WG4 summary talk ~Performance frontier~

2016/7/8

TTC meeting @ Saclay

WG4 S. Aull, A. Grassellino, K.Umemori

WG3 S. Belomestnykh, J. Hao, E. Jensen

(Joint session for High gradient and High-Q)

Thin film and new materials

6 talks

- Nb3Sn

  Daniel Hall 「Next generation Nb3Sn Cavities」

  Charles Reece 「Nb3Sn development at JLab」

- Nb thin film etc

  Guillaume Rosaz 「Production and R&D thin films activities at CERN for SRF applications」

  Anne-Marie Valente-feliciano 「Towards high performance Nb thin films via energetic condensation」

  Sebastian Aderhold / Genfa Wu 「Future thin film deposition efforts at FNAL」

  Yoshihisa Iwashita 「Activities on SRF thin film study at KEK &Kyoto U.」

High gradient / high-Q

7 talks

1. Summarize: what are the achievable gradients and Q at high gradients with state of the art ILC surface processing; where do we stand in terms of field emission

- Nick Walker 「XFEL ILC-recipe VT results (RI)」
- Rongli Geng 「Is current state of the art in FE an obstacle to 40MV/m (and beyond) operation?」

2. New results promising of very high gradients and high Q at very high gradients

- Sebastian Aderhold / Anna Grassellino 「New low T nitrogen treatments cavity results with record gradients and Q」

3. New samples studies indicating potential pathway to higher gradients

- Robart Laxdal 「New insights for reaching higher gradients from muSR sample studies」

4. Experimental max achievable gradients from Klystron measurements

- James Maniscalco 「Estimated gradient limitation insights for different surface processing from klystron measurements」

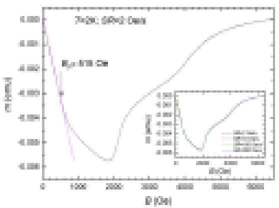
5. Theoretical predictions/explanations for maximum achievable gradients in SRF cavities

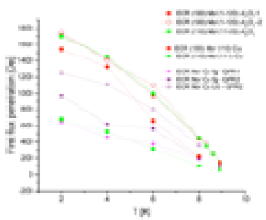
- Takayuki Kubo 「Reaching higher gradients in bulk Nb with nano-layer coating」
- Mattia Checchin 「Ultimate gradient limitation in Nb SRF cavities」

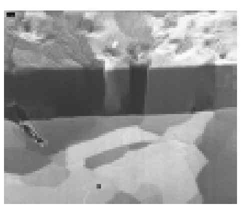
Thin film and new material

Film Development

Deposition parameters allow tuning the film properties - but have to be well controlled and fully understood





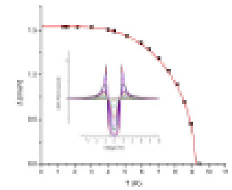


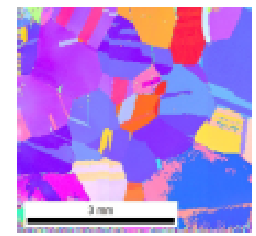
ALL film properties are a direct consequence of the film structure, defect/impurity content… thus the technique, environment, substrate are key factors

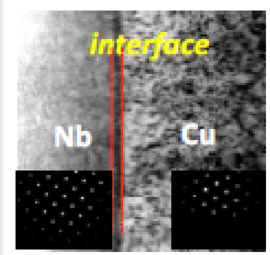
Full control of the deposition process & tailored SRF performance

UNDERSTANDING OF

- The **chemistry** of the involved species
  - **Reactivity**
  - **Stoichiometric sensitivity**
  - Reaction process **temperatures**
- l structure **dependence on substrate structure**
- In **nce of deposition energy** on resulting structure
- S **ivity to** the presence of **contaminating species, defects**
- **tion** of desired film against subsequent **degradation**







Careful **characterization of the attained composition and microstructure** (RHEED, STM, XRD, EBSD, AFM, optical profilometry, XPS, SIMS,TEM, FIB).

+

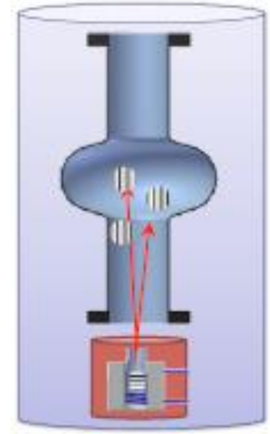
Close association with **resulting RF surface impedance & superconducting** properties (λ, Δ, T_c, H_c, RRR)

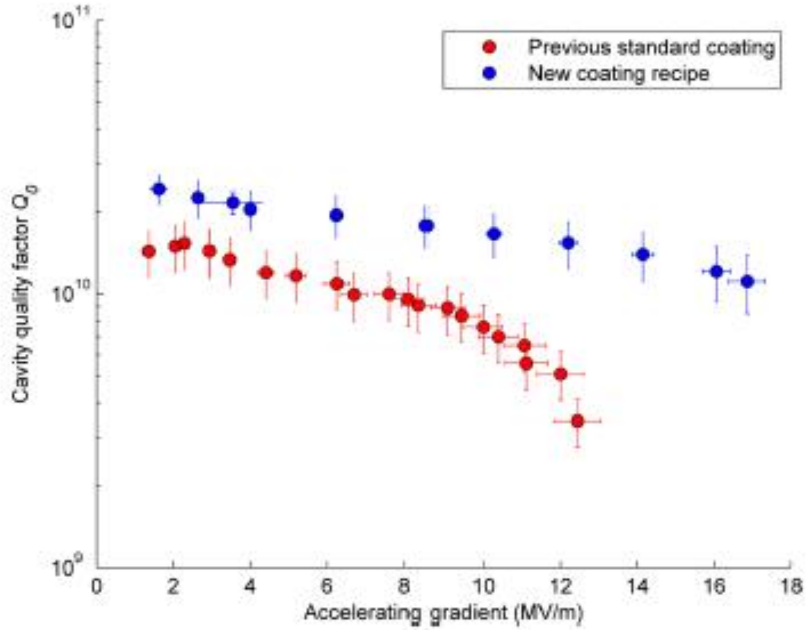
Towards high performance Nb thin films via energetic condensation

A.-M. Valente (JLab)

Nb_3Sn by reactive diffusion

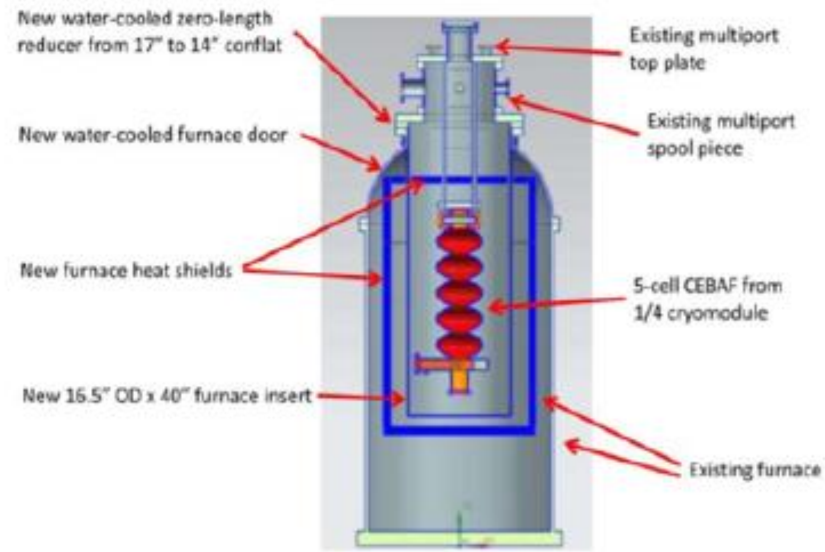
- JLab joined the activities and prepares for coating 5-cell cavities.
- Cornell further improved recipe, increasing the quench field.





Next Generation Nb_3Sn cavities: Current performance, limitations, and considerations for practical use,

D. Hall/M. Liepe (Cornell)

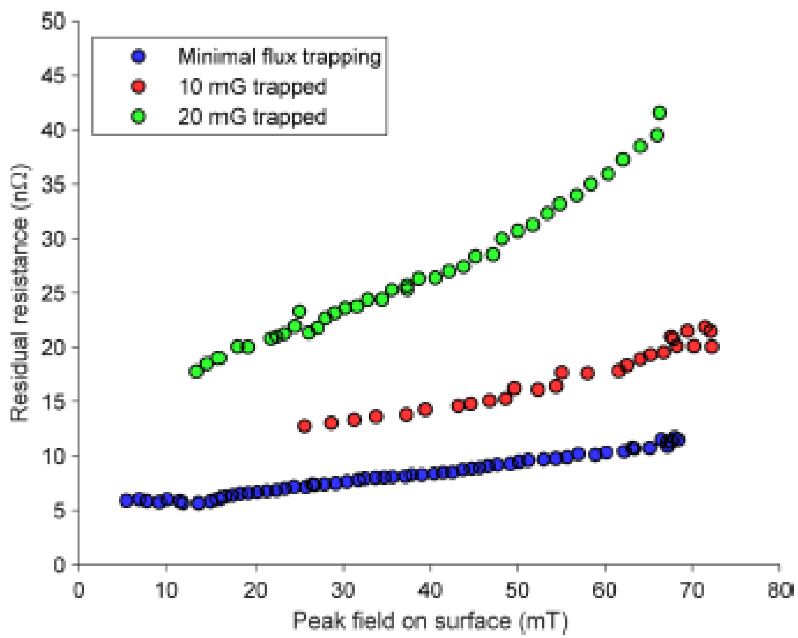


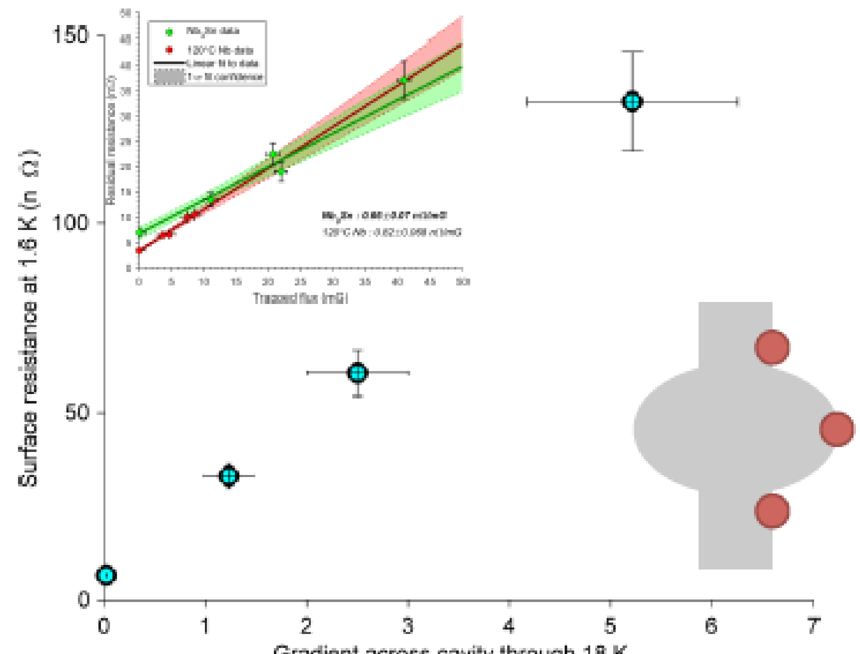
Nb_3Sn Developments at JLab,

C. Reece/ G. Eremeev (JLab) & U. Pudasaini/ M. Kelley (W&M)

Nb3Sn: Trapped Flux Sensitivity

- Surface resistance increase with trapped magnetic field similar to 120C baked bulk Nb
- Strong surface resistance increase with temperature gradient — similar to Nb/Cu —> thermal electric currents at the metal-metal interface?

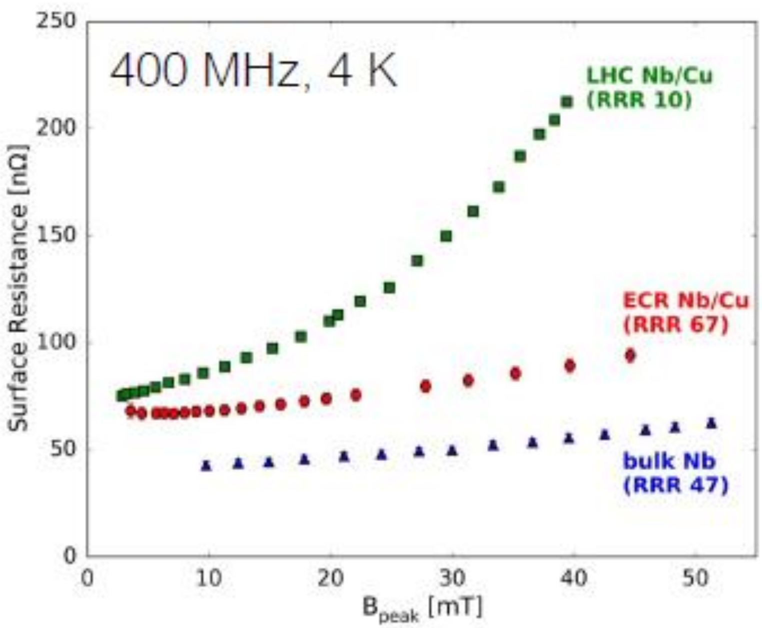




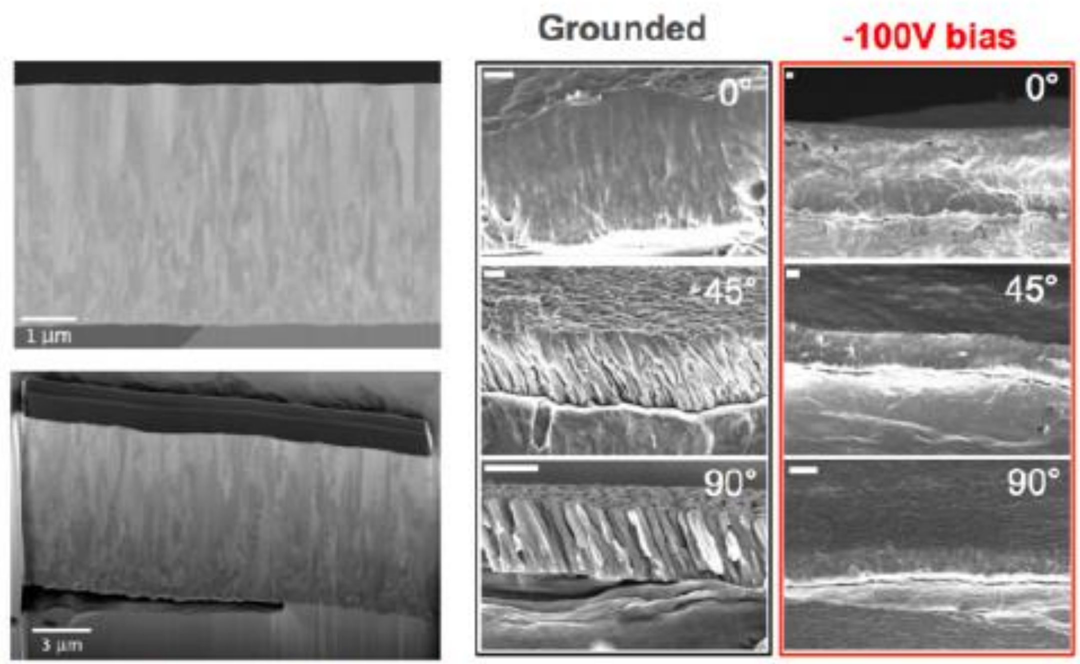
Next Generation Nb_3Sn cavities: Current performance, limitations, and considerations for practical use, D. Hall/M. Liepe (Cornell)

Energetic Condensation: the Pathway to Denser Films

- Energetic condensation techniques (ECR, HIPIMS,…) show improved Nb film microstructure.
- First RF measurements on samples show significantly mitigated Q-slope

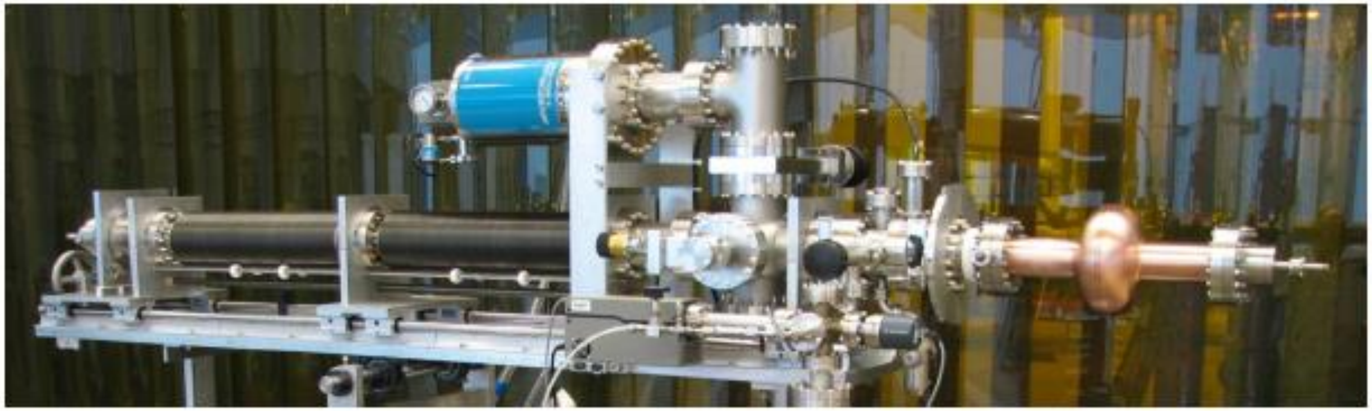


A.-M. Valente (JLab) & S. Aull (CERN)



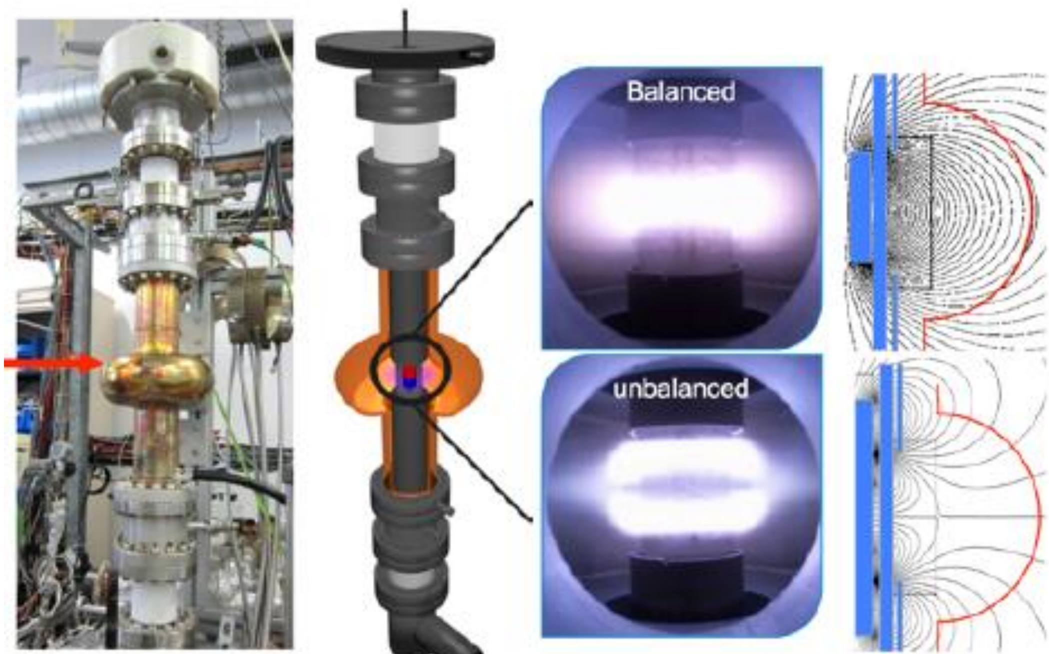
Production and R&D thin films activities at CERN for SRF applications, G. Rosas (CERN)

Nb/Cu: Cavity Deposition

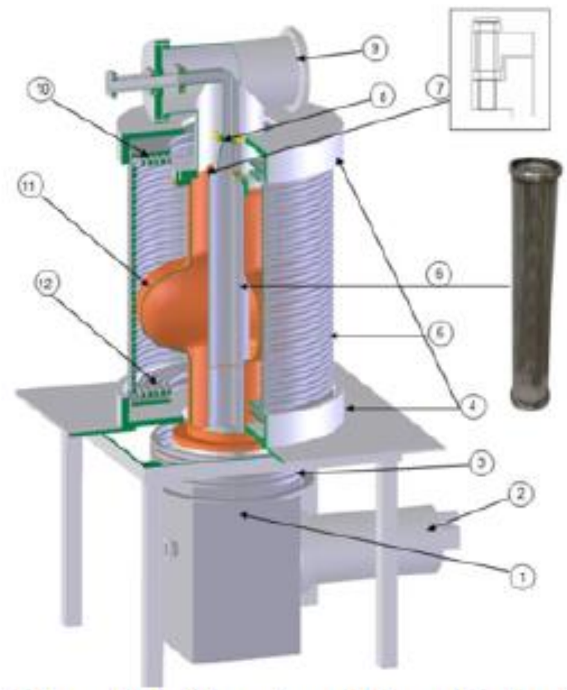


Towards high performance Nb thin films via energetic condensation

A.-M. Valente (JLab)



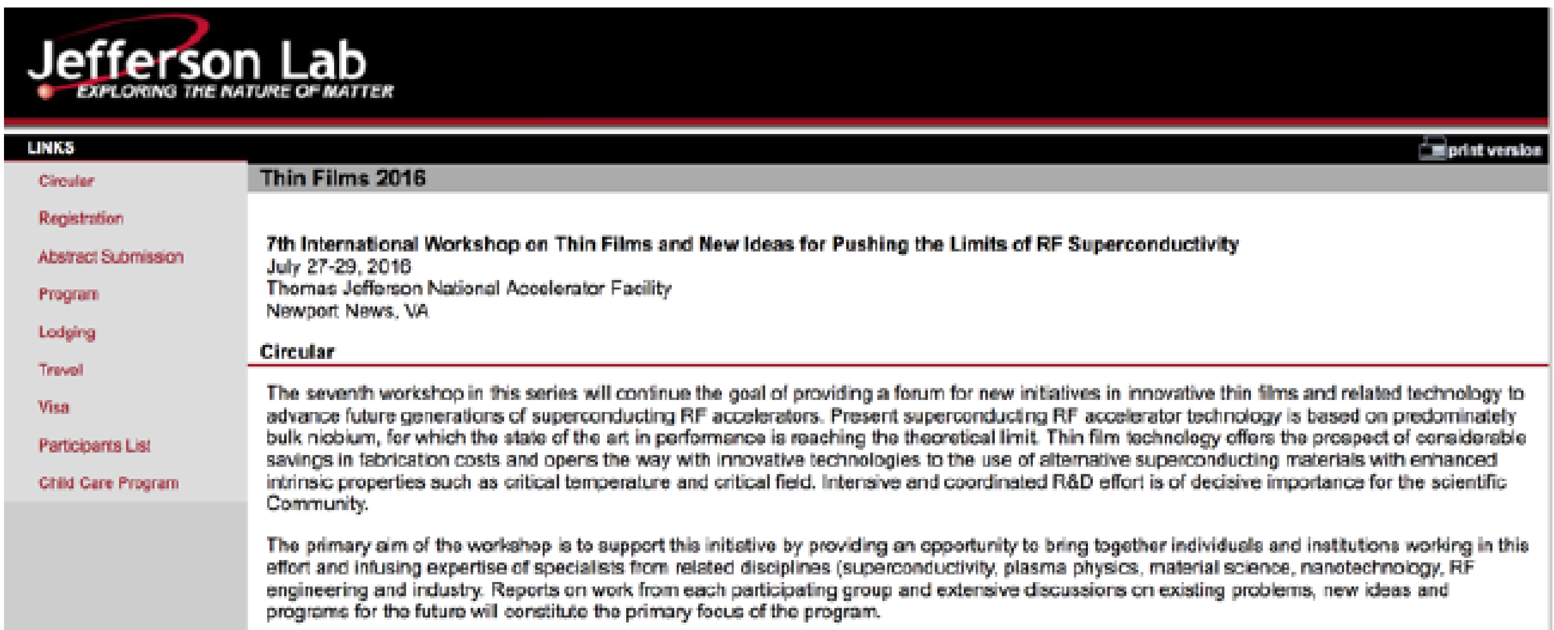
Production and R&D thin films activities at CERN for SRF applications, G. Rosas (CERN)



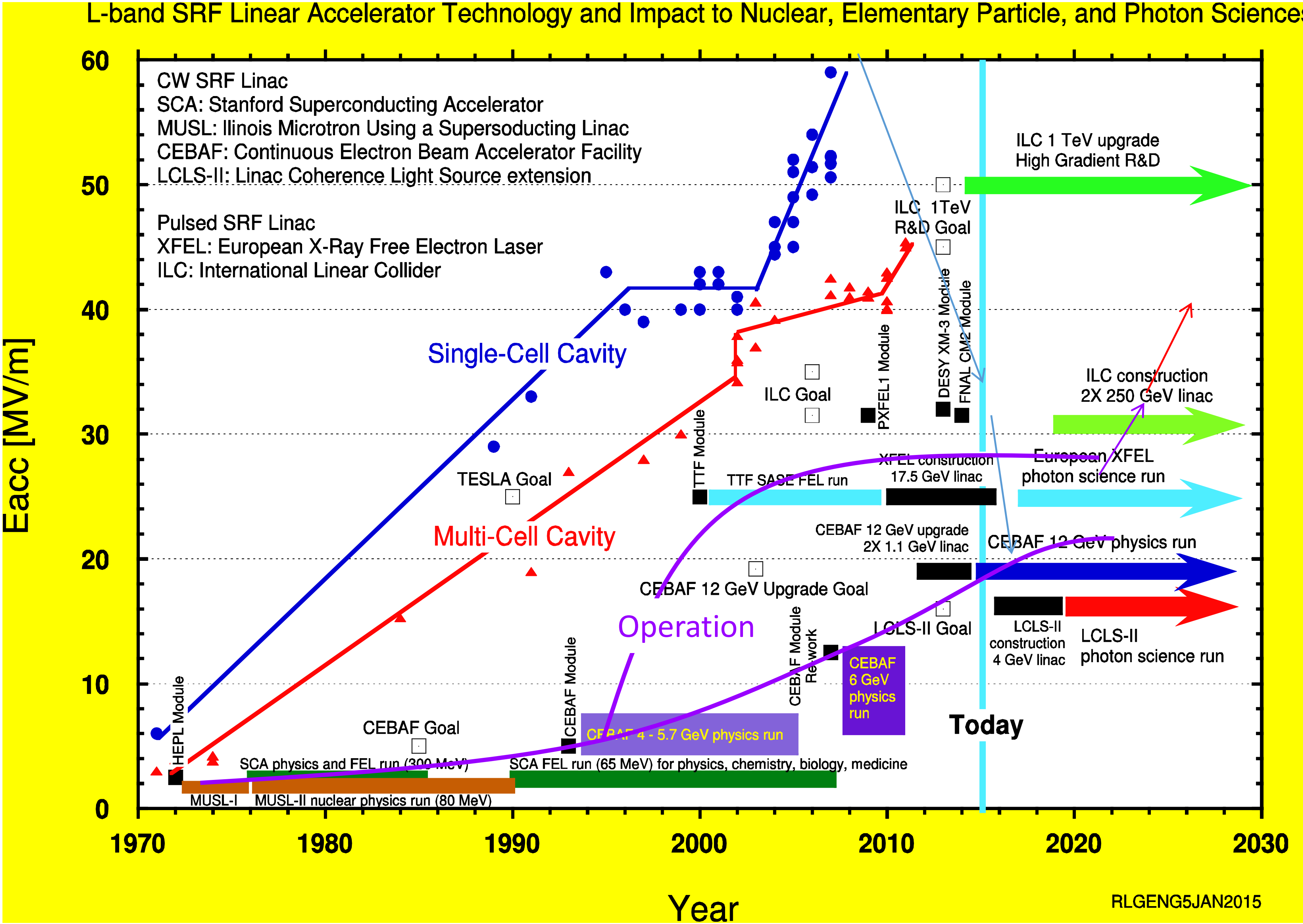
Future thin film deposition efforts at FNAL, G. Wu/M. Checchin (FNAL)

Conclusion

- the new material/thin film community is growing, understanding of recipes are advancing, performance is improving
- Synergies between Nb3Sn and Nb/Cu could speed up understanding the relation between material properties and SRF performance



High gradient / High-Q

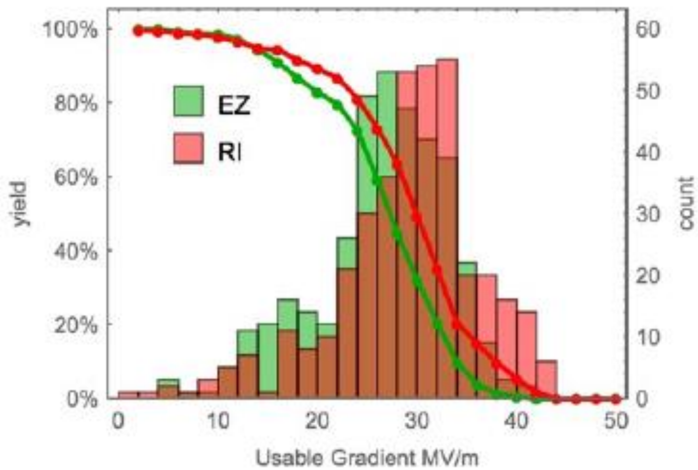


Rongli Geng「Is current state of the art in FE an obstacle to 40MV/m (and beyond) operation?」

Nick Walker「XFEL ILC-recipe VT results (RI)」

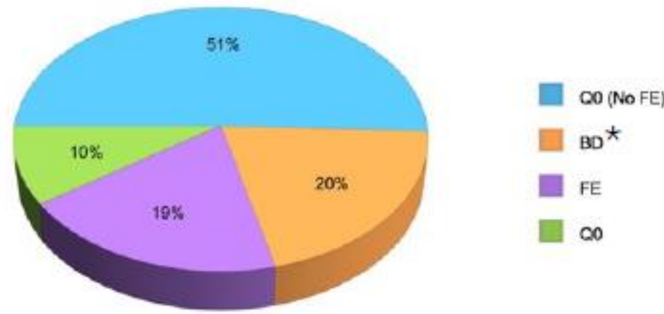
European XFEL

Test results: USABLE GRADIENT

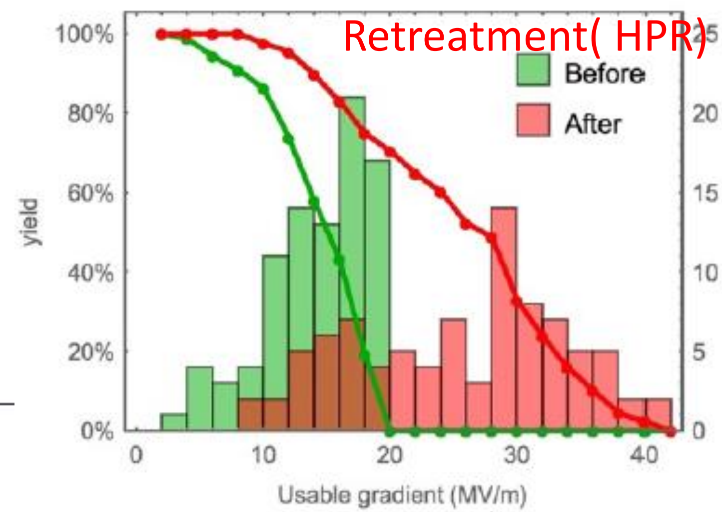


	RI	EZ	Total
Tests	375	367	742
G_{AVG} (MV/m)	29.1	26.4	27.8
G_{RMS} (MV/m)	7.4	6.6	7.1
yield @ 20MV/m	89%	83%	86%
yield @ 26MV/m	73%	59%	66%
yield @ 28MV/m	63%	45%	54%

"As received" test



* few cases of power limitation, HOM coupler heating etc.



Retreatment (additional HPR) is effective to recover performance. From some model analysis, including retreatment of cavity, ~50% of cavity can be operated at 35 MV/m

Summary of Achieved High Gradient

- 36 MV/m one 9-cell without beam (HTC @ FNAL)
  - 57hours
- 31.5 MV/m, 7 9-cell without beam (ASTA @ FNAL)
  - unknown hours
- > 30 MV/m, several 9-cells with beam(FLASH)
  - 15 hours at 3 mA
  - Several hours close to 9 mA

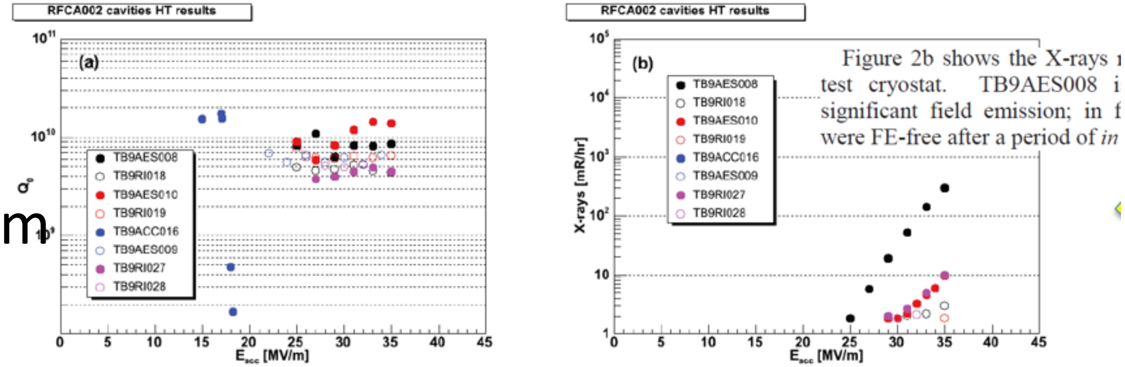
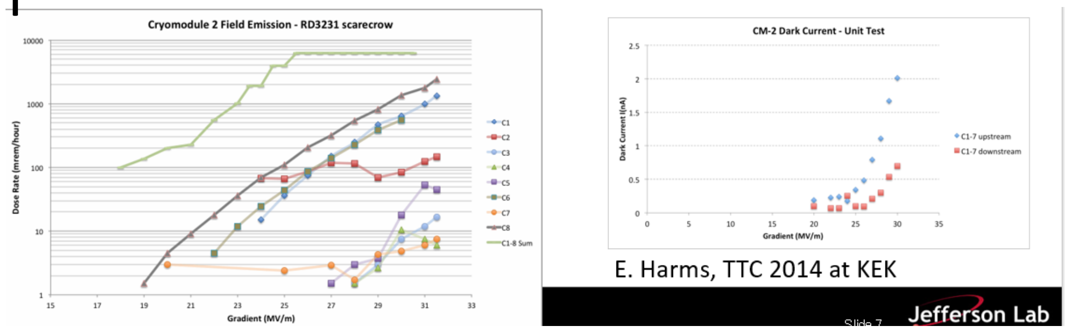
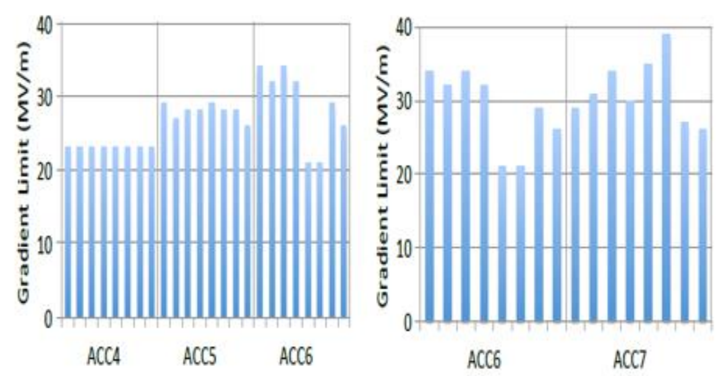


Figure 2: (a) Q_0 vs. E_{acc} from the last horizontal test of the RFCA002 cavities. (b) X-rays vs. E_{acc} from the last horizontal test of the RFCA002 cavities. Note the y-axis range differs from Figure 1b.



- There is some operation experiment at 30 -35 MV/m, but not for > 40MV/m.
- Propose test operation of cavity > 40 MV/m

Figure 3.2 Measured cavity-gradient limits for the cavities in the FLASH Accelerator cryomodules for the 9mA studies



(a) Modules ACC4,5,6 (2008-2009) (b) Modules ACC6,7 (2010-2012)

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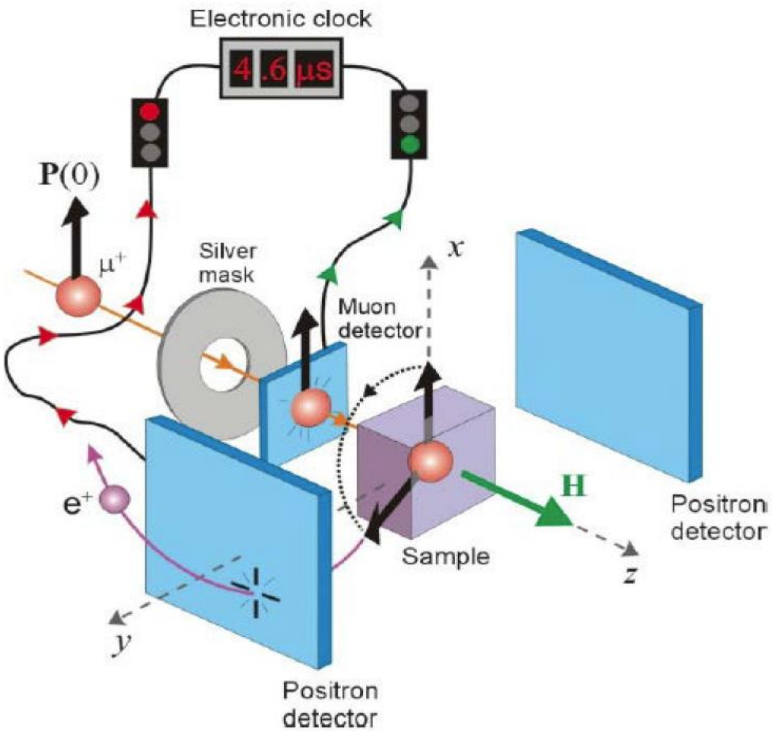
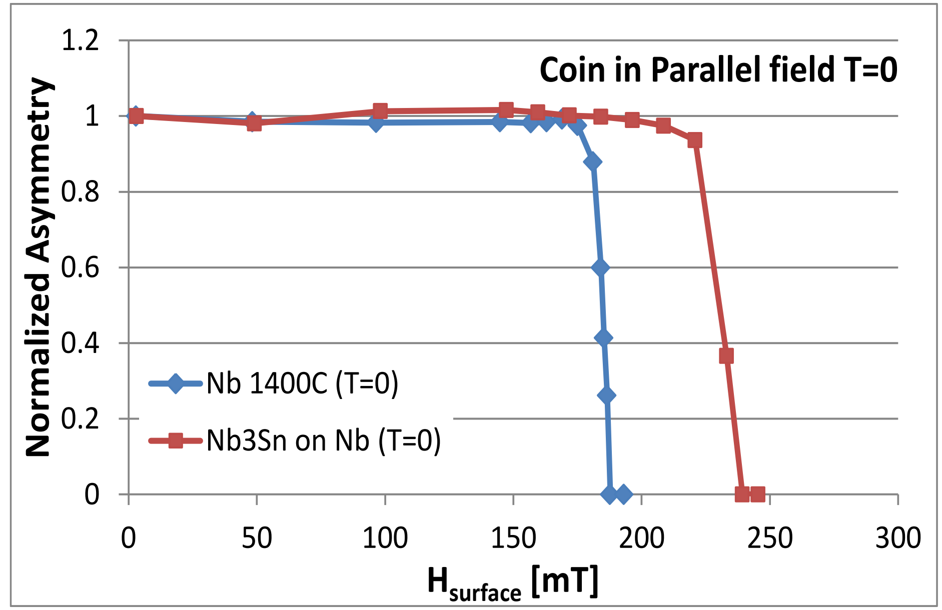
Robart Laxdal「New insights for reaching higher gradients from muSR sample studies」

Muon Spin Rotation – muSR



- The time evolution of the asymmetry in the two signals gives a measure of the local field in the sample



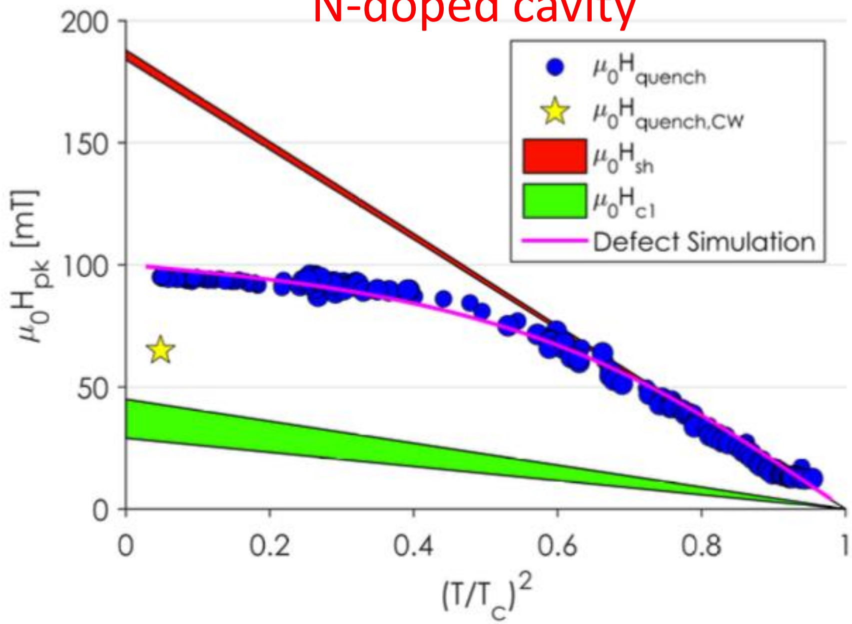
- An uncoated Nb sample in parallel geometry has flux breaking in at 180mT (at T=0) – consistent with H_{c1}
- A Nb coin coated with Nb3Sn has flux breaking in at 230mT (at T=0) consistent with H_{sh} of Nb

A layer of higher T_c material on niobium can push the field of first flux entry from a field consistent with H_{c1} to a field consistent with H_{sh}

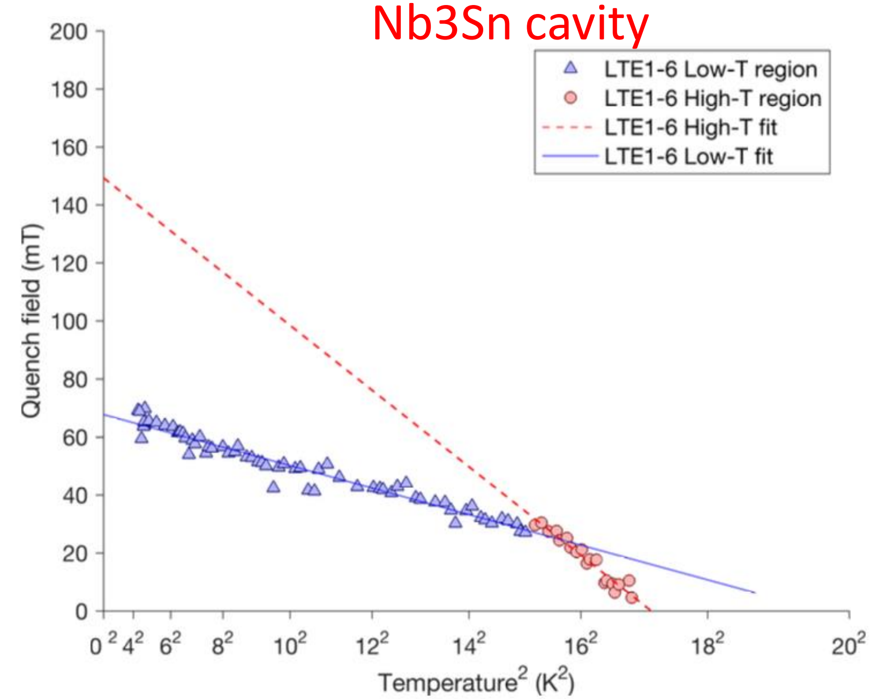
James Maniscalco「Estimated gradient limitation insights for different surface processing from klystron measurements」

Motivation: Klystron test can escape from global thermal effects

N-doped cavity



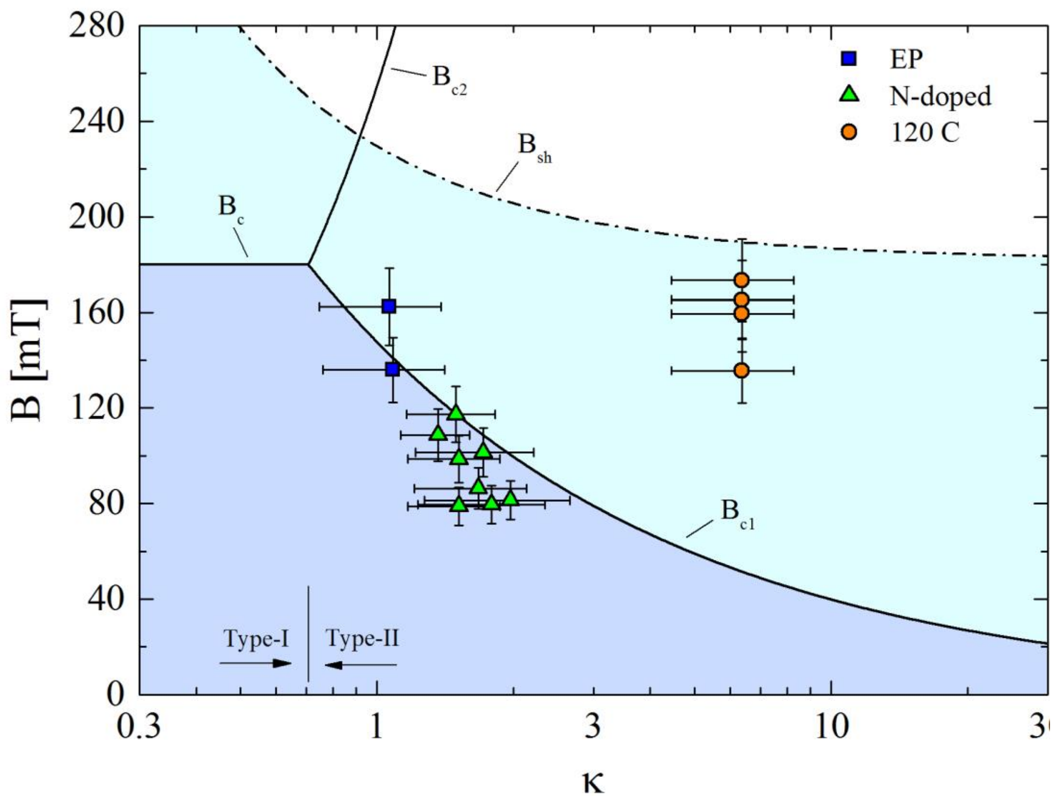
Nb3Sn cavity



- High T: limited by flux entry at Bsh
- As T decreases, Bpk diverges, indicating thermal effects

Two slope can clearly be seen from klystron analysis

CW quench field data



N-doped cavities so far quench **below** B_{c1}

→ statistically, N-doped cavities are quenching close or below the lower critical field

120 C baked cavities quench always **above** B_{c1}

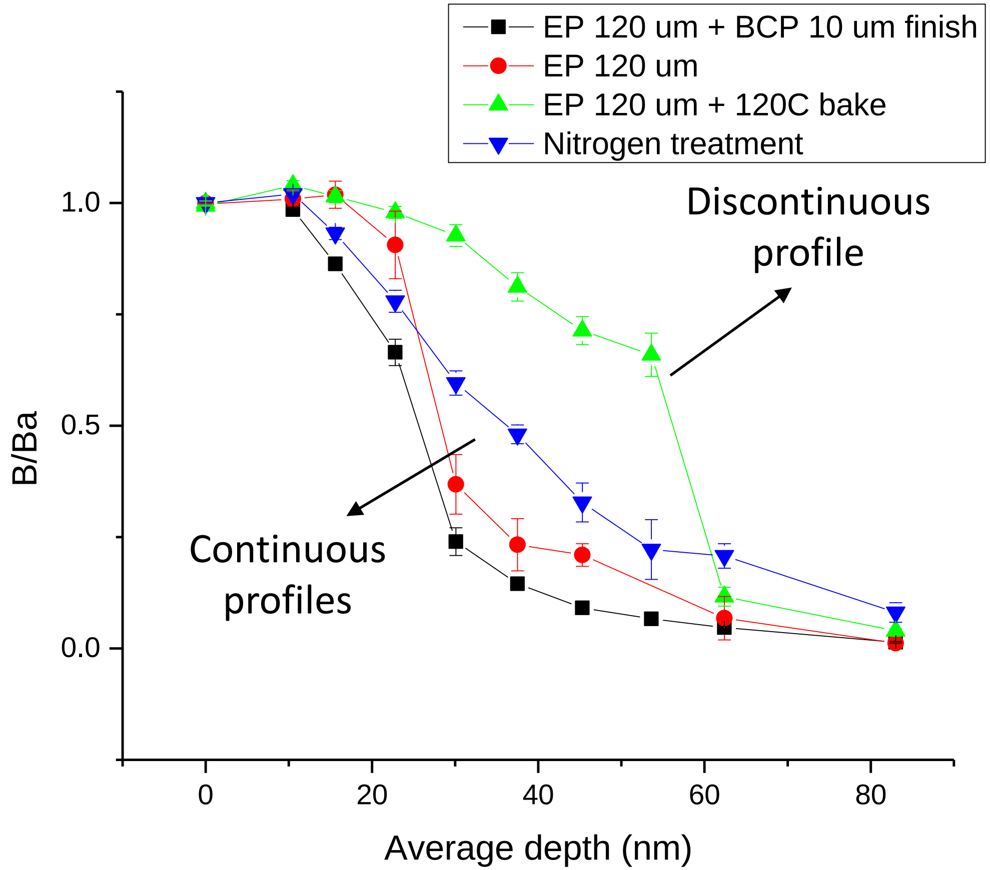
→ 120 C baked cavities can reach the metastable Meissner state above the lower critical field

$H_c(0) = 180\ mT$ [1] $\lambda_0 = 39\ nm$ [2] $\xi_0 = 38\ nm$ [2]

[1] S. Casalbuoni *et al.*, Nucl. Instr. Meth. Phys. Res. A 583, 45 (2005)
[2] B. W. Maxfield and W. L. McLean, Phys. Rev. 139, A1515 (1965)

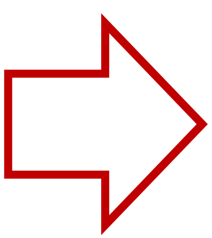
Sebastian Aderhold / Anna Grassellino
「New low T nitrogen treatments cavity results with record gradients and Q」

Surface of 120C bake vs N doping vs EP, via LE-muSR



N-doped, EP and BCP do not show discontinuous field penetration profile
→ constant concentration profile

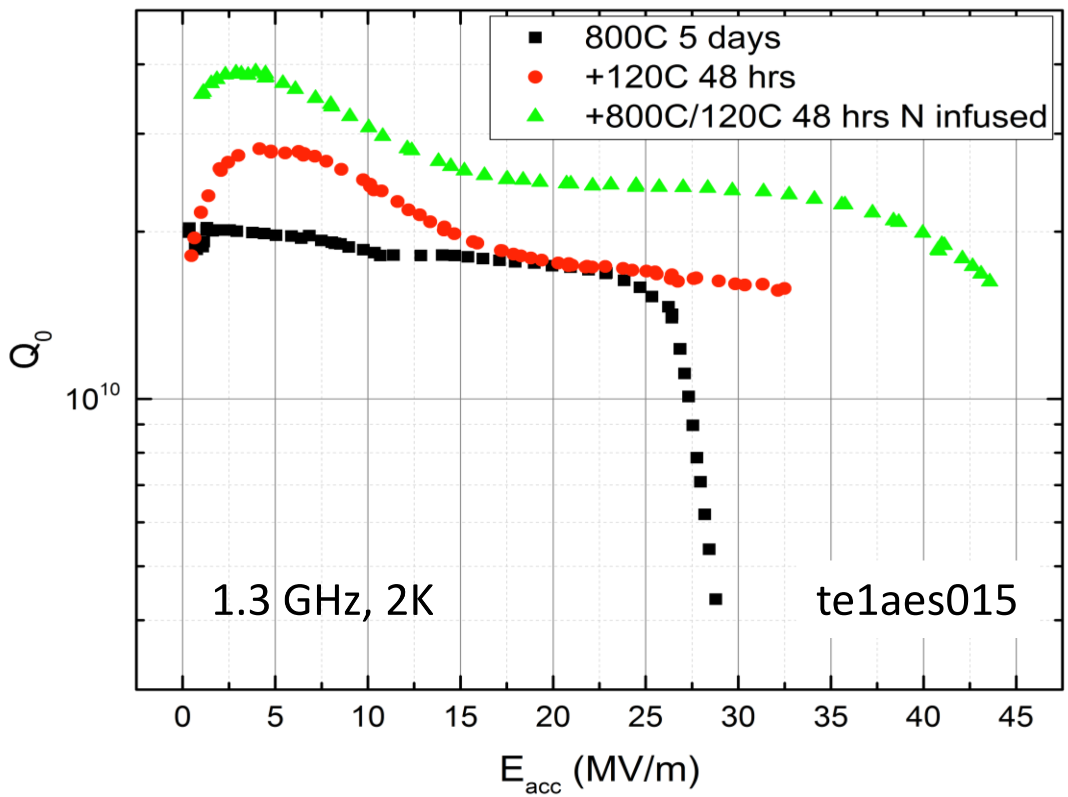
Standard 120 C baked does present discontinuous field penetration profile
→ dirty layer!



120 C baked cavities quench above B_{c1} likely because of the dirty layer.
Nitrogen-infused cavities may exploit the same phenomenon, but bringing also benefit for the Q!

Sebastian Aderhold / Anna Grassellino
「New low T nitrogen treatments cavity results with record gradients and Q」

Nitrogen Infusion
systematic improvement in Q and quench fields



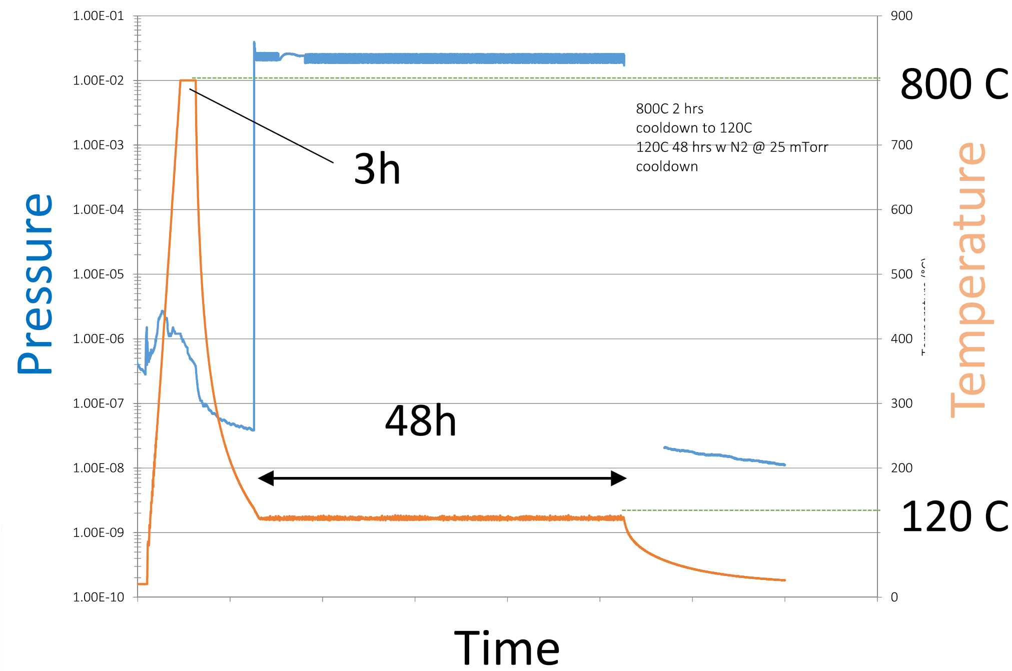
- Clear evolution trend confirming improvement in Q and quench field
- NO EP between furnace treatments: comparing same morphological surface, just different impurity content

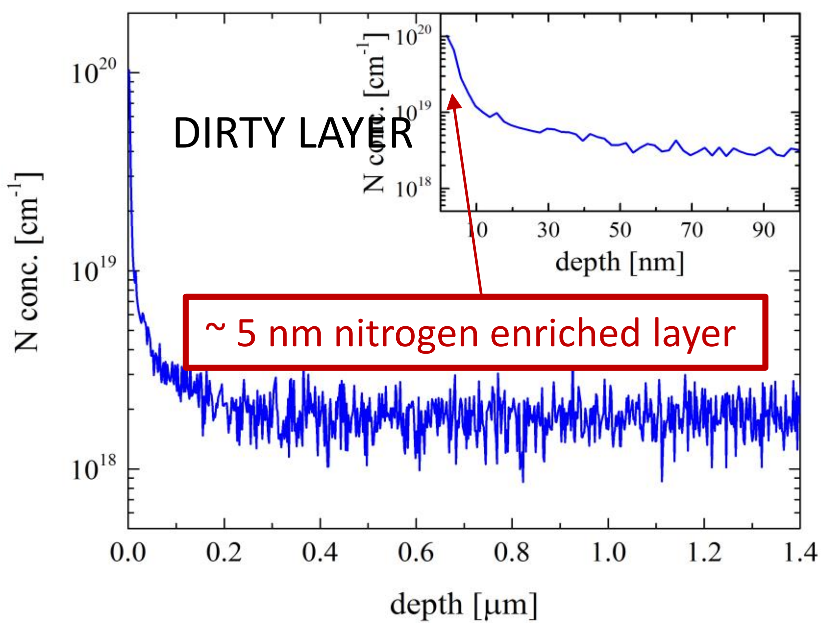
Sebastian Aderhold / Anna Grassellino

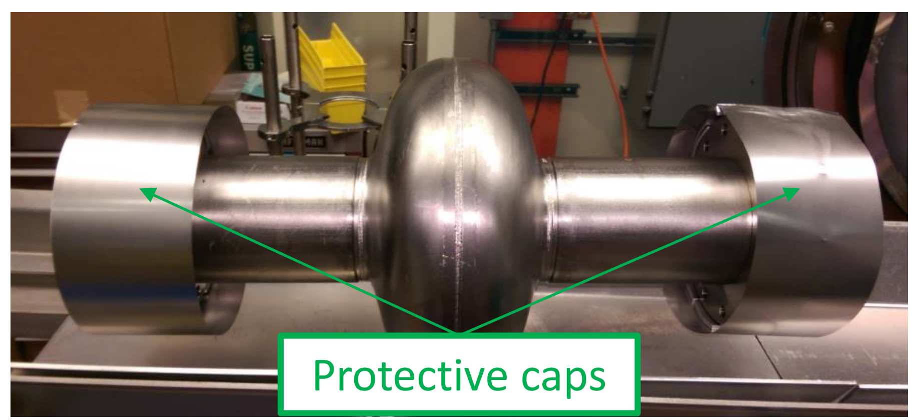
「New low T nitrogen treatments cavity results with record gradients and Q」

Example of nitrogen infusion treatment - engineering a thin dirty layer with N2, on a clean bulk

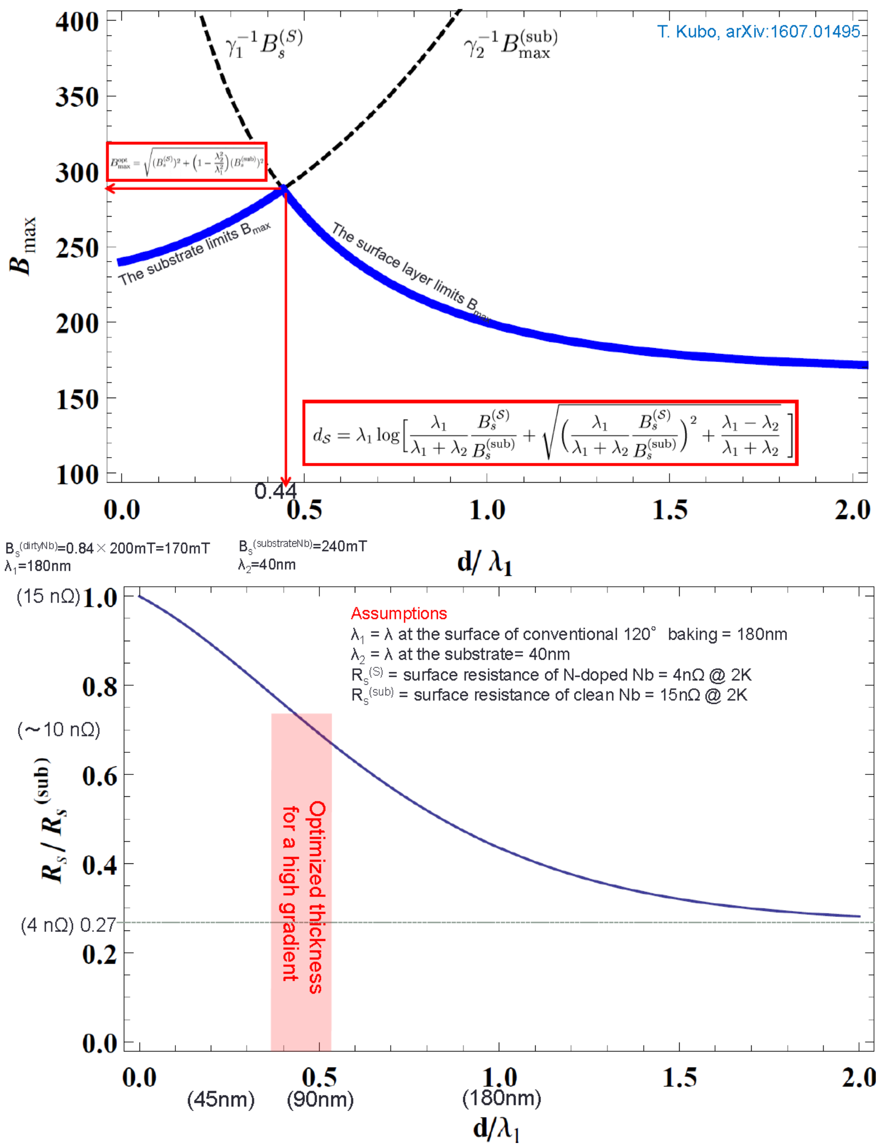
- Bulk electro-polishing
- High T furnace with caps to avoid contamination:
  - 800C 3 hours HV
  - 120C 48 hours with N_2 (25 mTorr)
- NO chemistry post furnace
- HPR, VT assembly







Effect of the dirty layer on clean bulk superconductor



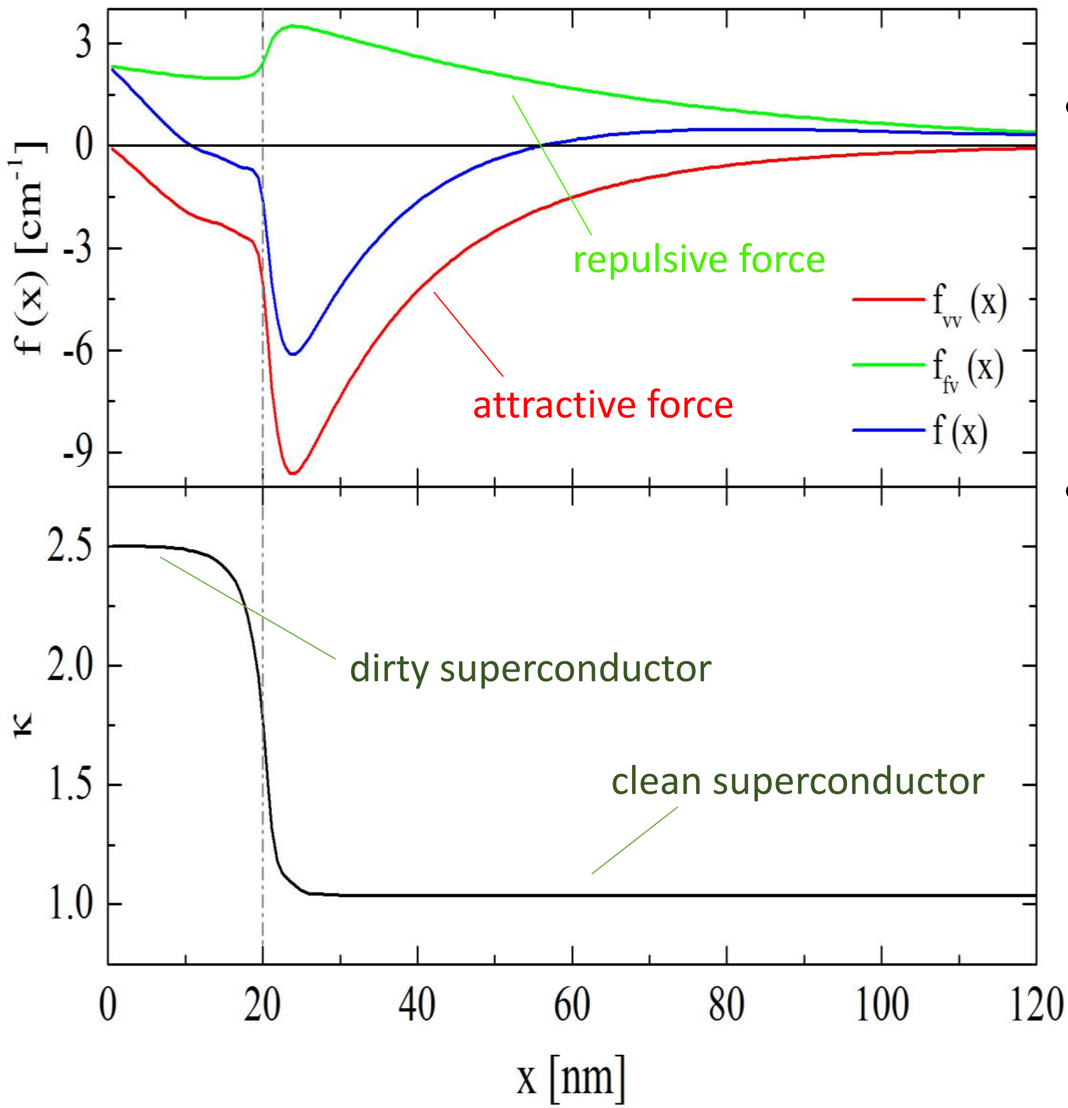
1. The quench field is increased up to a maximum value defined by the dirtiness and thickness of the layer

2. The surface resistance is a "weighted" average of the surface resistance of the layer and of the bulk

3. Quench field and surface resistance can be tuned as needed by engineering the dirty layer at the surface

Mattia Checchin「Ultimate gradient limitation in Nb SRF cavities」

Why the dirty layer increases the quench field?

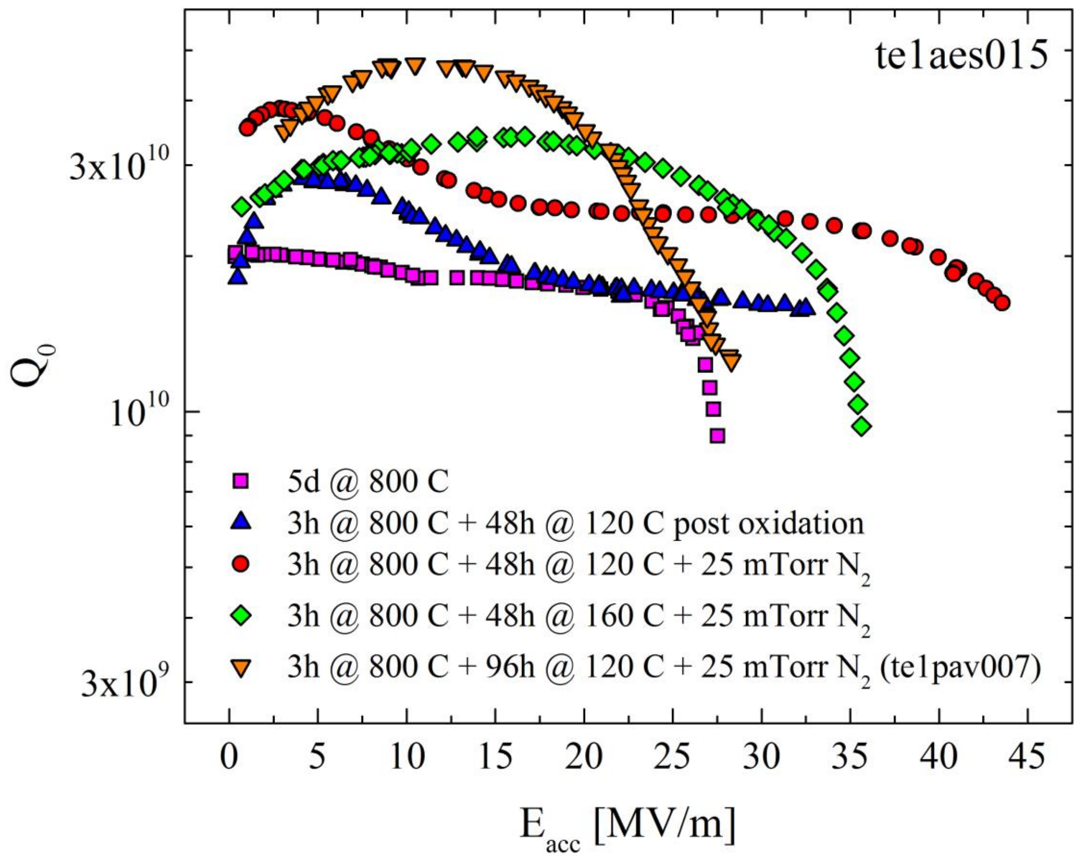


- The attractive force (to the surface) acting on the vortex is enhanced at the interface dirty/clean superconductor
- Such force pushes more efficiently the vortex outside the superconductor

The penetration of the magnetic field is delayed!

Sebastian Aderhold / Anna Grassellino
「New low T nitrogen treatments cavity results with record gradients and Q」

Moving to even higher Q – and maybe gradients too – R&D continues to better engineer ideal nanometeric N layer



Conclusion

[High gradient and High-Q]

- At present operation of cryomodule with 35MV/m could be possible. No experience on 40 MV/m operation.
- Field emission is on-going target to improve cavity performance.
- Understanding of materials and thin/multi layers are proceeded by both experimental and theoretical approach.
- Low T nitrogen treatment was proposed and opened the way to control both of cavity gradient and Q.