N-doping trial at KEK
～not successful example～

2015/12/1

TTC meeting WG1

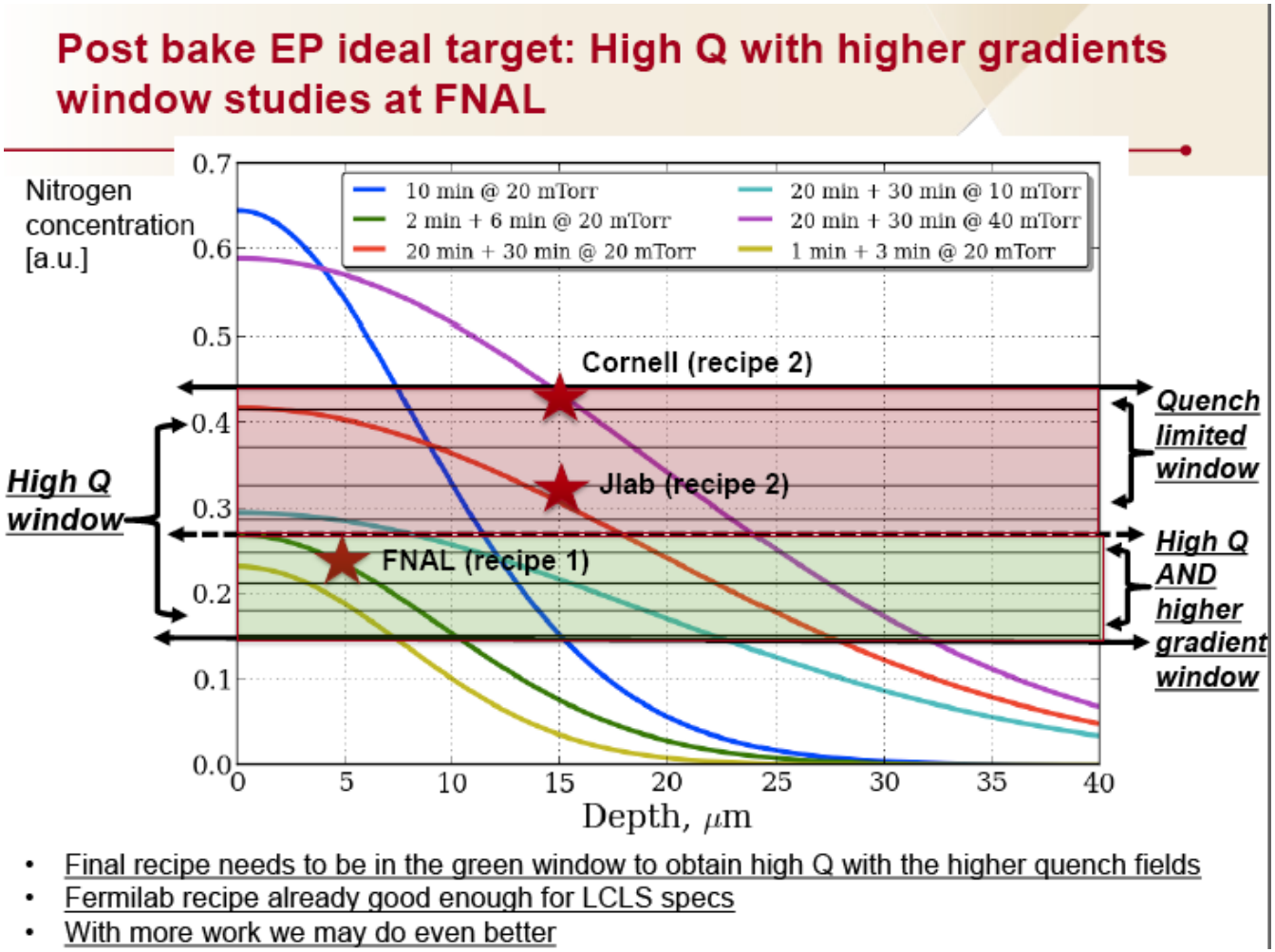
Kensei Umemori (KEK)

We tried three N-doping parameter

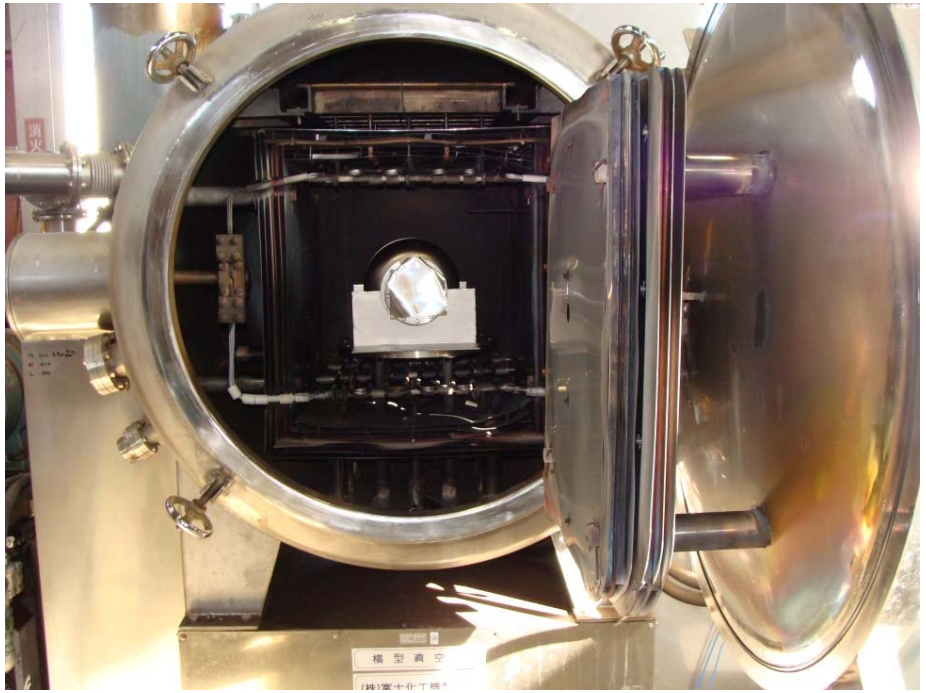
(1) 800deg, 3h + 3.3Pa N-dope, 2min + 800deg, 6min

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

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



N-doping system(1) ~small furnace



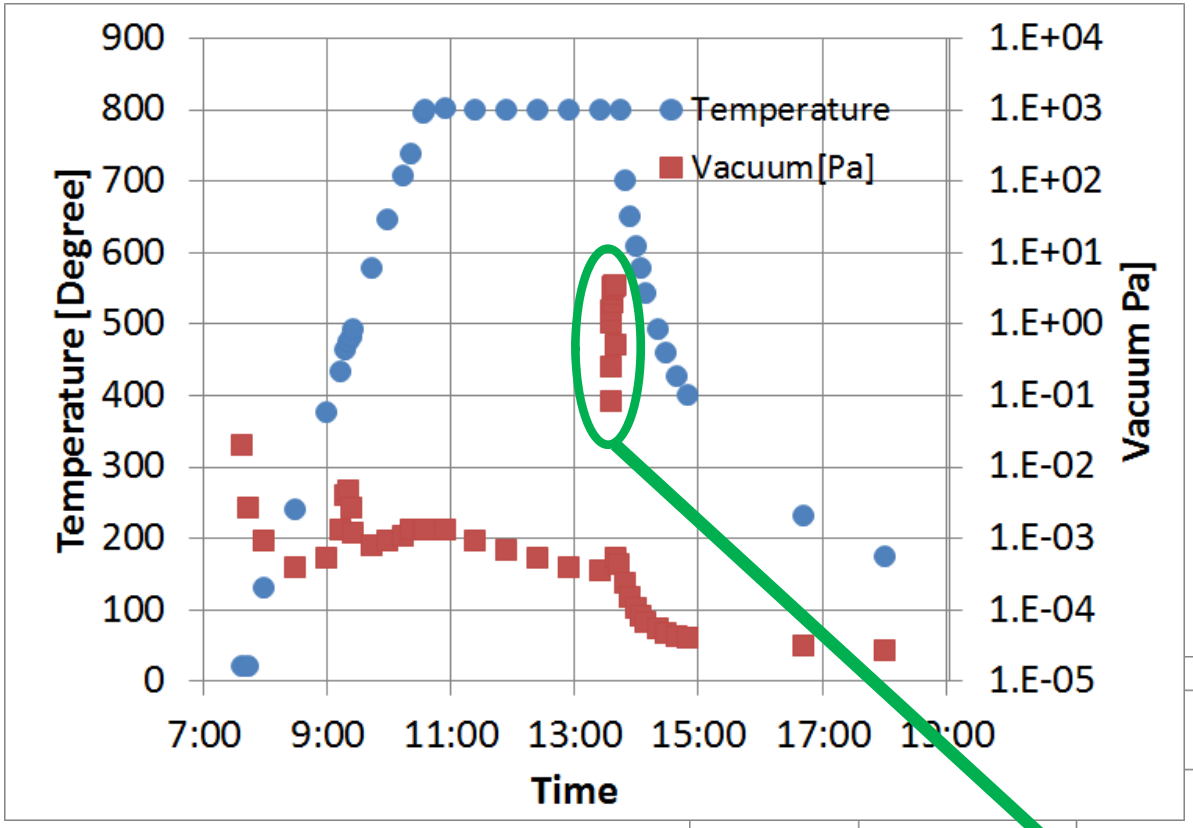
・Simple N-doping system was constructed on small furnace which was for single-cell cavity annealing.

・Nitrogen pressure is controlled by manual valve.

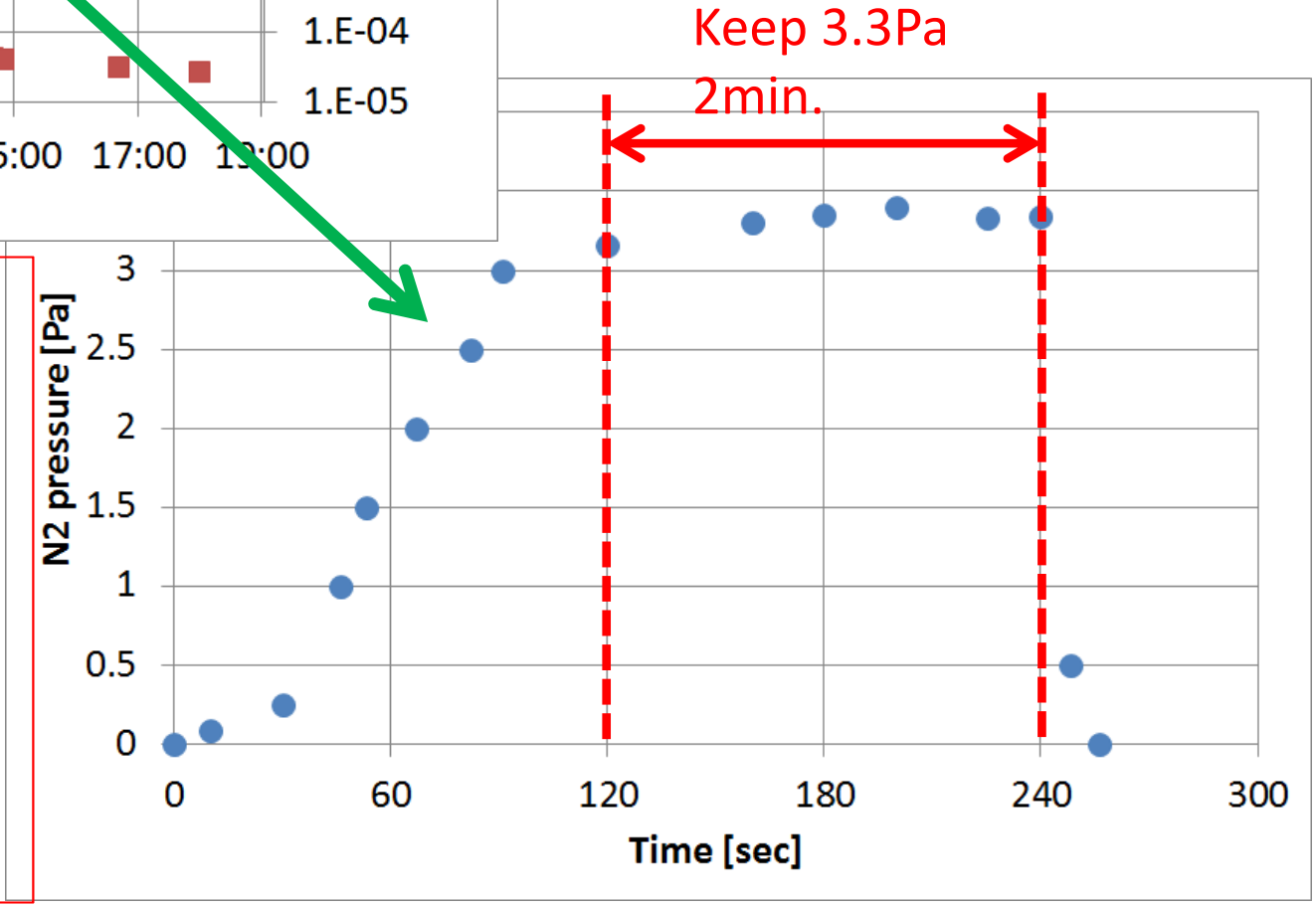
・Nitrogen pressure is monitored by convection gauge.

・No cryopump. Diffusion pump works.

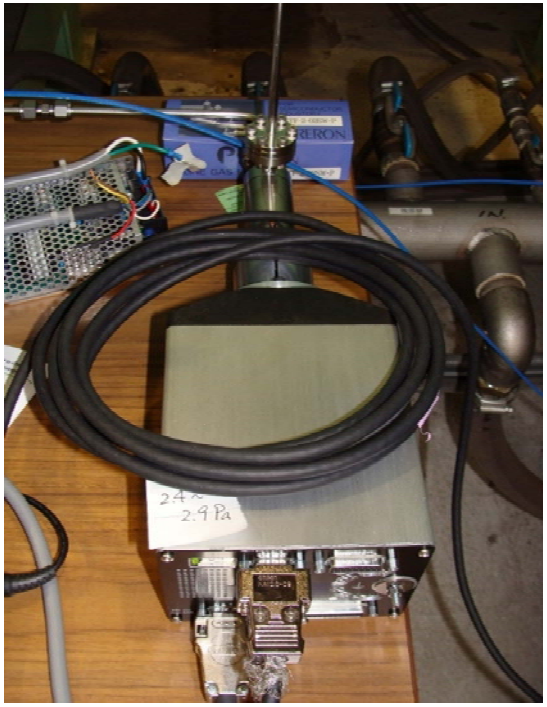
Typical N-doping by small furnace

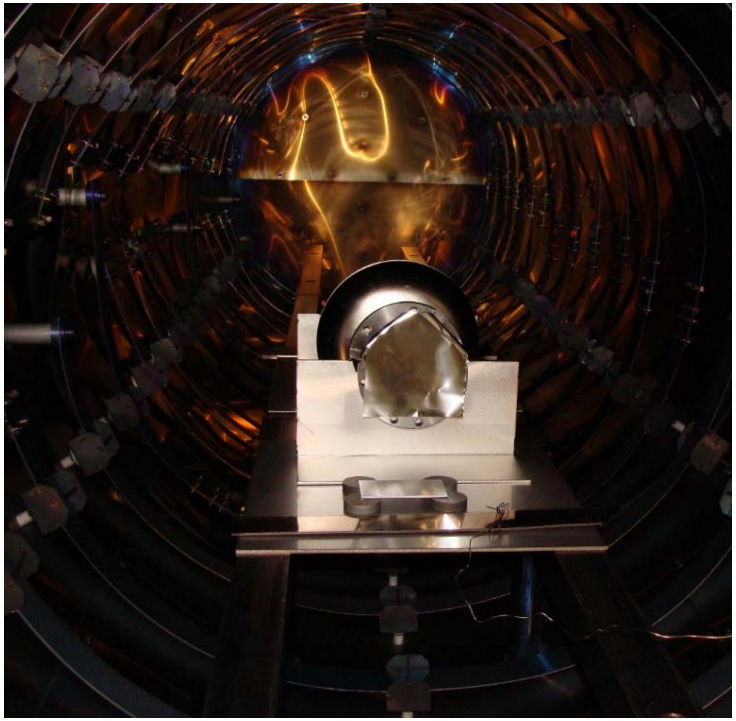


- Upto 800C with 3hours
- Keep 800C, 3hours
- N-doping
  - -- Stable state within 2min.
  - -- Keep 3.3Pa, 2min.
  - -- After valve close, vacuum recover quickly
- Keep 800C, 6min
- Heater OFF ⇒ cool down



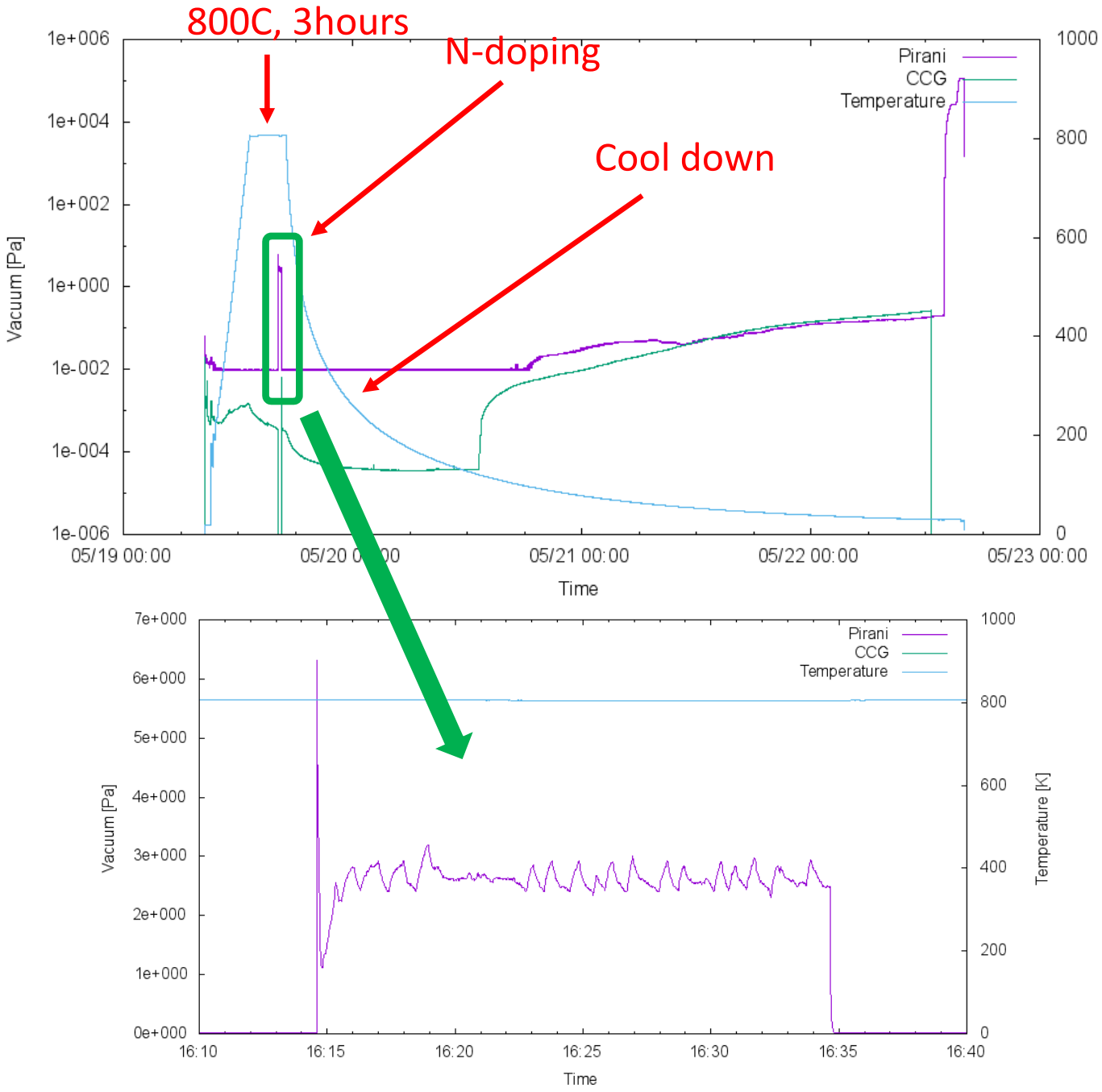
N-doping system(2) ~large furnace





・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 large furnace

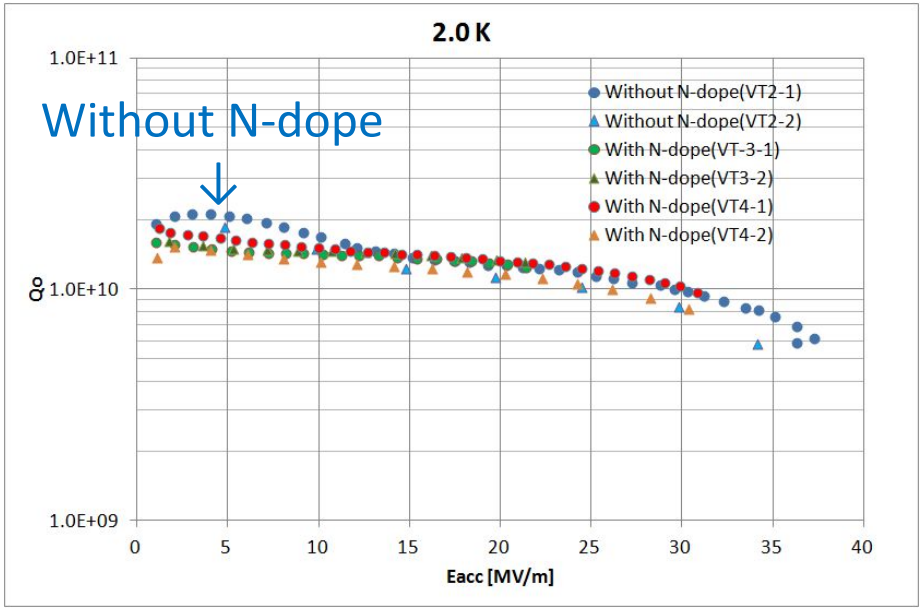


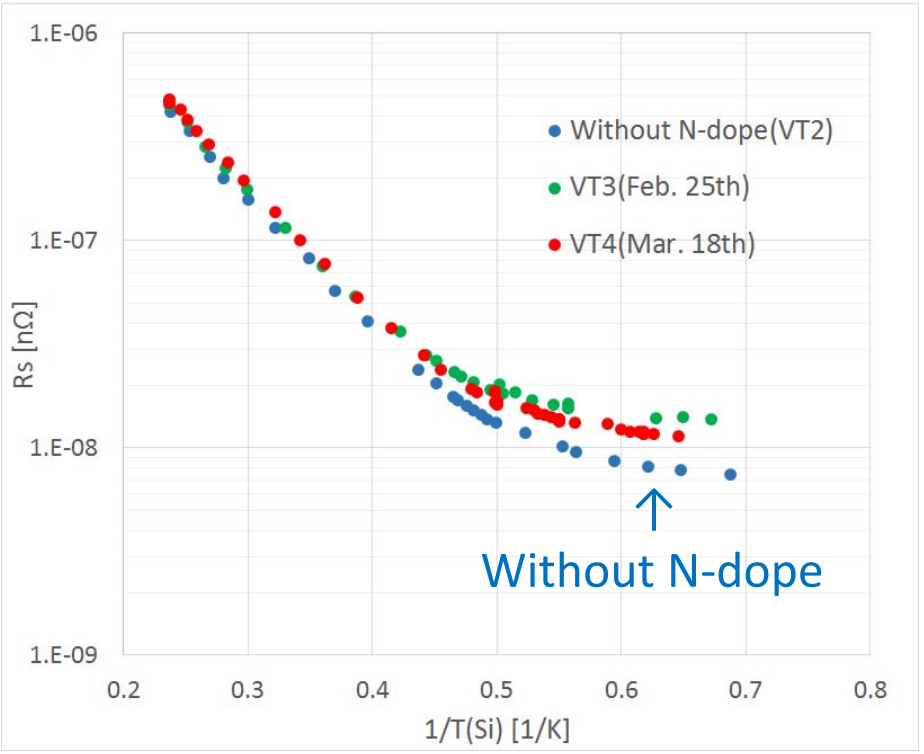
- Upto 800C with 3hours
- Keep 800C, 3hours
- N-doping
  - -- Stable state within 1min.
  - -- Keep 2.7Pa, 20min.
  - -- After valve close, vacuum recover quickly
- Keep 800C, 30min
- Heater OFF ⇒ cool down

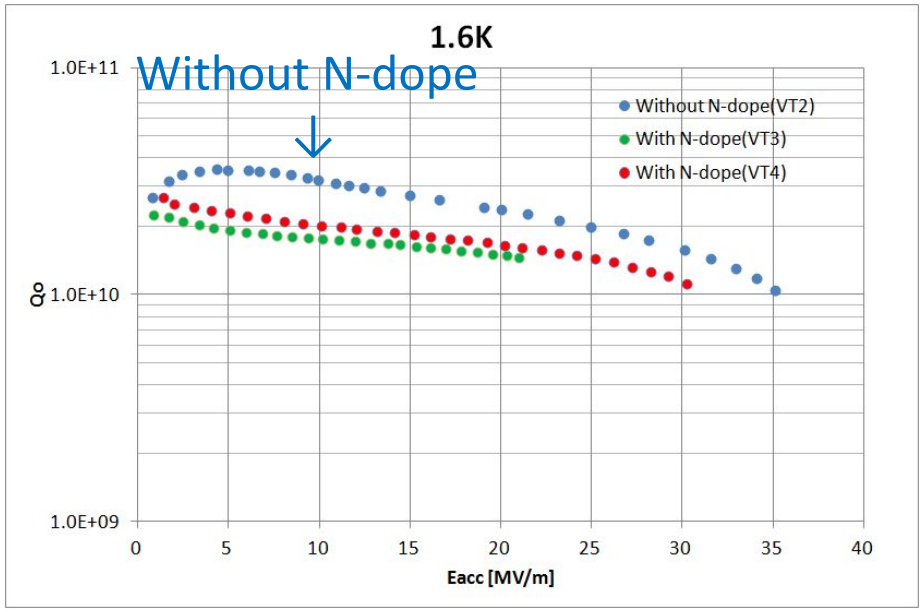
History of Fine grain(Tokyo-denkai) single-cell cavity

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)

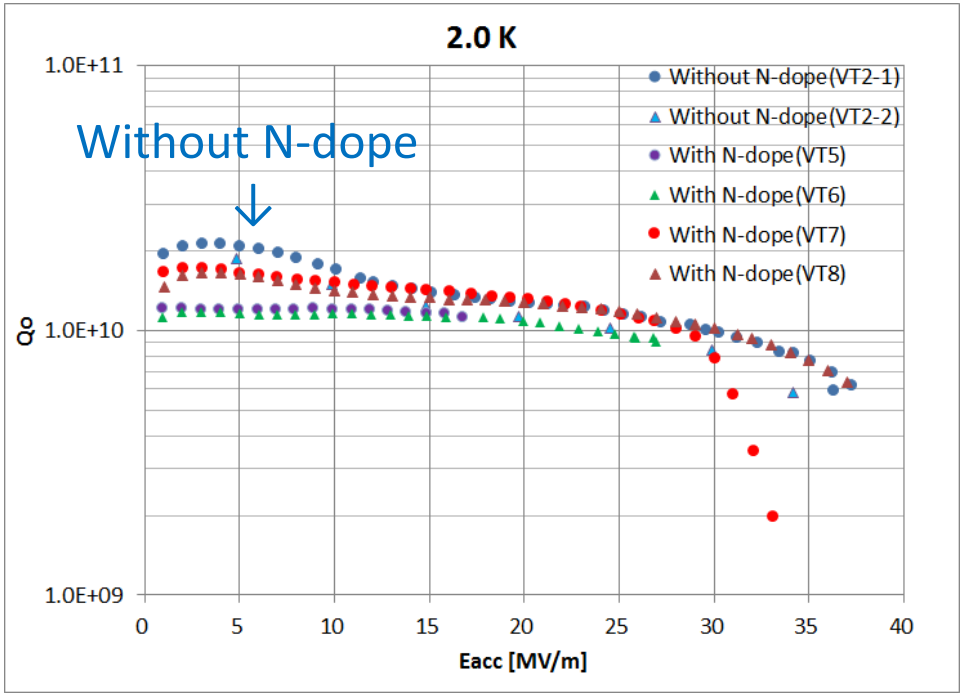


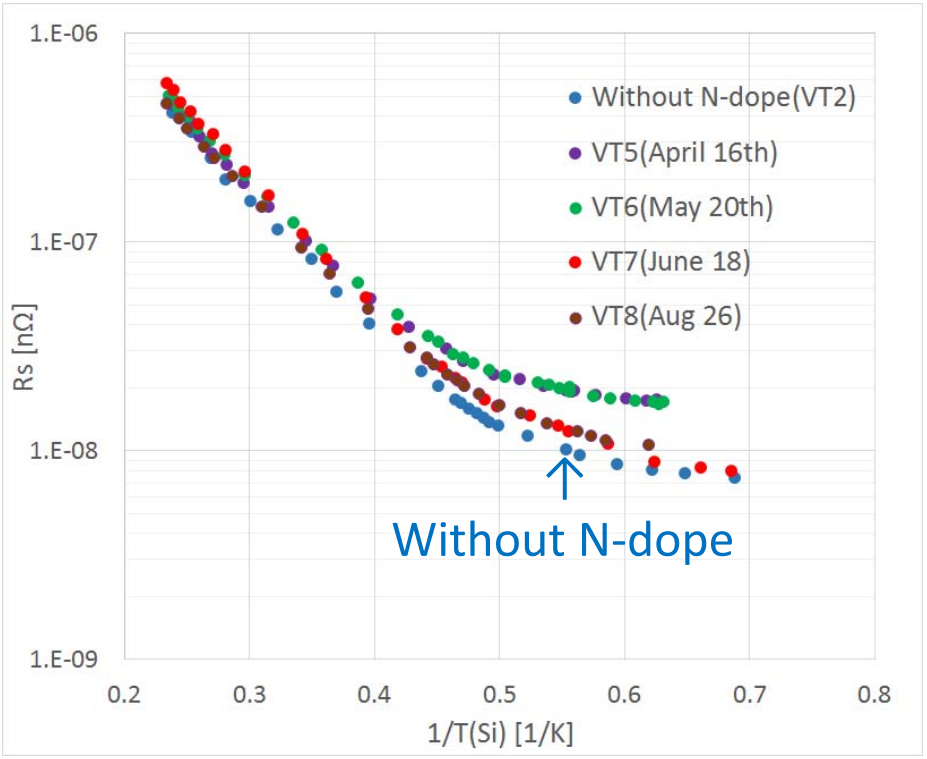


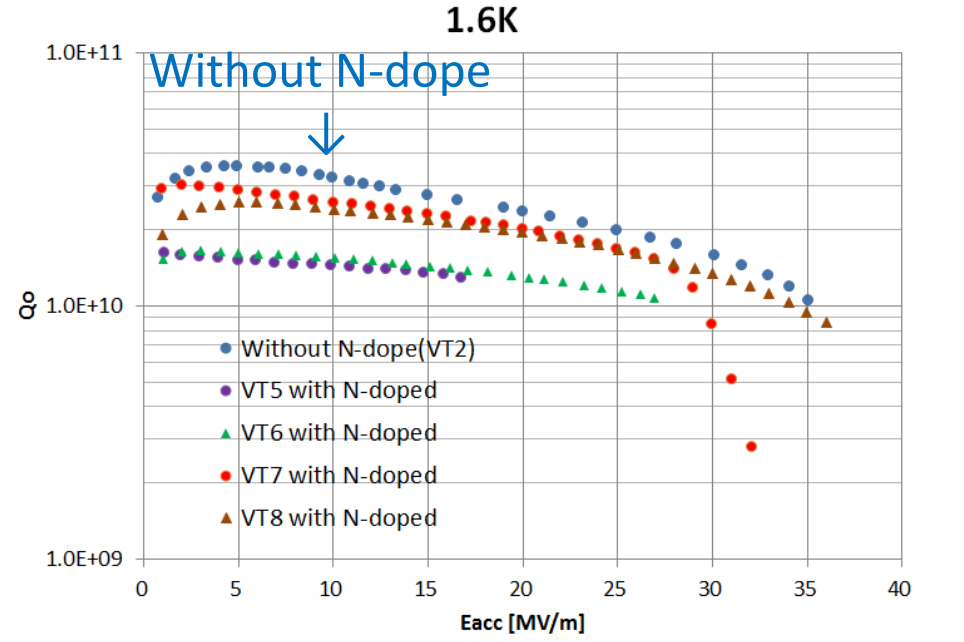


- Two times VT after N-dope, with 5um EP and additional 10umEP
- Q value degraded compared with No N-doping case.
- Quench field decreased to 22MV/m and 30 MV/m.

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





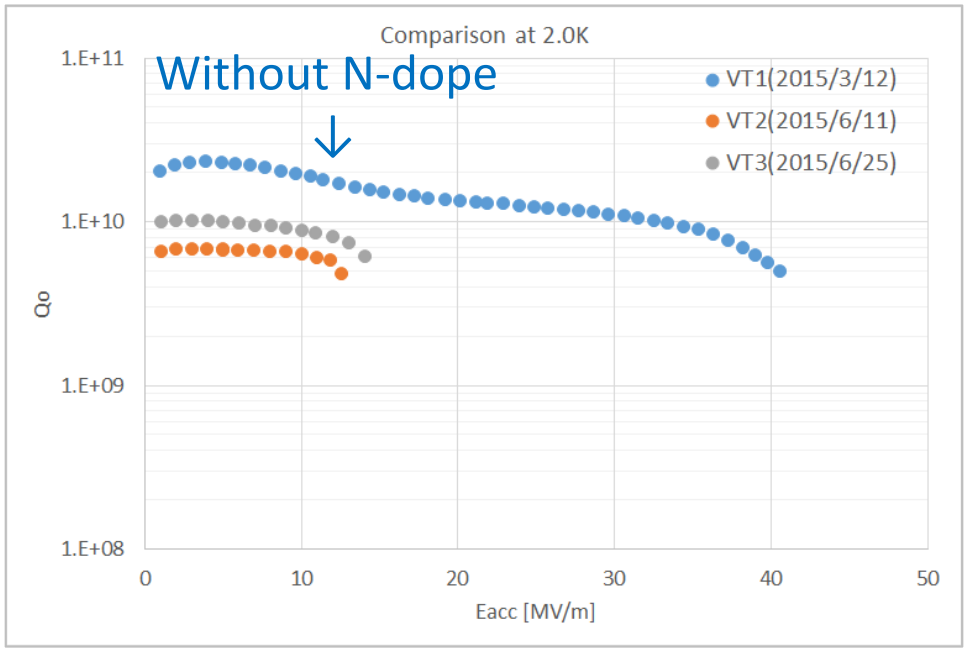


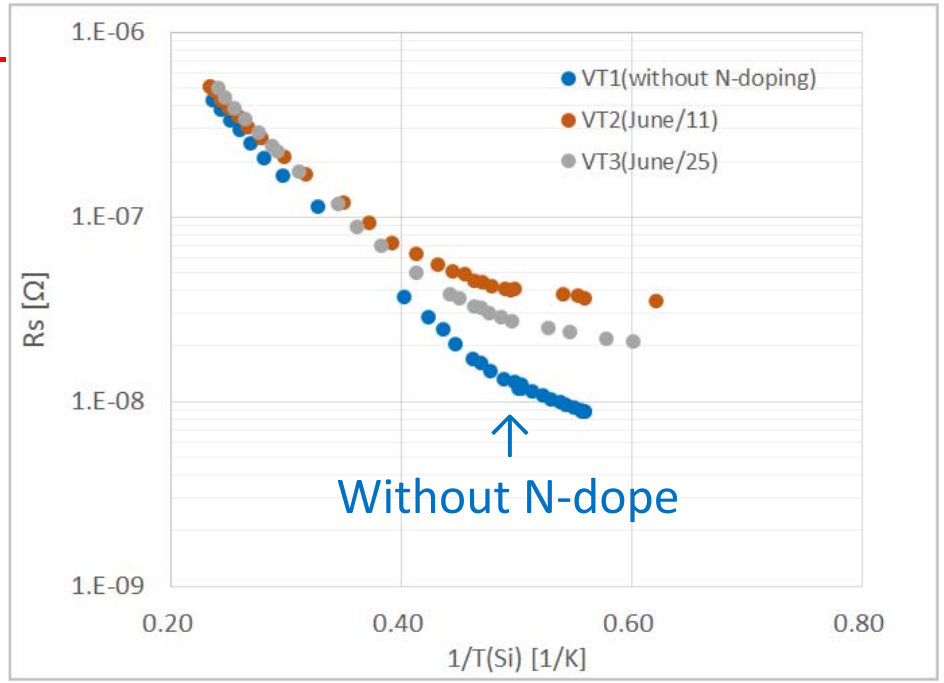
- Four times VT was carried out after N-doping, with 15um EP and additional 10um, 10um, 10um EP.
- Q values were always low.
- Quench field decreased to 17MV/m, and recovered with additional EP. Quench locations are different for every measurements.

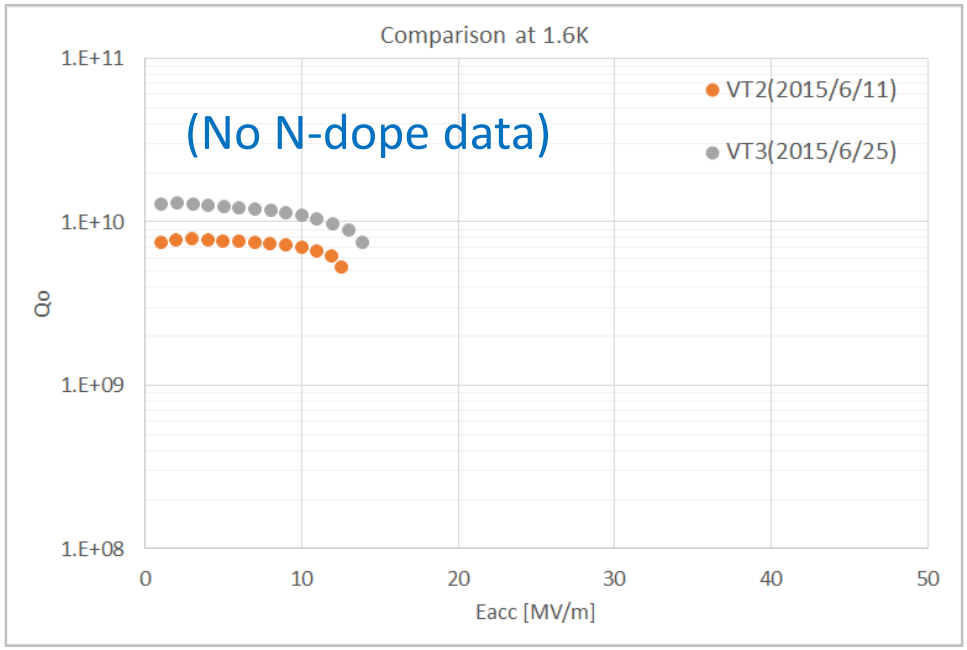
History of Fine grain(ULVAC) single-cell cavity

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)	

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







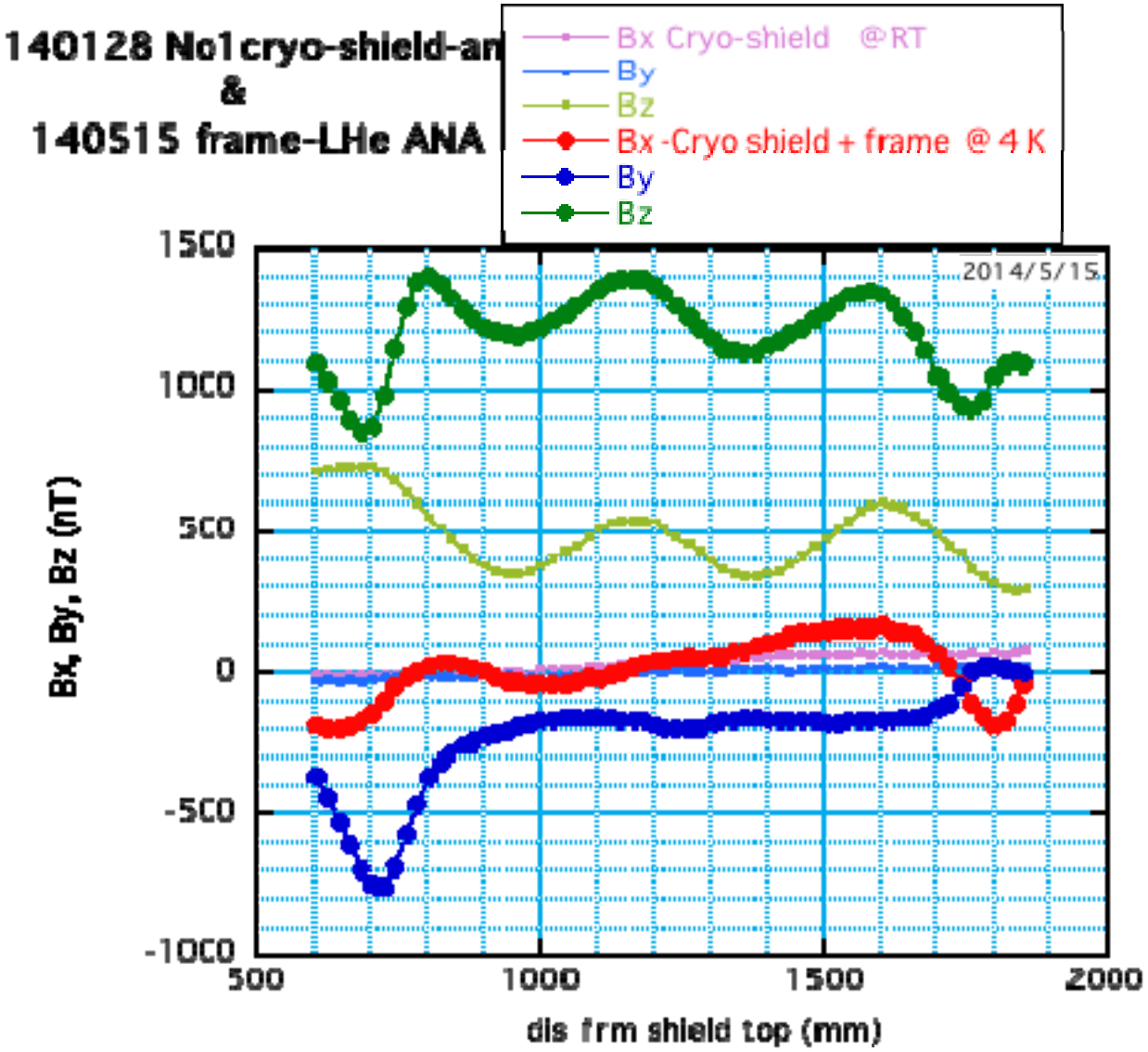
- Two times VT after N-doping, with 15um EP and additional 15um EP.
- Q values were drastically degraded.
- Quench field decreased to 13MV/m.
- Q values and quench field recovered little bit after additional EP.
- Quench location was same for both VTs.

Discussion

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)
   - ➢ Difference on N-doping system?
2. Effect doe to remnant field on vertical test cryostat.
   - 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.

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

Near future trial

- Measure our N-doped cavity at FNAL
  - Perform vertical test at good magnetic condition
  - Compare with results at KEK
- Improvement of KEK vertical test system
  - Improvement of monitors: flux gate sensor, temperature sensors, etc.
  - Improvement of magnetic field condition: Better magnetic shielding. Apply coils to control magnetic field.
  - R&D for cooling procedure.
  - Re-examination of support tools and so on.

Summary

- N-doping systems were constructed on small and large furnace at KEK machining center and N-doping procedures were applied.
- Three different N-doping conditions were applied, referred to FNAL, Cornell, J-lab parameters.
- After applying EP-2, vertical tests were carried out.
- Q-values decreased after N-doping.
- Quench field also decreased and recovered with additional EP.
- Quench locations are generally different for measurements.
- We will continue studied to understand the reason of bad performances.

N-doping seems to be easy, looking at U.S. results.
But it may require actually sophisticated magnetic condition for vertical test and cryomodules.