

Furnace at J-PARC





- J-PARC has oil-frre furnace with cryo-pump and TMP.
- We try to use it for N-doping / N-infusion.
- Preparation are is clean with filter, but furnace is not.

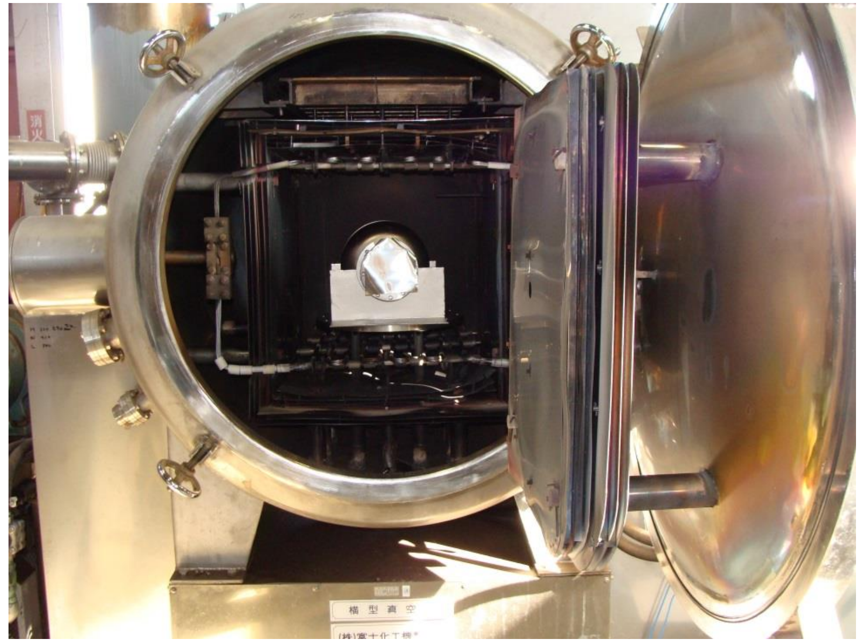
Summary

- KEK still continue efforts for high-Q.
- N-doping at KEK was not good, but doping at FNAL was fine.
- We started to remove magnetized components
- Solenoid coil was produced and cancelling was tried.
- We will do surface analysis of Nb.
- KEK support “high-Q & high-gradient study” for ILC R&D.
- Hope to have good results within a few year.

- I would like to ask all of you to help us to realize good performance of cavity for ILC.

Backup slide

N-doping system(1) ~small furnace



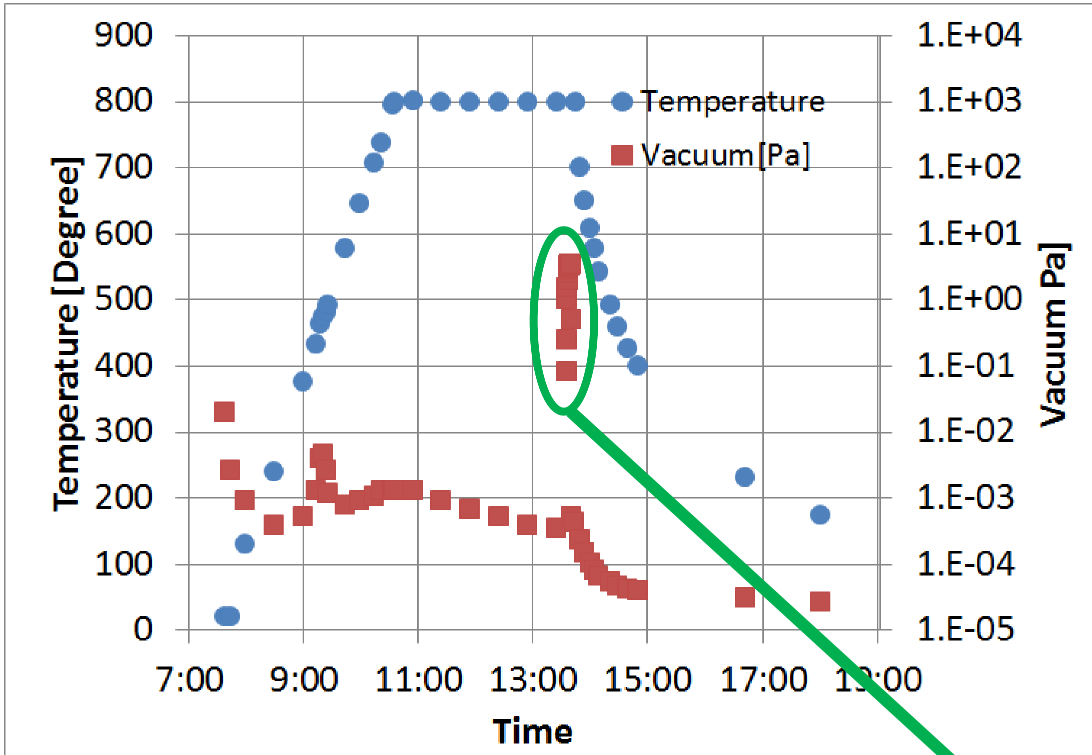
・Simple N-doping system was constructed on small furnace which was for single-cell cavity annealing.

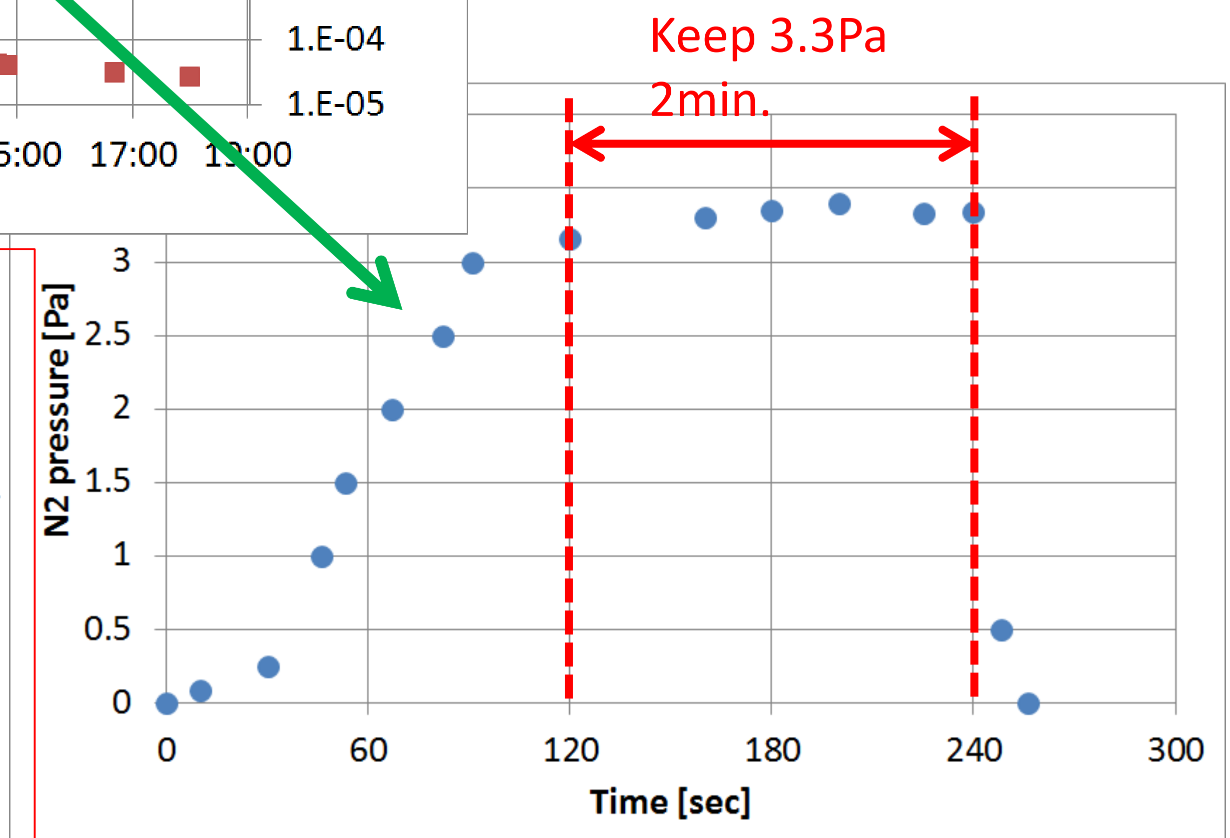
・Nitrogen pressure is controlled by manual valve.

・Nitrogen pressure is monitored by convection gauge.

・No cryopump. Diffusion pump works.

Typical N-doping by small furnace



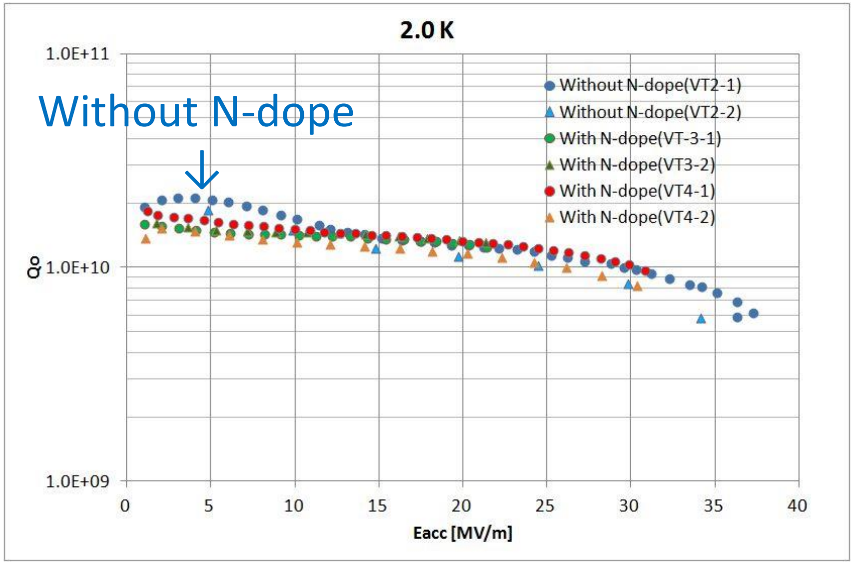


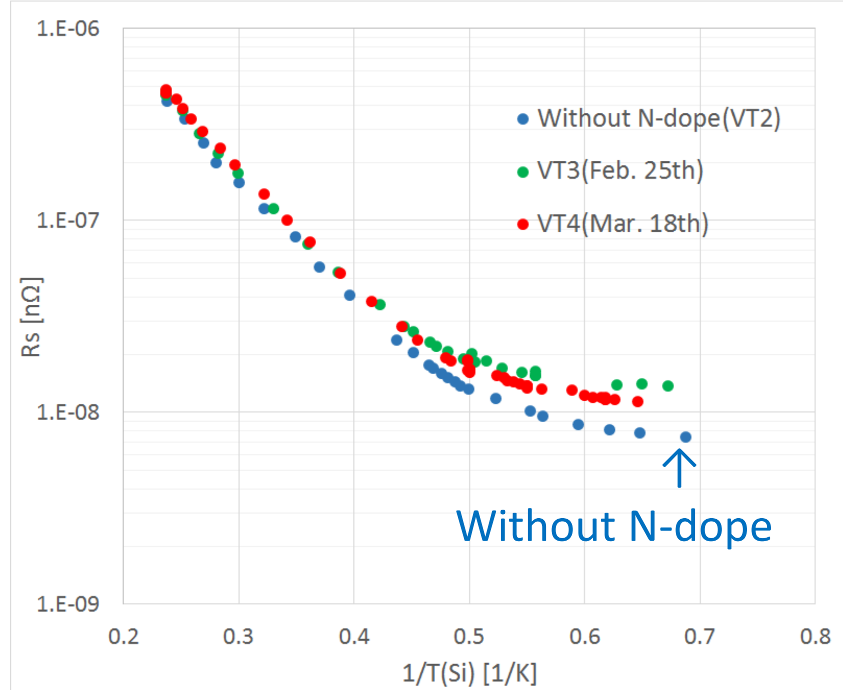
- Upto 800C with 3hours
- Keep 800C, 3hours
- N-doping
  - -- Stable state within 2min.
  - -- Keep 3.3Pa, 2min.
  - -- After valve close, vacuum recover quickly
- Keep 800C, 6min
- Heater OFF ⇒ cool down

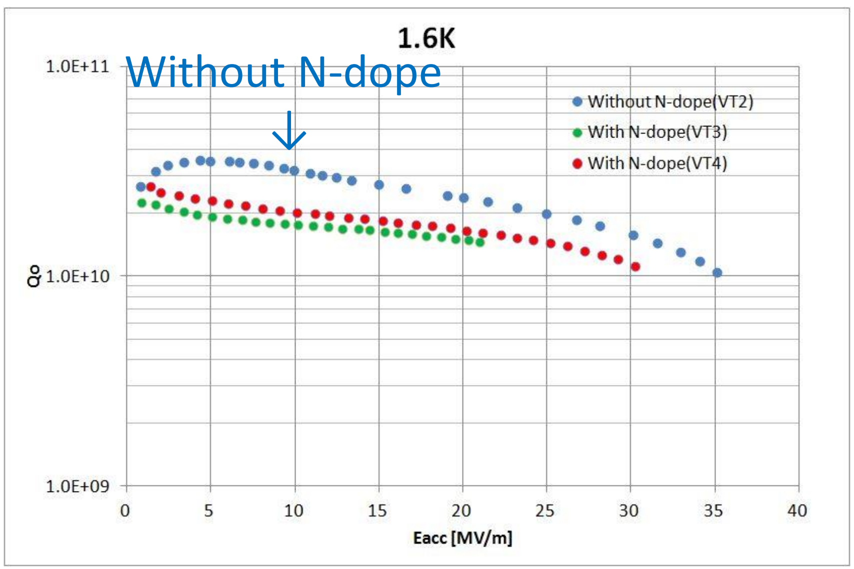
History of Fine grain(Tokyo-denkai) single-cell cavity

Date	Process	Details
2014/7～	EP-1(100um)⇒ anneal⇒ EP-2(20um)⇒ VT⇒EP-2(20um)	
2015/1/22	VT(2)	Confirm Eacc and Qo at bulk Nb condition
2015/2/9	**N-dope(1)**	**800deg, 3h + 3.3Pa N-dope, 2min + 800deg, 6min**
2015/2/17	EP-2(3)	5um EP-2, HPR, Assembly
2015/2/25	VT(3)	
2015/3/10	EP-2(4)	10um EP-2, PR, Assembly, Baking(140deg, 48hours)
2015/3/18	VT(4)	
2015/4/3	**N-dope(2)**	**800deg, 3h + 5.5Pa N-dope, 20min + 800deg, 30min**
2015/4/7	EP-2(5)	15um EP-2, PR, Assembly, Baking(140deg, 48hours)
2015/4/16	VT(5)	
2015/5/11	EP-2(6)	10um EP-2, PR, Assembly, Baking(140deg, 48hours)
2015/5/20	VT(6)	
2015/6/9	EP-2(7)	10um EP-2, PR, Assembly
2015/6/18	VT(7)	
2015/8/18	EP-2(8)	10um EP-2, PR, Assembly, Baking(140deg, 48hours)
2015/8/27	VT(8)	

VT results (3.3Pa N-dope, 2min)

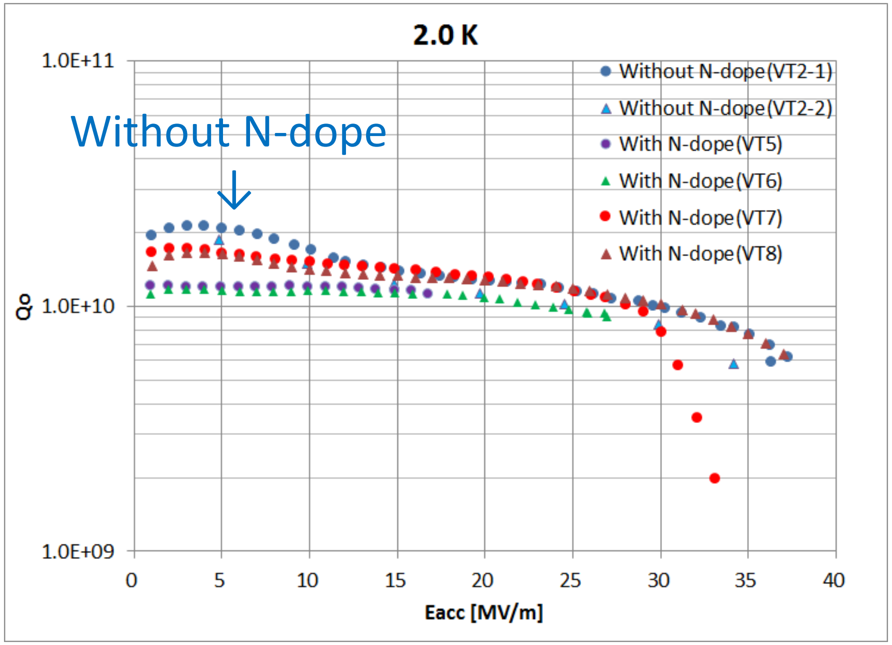


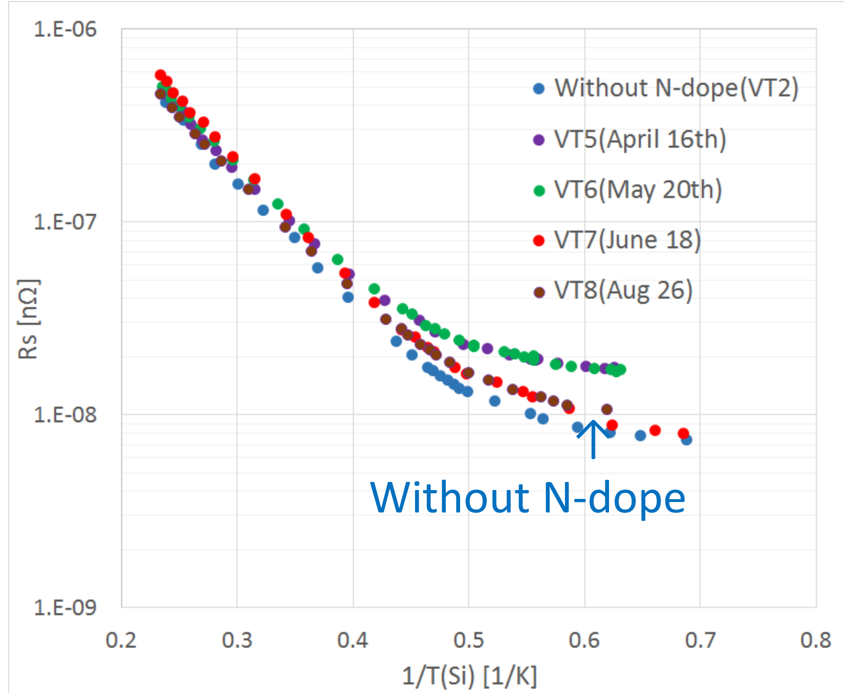


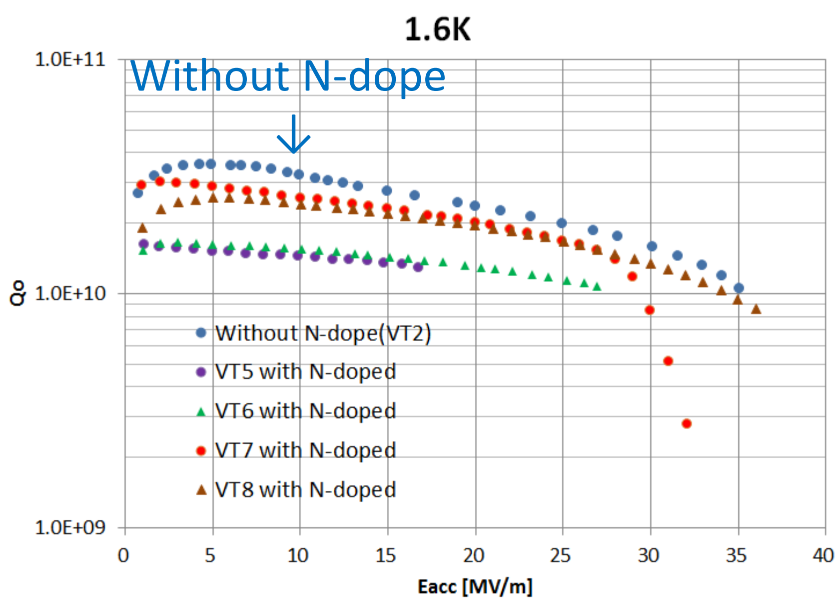


- Two times VT after N-dope, with 5um EP and additional 10umEP
- Q value degraded compared with No N-doping case.
- Quench field decreased to 22MV/m and 30 MV/m.

VT results (5.5Pa N-dope, 20min)





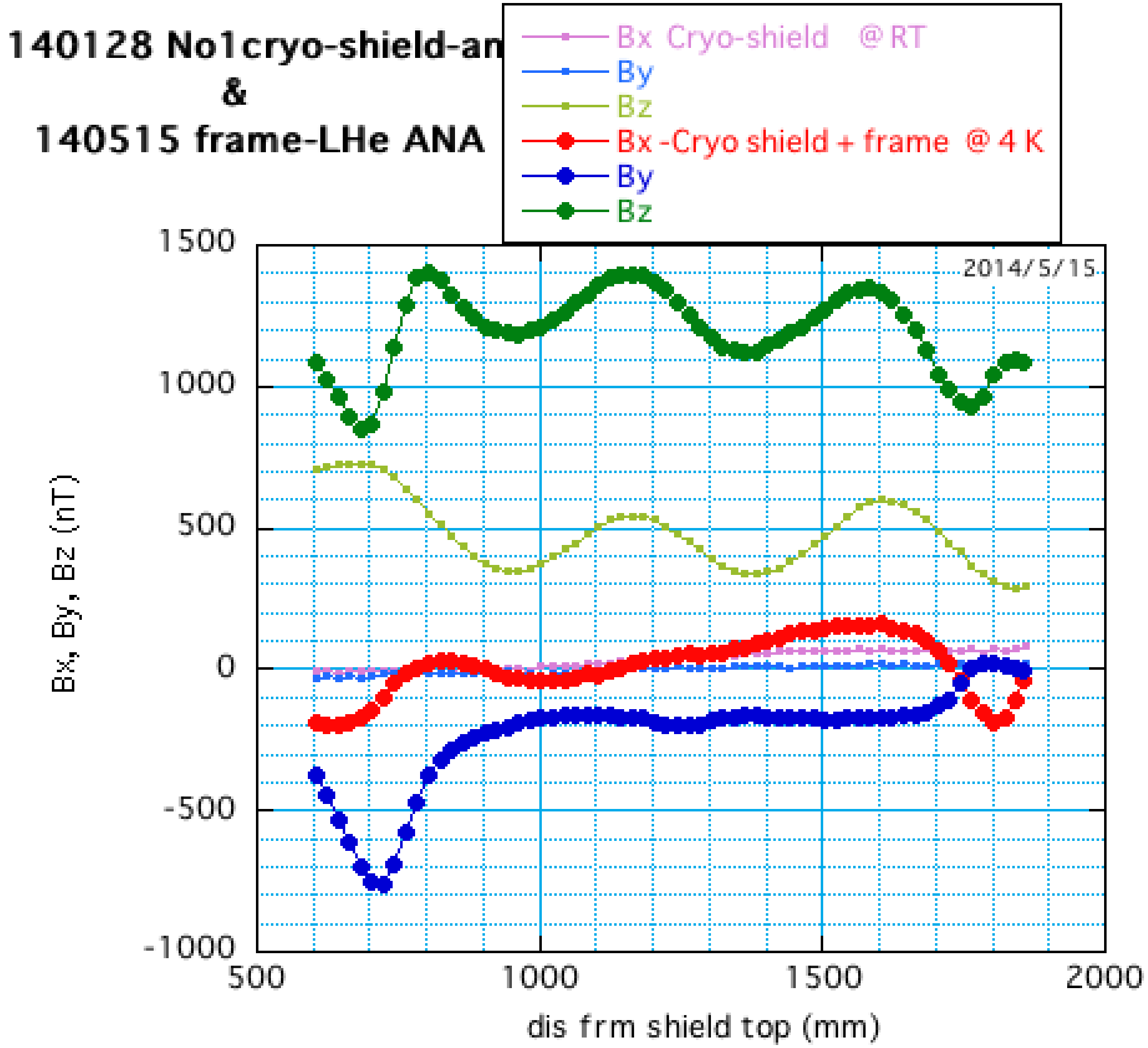


・Four times VT was carried out after N-doping, with 15um EP and additional 10um, 10um, 10um EP.

・Q values were always low.

・Quench field decreased to 17MV/m, and recovered with additional EP. Quench locations are different for every measurements.

Remnant field inside STF VT cryostat(@4K)



- Measurement was done with support tools for 9-cell measurement at 4K.
- Remnant field was 12～13mG.
- Part of contribution come from support tools ～5mG