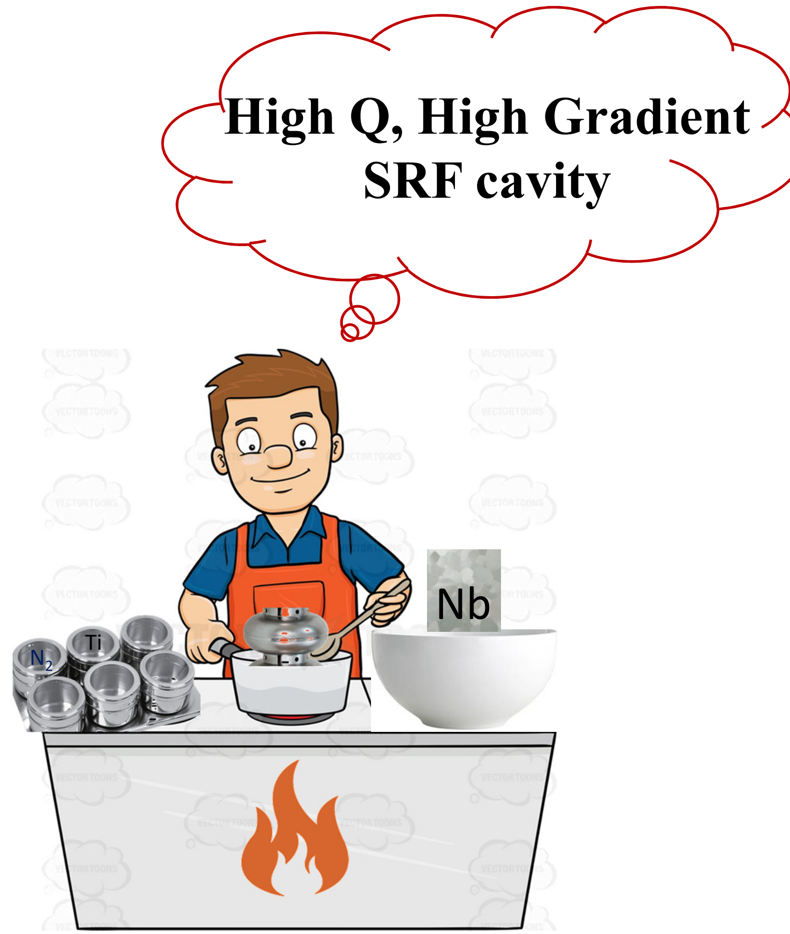
RECENT DEVELOPMENT ON NITROGEN INFUSION WORK TOWARDS HIGH Q AND HIGH GRADIENT



Pashupati Dhakal

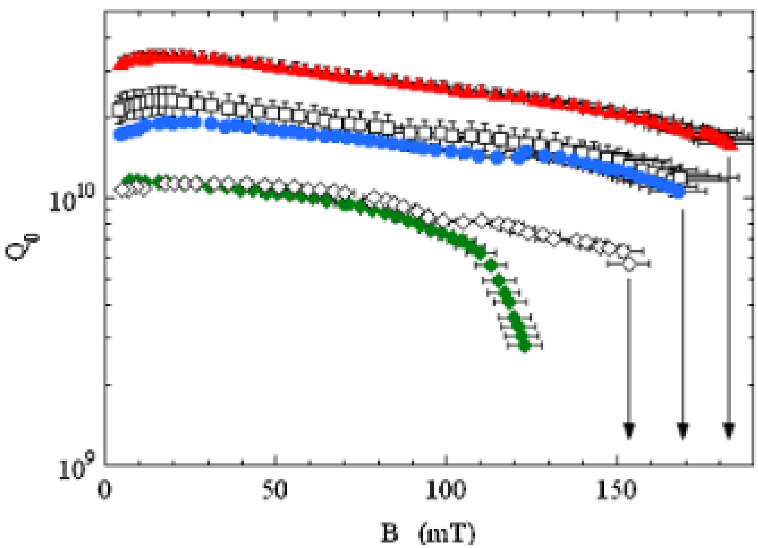
Monday, July 1, 2019

TUFUA5

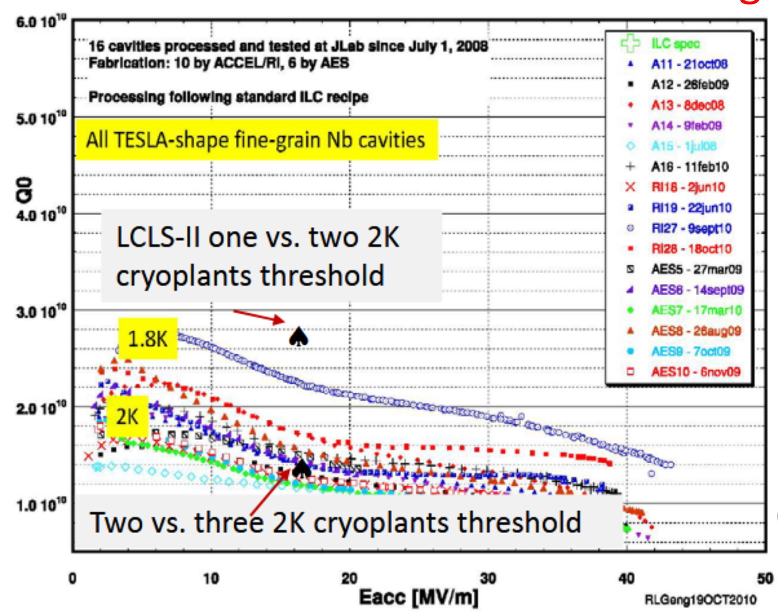
Let's Re(Search), Before 2012/13

- Low temperature baking (LTB) was the final step before rf test primarily to cure high field Q-slope and some increase in Q_0 at 2.0K due to reduction in BCS surface resistance as a result of reduced electronic mean free path.
- No unanimous model is available but its linked to "oxygen diffusion", "near surface hydrogen reduction", "nano-hydride precipitations", "vortices" and etc………

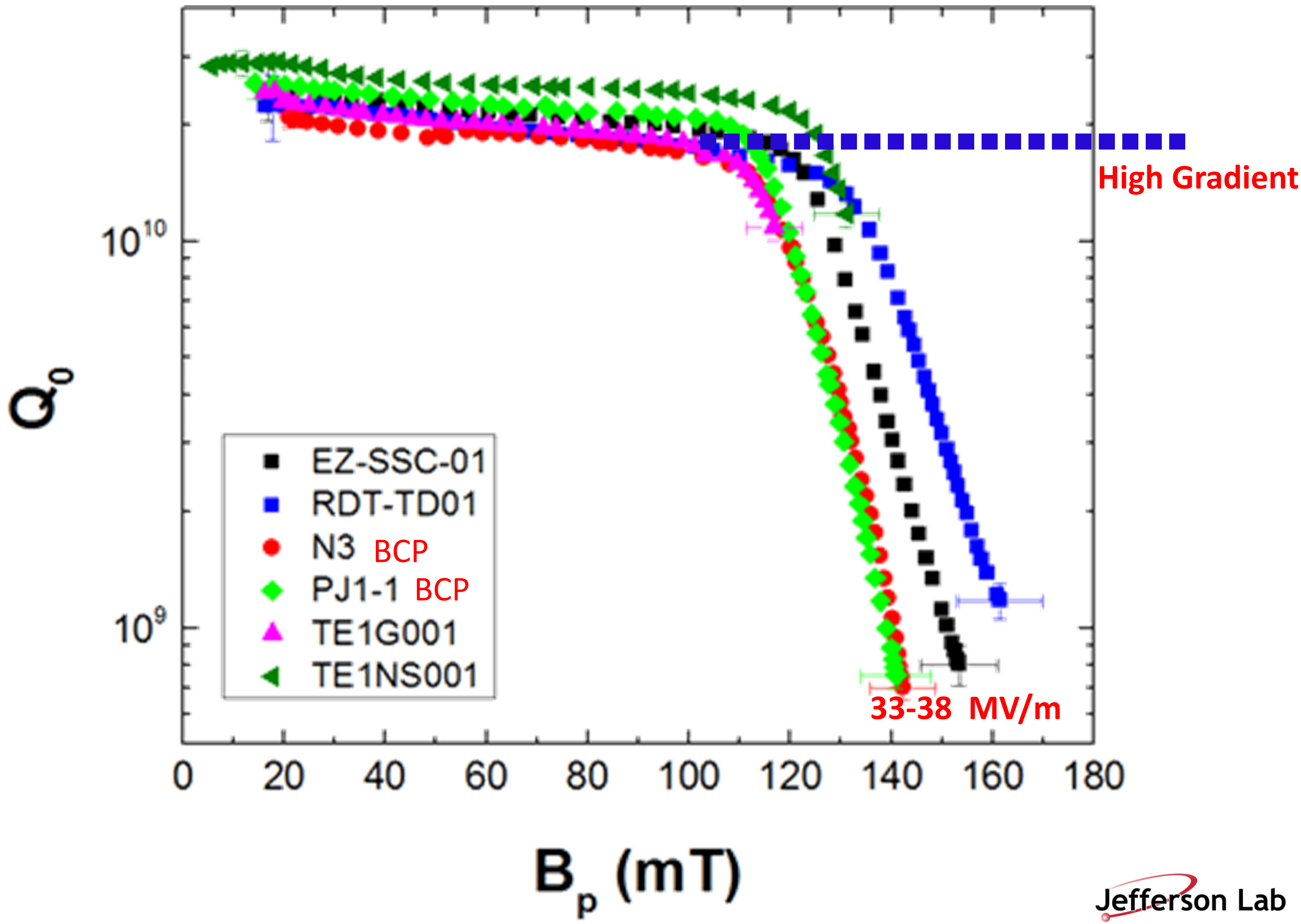
R. Geng



CIOVATI *et al.* Phys. Rev. ST Accel. Beams **13**, 022002 (2010)



High Gradient



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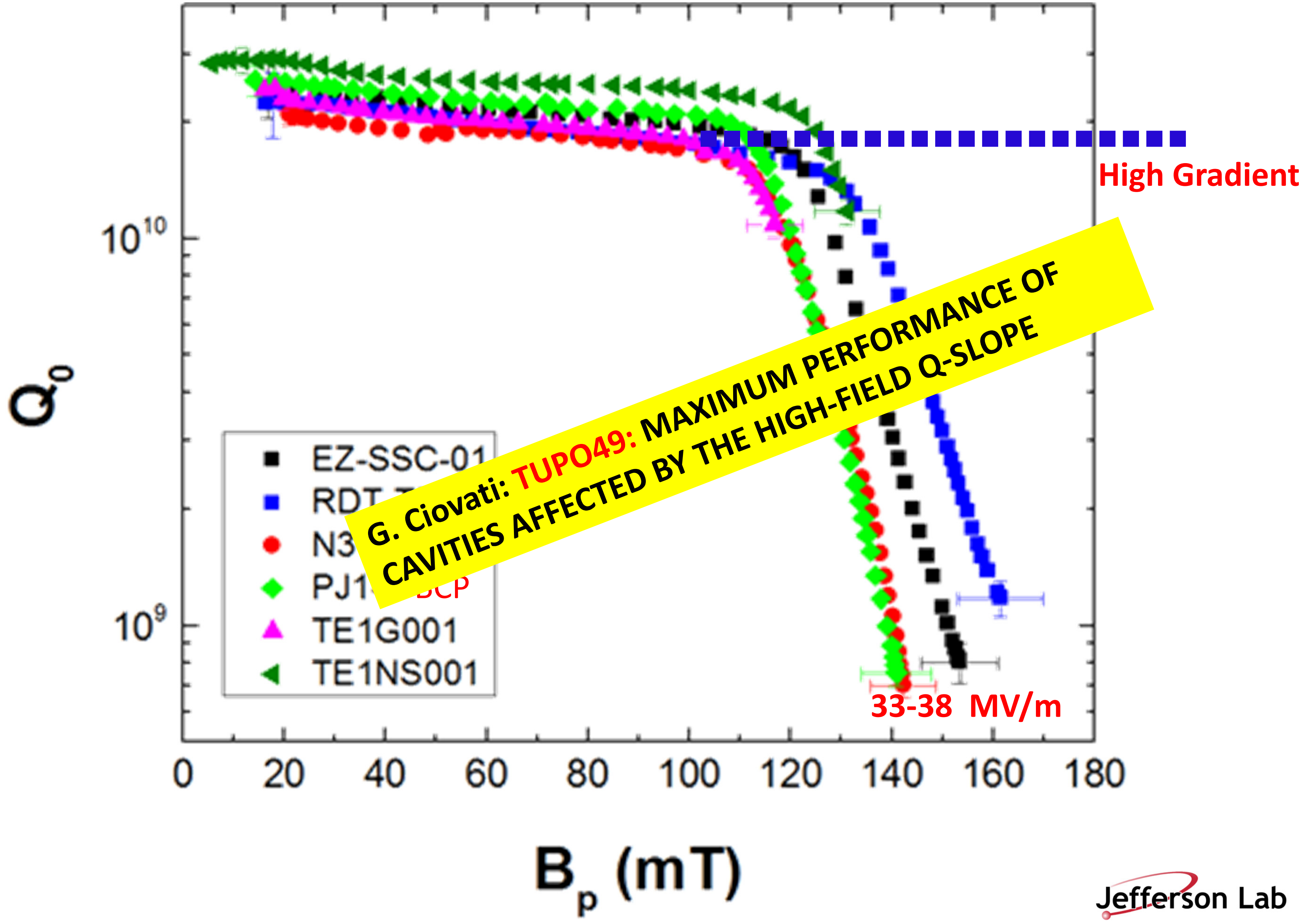
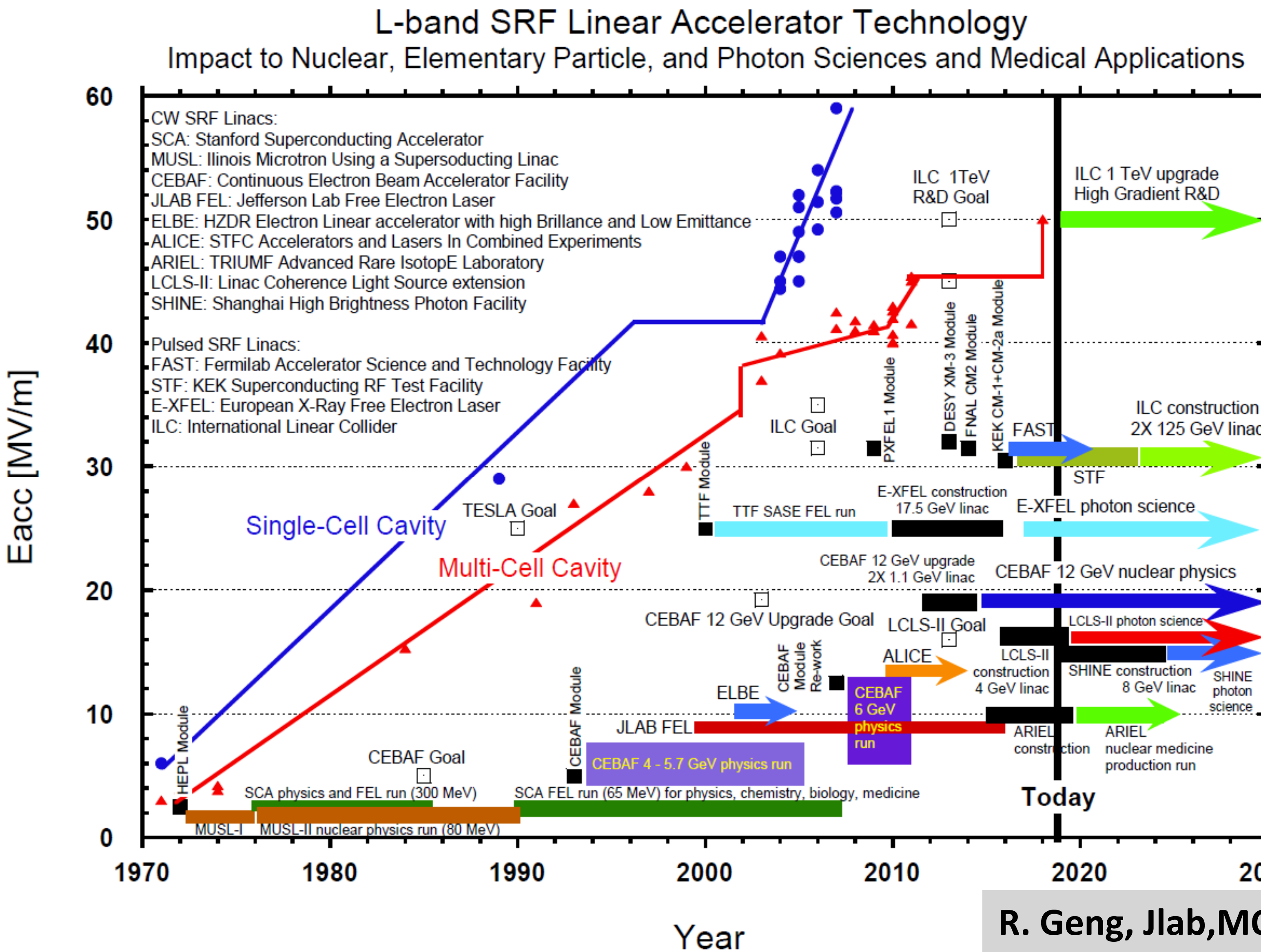
High Gradient

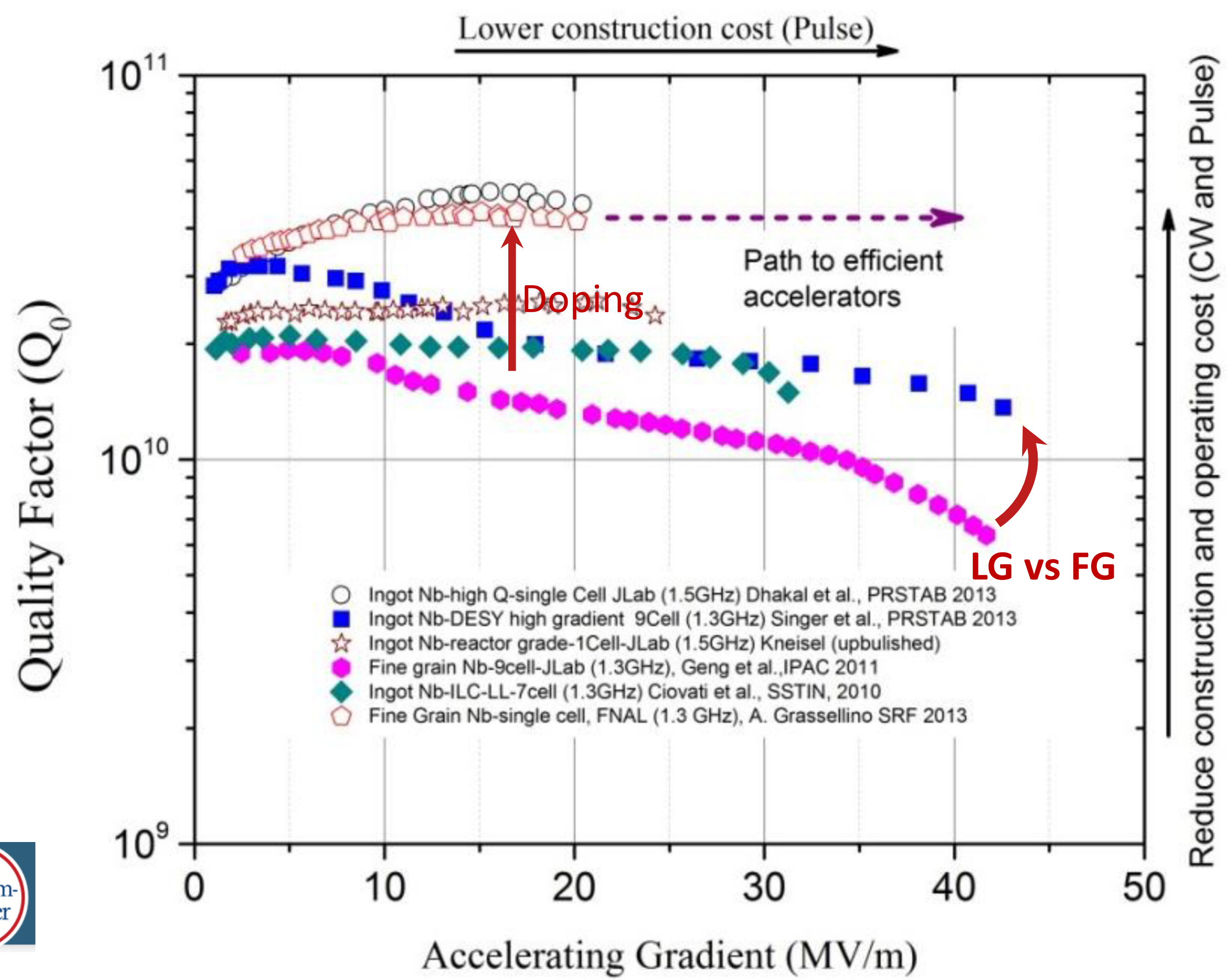


Let's Re(Search)



R. Geng, Jlab,MOPO64

Towards High Q→ Doping



Merriam-Webster

doping noun

dop·ing | \ ˈdō-piŋ \

Definition of *doping*

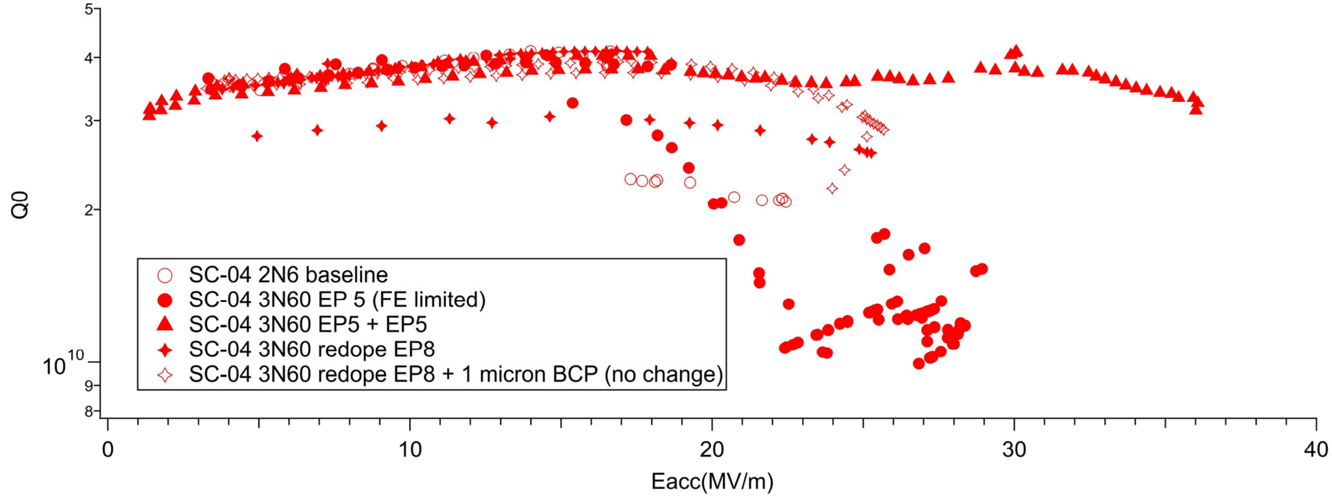
Use of substance or technique to improve performance

High Q

- Increase in Q_0 in medium field range (<25 MV/m) due to near surface material diffusion (Ti and N_2).
- Limited theoretical work to explain the *Q*-rise phenomenon, but the available data and models suggest that the effect is due to decrease in BCS surface resistance with RF field.
- The idea of increasing Q_0 at higher field reported by FNAL and reproduced in some labs with low temperature baking in nitrogen (without nitrogen)…
- With some "Recipes" of LTB in nitrogen, the Q-rise phenomenon were observed in medium field and quench field is extended to higher gradient.

High Q and High Gradient

- **The achievable gradient on doped cavities reduces ~40% compared to what would have been achieved with conventional processing.**
- **Modified doping recipe (3N60, 2N0,……) being worked on in order to increase the accelerating gradient with high Q.**
- **Low temperature baking in nitrogen, magic bake (two step bake) are being explored in order to achieve high Q and high gradient.**



A. D. Palczewski , Jlab TUFUA3

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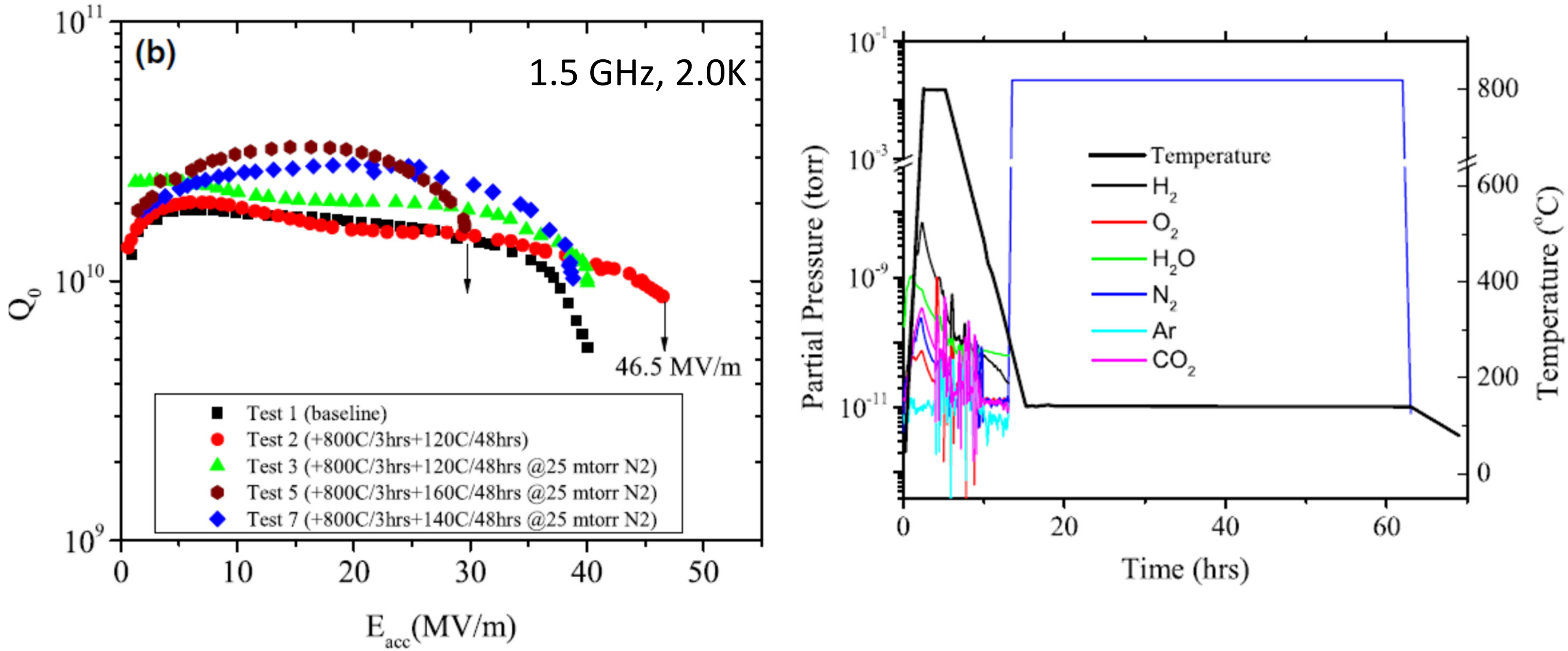
Low Temperature Baking in Nitrogen



- 1.5 GHz single-cell fine-grain Nb cavity (RRR>300)
- **N-infusion**: 800 °C/3h, N_2 at ~25 mTorr at 290°C, cooling to hold temperature maintained for 48 h

P. Dhakal et al., Phys. Rev. Accel. Beams. 21, 032001 (2018)

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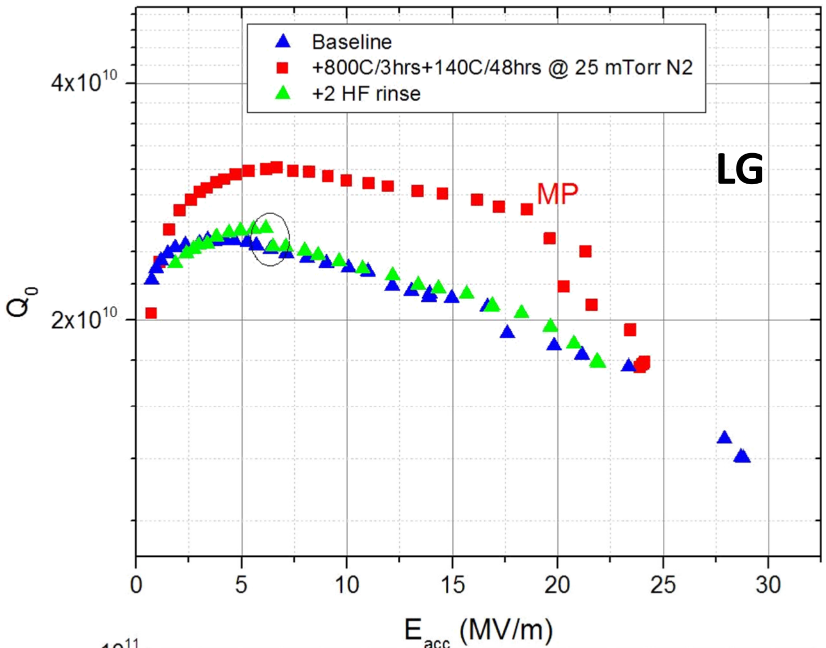
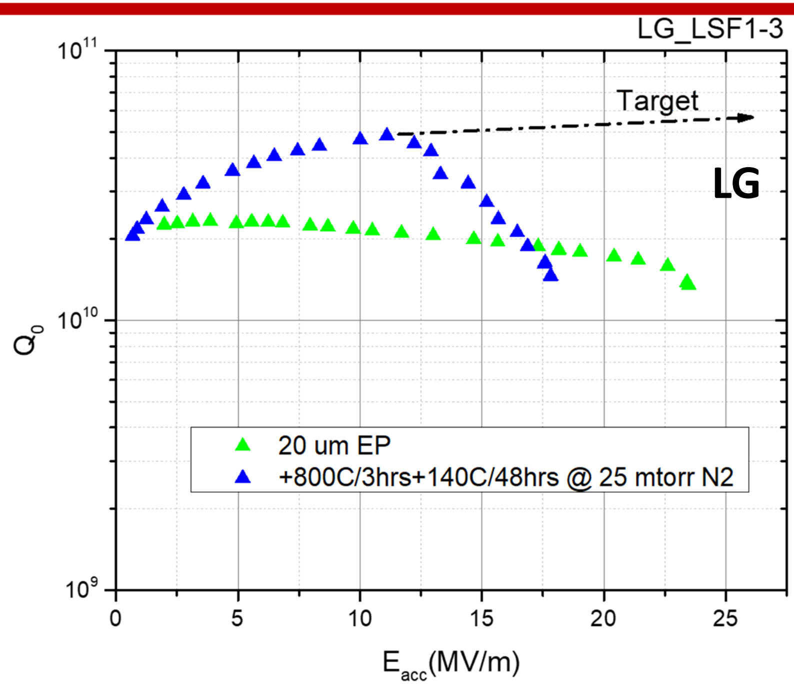
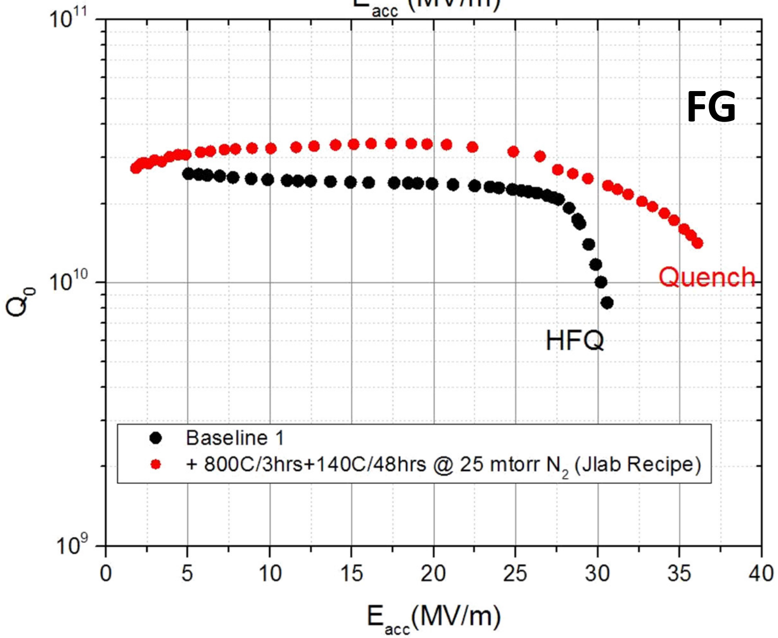
Earlier Results "LTB with N_2"





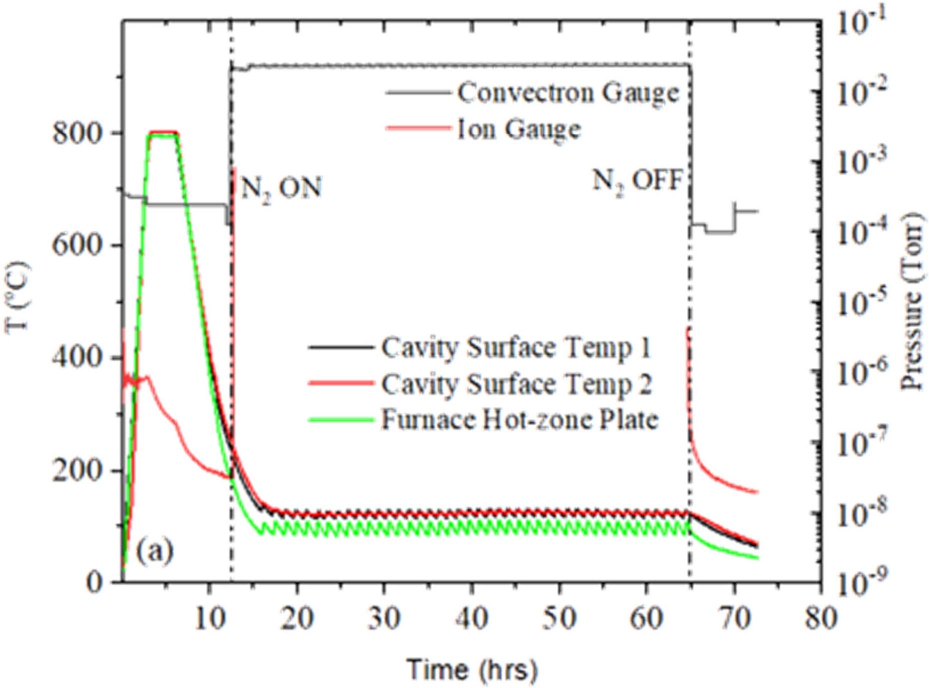


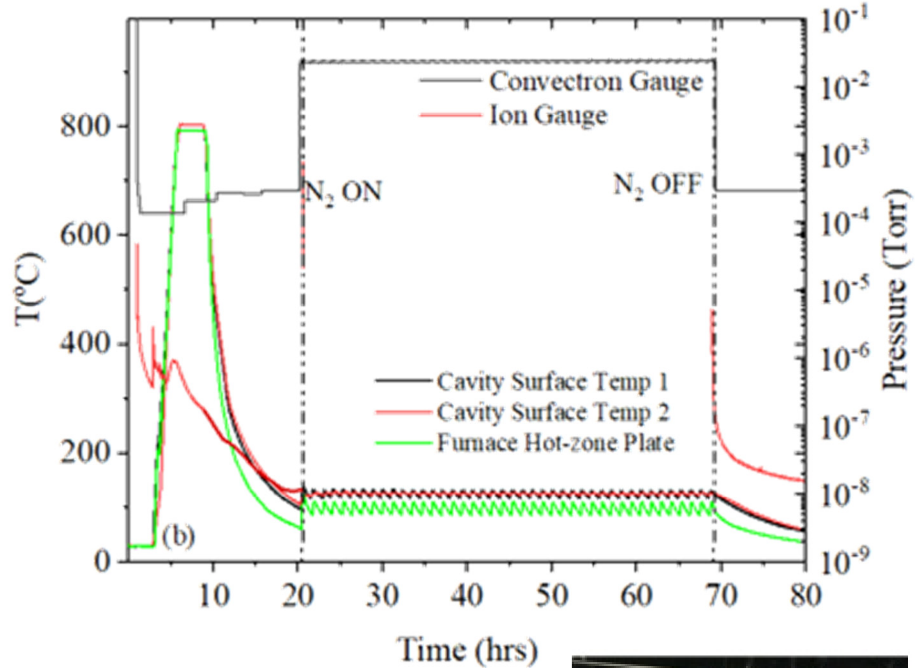
→ Temperature measured on the **wall of furnace**
→ The higher gas injection temperature
→ Cavity surface temperature unknown
→ No active RGA monitoring during the gas injection

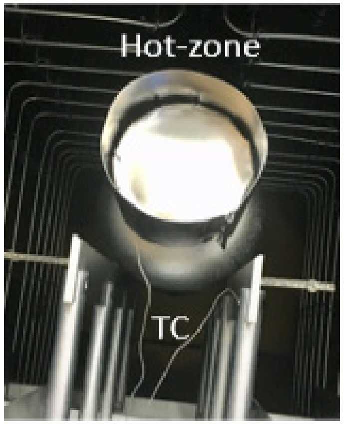
Able to get some high Q with high E_{acc}

Recent Results

Furnace control modifications

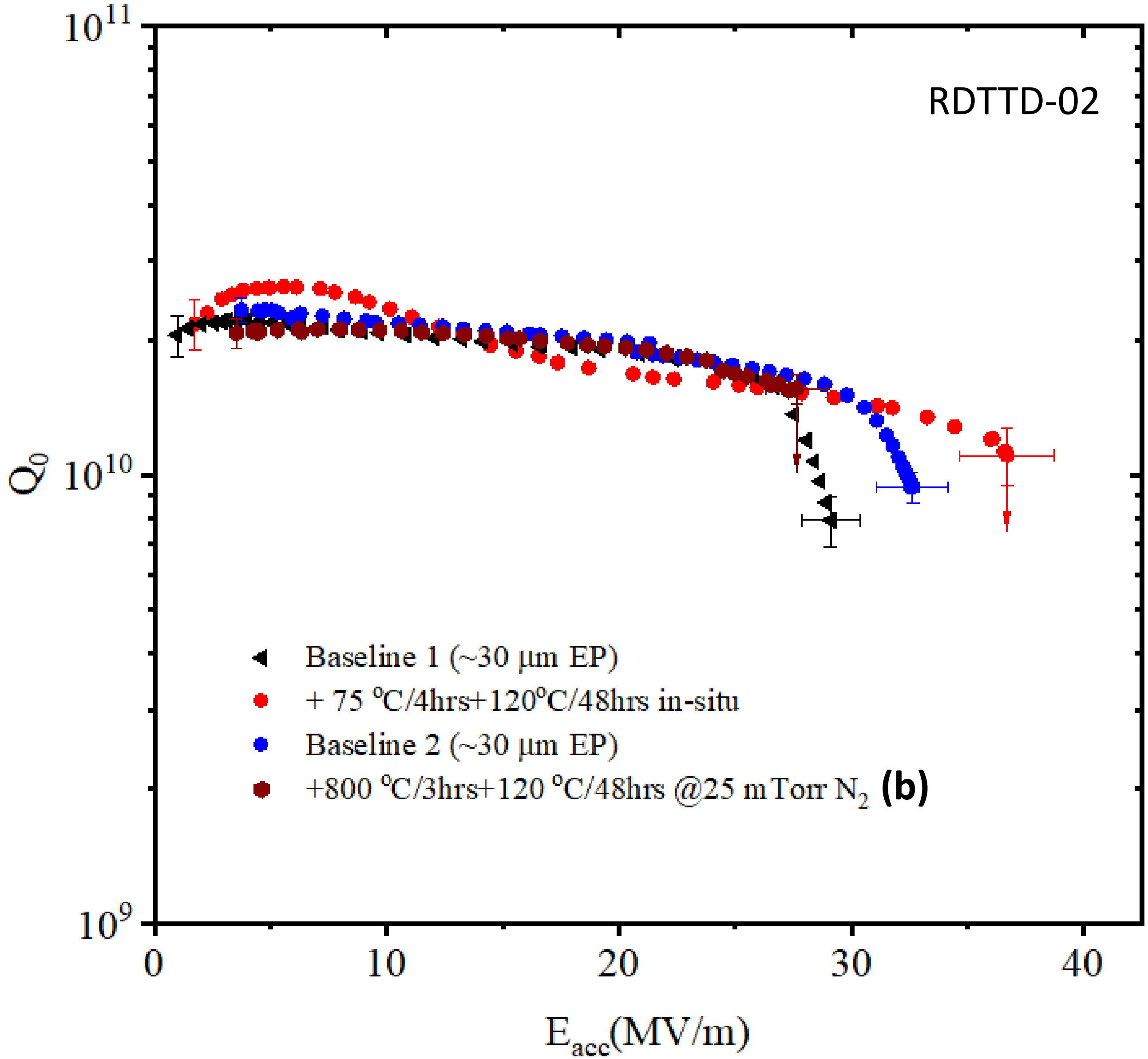






- **Thermocouples on cavity surface**
- **Can inject nitrogen at any temperature.**
  - **(a) N2 injection at higher temperature during cooldown**
  - **(b) wait for target temperature before N2 injection**

Recent Results



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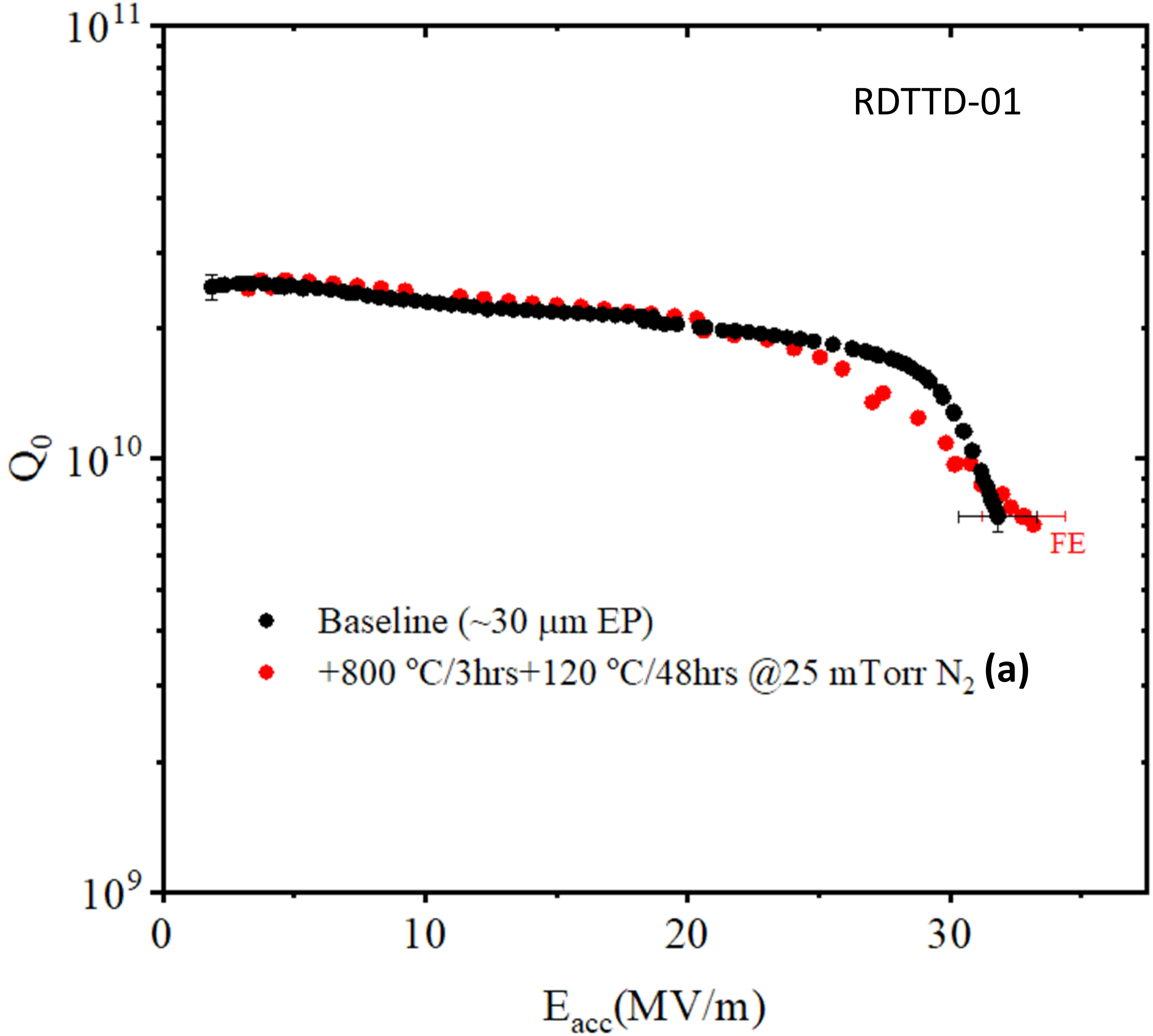
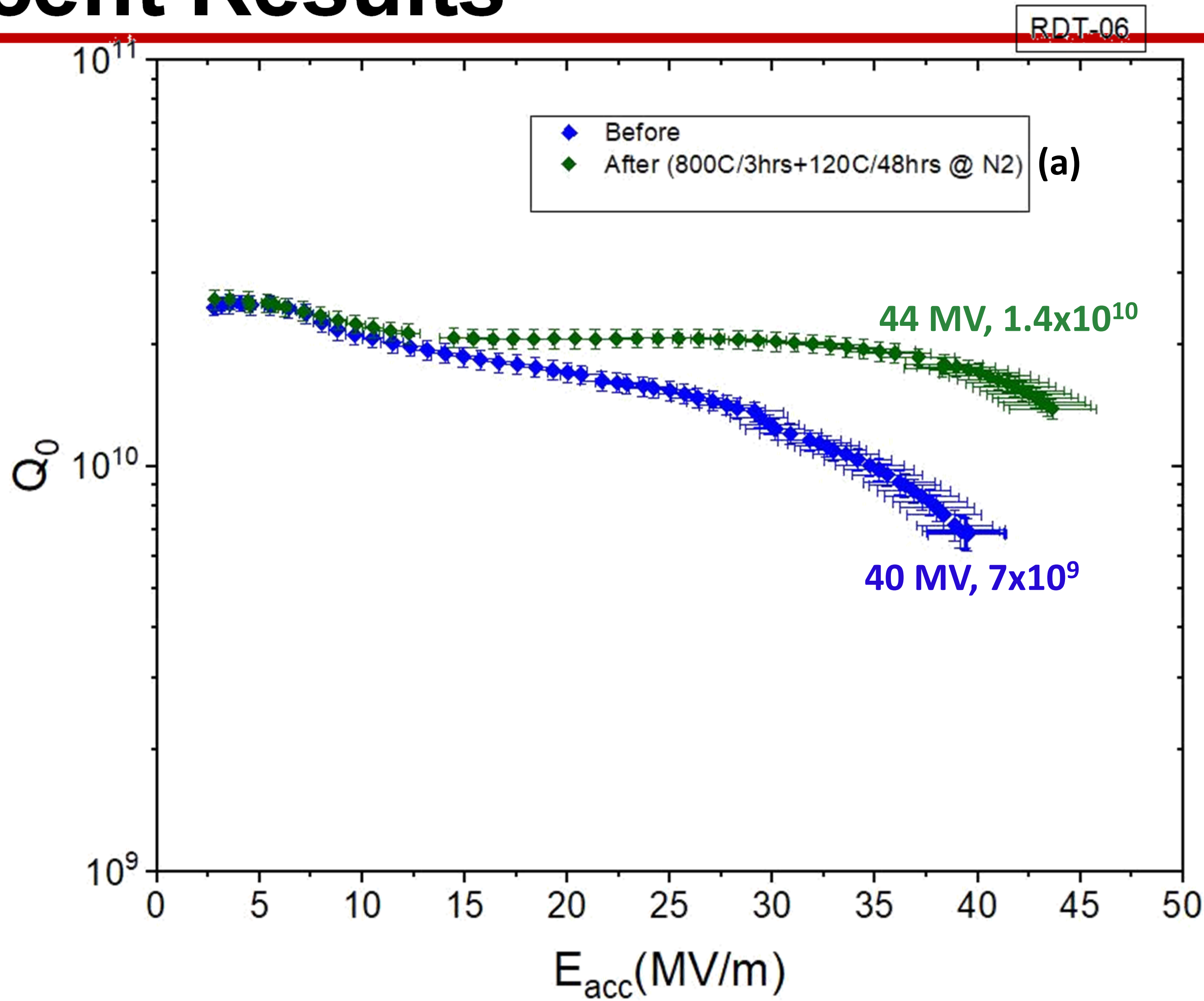
Recent Results



Recent Results



Recent Results

Table 1: Summary of rf Test Results

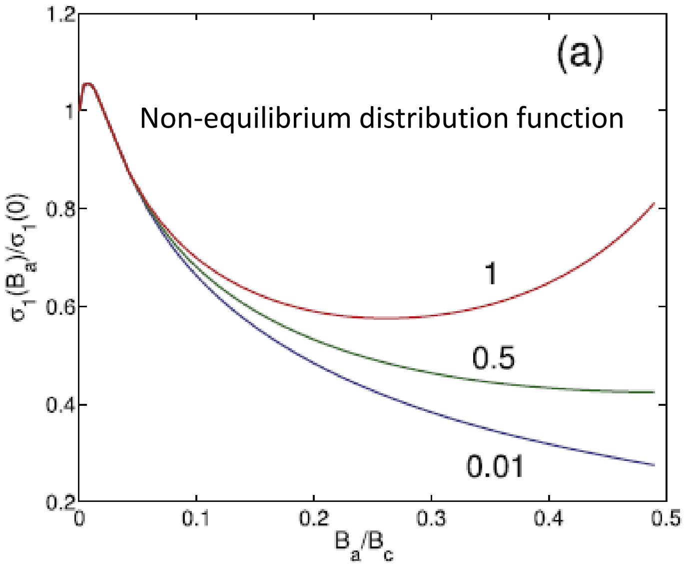
Cavity ID	f (GHz)	Cavity Treatment	$E_{acc,max}$ (MV/m)	$Q_0(E_{acc,max})$ 10^{10}	Limitation
		Baseline EP (~30 μm)	40±2	0.56±0.07	Q-slope
		+120 C/ 24 hours in test stand	46±2	0.87±0.09	quench
RDL-02	1.5	+800 C/3hrs+120/48hrs with 25 mtorr N_2#	40±2	1.0±0.1	quench
		+baseline+800 C/3hrs+140 C/48hrs with 25 mtorr N_2#	39±2	1.1±0.1	quench
		+baseline+800 C/3hrs+160 C/48hrs with 25 mtor N_2#	30±1	1.7±0.2	quench
RDT-14	1.3	Baseline EP (~30 μm)	31±2	0.8±0.1	Q-slope
		+baseline+800 C/3hrs+140 C/48hrs with 25 mtorr N_2#	36±1	1.4±0.2	quench
		Baseline EP (~30 μm)	32±1	0.82±0.08	Q-slope
RDT-06	1.3	+75 C /4hrs + 120 C/110 hours in test stand	39±2	1.1±0.1	quench
		+800 C/3hrs+120 C/48hrs in furnace	40±2	0.68±0.06	quench
		+800 C/3hrs+120 C/48hrs with 25 mtorr N_2#	44±2	1.4±0.1	quench
		+ ~ 8 μm EP	41±2	1.4±0.3	Q-slope
RDTTD-01	1.3	Baseline EP (~30 μm)	32±1	0.74±0.05	Q-slope
		+800 C/3hrs+120 C/48hrs with 25 mtorr N_2#	33±2	0.72±0.04	FE
		Baseline 1 EP (~30 μm)	29±1	0.8±0.1	Q-slope
RDTTD-02	1.3	Baseline 1 +75 C/4hrs+120 C/48hrs in test stand	37±2	1.1±0.2	quench
		Baseline 2 EP (~30 μm)	33±2	0.94±0.07	Q-slope
		Baseline 2+ 800 C/3hrs+120C/48hrs with 25 mtorr N_2	28±1	1.6±0.1	quench

#gas injected at elevated temperature (250-290°C)

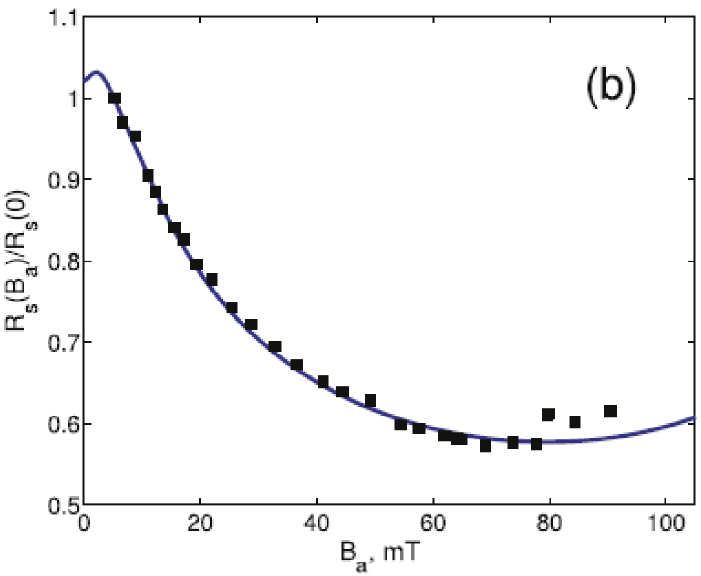
The average accelerating gradient E_{acc} = **37 ± 5 MV/m** with Q_0 = **(1.1±0.3)×10^10**

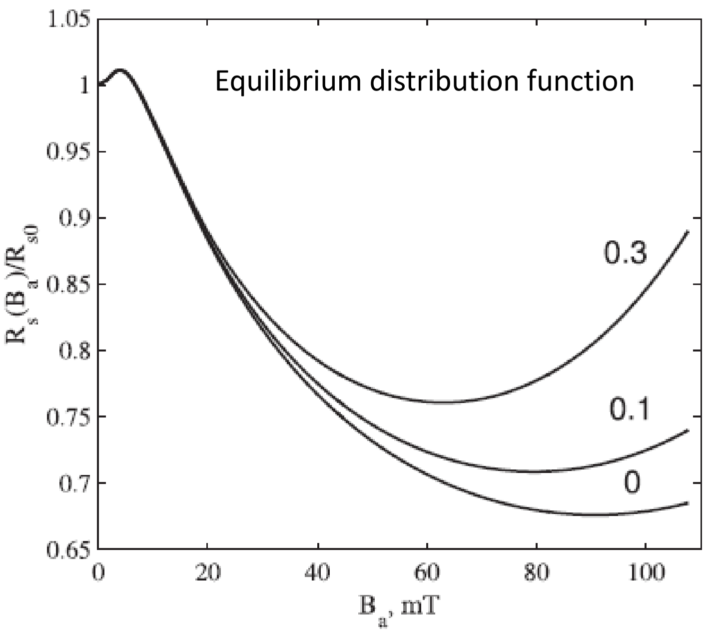
For details see proceeding

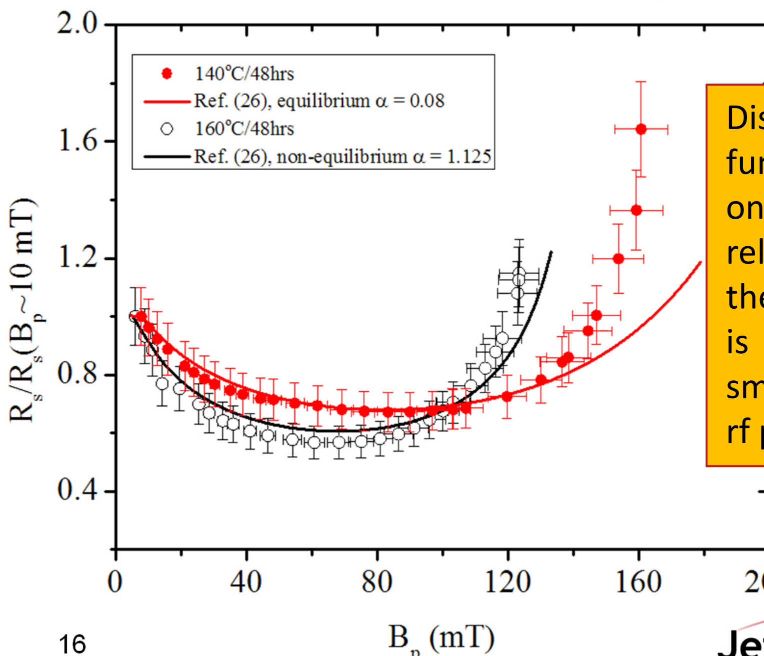
COMPARE WITH THEORY



Explain the Q-rise on Ti-doped cavities





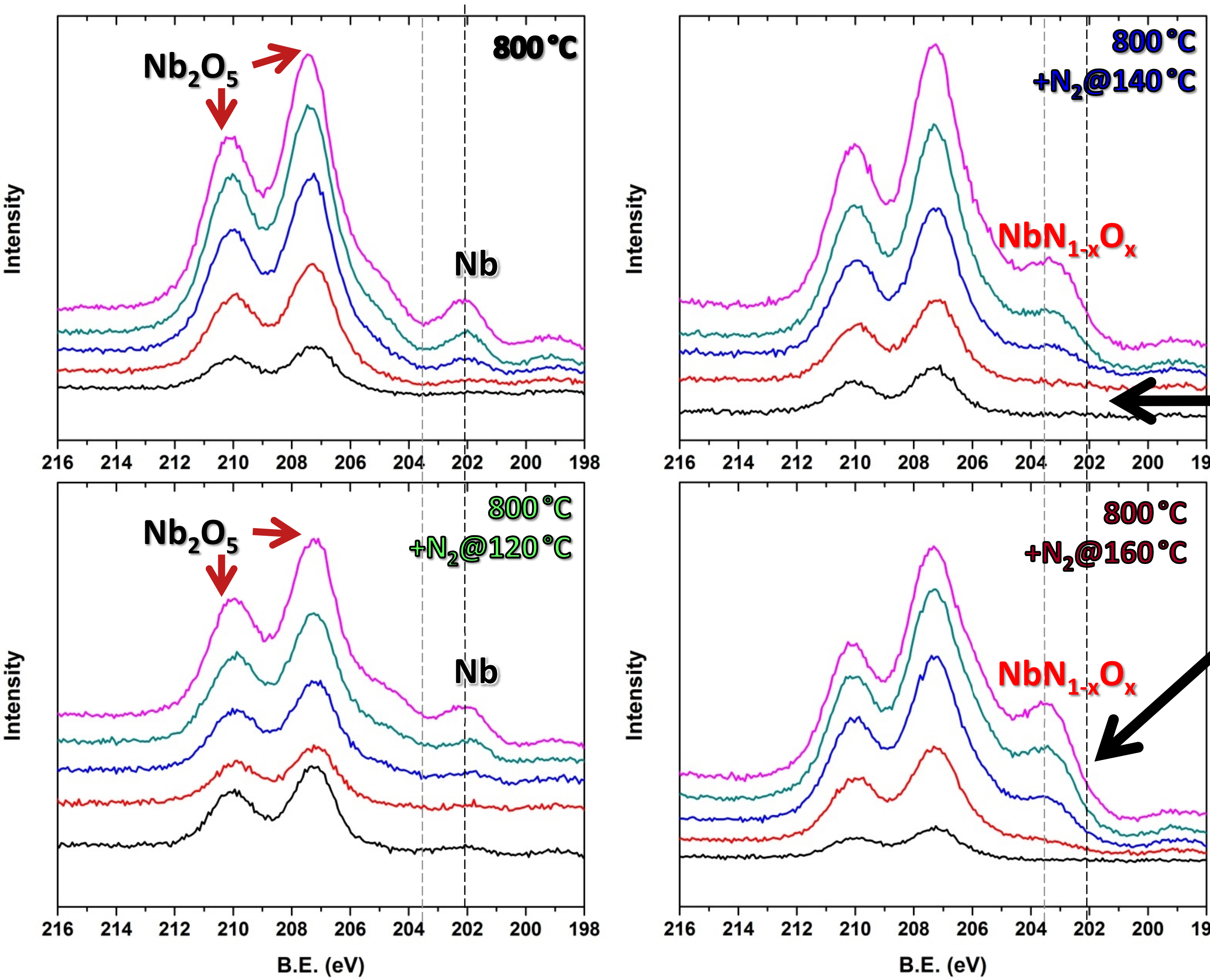


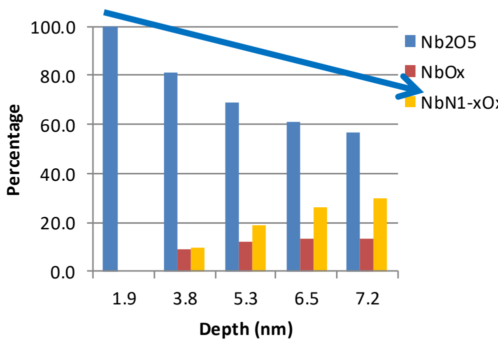
Distribution function depends on whether the relaxation time of the quasi particle is greater or smaller than the rf period.

Alex Gurevich 2017 *Supercond. Sci. Technol.* **30** 034004

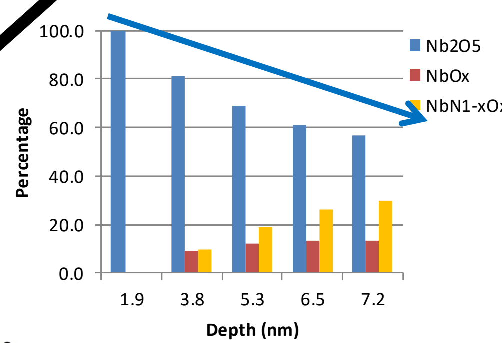
P. Dhakal et al., Phys. Rev. Accel. Beams. 21, 032001 (2018)

Sample Coupons





Nb peak is absent => **thicker dirty layer**



$NbN_{1-x}O_x$ is found on Nb baked at 140-160°C in N atmosphere

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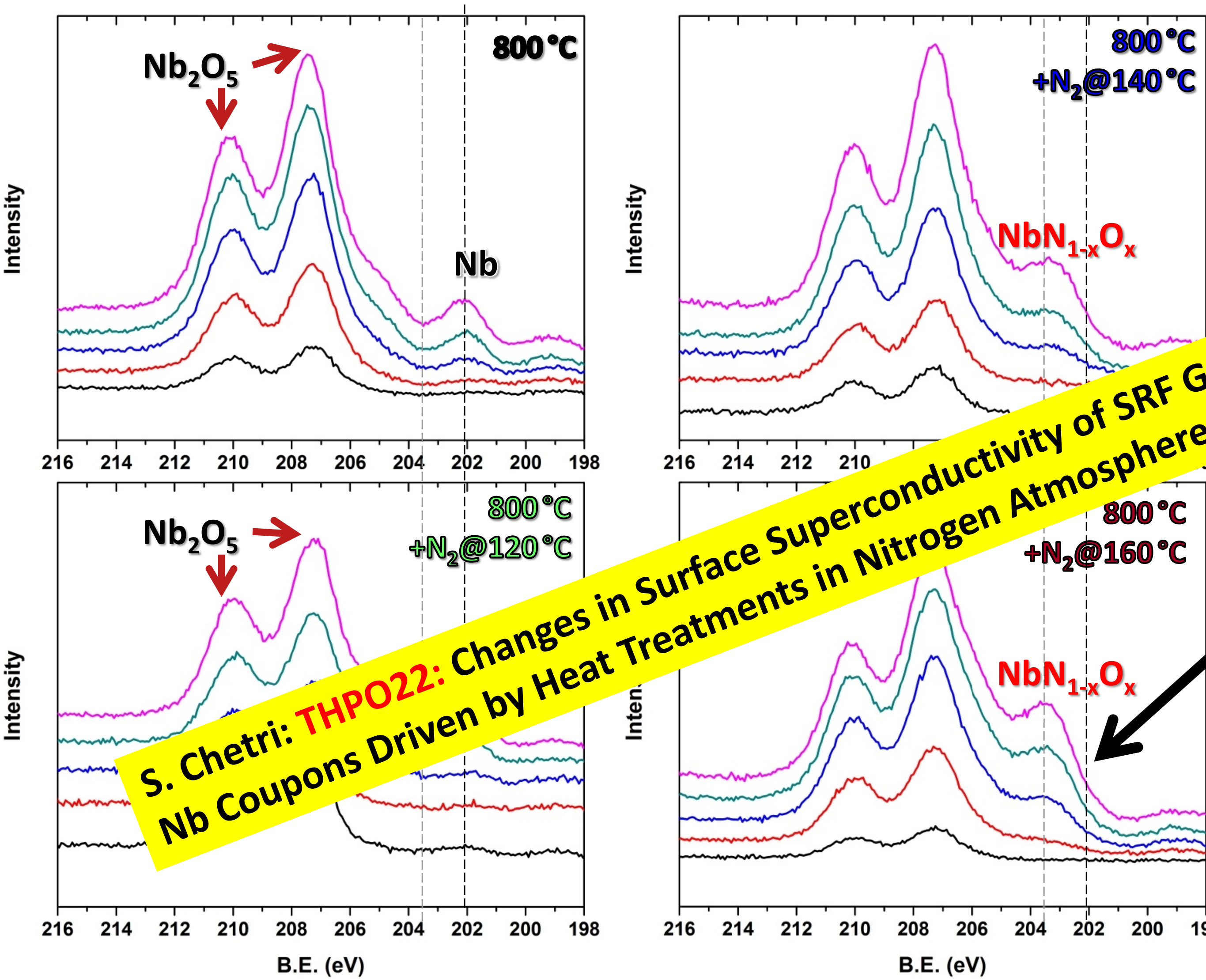
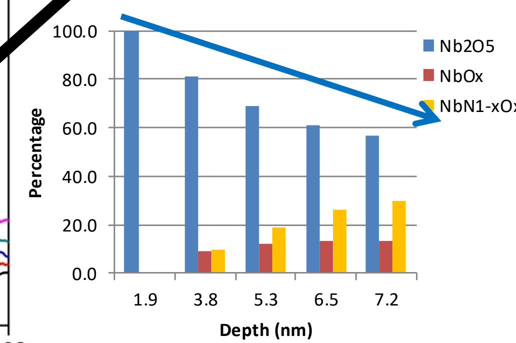
Sample Coupons



peak is absent => thicker dirty layer



S. Chetri: THPO22: Changes in Surface Superconductivity of SRF Grade High Purity Nb Coupons Driven by Heat Treatments in Nitrogen Atmosphere

$NbN_{1-x}O_x$ is found on Nb baked at 140-160°C in N atmosphere

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Summary

- High Q, high E_{acc} results are reproducible when gas injected at higher temperature (250-290 C).
- ~75C hold for 4 hours during 120 C baking didn't appear to be beneficial over the conventional 120C bake (statistics of 2 rf test).
- The influence of furnace contamination, cavity preparations before heat treatment plays significant role in the outcome of the cavity performance.
- Sample studies shows that the dirtier rf surface with $NbN_{1-x}O_x$ phase underneath the topmost Nb_2O_5 layer may be responsible for Q-rise.
- Explorations of several parameters such as the duration of bake time, optimal temperature and partial pressure of nitrogen is ongoing.


Thank you