Progress of 1.3 GHz SRF Cavities at Peking University

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Outline

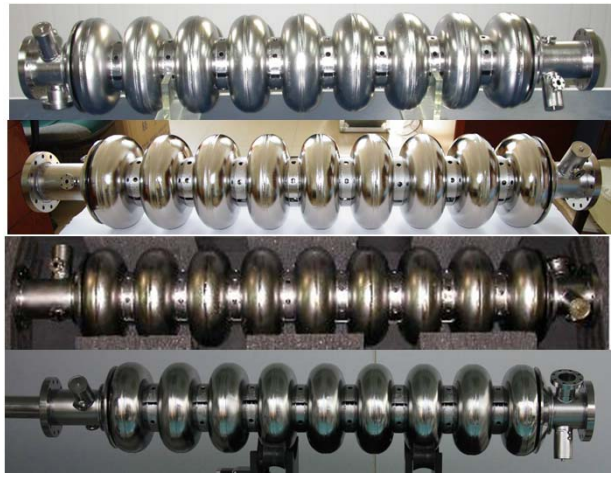
- Motivation and background
- New progress: series production of 9-cell large grain cavities
  - Fabrication
  - Treatment
  - Vertical test
  - Horizontal test
- N-doping researches of single cell cavity
- Summary

Motivation and background

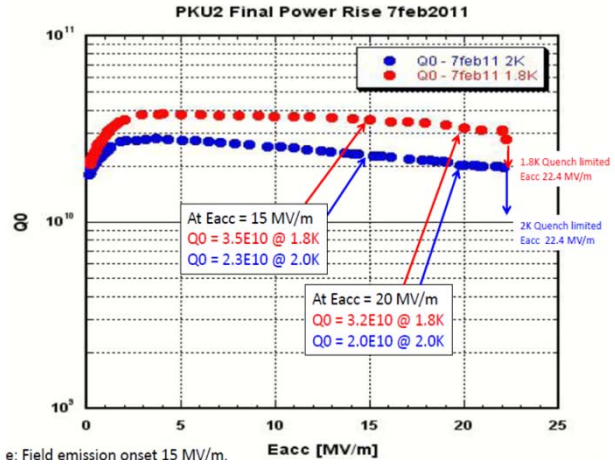
- The development of 1.3 GHz cavity is driven by large projects
- European XFEL and ILC need cavities with high gradient
- CW XFEL needs cavities with medium gradient and high Q, for example, LCLS-II and Shanghai XFEL (SCLF)

Motivation and background

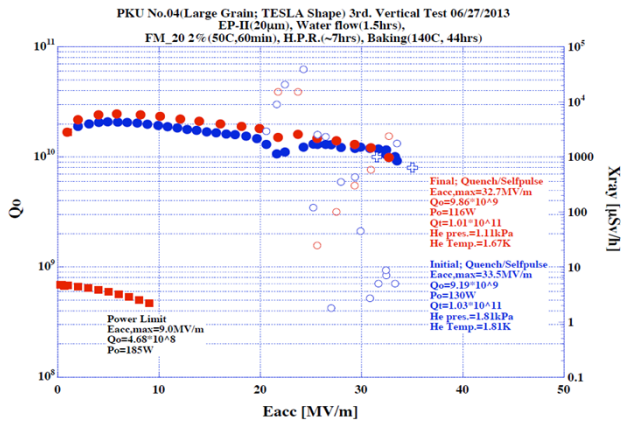
Early efforts for 9-cell cavities at PKU (collaboration with HIT, Jlab, KEK)



Cavity	Nb	Eacc (MV/m)	Q @ Emax	Q @ 16MV/m
PKU1	FG	23.0	6.0E09	1.1E10
PKU2	LG	22.4	2.2E10	2.0E10
PKU3	FG	28.6	4.0E09	7.0E09
PKU4	LG	32.6	1.0E10	1.6E10



- Eacc: 22.4 MV/m,
- Q_0=2E10 @ 20 MV/m, 2K

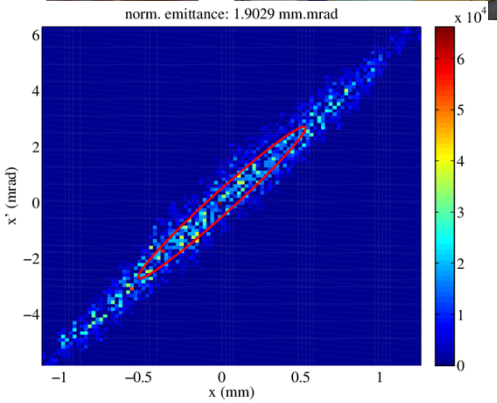


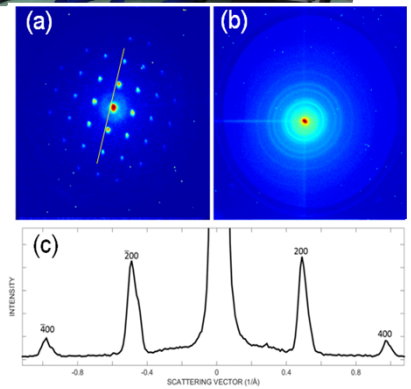
- Eacc: 32.6MV/m, Q_0:1E10 (1.8K)
- Reach ILC requirement

Motivation and background

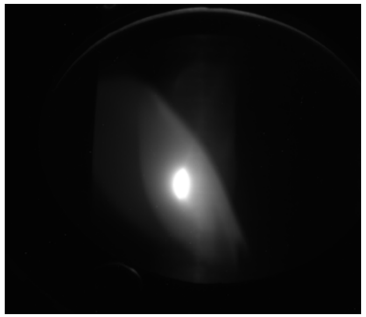
Stable electron beam loading with large grain cavities

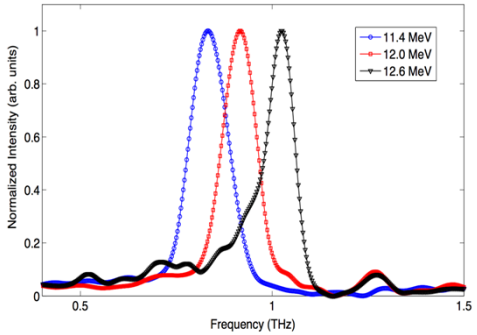
DC-SRF injector with 3.5-cell cavity (since 2014)





Cryomodule with 2×9-cell cavities (since 2015)



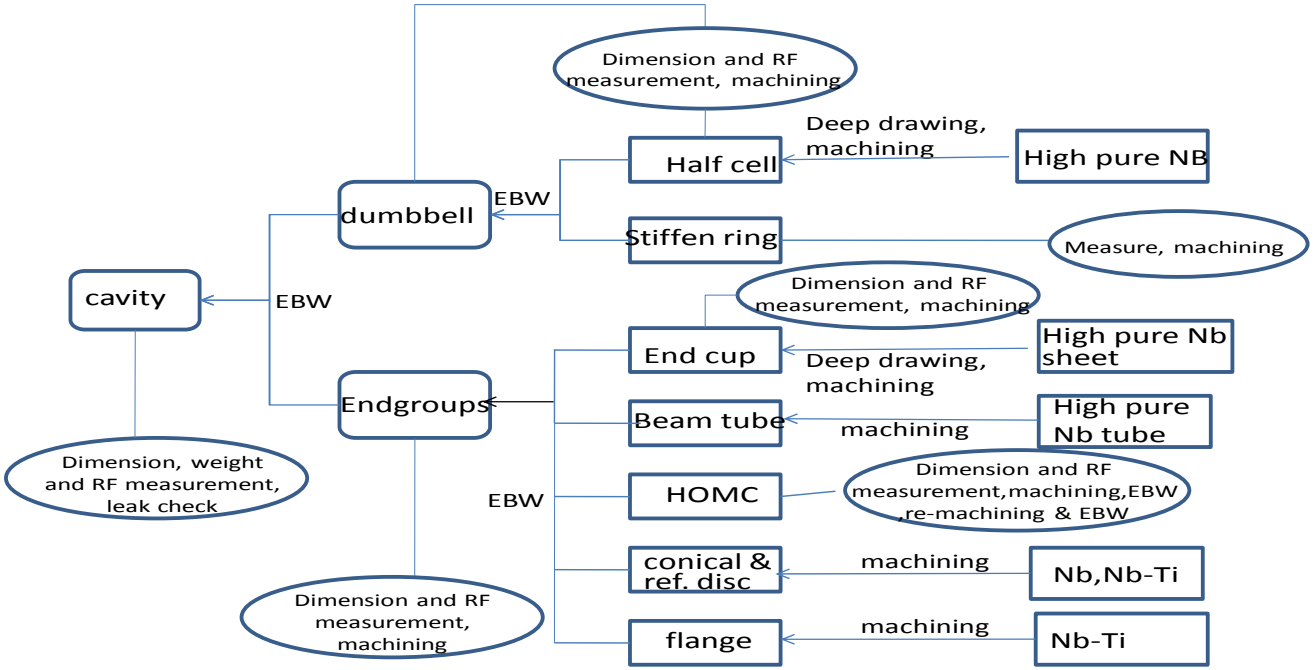


- 10~20 MeV, Ave. current ~1mA (long macropulse)
- Applications: UED, THz radiation

Motivation and background

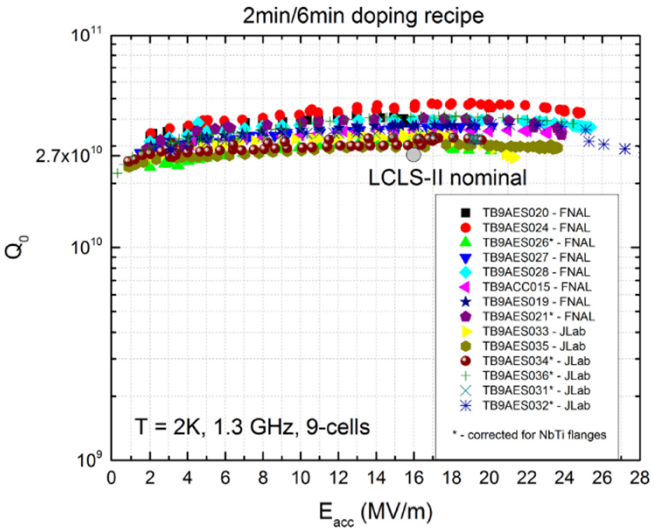
Recent researches

- Production study of 9-cell cavities
  - Driven by the needs of Collider/CW XFEL plans
  - Series production following the standard specification at PKU
  - Test of repeatability and consistency



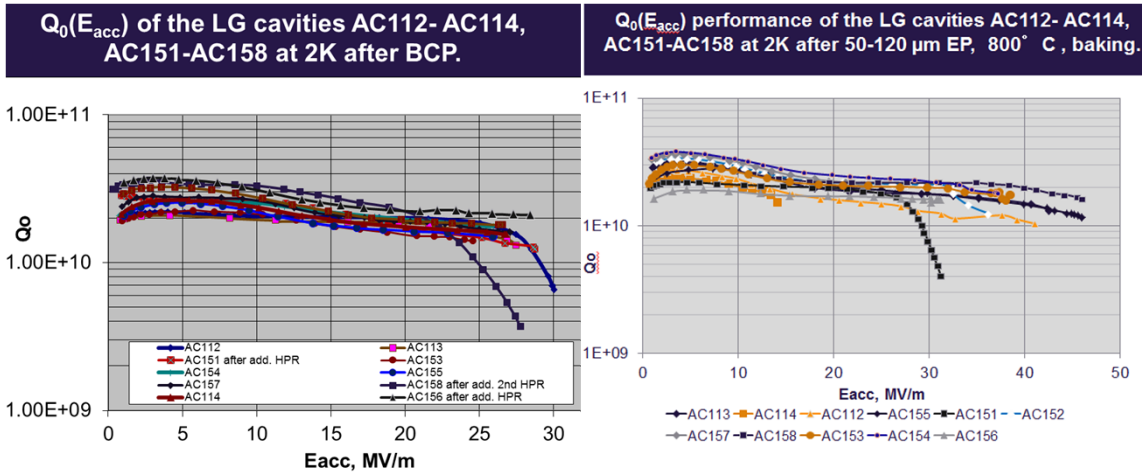
Methods to reach high Q for 1.3 GHz cavities

High Q tech.: N-doping



A. Grassellino, SRF2015

Optional tech.: Large Grain



W. Singer, TTC2011, Beijing

We choose large grain material for series production study to test the possibility of using LG cavities to get high Q

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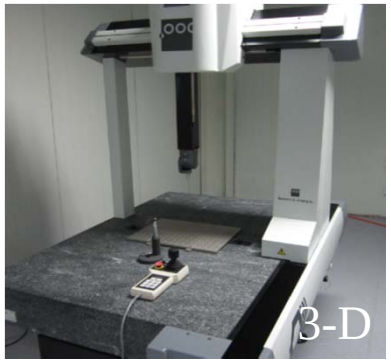
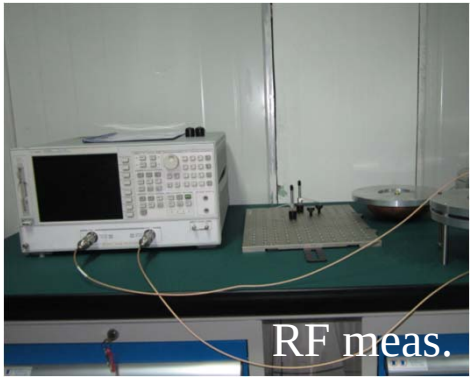
Series production of 9-cell large grain cavities

Ningxia Orient Superconductor Technology Co., Ltd (OSTEC)
(Founded by OTIC and PKU, 2011)


EBW machine


3-D


Deep drawing


RF meas.

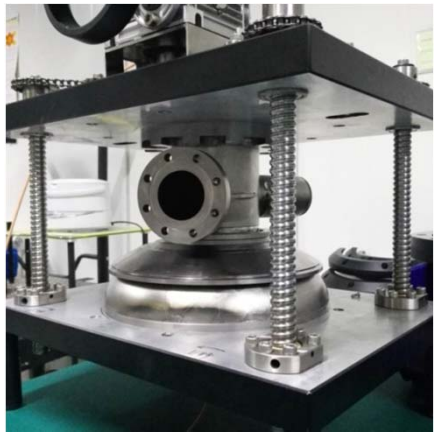

Clean Room


Machining center


Machining center

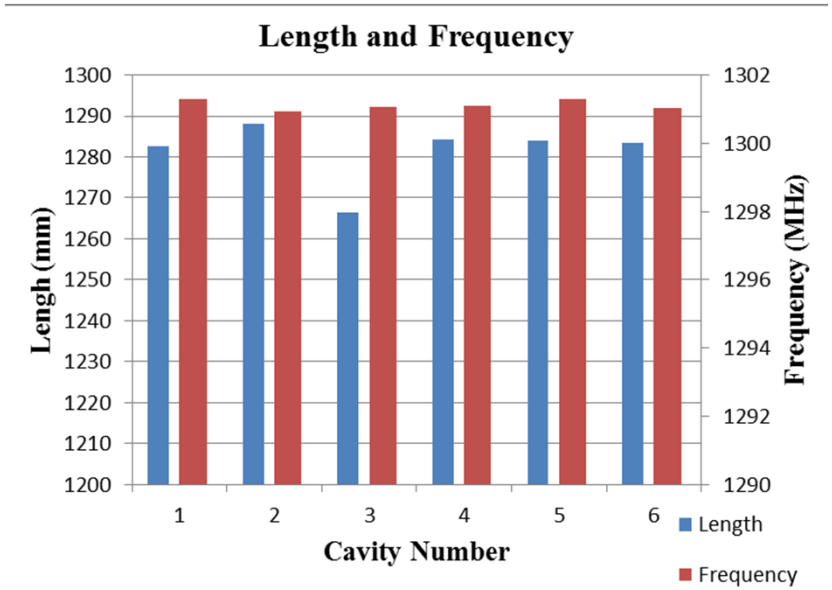
Series production of 9-cell large grain cavities

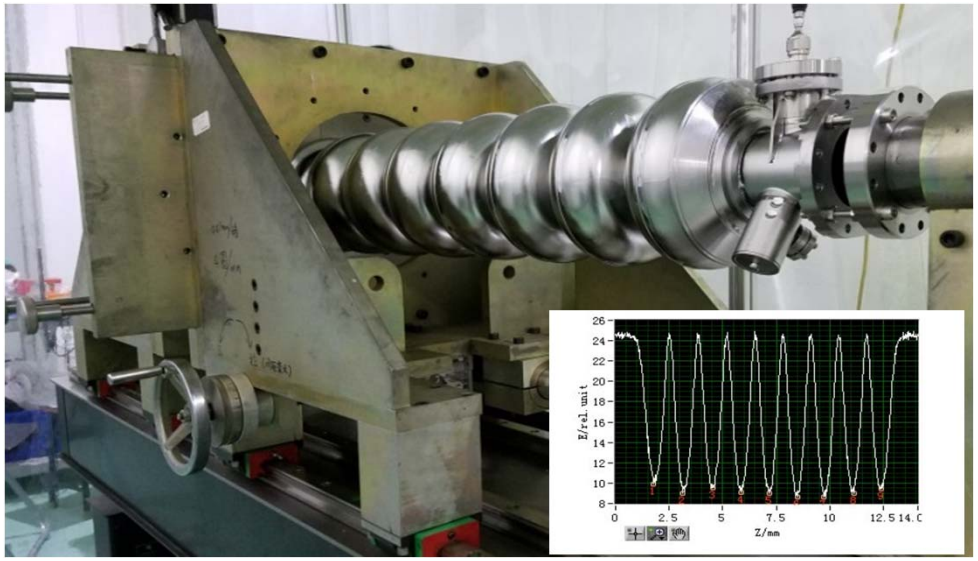
Strict quality control for every step



Series production of 6 LG 9-cell cavities (2016-2017)

Length, frequency and flatness





- $L \pm \sigma_L = 1284.5 \pm 2.1$ mm (cavity #3 excluded)
- $f \pm \sigma_f = 1301.12 \pm 0.14$ MHz
- within the tolerance
  - $\sigma_L : \pm 3$ mm
  - $\sigma_f : \pm 0.5$ MHz

Flatness before and after tuning

Cavity #	original	after tunting
1	69.9%	96.6%
2	57.3%	94.6%
3	66.7%	95.1%
4	75.6%	95.0%
5	63.0%	95.3%
6	60.0%	96.6%

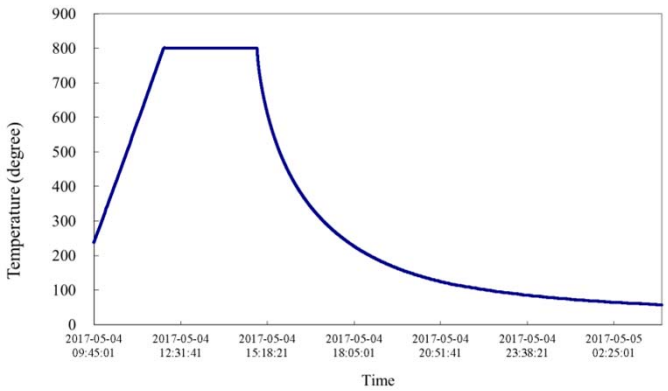
Post processes

- BCP (180 μm)
- HPR
- 800 °C 3 hrs degasing/annealing
- BCP (30 μm)
- Field flatness tuning
- Ultra sonic cleaning
- HPR
- Assembly
- HPR
- VT Assembly
- Vertical Test

Without EP

BCP

HPR



800 °C treatment

Clean room assembly + HPR

Setup of Vertical Test System (VTS)

Cryo. system

2K pumps

VTS dewar

Insert

Magnetic shield

- double mag. shield,< 10 mGs
- mass flow: 10 g/s @30 mbar
- cooling capacity:>200W@2K

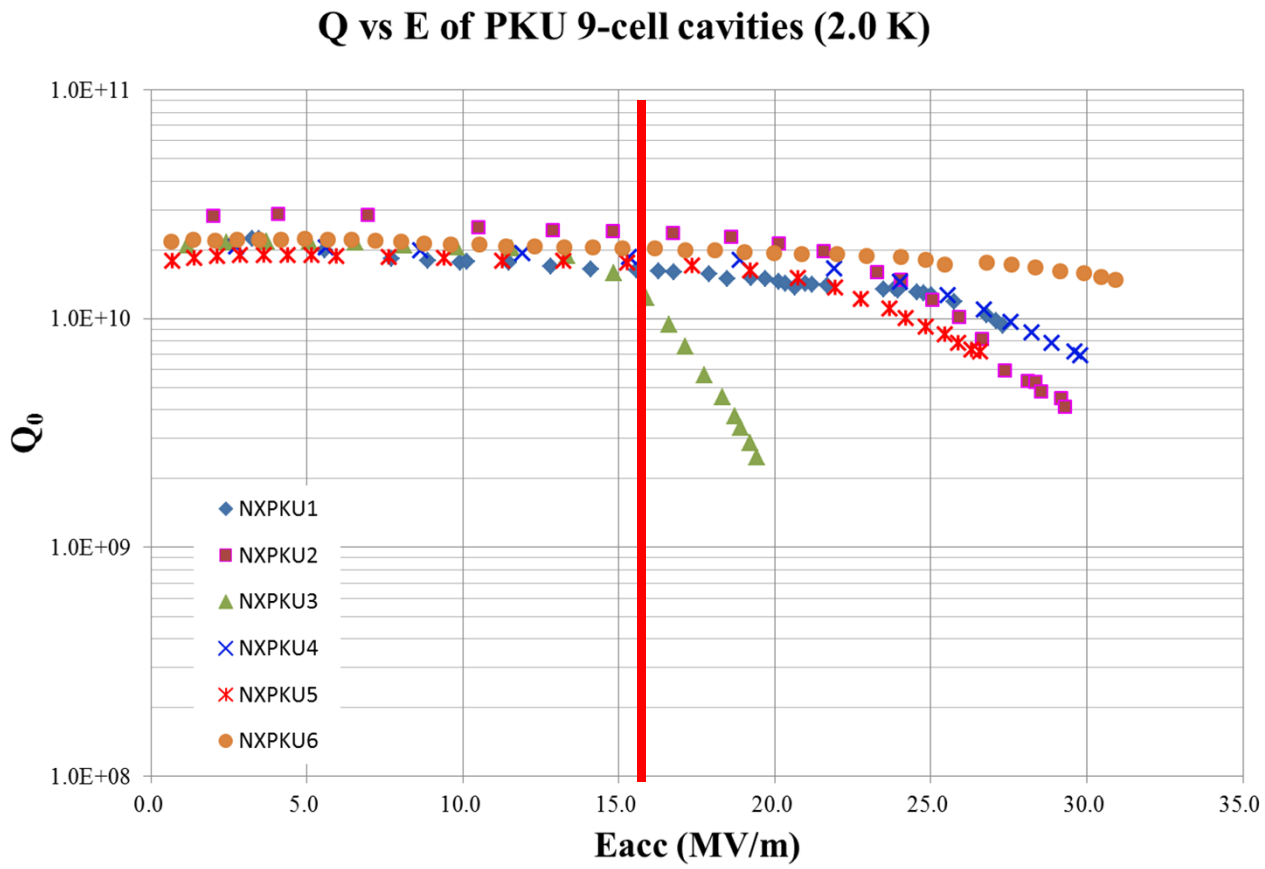
Vertical Test

Vertical test of 6 large grain 9-cell cavities (April ~ June, 2017)

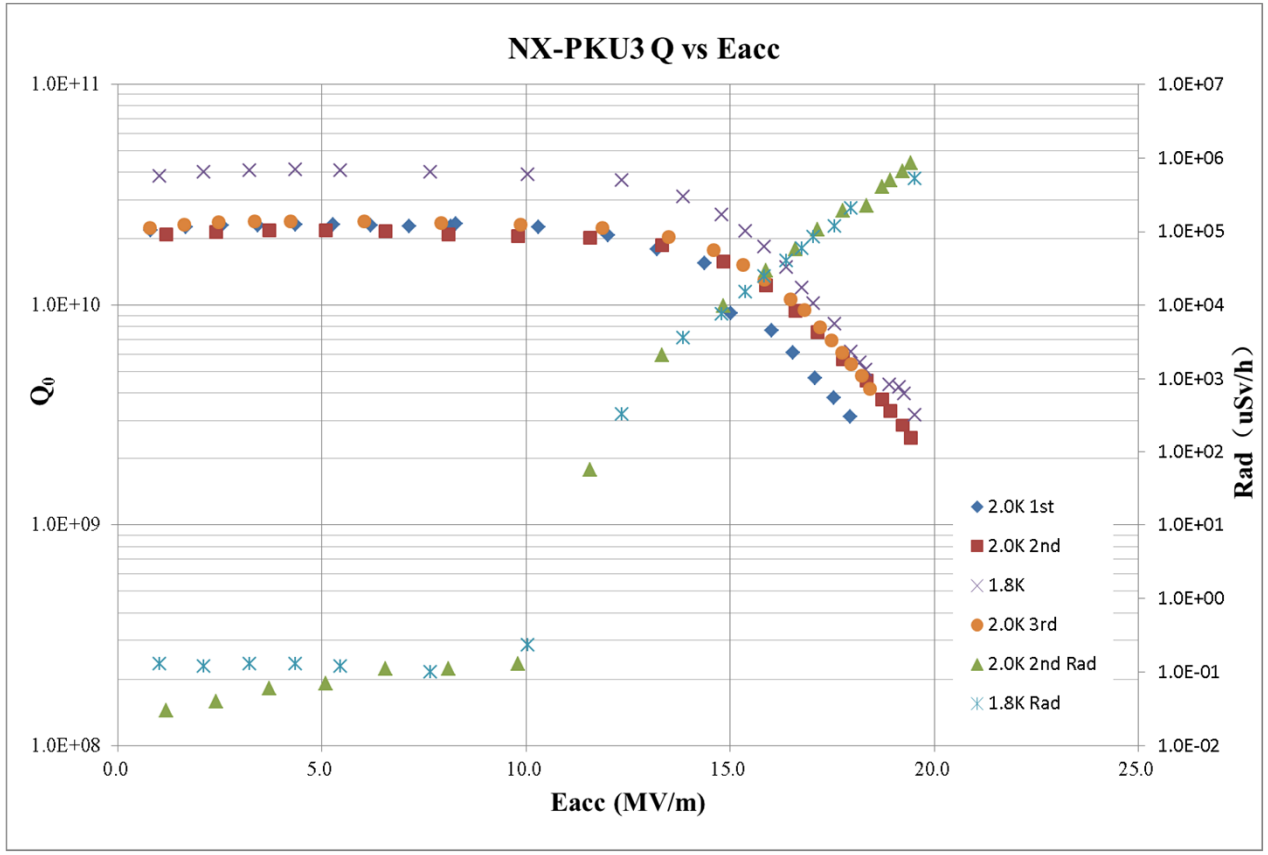
Q vs E curves of 6 large grain cavities at 2 K

- All cavities follow the same procedure
- #1,3,4,6, 1st test
- #2,5, 2nd test, with additional HPR

- E_{acc} of 5 cavities larger than 25 MV/m
- Q_0~1.6-2.4E10 @ 16 MV/m

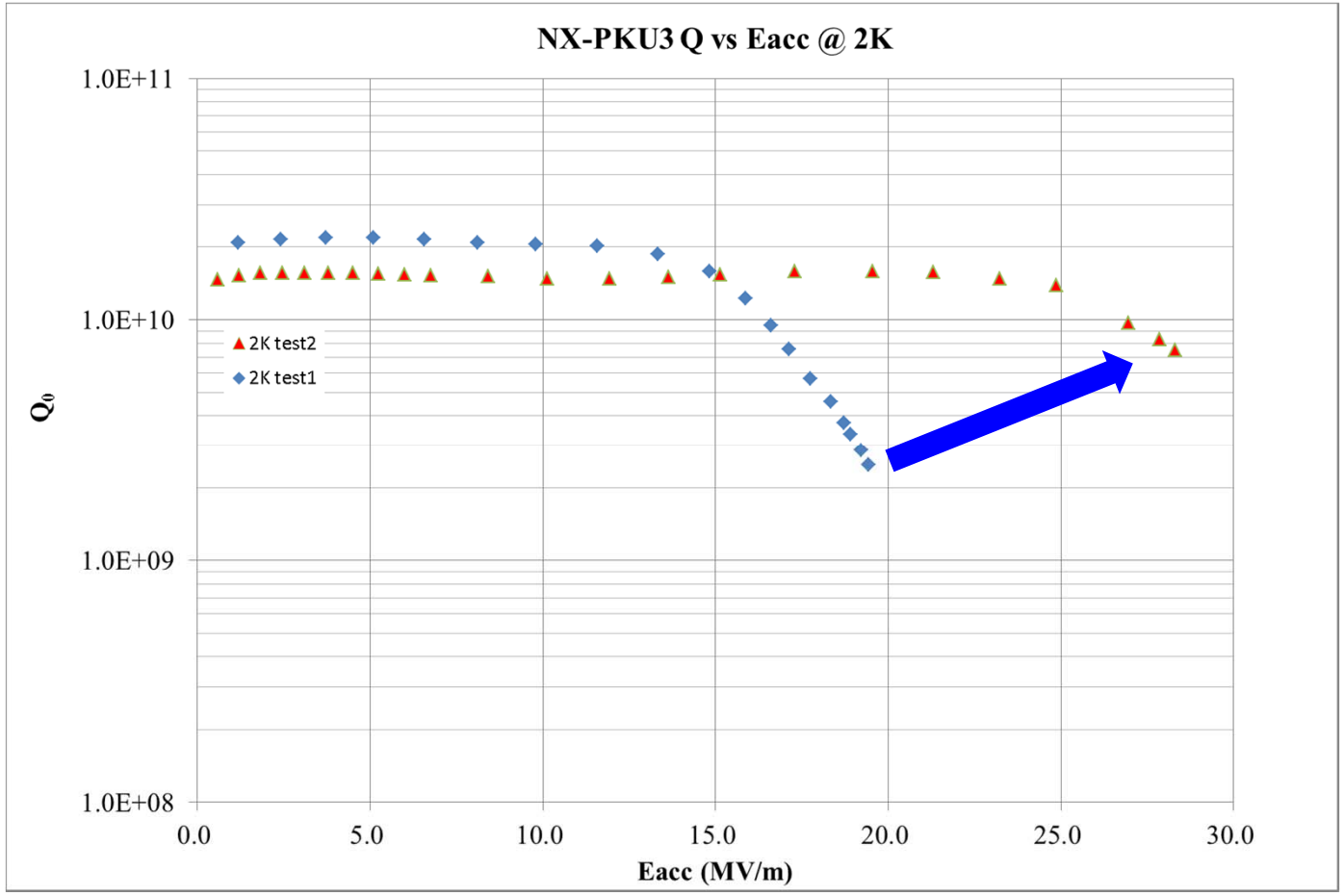


NX-PKU3 cavity



- strong FE due to HPR accident

NX-PKU3 cavity, 2nd test

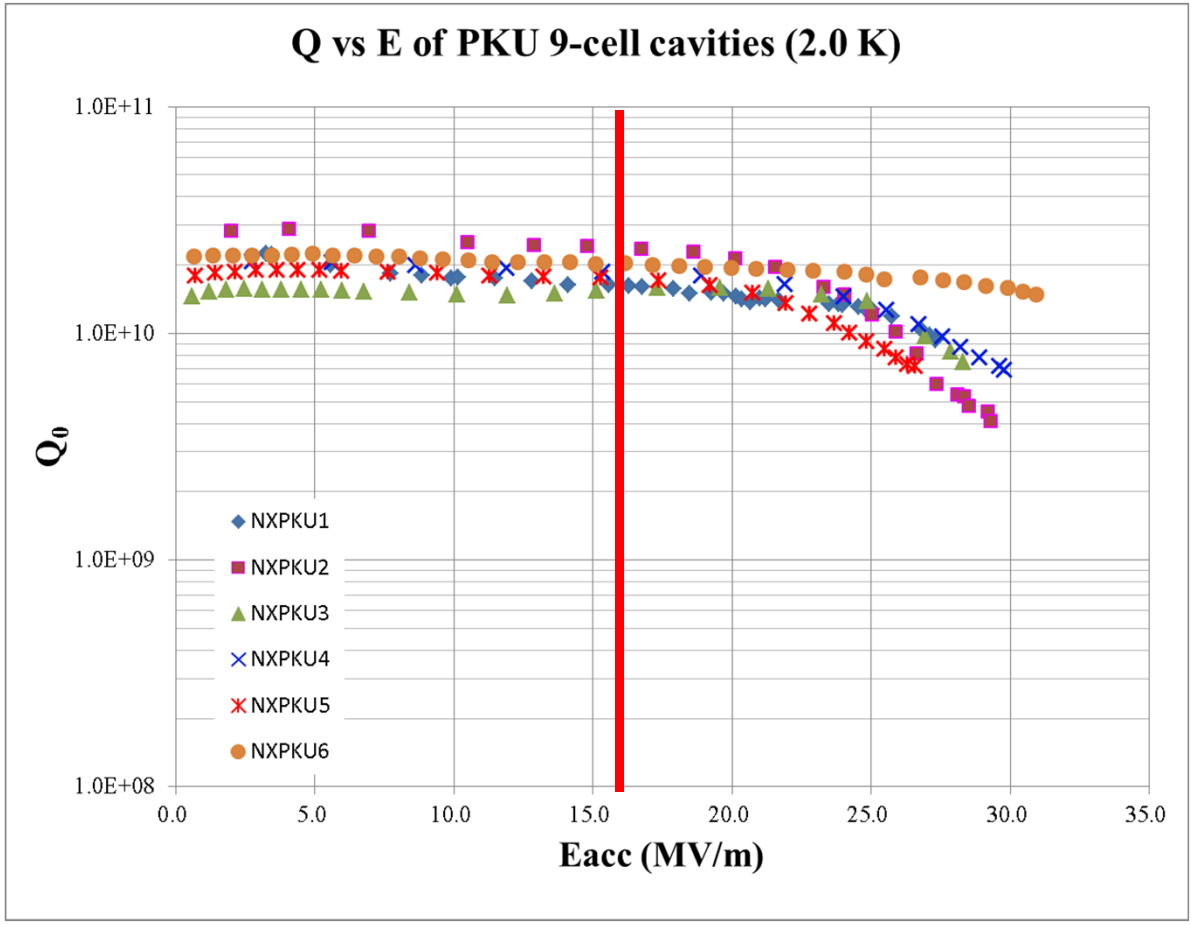


- Additional BCP 30 μm + HPR 6 hr
- 2nd test, Eacc -> 28.3 MV/m

Q vs E curves of 6 large grain cavities at 2 K

- #3, 2nd test (Sept. 2017), with additional BCP &HPR

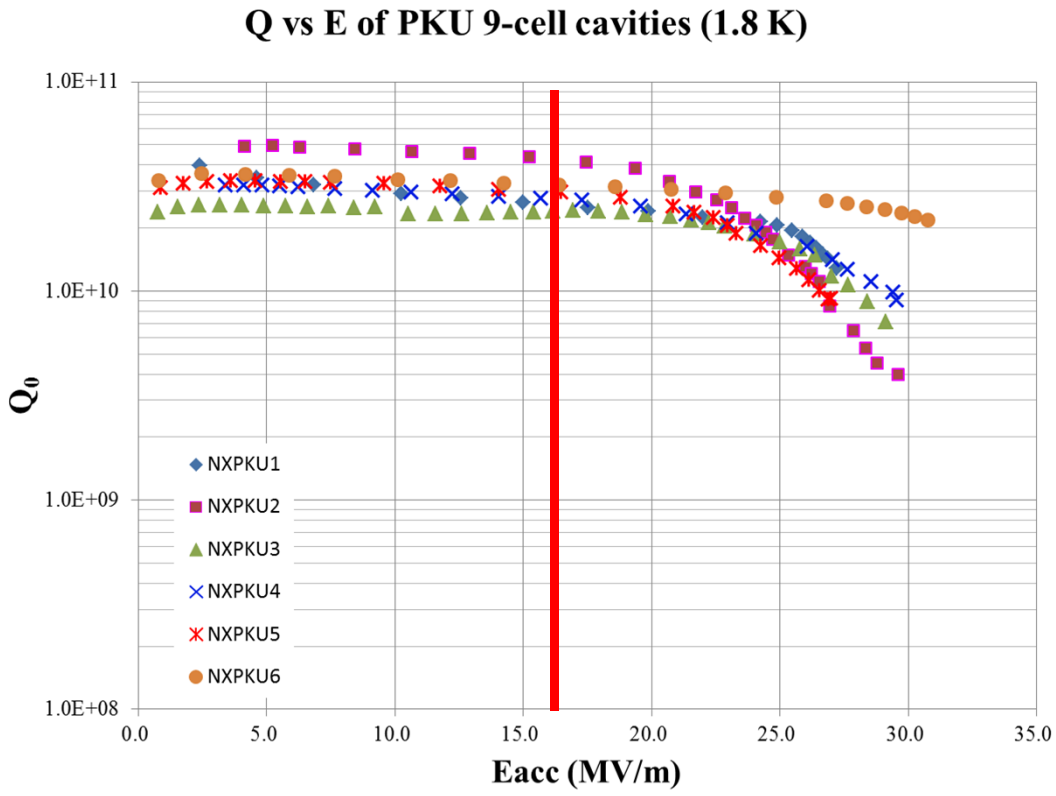
  - E_{acc} of all 6 cavities larger than 25 MV/m
  - Q_0~1.6-2.4E10 @ 16 MV/m



Q vs E at 1.8 K

- $Q_0(1.8K)/Q_0(2.K)$ = 1.50-1.79 (@~16 MV/m)
- Advantage of running at 1.8 K when the ratio >1.33

Cavity	$Q_0(2.K)$	$Q_0(1.8K)$	Ratio
#1	1.6E10	2.6E10	1.63
#2	2.4E10	4.3E10	1.79
#3	1.5E10	2.4E10	1.60
#4	1.8E10	2.7E10	1.50
#5	1.7E10	3.0E10	1.76
#6	2.0E10	3.2E10	1.60



Operation at 1.8 K with large grain cavity has obvious advantage

Horizontal tests of 1.3 GHz 9-cell large grain cavities

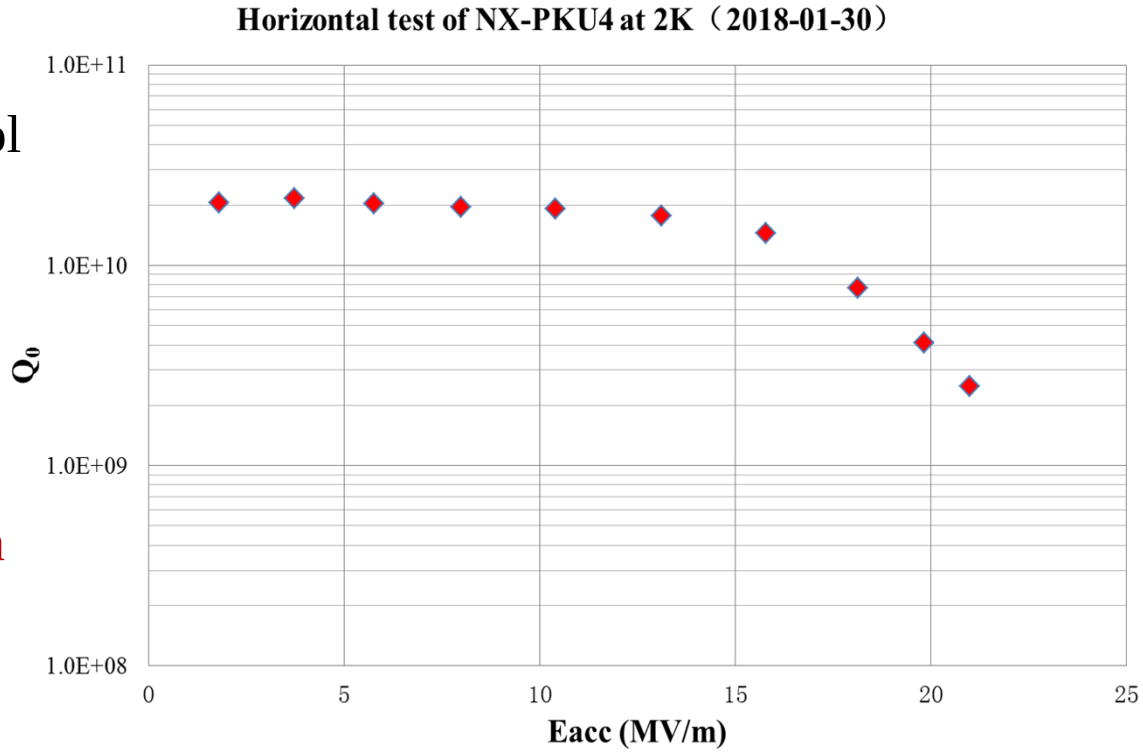
Cavities were installed into the 2×9-cell cryomodule for horizontal test

Horizontal tests of 1.3 GHz 9-cell large grain cavities

Horizonal test setup:

- LLRF: Self-Excitation control loop
- Pulse mode: 0.5 Hz, 700 ms
- Qe~6×10^8 for Q-E measurement

E_{acc} >20 MV/m without quench



Q-drop after 15 MV/m

Caused by Cryogenic capacity limitation (~55 W at 2 K for cooling down both 3.5-cell injector and 2×9-cell cryomodule) and probably field emission

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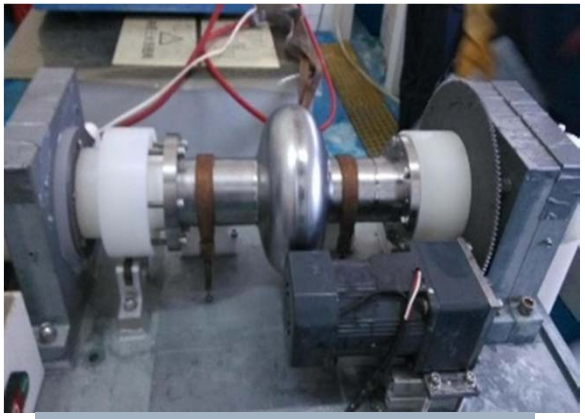
Preliminary N-doping for single cell large grain cavity

furnace

- Single-cell cavities
- 800°C 3 hours
- N-doping at 2.67-4.0 Pa (20-30 mTorr), 20/30 min
- EP 15 μm
- Ethanol rinsing
- HPR

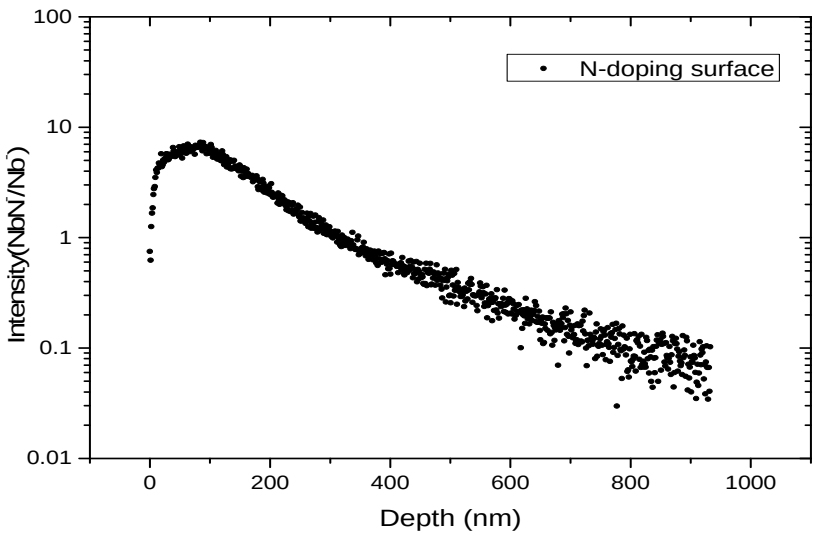


Simple EP device

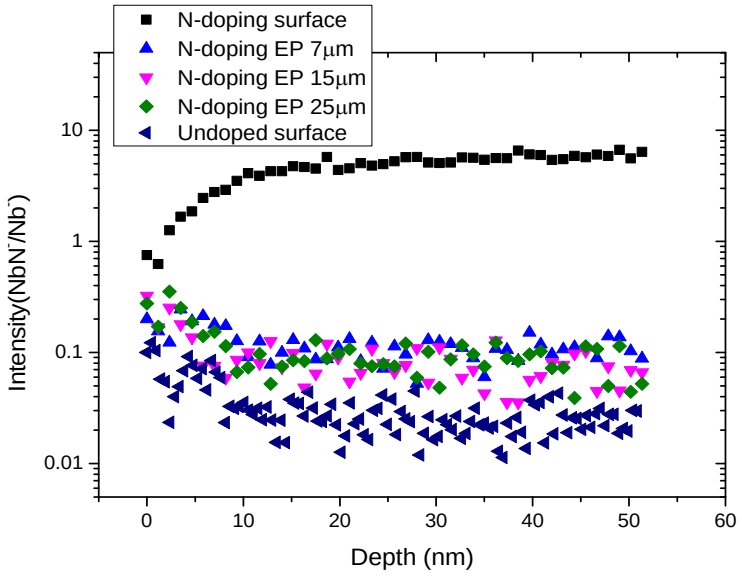
HPR

Preliminary N-doping for single cell large grain cavity

Nitrogen content of N-doped samples（TOF-SIMS）



top1μm



different depth

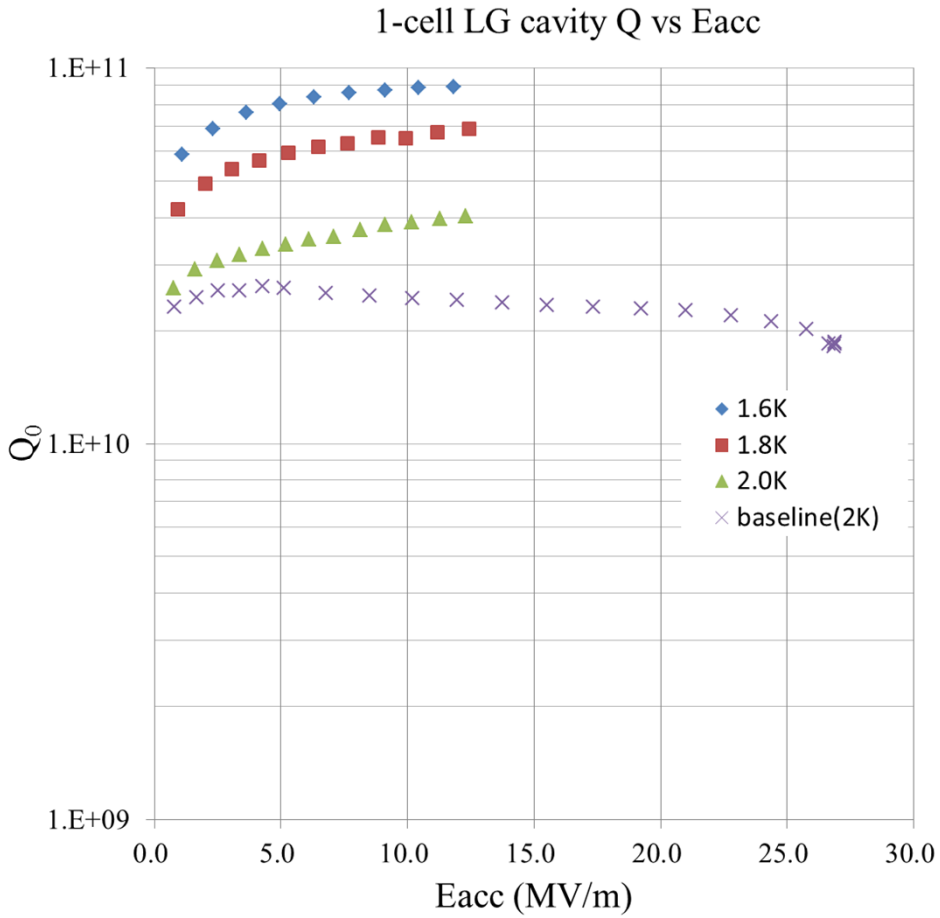
EP 15 μm is enough to remove the bad NbN phase

Preliminary N-doping for single cell large grain cavity

Vertical test of N-doped single cell LG cavity

- 4×10^{10} @ 12.3 MV/m, 2K
- 7×10^{10} @ 12.4 MV/m, 1.8K
- obvious anti-Q-slope
- low Eacc:
  - Simple EP device
  - EP parameters need to be optimized

- Next:
  - Researches with more single cell cavities
  - N-doping with 9-cell cavities



Summary

- Six 1.3 GHz large grain 9-cell cavities have been fabricated, treated and tested at PKU.
- Only with BCP, all of 6 cavities reach gradient larger than 25 MV/m, the intrinsic Q values are about 2×10^{10} at 16MV/m and 2.0 K.
- Repeatable production of 1.3 GHz large grain 9-cell cavities is realized with industry.
- N-doping researches have been carried out with single cell cavities.

Thank you for your attention !