CEPC High Q Cavity Study

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Contents

CEPC Cavity Specification

New!

Cavity	Vertical test	Horizontal test	Amount
650 MHz 2-cell Cavity	4E10 @ 22 MV/m	2E10 @16 MV/m	336
1.3 GHz 9-cell Cavity	3E10 @ 25 MV/m	2E10 @ 20 MV/m	160

Similar as E-XFEL, LCLS-II, ILC

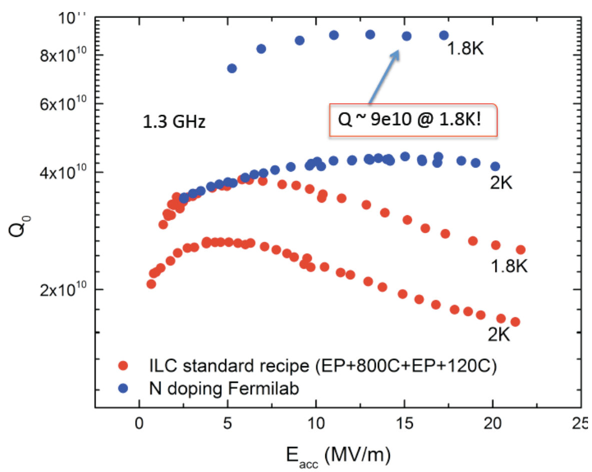
Very high!

Contents

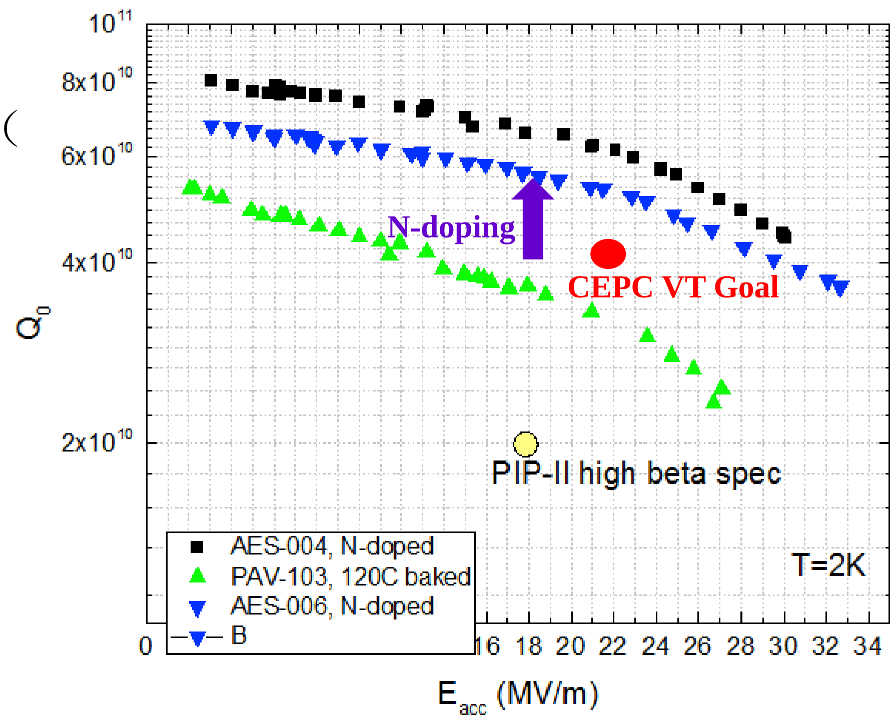
1. Introduction
2. N-doping, N-infusion
3. Nb_3Sn and Fe-based superconductor film
4. 650 MHz cavity for CEPC main ring
5. 1.3 GHz cavity for CEPC booster
6. Summary

High Q cavity through N-doping

- Research Content： Increasing Q_0(at high Electric field) of SC cavity through **N-doping**, Nb_3Sn……
- Target： Q_0=4e10@E_{acc}=22MV/m （650MHz cavities for vertical test at 2K）



N-doping for 1.3 GHz cavity



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

N-doping application: LCLS-II

Cavity	VTS		pCM			
	Eacc [MV/m]	Q_0 (2K) @16MV/m	Max Gradient Reached * [MV/m]	Usable Gradient ** [MV/m]	FE onset [MV/m]	Q_0 (2K) @ 16MV/m***
TB9AES021	23	3.1E+10	19.6	18.2	14.6	2.6E+10
TB9AES019	19.5	2.8E+10	17	16.8	15.6	2.6E+10
TB9AES026	21.4	2.6E+10	17.3	17.2	No FE	2.7E+10
TB9AES024	22.4	3.0E+10	16.5	16.0	No FE	2.5E+10
TB9AES028	28.4	2.8E+10	14.9	13.8	11.5	2.4E+10
TB9AES016	18	2.8E+10	16.7	16.7	14.5	2.9E+10
TB9AES022	21.2	2.8E+10	17.4	17.1	12.7	3.2E+10
TB9AES027	22.5	2.8E+10	16.8	16.6	13.8	2.5E+10
Average	**22.1**	**2.8E+10**	**17.0**	**16.6**	**14.7**	**2.7E+10**
Total Voltage	**176.4**		**136.2**	**132.5**		

Immediate application: LCLS-II, 2.7e10@16MV/m.

Preliminary results for 1st LCLS-II cryomodule (FNAL)

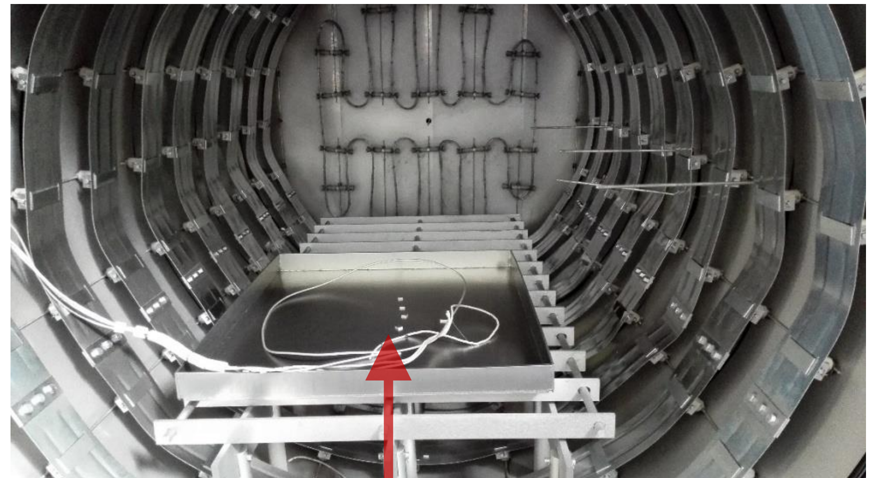
N-doping recipe adopted by LCLS-II

1. 800°C/900 °C anneal 3 hours for Hydrogen degas
2. **Nitrogen injection 2 minutes at ~3.5 Pa**
3. **Nitrogen anneal 6 minutes**
4. Nature cooldown

Two steps of N-doping at IHEP

- **1st step: N-doping of Nb sample, Secondary Ion Mass Spectrometry (at Tsinghua University)— N concentration within Nb surface increase or not?**
- 2nd step: cavity N-doping, Electric Polishing, vertical test — Q increase or not?

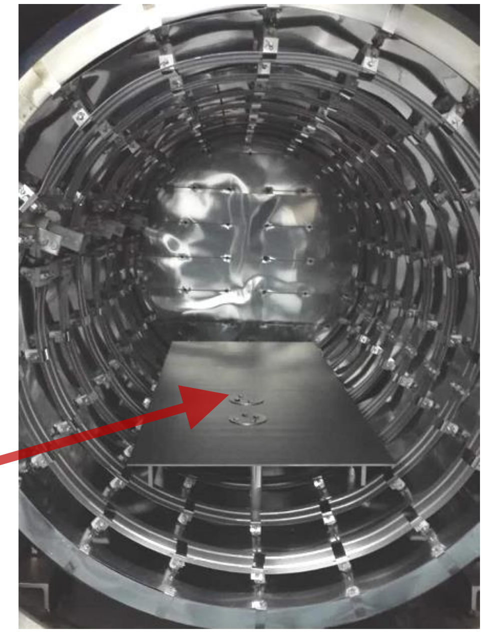
N-doping of Nb samples at IHEP



N-doping of Nb sample at IHEP

- The furnace is equipped with diffusion pump, which is not oil-free and dirty.
- Many times of Nb sample N-doping experiments, SIMS results show they all failed.

N-doping of Nb samples at OTIC

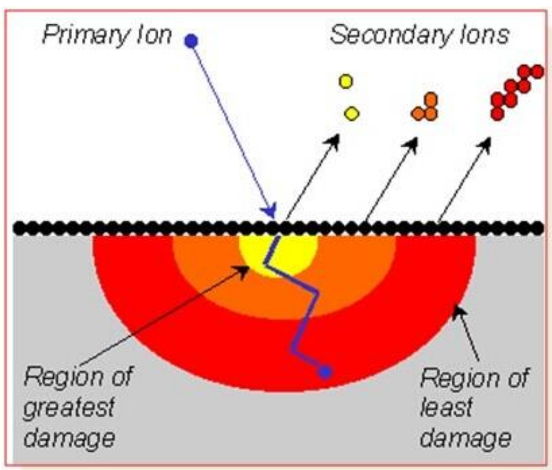


N-doping of Nb sample at OTIC

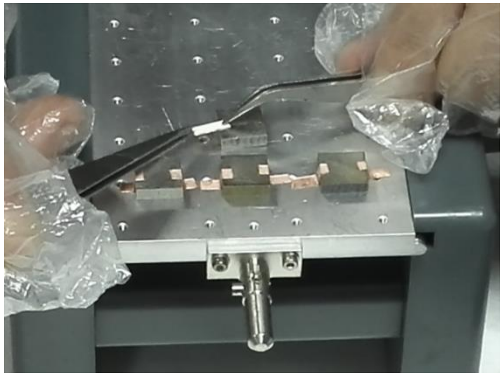
- Oil-free pumping system: two COOLVAC10000 CL-V（DN500 ISO-K，N_2 pumping speed 10 000l/s) cryo-pumps by Leybold、one roots pump (1200L/S)、one screw pump.
- The heater is made by **Tantalum**, not molybdenum. N-infusion isn't allowed, because people worry that N_2 injection at 120C may harm the heater.

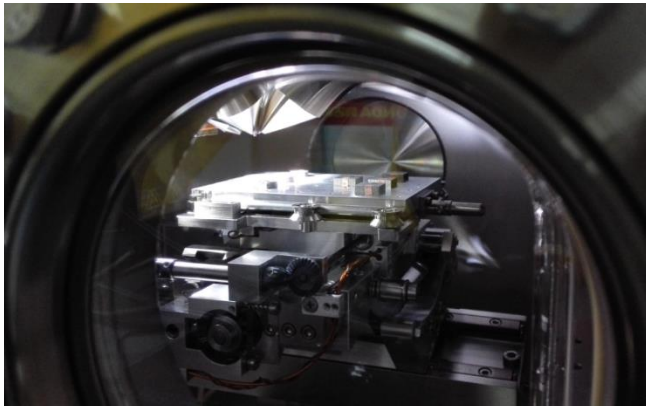
SIMS

- N and H are key elements of N-doping, so SIMS is adopted to study their distribution along the depth in the Nb surface.
- The SIMS machine we use is made by ION-TOF GmbH (Germany). The type is TOF.SIMS 5-100.
- 1st ion beam: Bi3++, 1keV, 45deg inject, scan area 100*100 um.
- Sputtering beam: Cs+, 1keV, 45deg inject, Sputtering speed=0.14nm/s for SiO_2 (14 um need 28 hours).



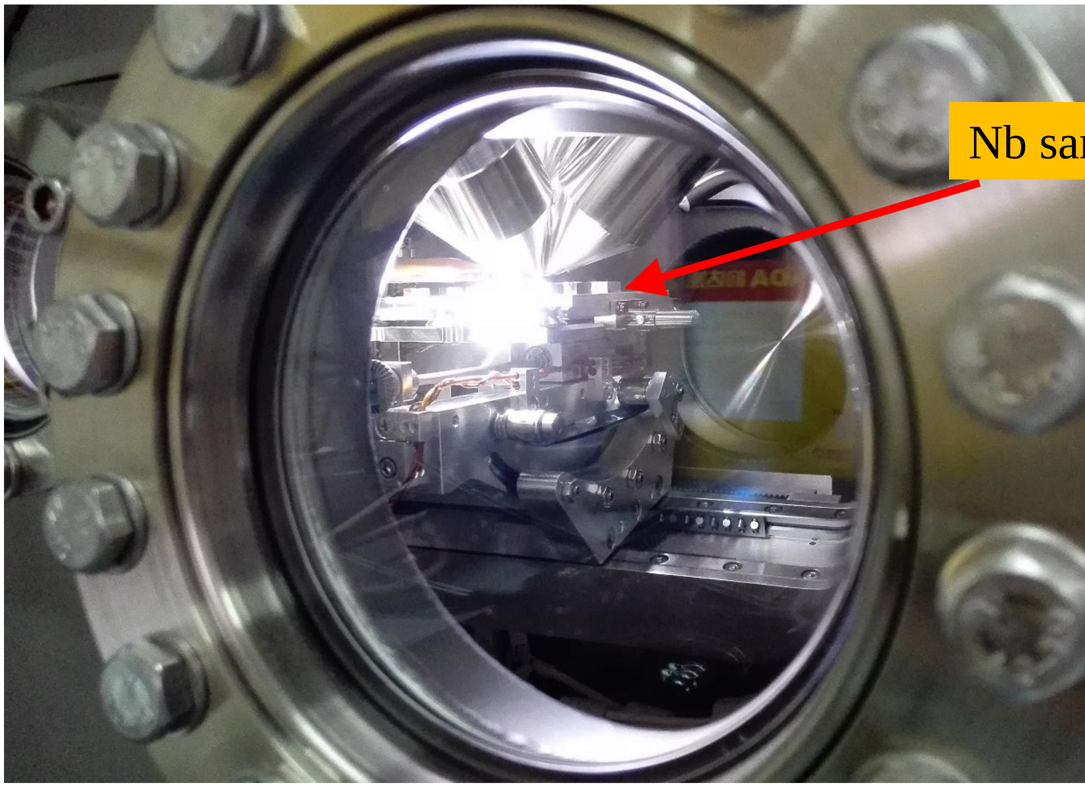
Principle of SIMS



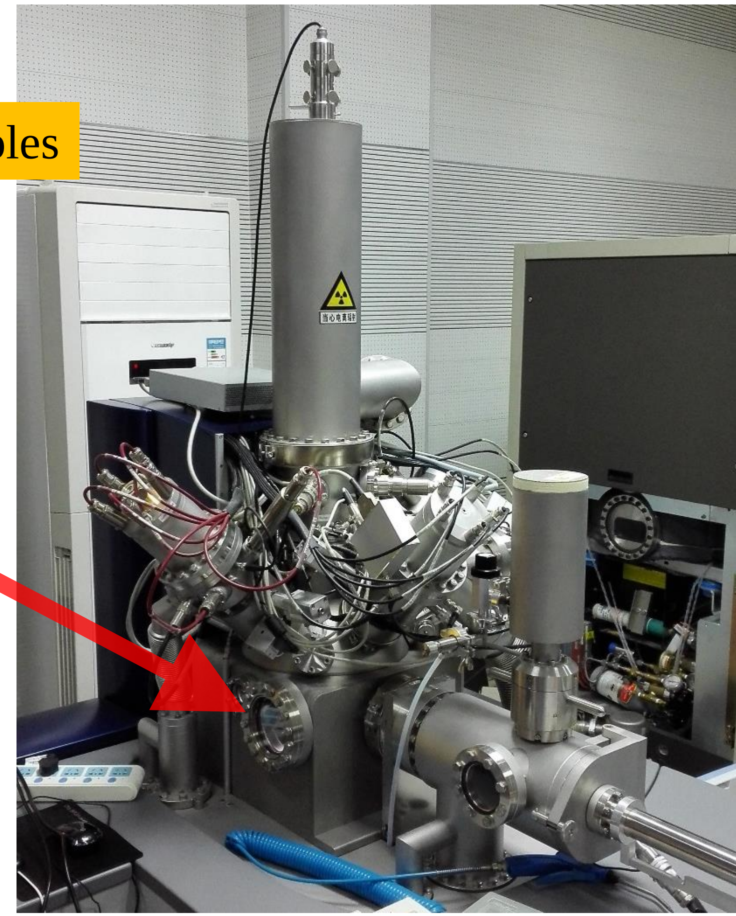


Nb Sample (10*10mm)

SIMS ongoing

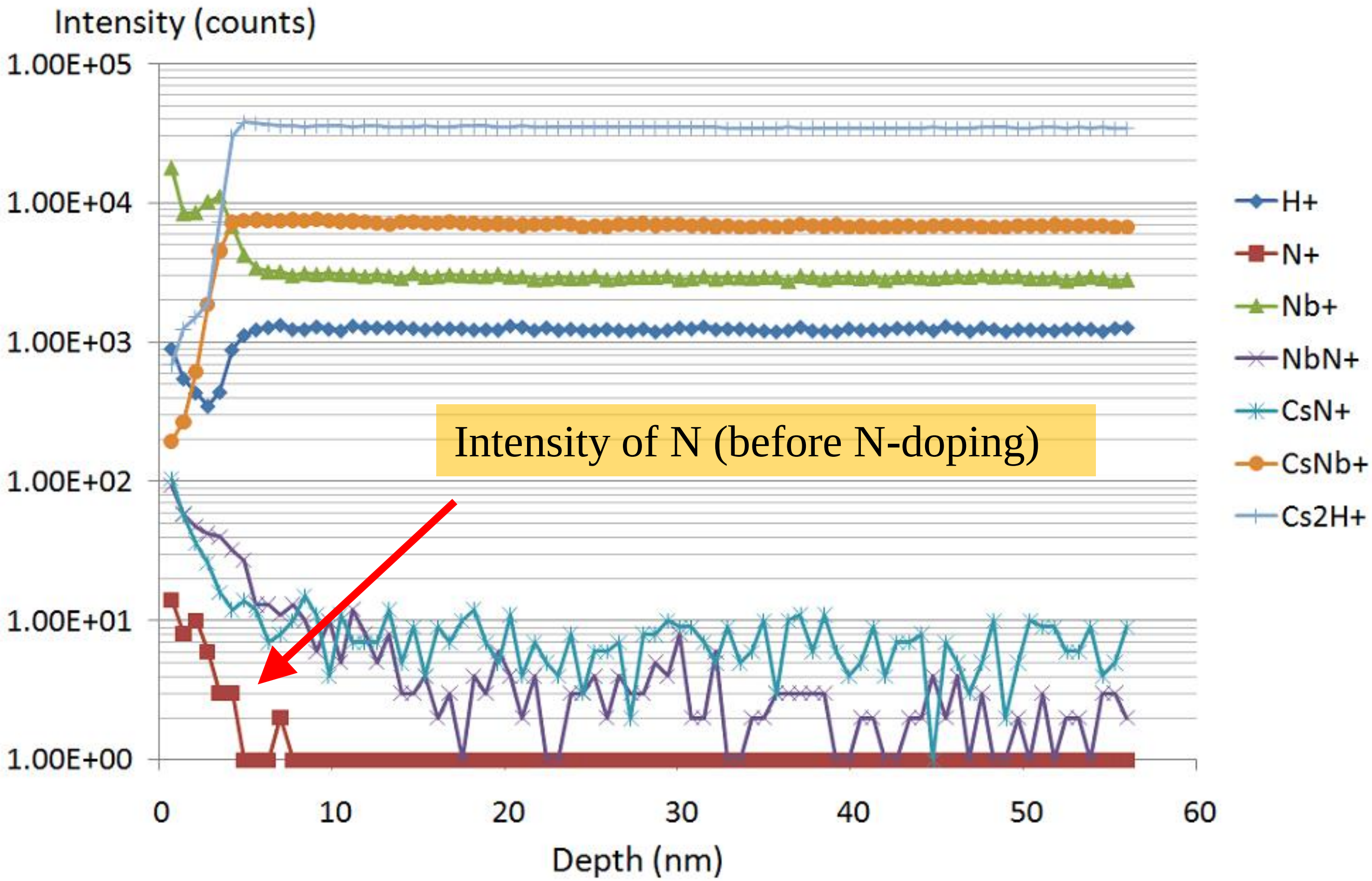


Nb samples

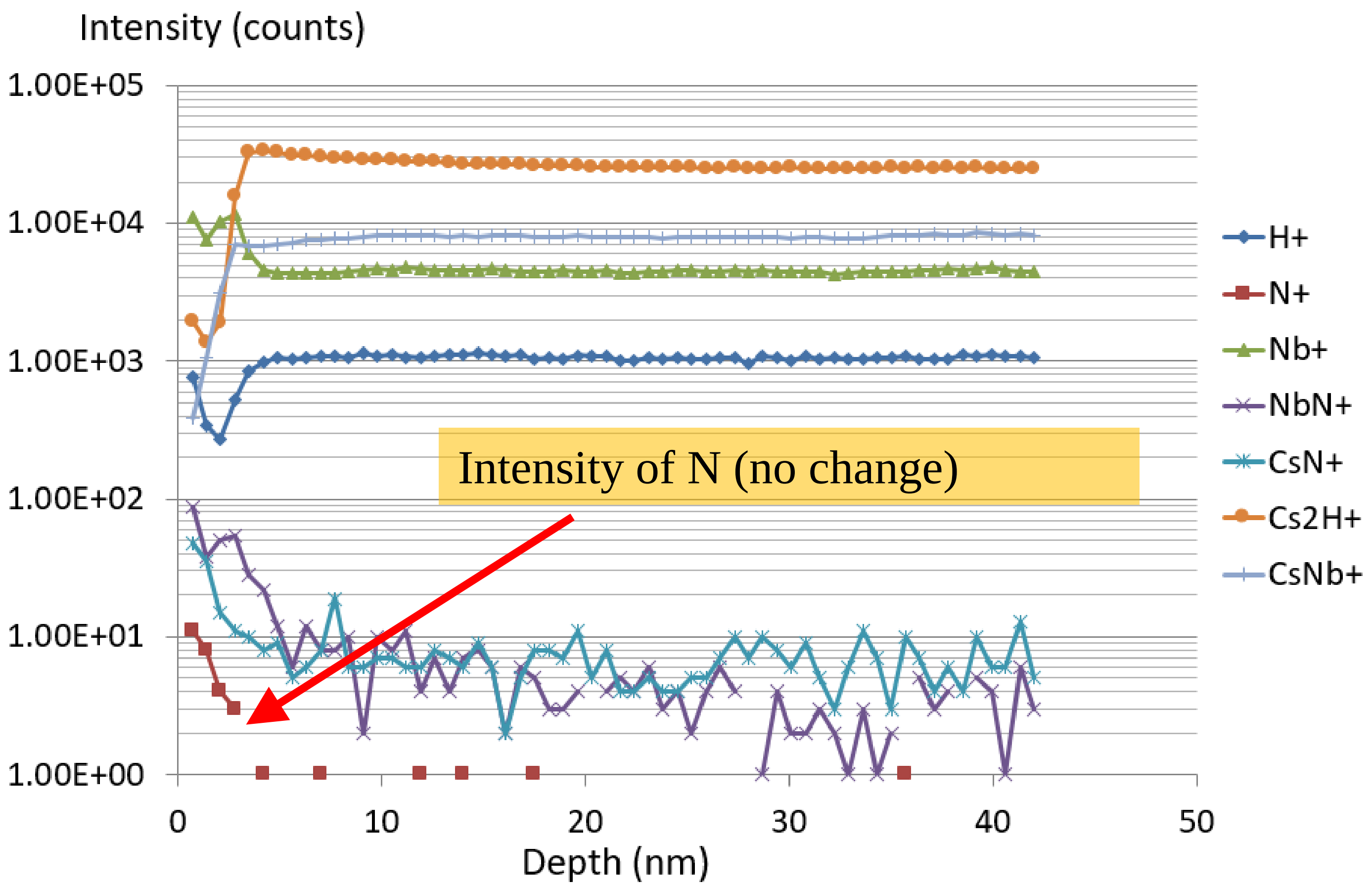


SIMS experiments at Tsinghua University

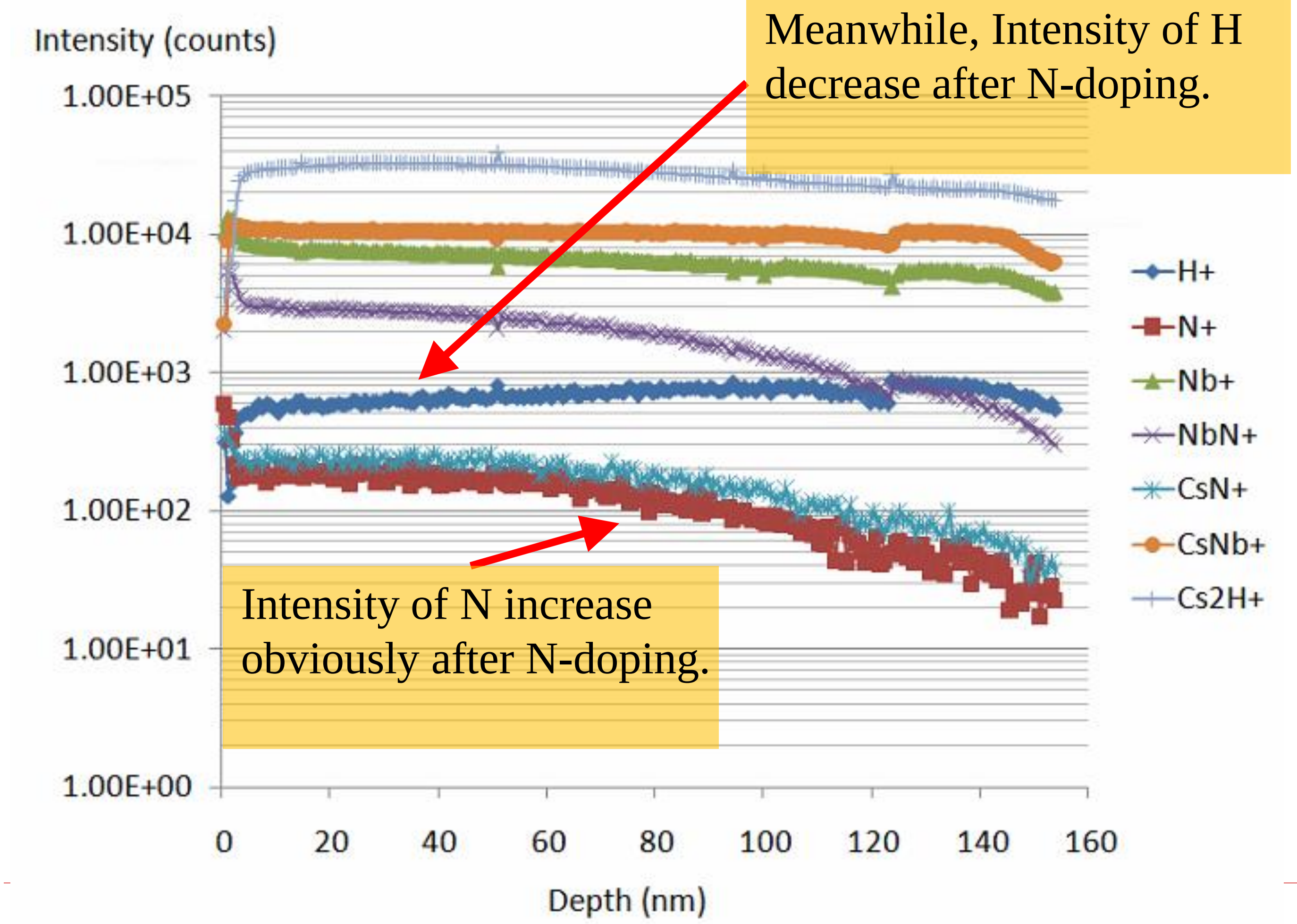
SIMS result before N-doping



SIMS result after N-doping at IHEP



SIMS result after N-doping at OTIC



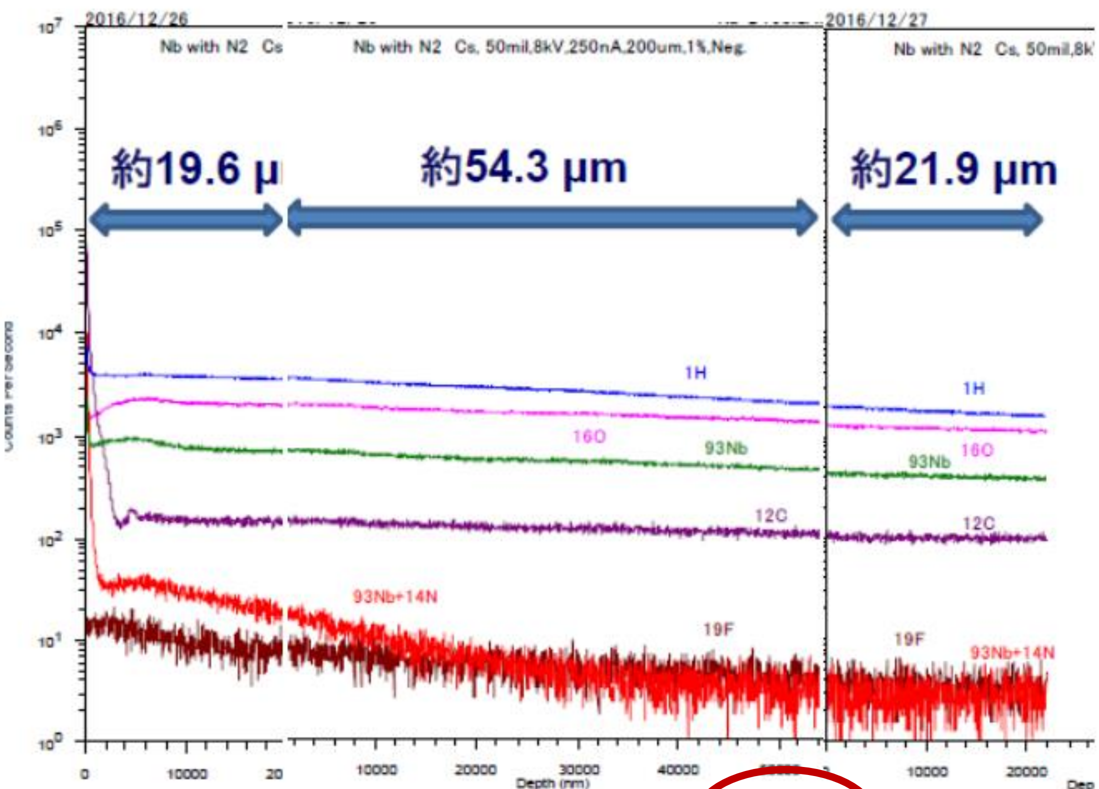
Intensity of NbN, CsN also increase after N-doping.

After ~5 um EP, N, NbN and CsN all disappear.

SIMS for N-doped sample(~100um)

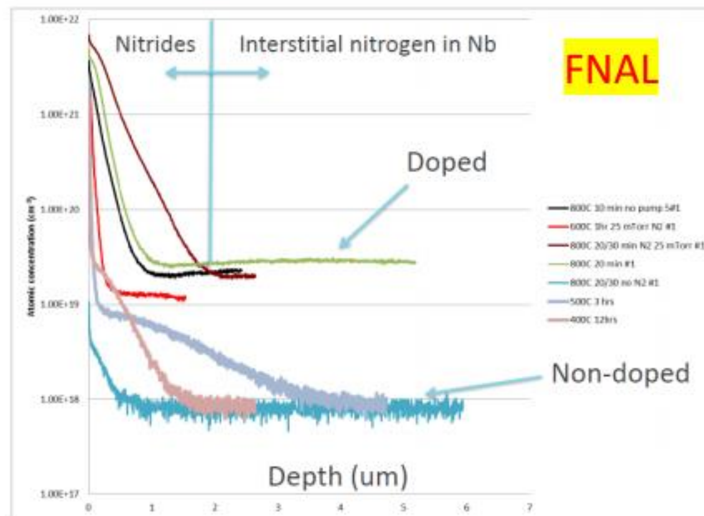
Analyzed by ULVAC

Total of three measurements



- Rapidly decrease until ~1um **Nitrides?**
- Flat up to ~10um **N atom?**
- Then gradually decrease (down to lower limit)
- N behavior seems to be similar

What does N treatment do? N depth profiles by SI



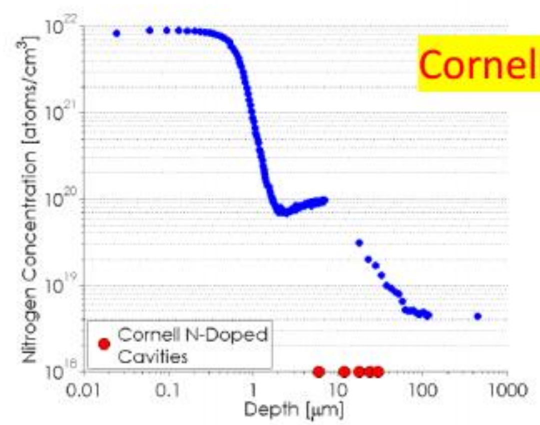
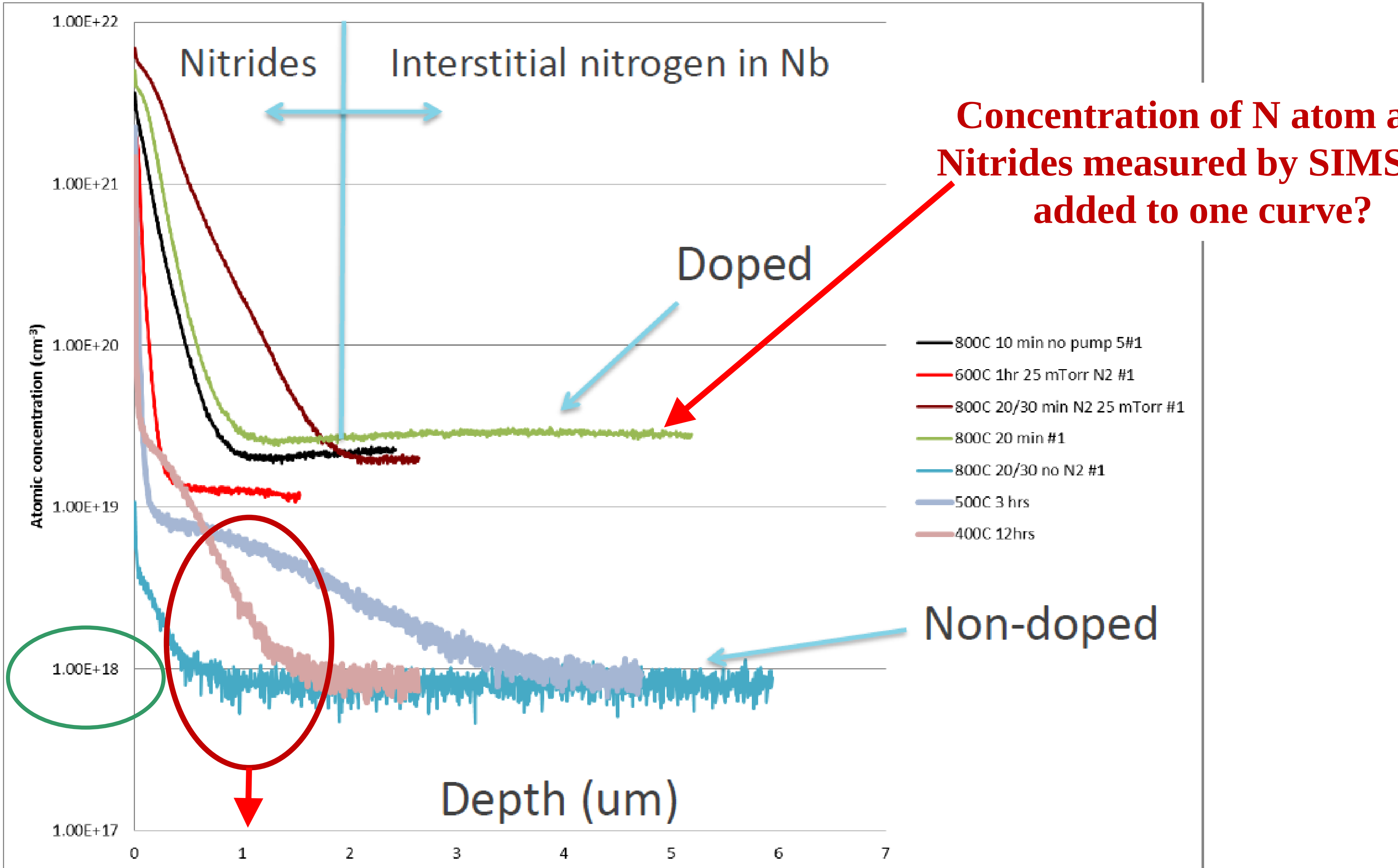
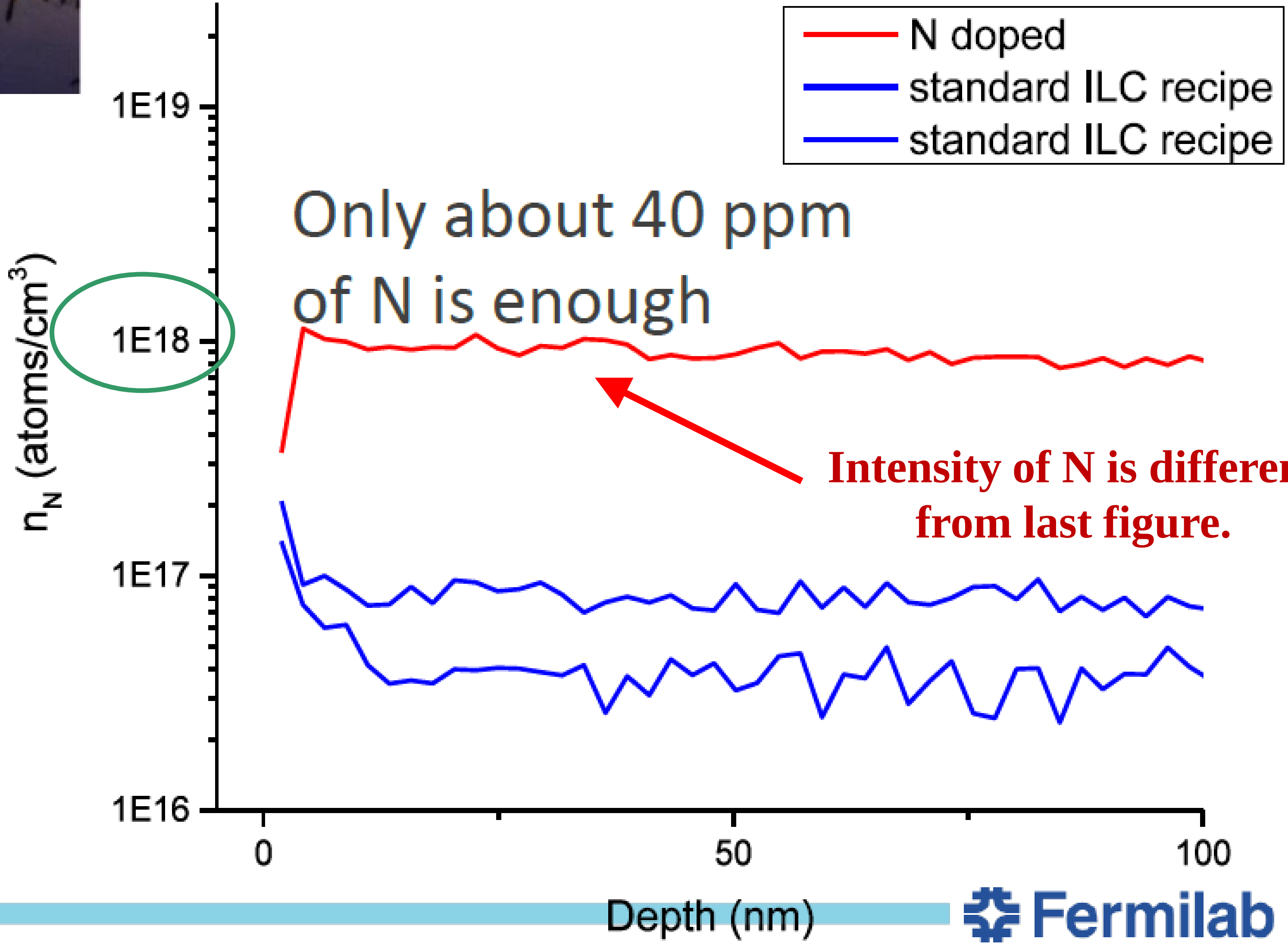


Figure 6: SIMS results from a sample treated with TE1-4 and TE1-5. Single-cell cavities are also included for reference.

What does N treatment do? N depth profiles by SIMS



Only about 40 ppm of N is enough

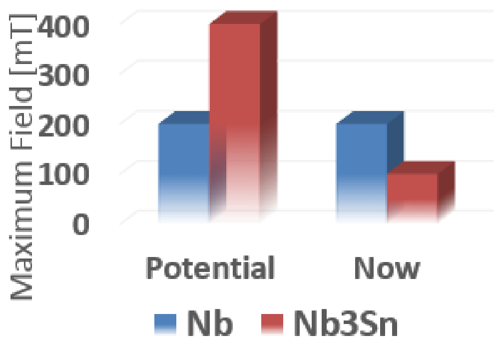


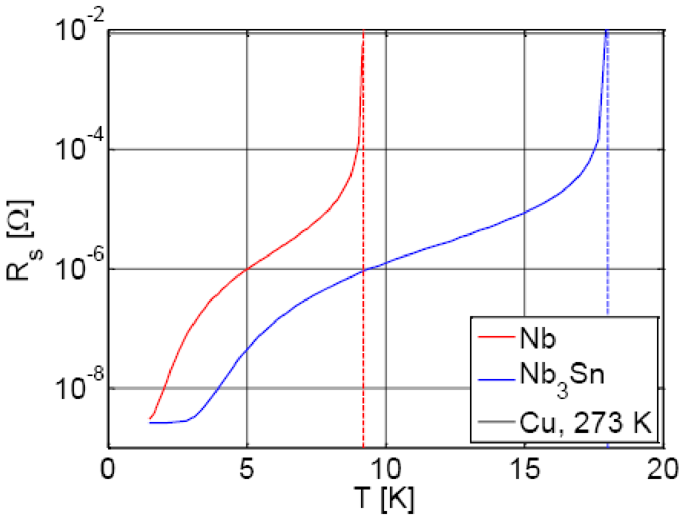
Intensity of N is different from last figure.

Contents

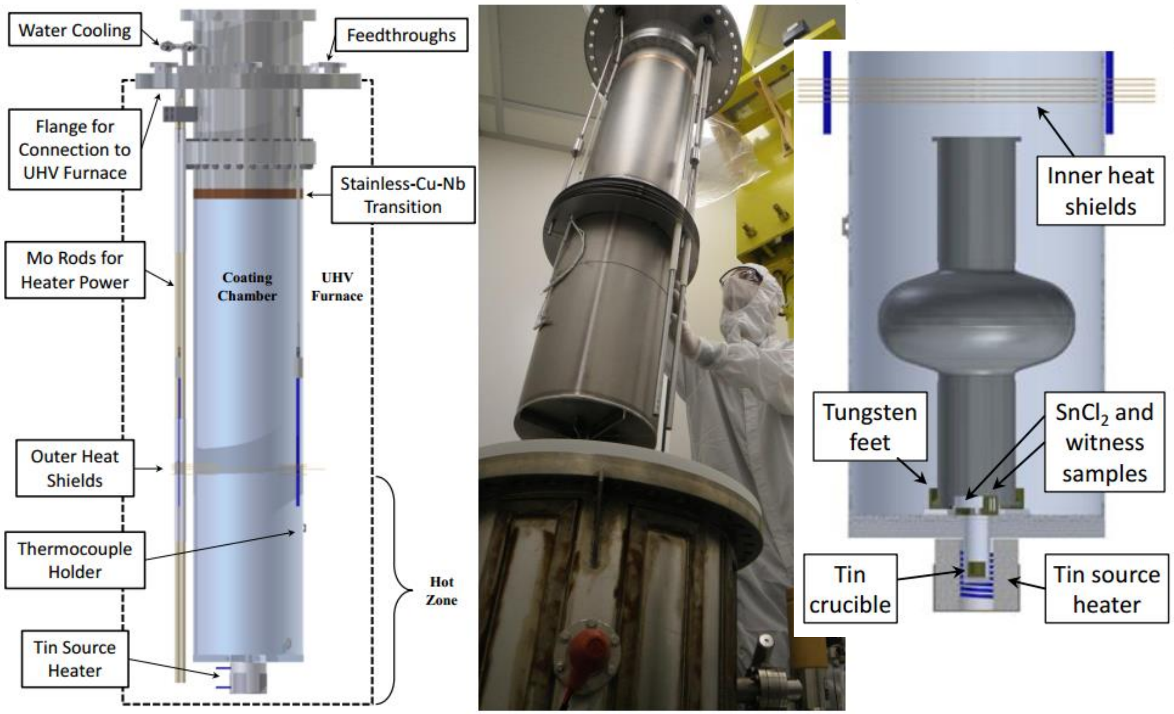
Nb_3Sn

- Niobium cavity coating with Nb_3Sn can work at 4.2K, which save much cost than 2K.
- Nb_3Sn is predicted to have 2x magnetic field limit of niobium.

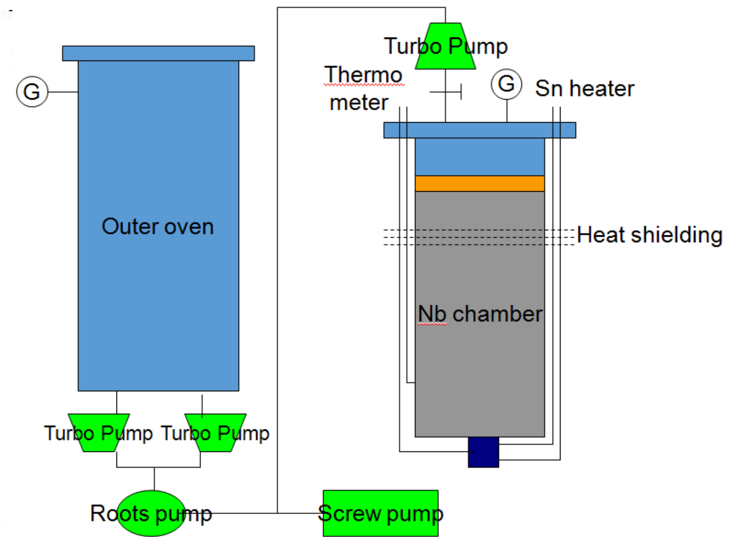




Schematic of Nb_3Sn furnace



Cornell Nb_3Sn Coating Furnace

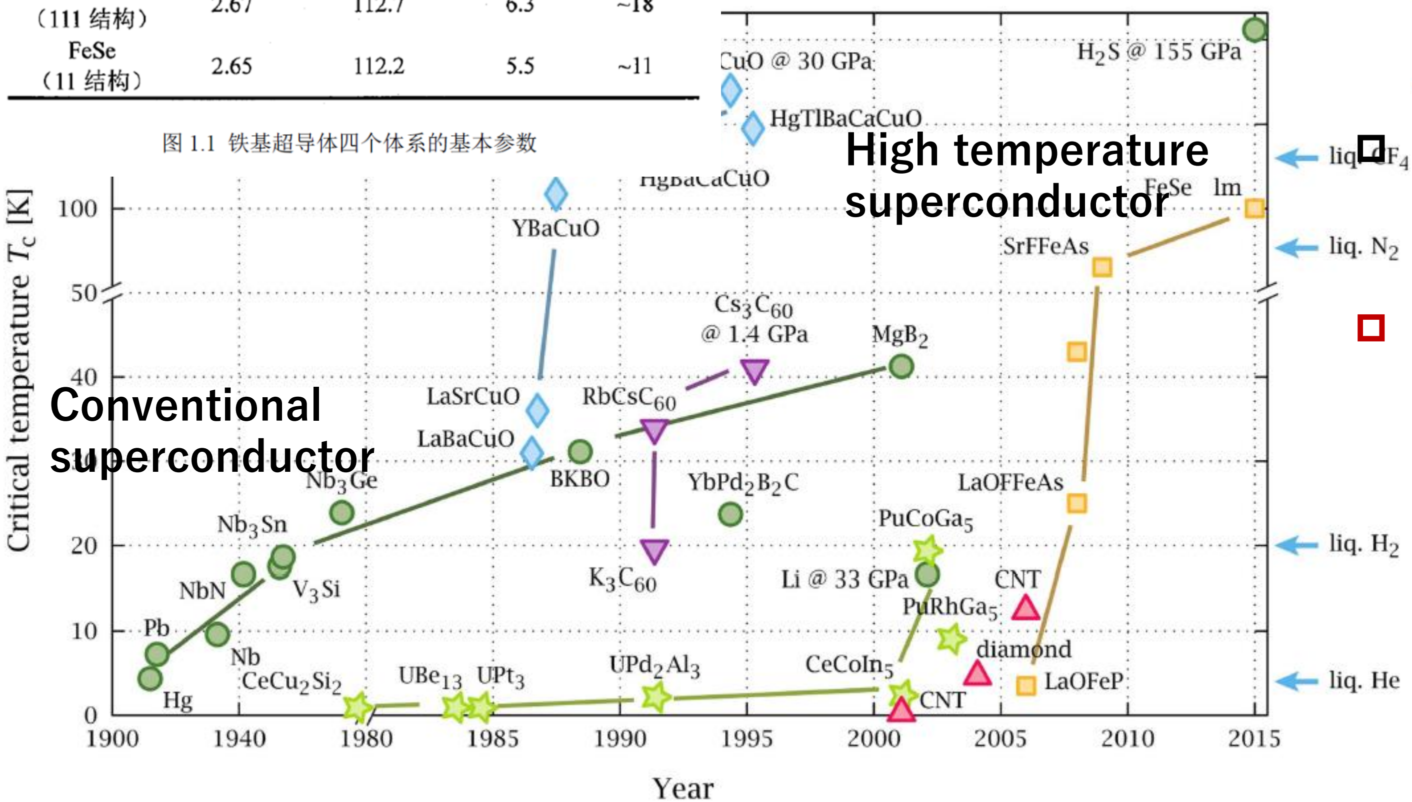


Nb_3Sn Coating Furnace at IHEP (complete in 2018)

Fe-based Superconductor for SRF Cavity

	铁原子间距（Å）	铁与近临两原子间键角（°）	铁层间距（Å）	超导转变温度（K）
ROFeAs（1111 结构）	2.84	107.4	8.3	~56
AFe_2As_2（122 结构）	2.77	108.9	6.5	~38
LiFeAs（111 结构）	2.67	112.7	6.3	~18
FeSe（11 结构）	2.65	112.2	5.5	~11

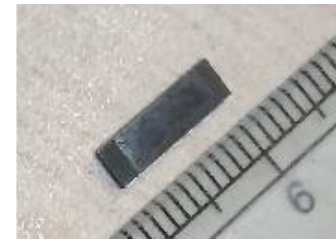
图 1.1 铁基超导体四个体系的基本参数



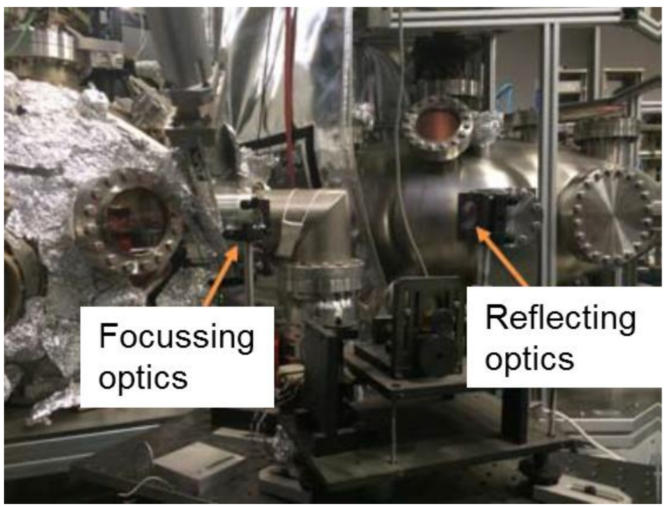
- World's first 100 m Fe-based superconducting wire by IEE, CAS, China (Aug. 2016)
- High Tc Superconductivity Collaboration of China (lead by Yifang Wang) has decided to push the use of Fe-based superconductor in SRF.

Fe(TeSe) Thin Film Study at IHEP

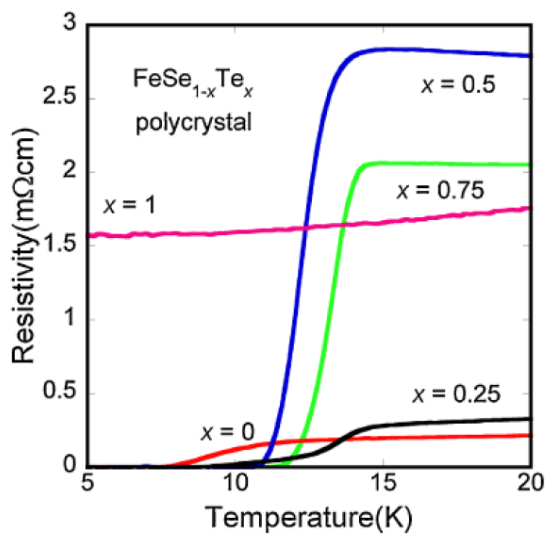
- SrTiO$_3$ substrate with Nb doping (for better electrical conductivity)
- Preparation method: Pulsed Laser Deposition (PLD)
- Research on oxidation of Fe(TeSe) thin film
- Next step: make proper Fe-based material for SRF application.

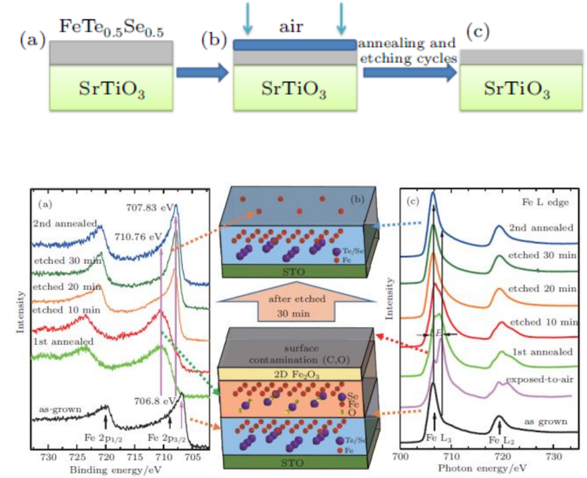


Fe(TeSe) thin film sample



PLD Equipment



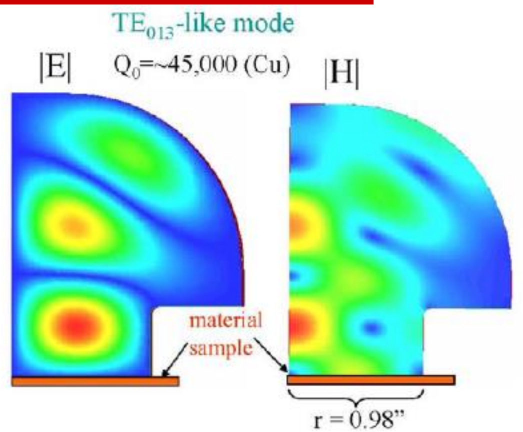


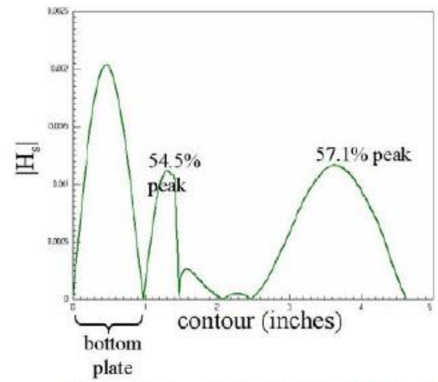
Chinese. Phys. B Vol. 25, No. 9 (2016) 097402

Rs measurement of film

"Mushroom" Cavity

- Probe H_{max} with pulsed rf





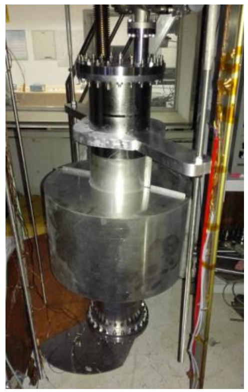
Nantista SLAC PAC 2005

- Superconducting materials test cavity
  - No surface electric fields (no multipacting)
  - Magnetic field concentrated on bottom (sample) face
- X-band (~11.424 GHz):
  - high power available
  - fits in cryogenic Dewar
  - Relatively large (2-3") samples required

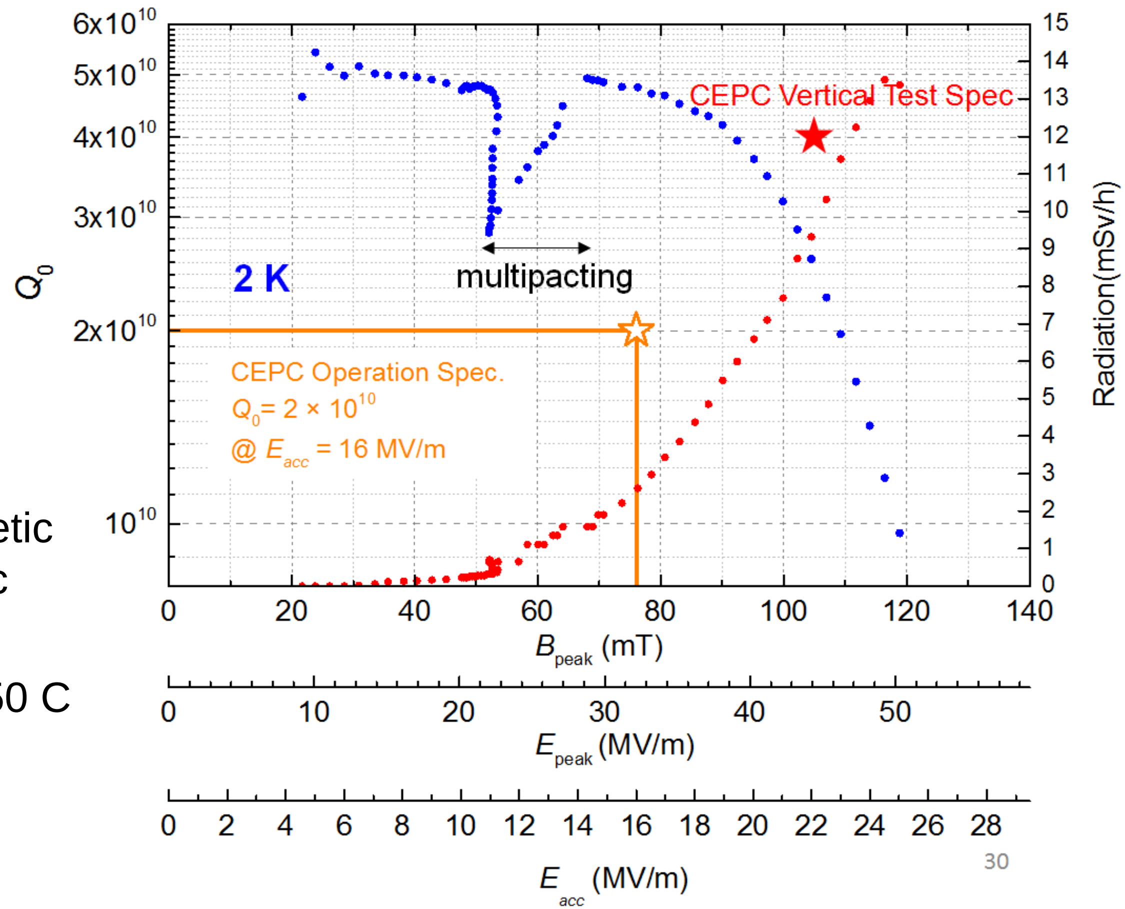
f (GHz)	A_{Sample}	A_{rf}	$R_{sens}(\Omega)$	B_{max}
11.4	19.6 cm^2	~8 cm^2	?	?

Contents

650 MHz Single Cell Cavity Test before N-doping

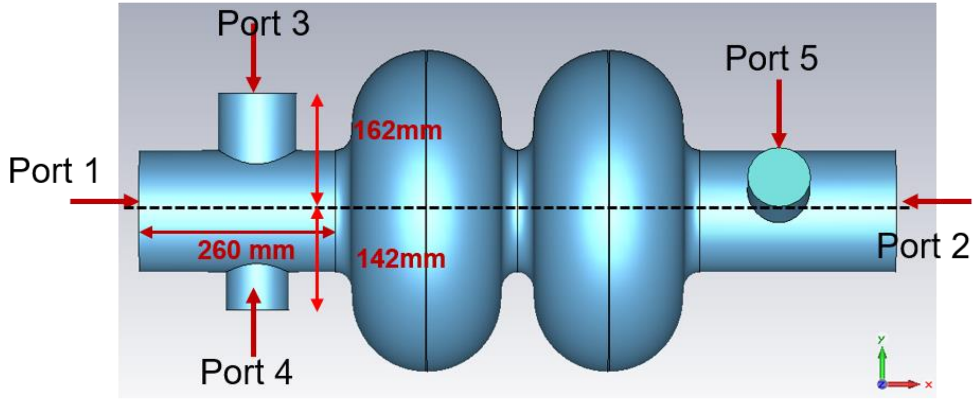


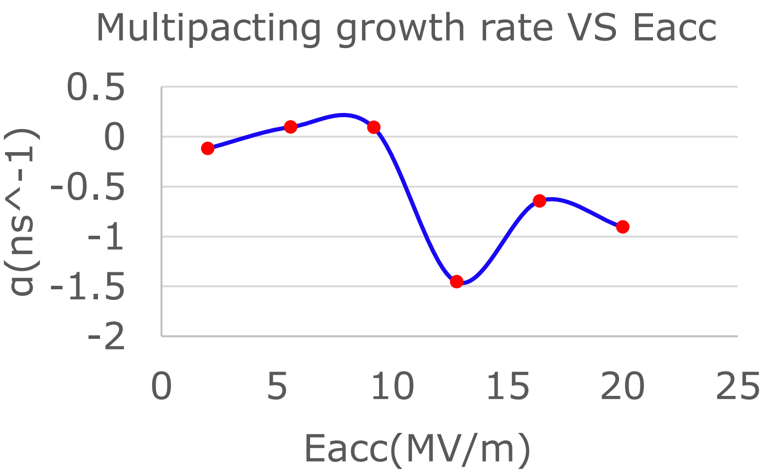
- Old RF design: B_p / E_{acc} = 4.75 mT/(MV/m)
- Shielded dewar, remnant magnetic field 20 mG. Additional magnetic shield around cavity.
- Fine grain, 130um BCP + 3 h 750 C annealing + 30um BCP + 120 C bake 48 h



RF design of 650MHz 2-cell cavity

Parameters	Value
R/Q (Ω)	212.731
G	284.113
Ep/Eacc	2.38
Bp/Eacc [mT/(MV/m)]	4.17

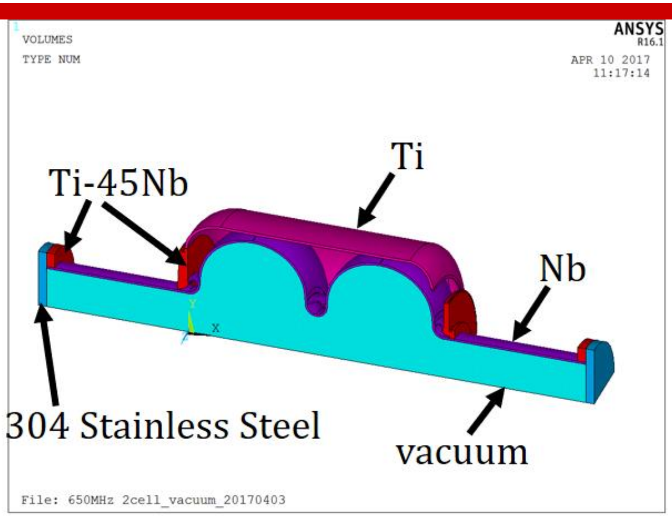


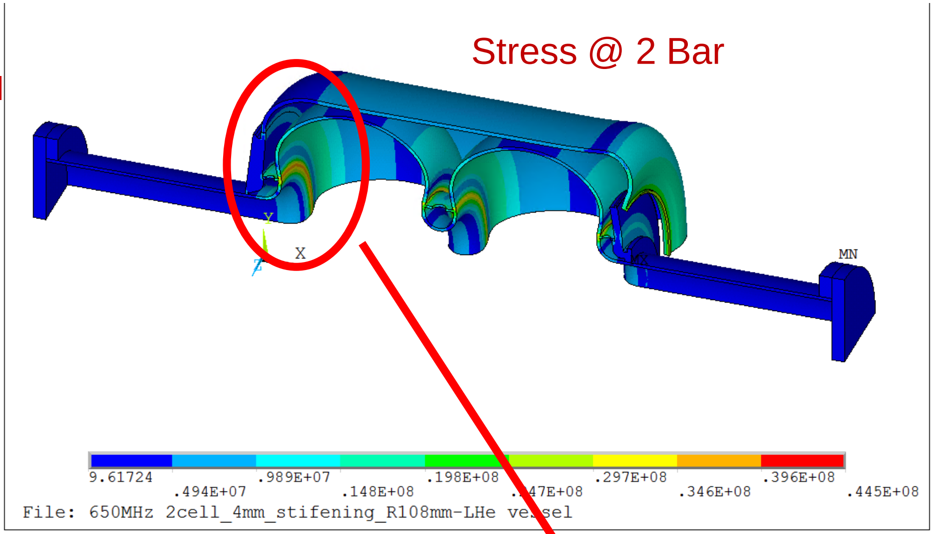


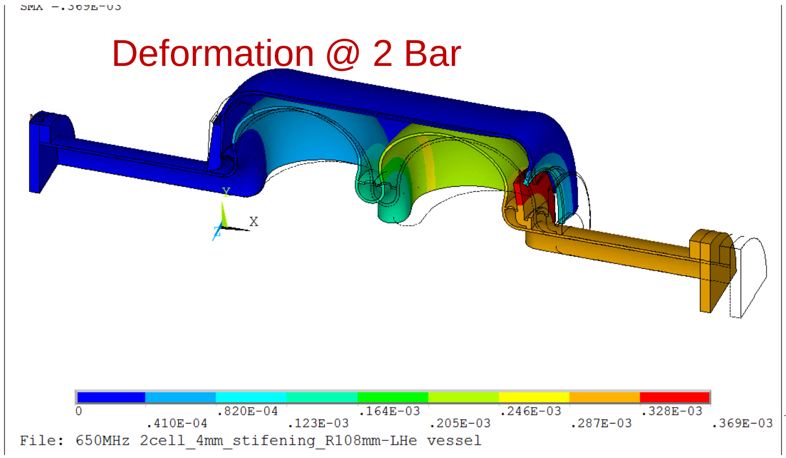
	P (W) (U=1J)	各个法兰面的Qe
Port 1	0.001867	2.19E12
Port 2	0.001352	3.02E12
Port 3	0.005441	7.51E11
Port 4	0.003435	1.19E12
Port 5	0.003320	1.23E12

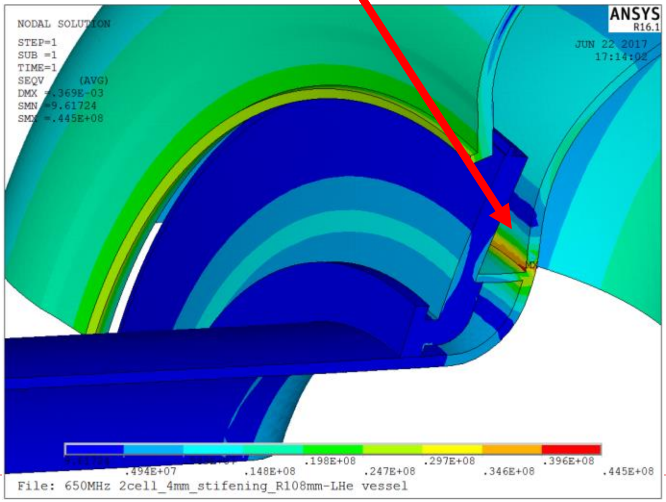
Qe (all ports)：2.65E+11. If *Q0* = 4E10，then *Q0* (measured) decrease to 3.48E10.

df/dp simulation



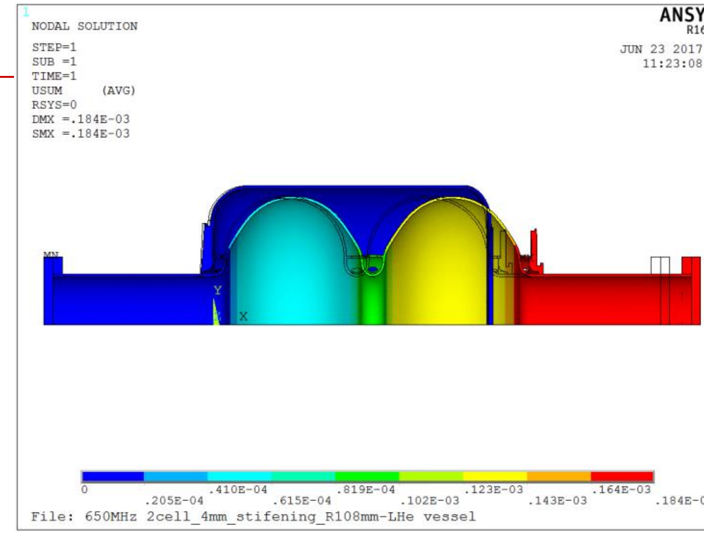




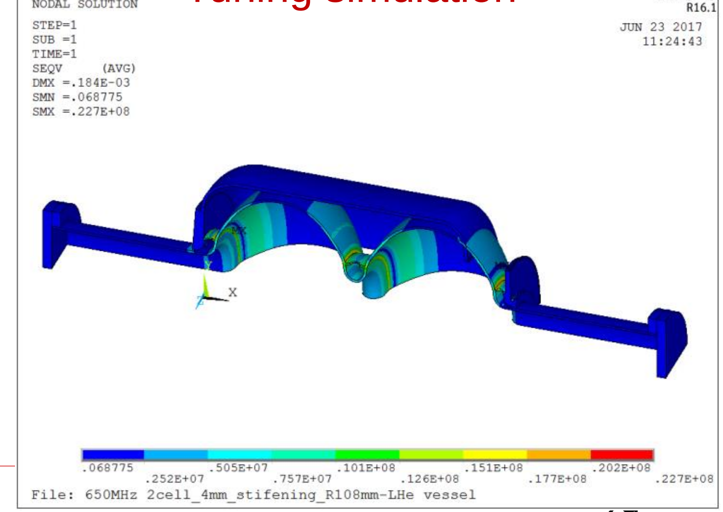


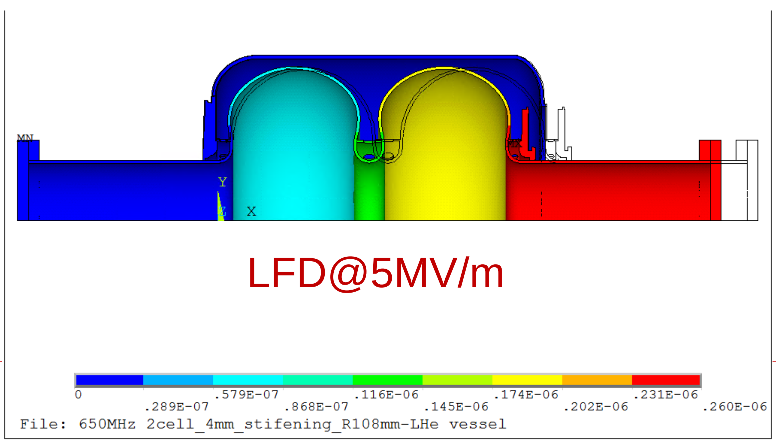
Mechanical analysis

- df/dp
  - -68.7 Hz/mbar
  - The stress under 2 bar (44.5 MPa)
- Tuning
  - Tuning sensitivity s: **310 kHz/mm**
  - Stiffness k: **16001N/mm**
- LFD
  - LFD coefficient= -4.16 Hz/(MV/m)^2



Tuning simulation

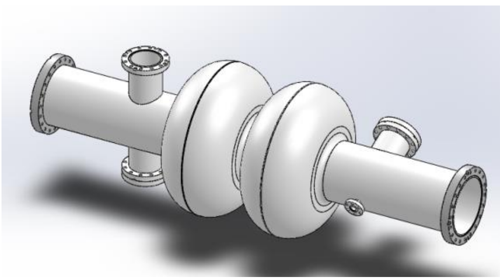


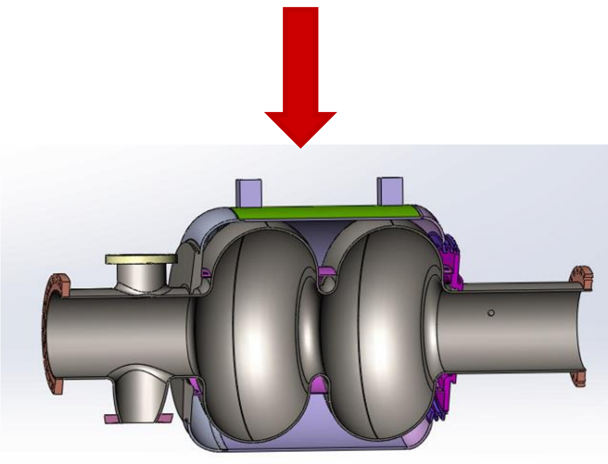


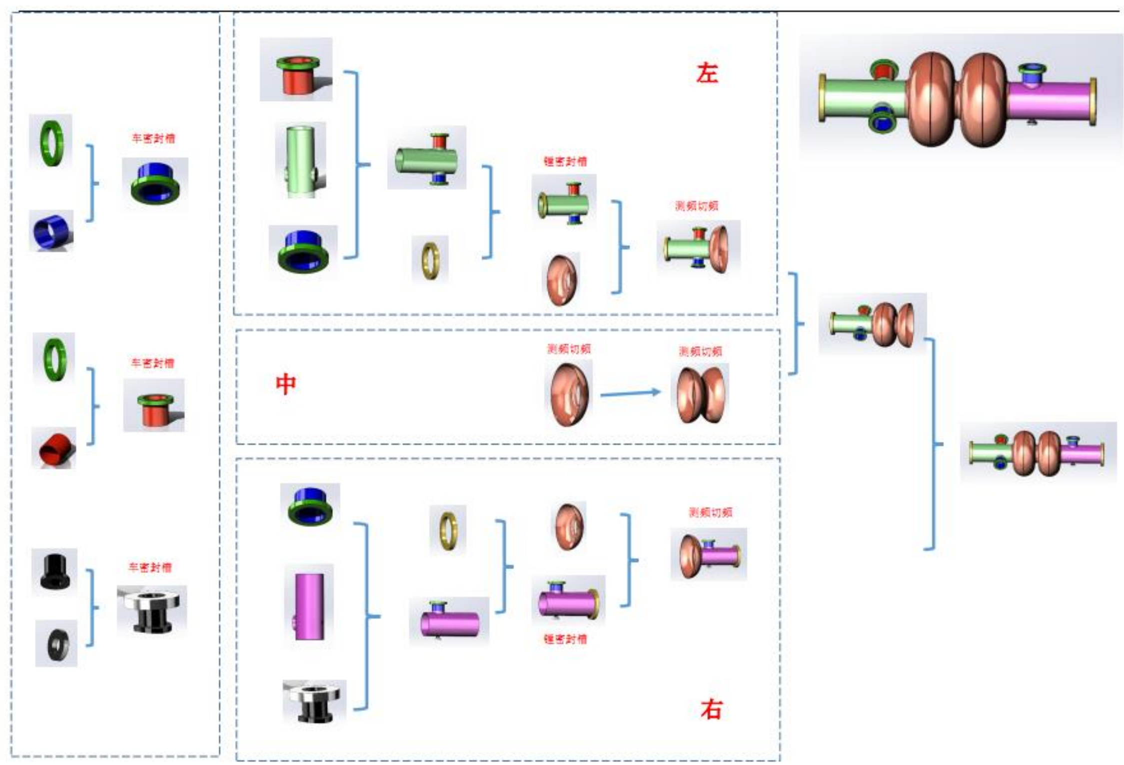
LFD@5MV/m

Fabrication

- A prototype of 650 MHz 2-cell cavity has begun fabrication at IHEP factory.







Contents

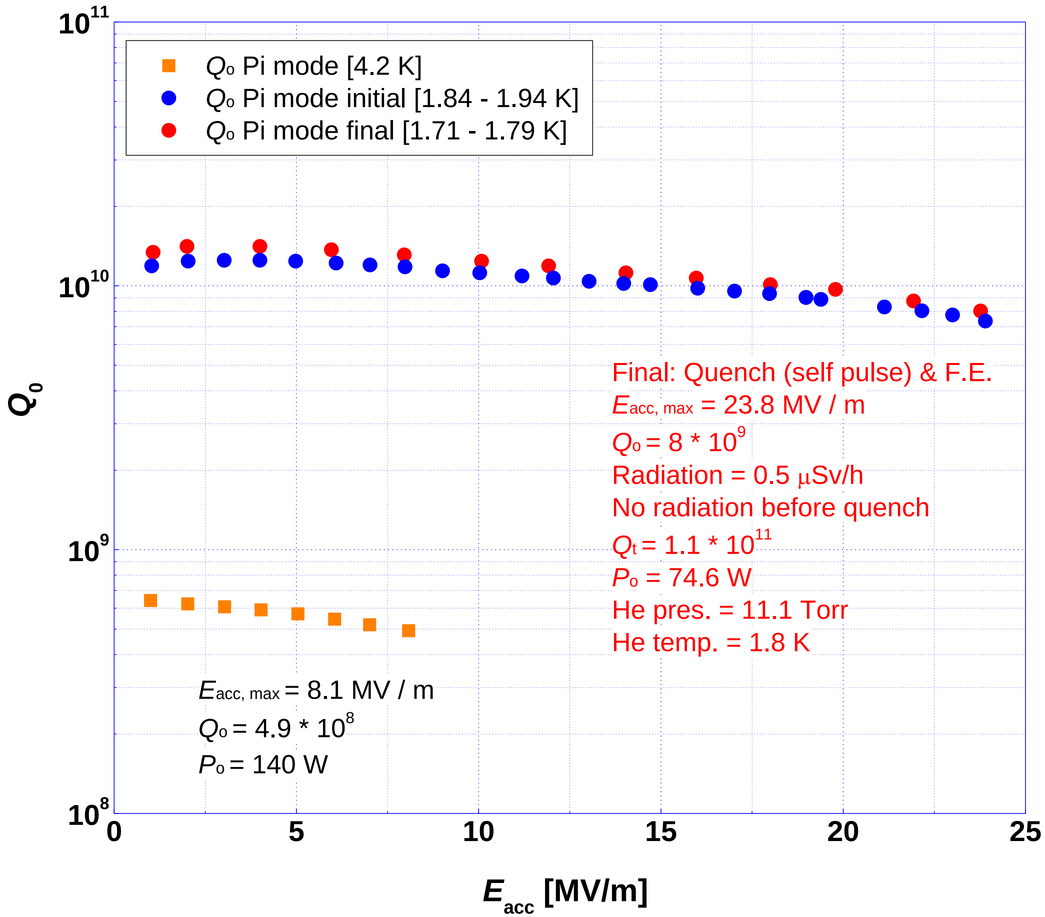
1.3 GHz cavity for CEPC booster

- 1^{st}, high gradient, 35MV/m at May 2018.
- 2^{nd}, high Q.
- Tesla type: Single-cell ----- 2-cell ----- 9-cell

6. Summary

- N-doping collaboration: N-doping related experiments of Nb samples and 1.3GHz (650 MHz) cavities both at KEK and IHEP. Those include N-doping/N-infusion in furnace at IHEP or KEK, material analysis (SIMS, TEM, SEM, XPS…) at IHEP or KEK, **surface process and vertical test of cavity at KEK.**
- We've already two 650MHz single-cell cavities for N-doping on hand now, which have received BCP and vertical test at IHEP. We can send the 650MHz Solid state amplifier (>300W) to KEK for vertical test, too.
- We've several 1.3 GHz single-cell cavities (Tesla-type) on hand. They can all be shipped to KEK for N-doping and vertical test.
- In late 2016, one 1.3 GHz 9-cell cavity received surface process and vertical test at KEK, which reach 8e9@24MV/m。

6. Summary



Low Q_0 at low field

TESLA cavity G = 271 Ω

@ 1MV/m

Q_0 = 1.19E10 @ 1.93 K

(R_{BCS} @ 1.93 K = 8.2 nΩ)

Q_0 = 1.34E10 @ 1.73 K

(R_{BCS} @ 1.73 K = 3.2 nΩ)

6. Summary

- Nb cavity coating with Nb_3Sn: high temperature coating technique exchange, material analysis (SIMS, TEM, SEM, XPS…) at IHEP or KEK, **surface process and vertical test of cavity at KEK.**
- Fe-based superconductor: make film (IHEP), material analysis (SIMS, TEM, SEM, XPS…) at IHEP or KEK, **measurement of T_C, $H_{C,RF}$, Rs at KEK**. Cavity coating with film is difficult nowadays.

Thanks for your attention!