



# N-doping research at IHEP

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# Outline

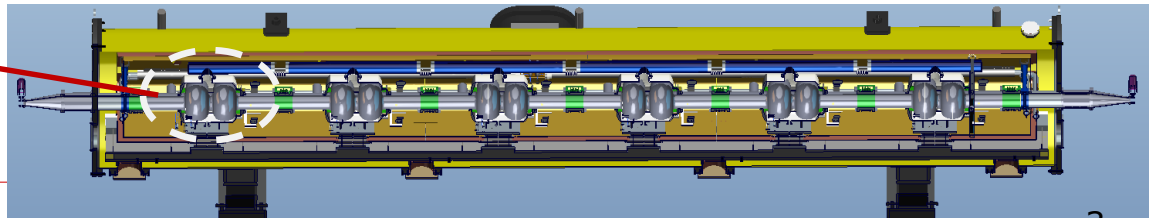
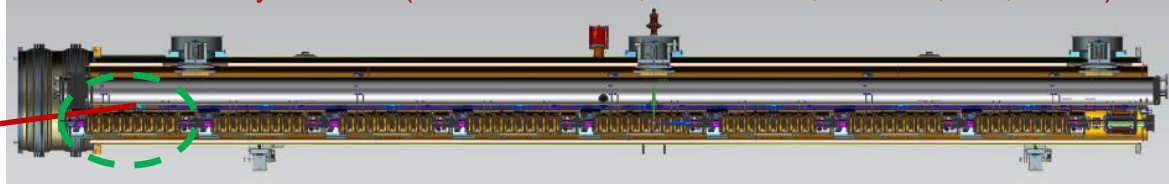
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1. Introduction
2. N-doping of Nb sample
3. N-doping of 650 MHz single-cell cavities
4. Summary

# SRF cavities for CEPC

	Cavity amount	Gradient (MV/m)	Q for long period	Gradient in horizontal test (MV/m)	Q in horizontal test	Gradient in vertical test (MV/m)	Q in vertical test
650 MHz 2-cell cavity	240	19.7	1.5E10	22	2E10	22	4E10
1.3 GHz 9-cell cavity	96	19.8	1E10	22	2E10	24	2E10

1.3 GHz Cryomodule (8 cavities inside, as E-XFEL, LCLS-II, ILC, SCLF)



650 MHz Cryomodule (6 cavities inside, new!)

# Surface resistance ( $R_s$ ) of SRF cavity

$$R_S = R_{BCS} + R_{RES}$$

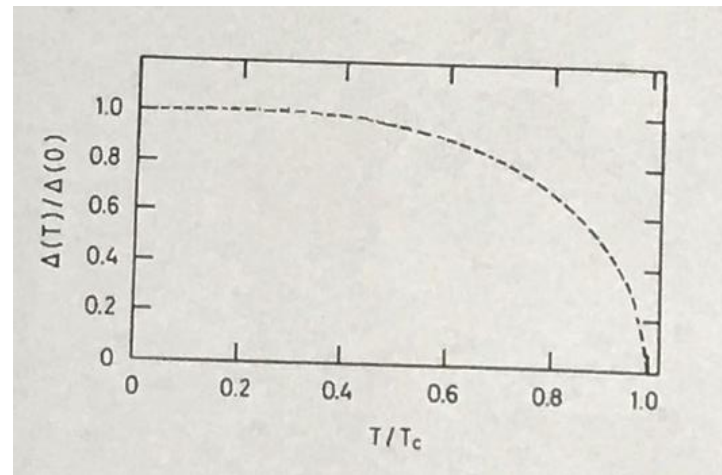
Depend on smoothness, cleanliness and flux trapping, etc

$$R_{BCS} = A(1/T) f^2 \exp(-\Delta(T)/kT)$$

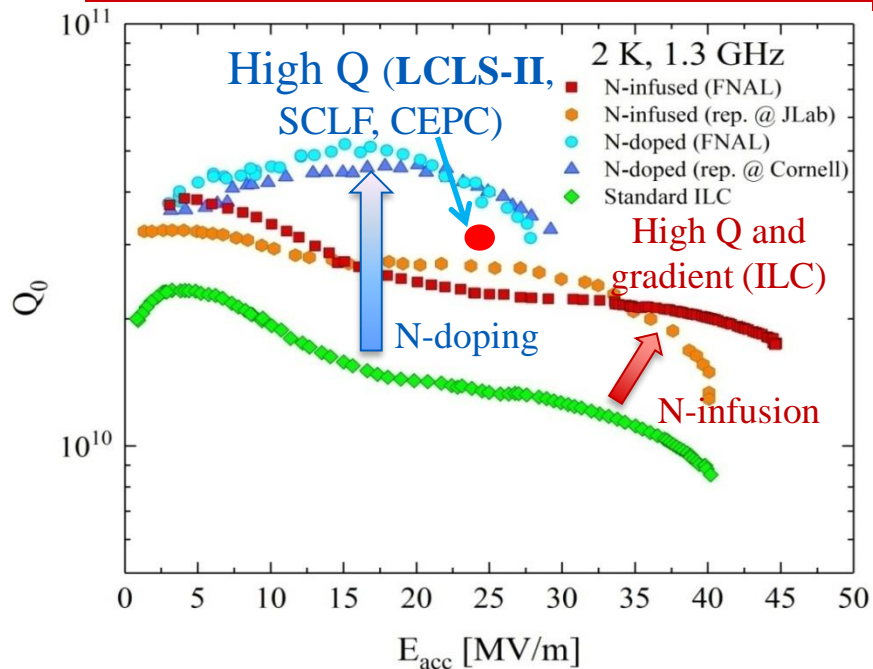
If  $T < T_c/2$ , then  $\Delta(T) \approx \Delta(0)$

$A$  is a constant related with London penetration depth, coherent length, Fermi velocity, mean free path...

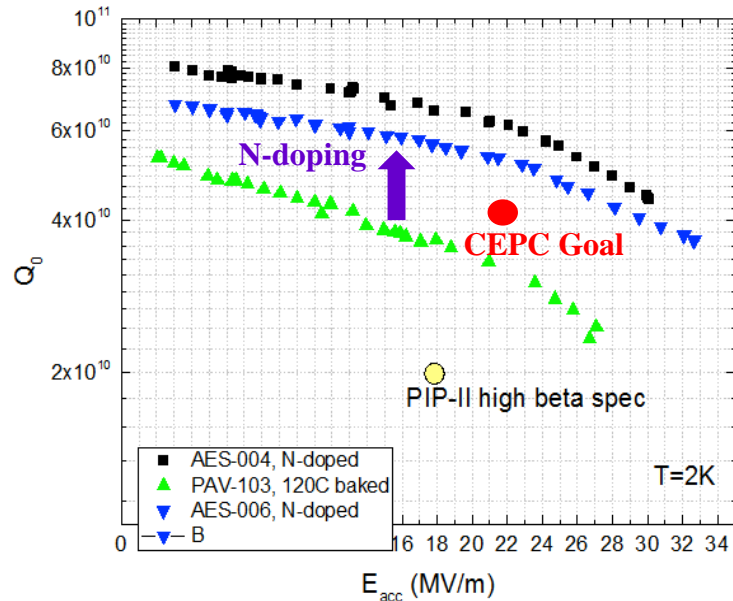
$\Delta(T)$  is the energy gap.



# N-doping and N-infusion: reduce $R_{BCS}$ , increase Q!

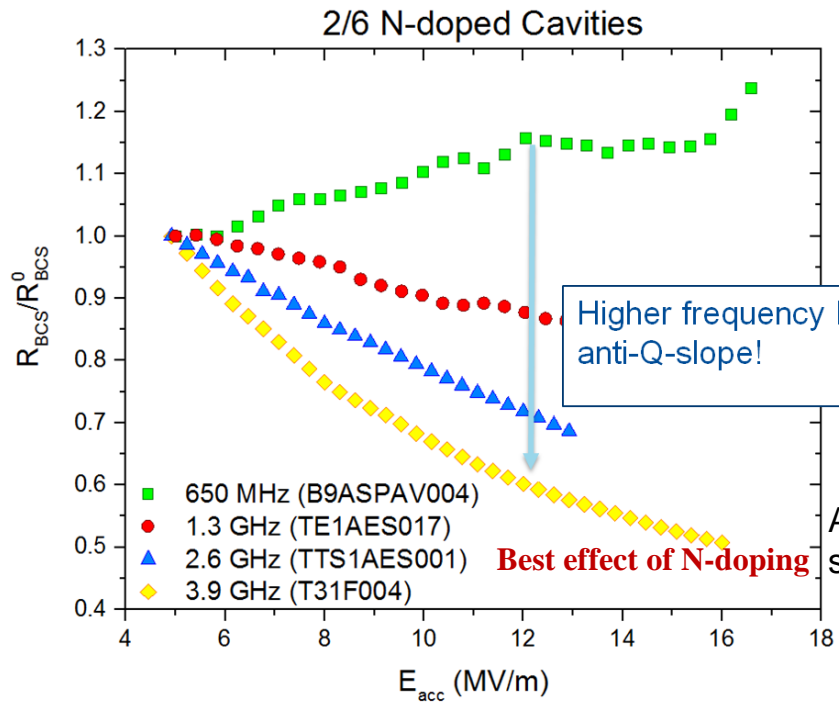


A. Grassellino, ICFA seminar 2017

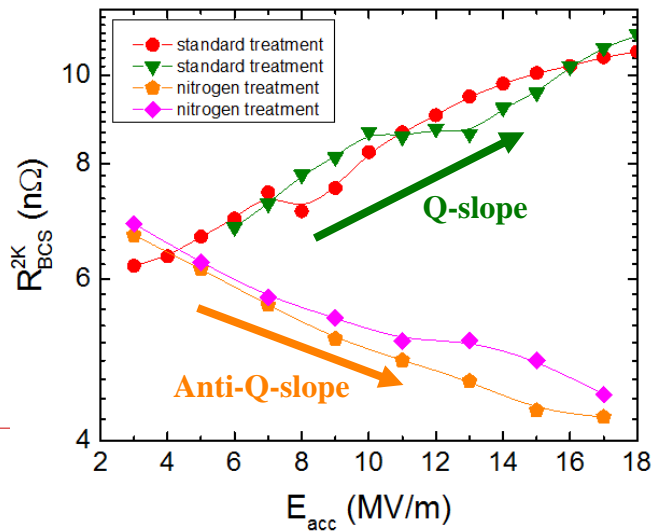


N-doping for PIP-II 650 MHz single-cell cavity

# N-doping with different cavities



A. Grassellino, ICFA seminar 2017





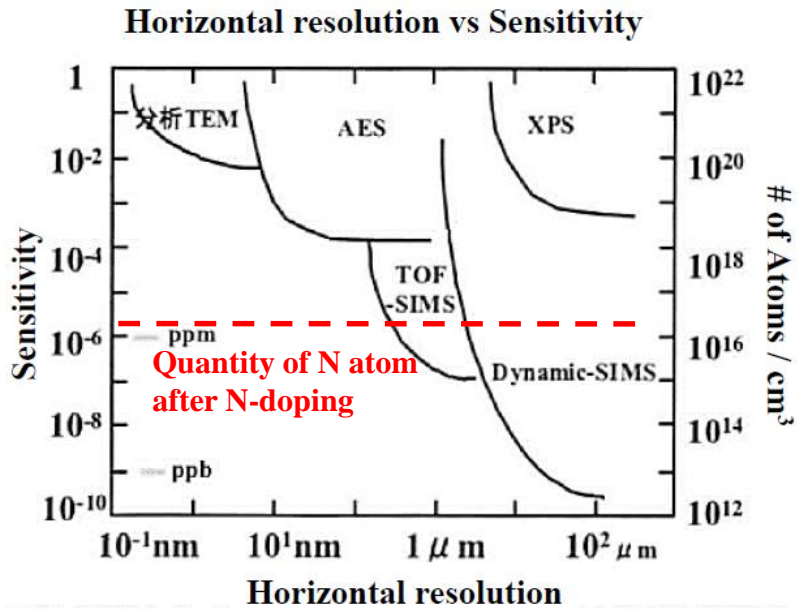
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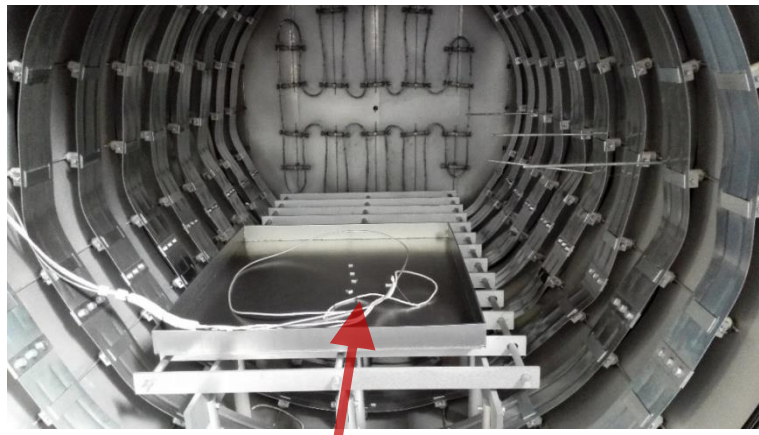
# Experiments of Nb samples

- Common material experiments: Secondary Ion Mass Spectrometry (SIMS), Scan Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), X-Ray Diffraction (XRD).....
- Superconducting experiments: R-T, M-T, Magnetic Force Microscopy (MFM), Scanning Tunneling Spectrum (STS).....





## N-doping of Nb samples with IHEP old Furnace



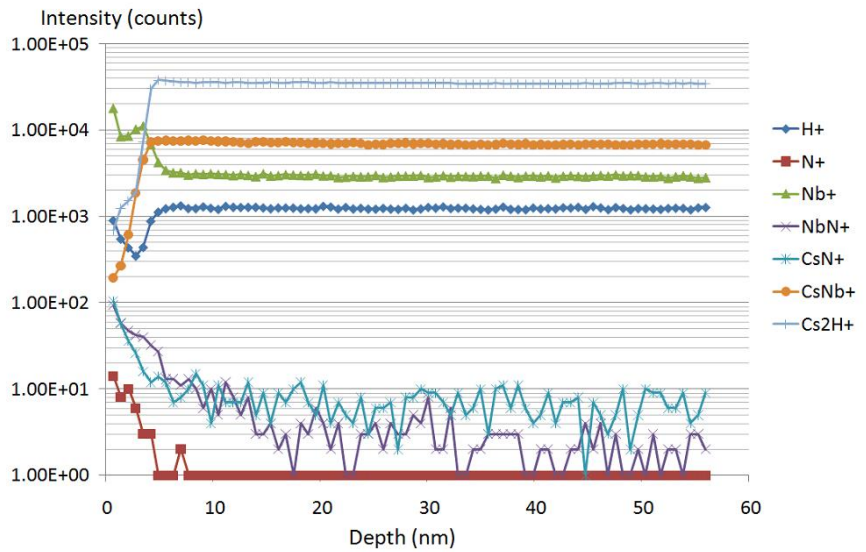
N-doping of Nb samples



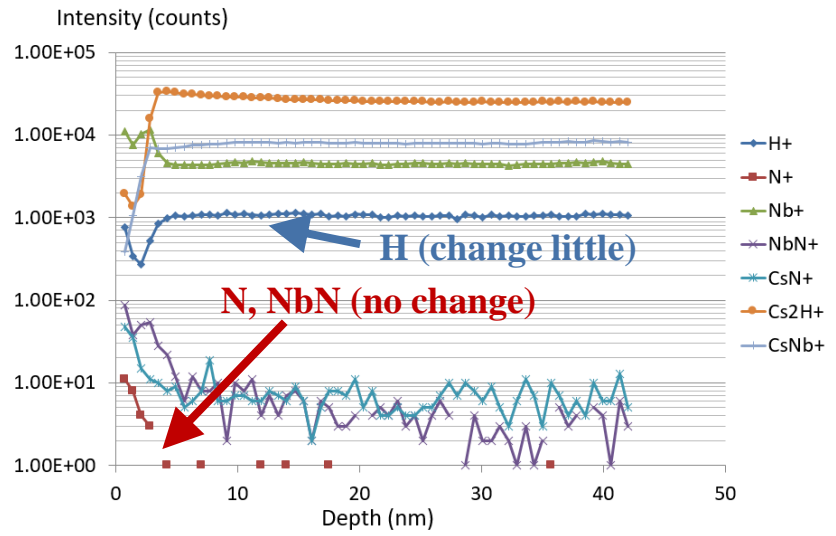
TOF-SIMS

- The old furnace at IHEP is equipped with diffusion pump, which is not oil-free and dirty.

# Results of SIMS

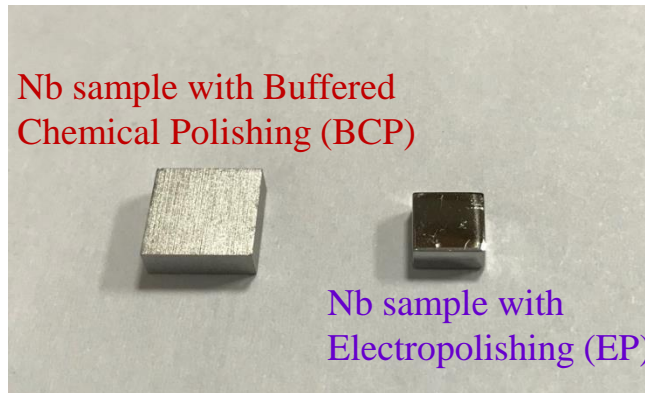


**Before N-doping**



**After N-doping**

## N-doping of Nb samples with OTIC Furnace



Furnace at Ningxia Orient Tantalum Industry Co., Ltd (OTIC)

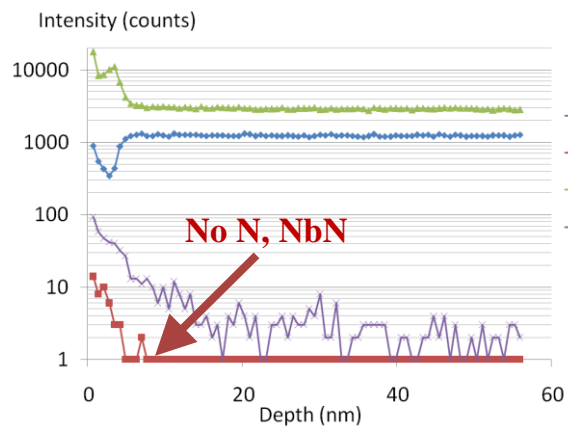
- Oil-free pumping system: two COOLVAC10000 iCL cryo-pumps by Leybold、 one roots pump (1200L/S)、 one screw pump.
- The heater is made by **Tantalum**, not molybdenum. N-infusion isn't allowed, because  $N_2$  injection at 120C for 48 hours may harm the heater.



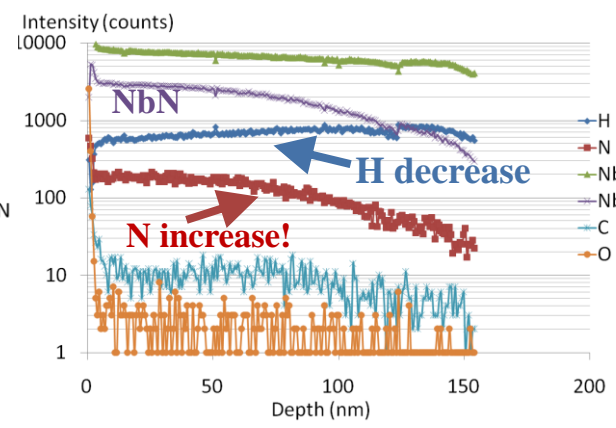
# SIMS Results of N-doping at OTIC and KEK



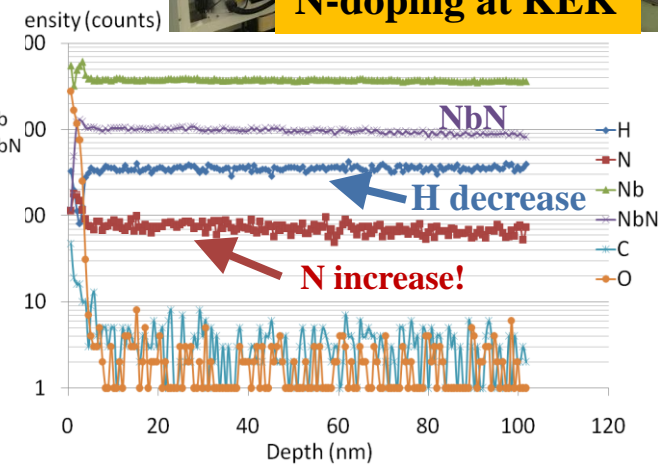
**N-doping at KEK**



**Before N-doping**



**N-doping at OTIC  
(~3 Pa, 800°C for 2 minutes)**

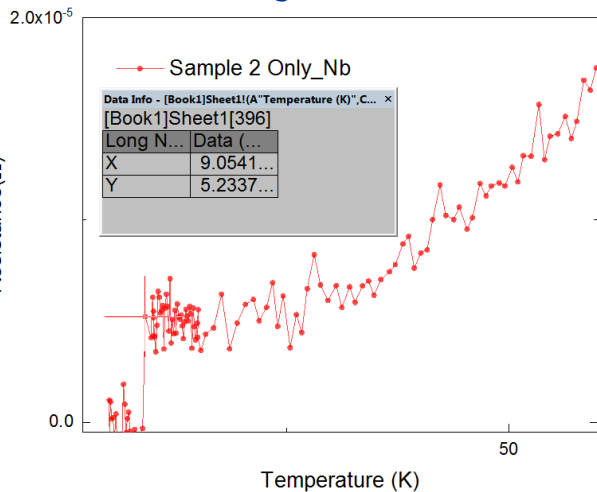


**N-doping at KEK  
(~3 Pa, 800°C for 2 minutes)**

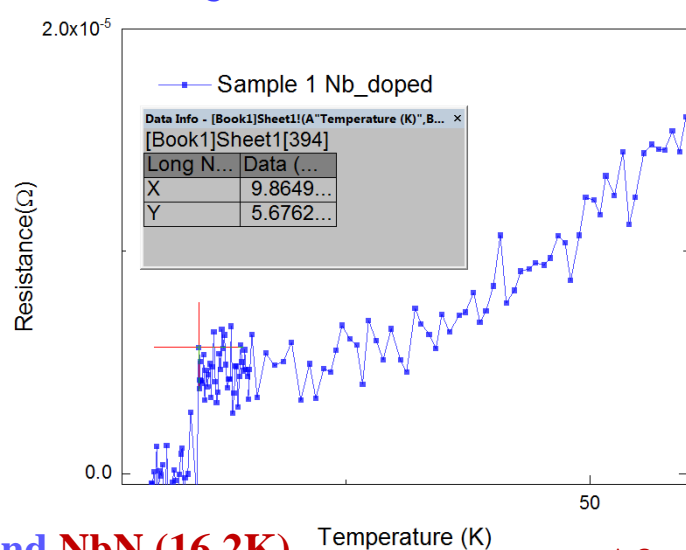


# Results of SEM, R-T

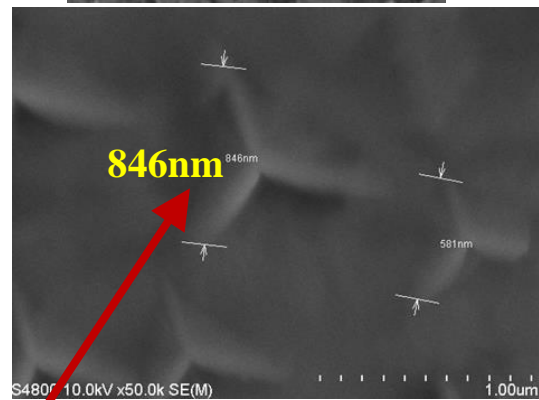
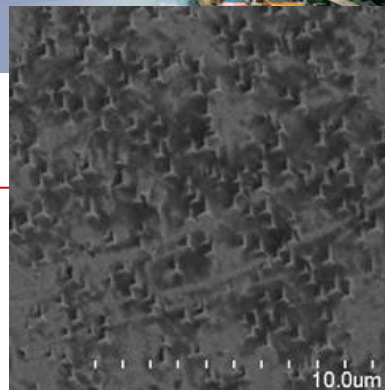
9.05K:  $T_C$  of pure Nb



9.86K:  $T_C$  of Nb N-doped at KEK

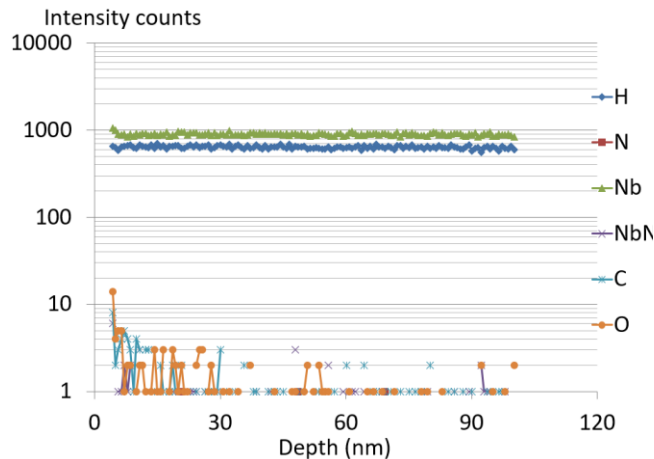


9.86K is between Nb (9.23K) and NbN (16.2K), a mixture of Nb and NbN.

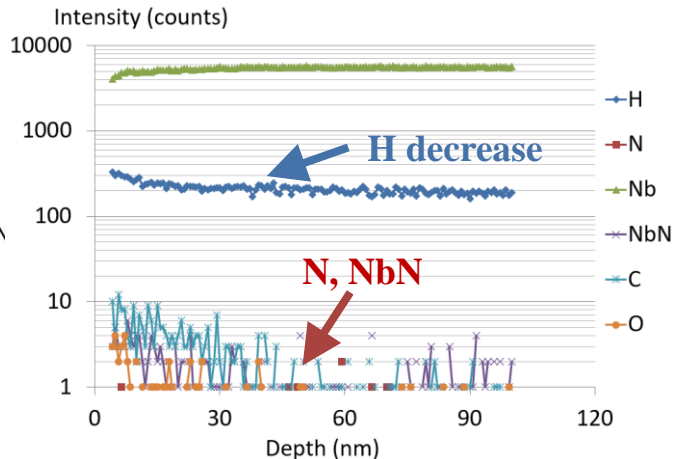


After N-doping, clear formation of NbN precipitates in the surface.

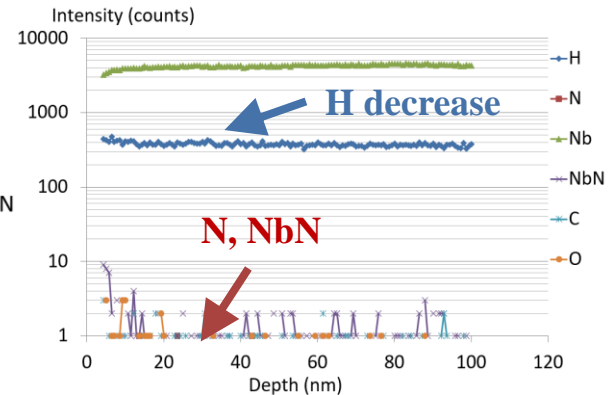
# SIMS Results of N-infusion at KEK (1)



**BCP sample  
before N-doping**

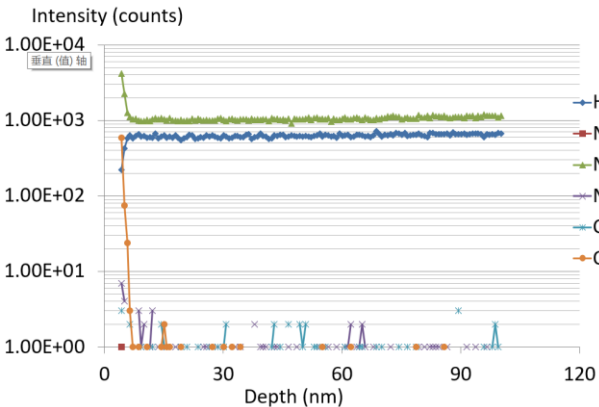


**BCP sample after N-infusion  
(~3 Pa, 125°C for 48 hours)**

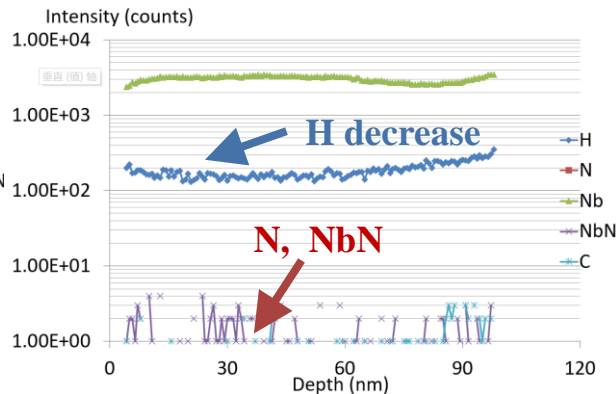


**BCP sample after N-infusion  
(~3 Pa, 160°C for 48 hours)**

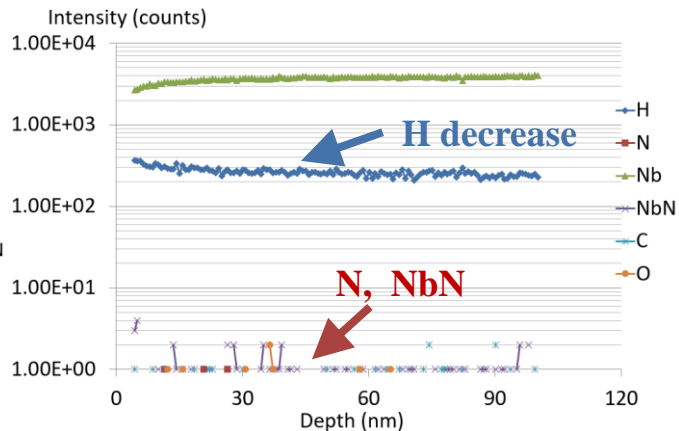
## SIMS Results of N-infusion at KEK (2)



EP sample before N-doping



EP sample after N-infusion  
( $\sim 3$  Pa,  $125^\circ\text{C}$  for 48 hours)



EP sample after N-infusion  
( $\sim 3$  Pa,  $160^\circ\text{C}$  for 48 hours)

TOF-SIMS may not be fit for N-infusion for fewer N atoms.

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## N-doping process

- ❑ 1<sup>st</sup>, the baseline vertical test of 650 MHz single-cell cavity before N-doping.
- ❑ 2<sup>nd</sup>, this cavity received light BCP and was N-doped.
- ❑ 3<sup>rd</sup>, the cavity received High Pressure Rinsing (HPR), following with class -10 assembly for vertical test.
- ❑ 4<sup>th</sup>, the cavity received vertical test again.



N-doping



HPR

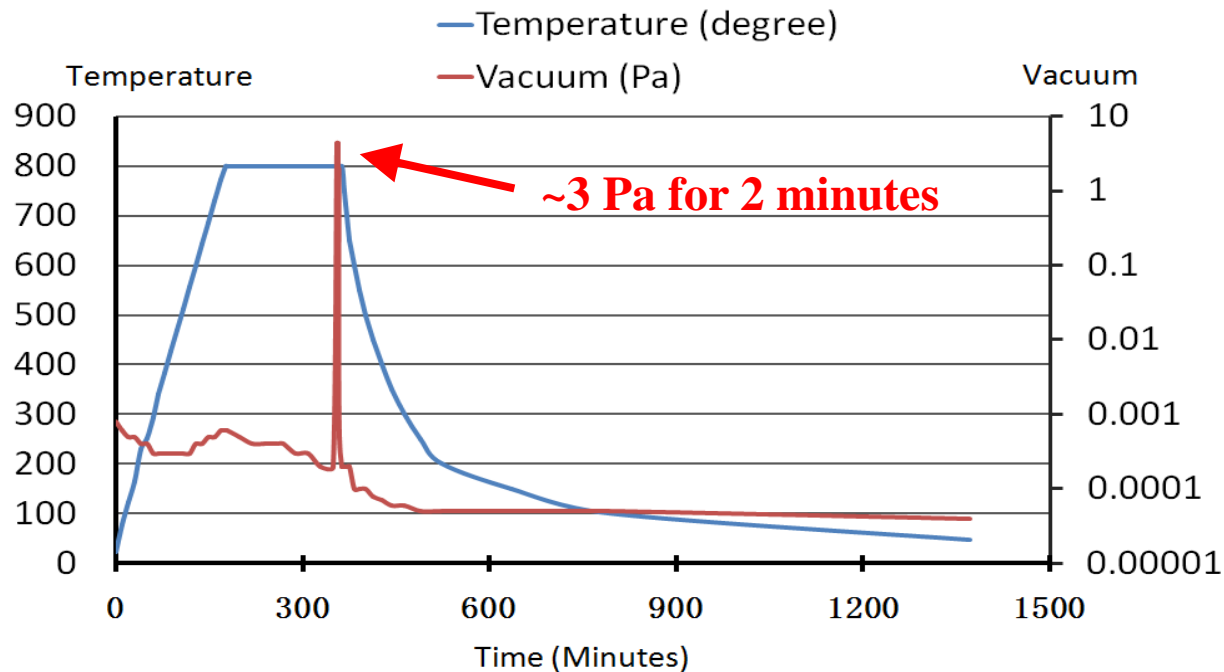


Assembly



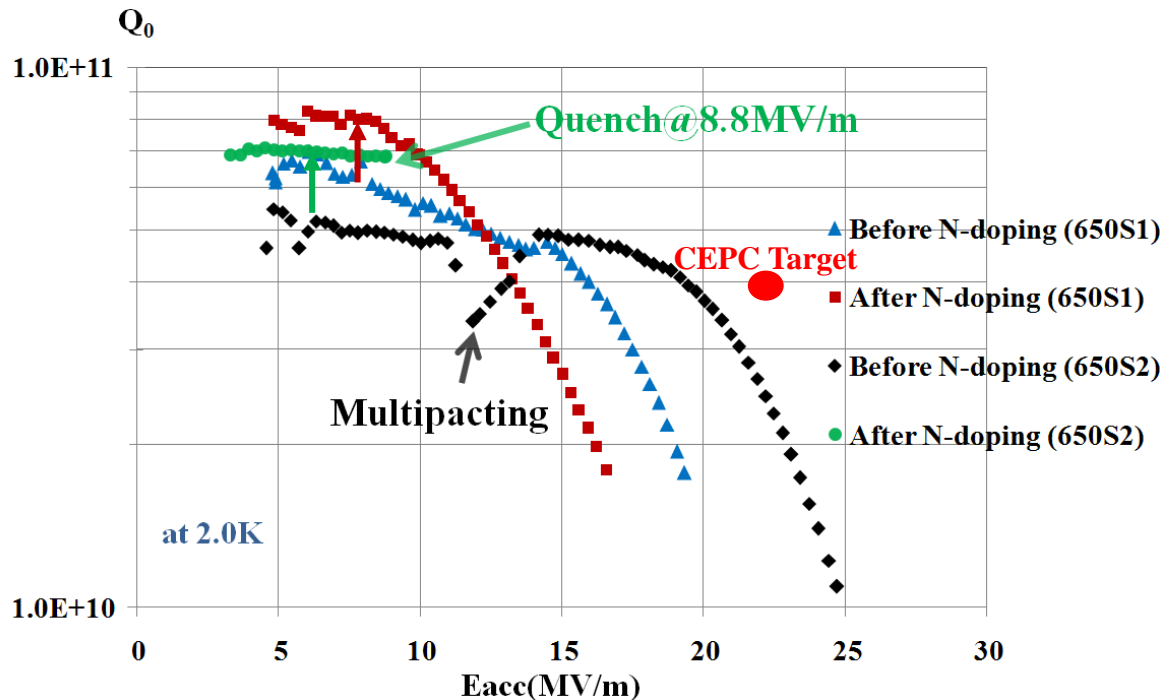
Vertical test

# Vacuum and temperature curve during N-doping



## Vertical test results

- After N-doping,  $Q_0$  increased obviously at low field for both cavities.
- 650S1:  
 $Q_0=7e10@Eacc=10MV/m$ .  
 But  $Q_0$  decreased quickly at high field ( $>10 MV/m$ ) because of no BCP/EP after N-doping.
- 650S2: Quench at  $Q_0=6.9e10@Eacc=8.8MV/m$ .



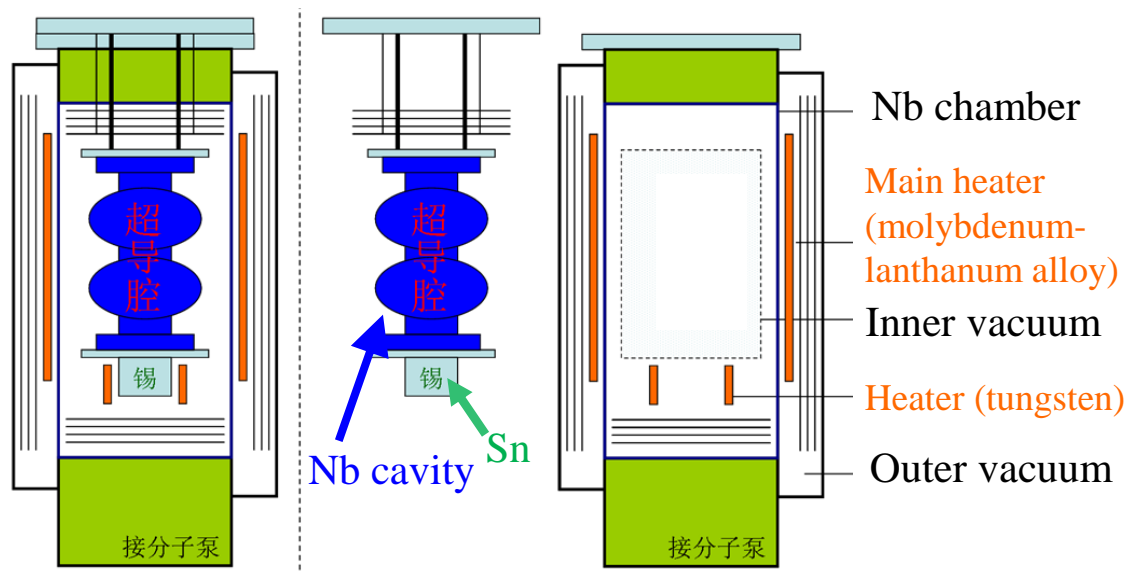
## Summary

- Next, increase Q value at high field.
  - Electropolishing facility is under development, which will be completed in late 2018.
  - N-doping/N-infusion technology is being improved. A new surface will be shipped to IHEP in middle 2018, which is equipped with two cryo-pumps (CTI OB400, 12000 L/s for H<sub>2</sub>).
  - Reduce  $R_{RES}$ : flux expulsion, clean assembly...
- 650MHz → 1.3GHz, 3.9GHz. Study the difference of N-doping/N-infusion performance.



Components of EP facility

# Nb<sub>3</sub>Sn coating with bulk Nb



Parameters	Value
Min vacuum	5.0E-5 Pa
Max temperature	1400°C
Min vacuum@1400°C	9.0E-4 Pa
Uniform temperature area	Φ 300mm×500mm

**It'll be shipped to IHEP in late 2018.**

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**Acknowledgements: KEK, OTIC and PKU.**

**Thanks for your attention!**