New processing methods for niobium SRF resonators for maximization of quality factor for CW applications

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Outline

- Planned machines operate in CW mode
- Microwave surface resistance for standard treatments: *new methodology developed* to extract the the temperature dependent and independent component as a function of field

- *New* processing techniques for Q maximization:
  - 120C bake followed by HF rinse
  - Annealing followed by HPR only (no material removal via chemistry)
  - Heat treatments in nitrogen atmosphere

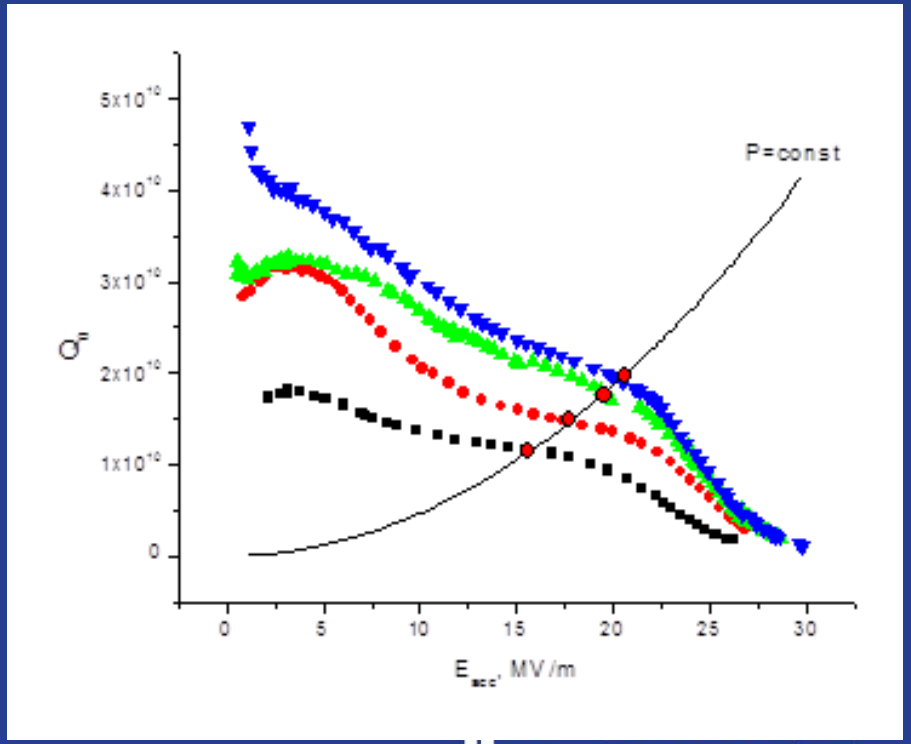
Motivation for higher Q

- RF load in CW regime determines the power consumption of a cryogenic system and thus:
  - Capital cost of the cryogenic system (significant impact on project)
  - Operational cost ~ RF load ~ Q_0^{-1}
  - High Q_0 allows higher gradient at CW and, thus, allows lower capital cost of the linac.

$$Q_0 = \omega U / P_{diss} = G / R_s$$

CW machines: high Q_0 → low surface resistance is crucial

$$R_s = R_{BCS}(T) + R_0$$



What is Q and $R_s(B)$ for standard treatments?

Field Dependence of Surface Resistance for typical treatments

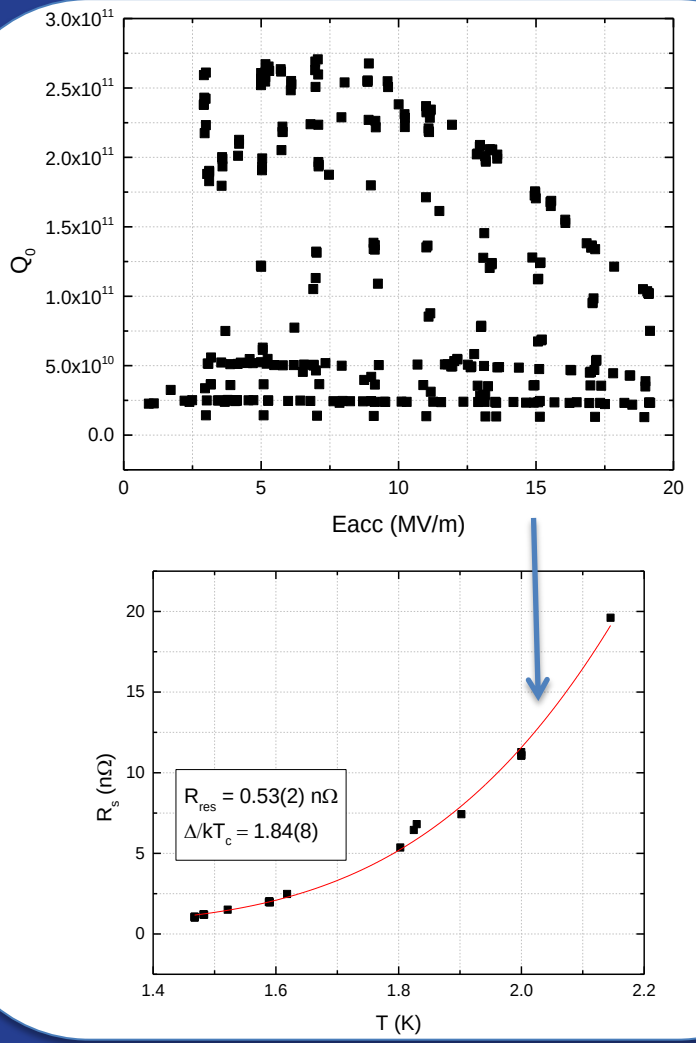
- $Q = G/R_s$, where $R_s = R_{BCS}(T) + R_{residual}$
- Crucial question – how does *medium field Q-slope* emerge from its components R_{BCS} (B) and $R_{residual}$ (B)?
- Answering allows:
  - Obtain *$R_s(B,T)$ predictions for any standard treatment* (EP, BCP, mild bake, anneal…) to design accelerators -> missing input for optimization
  - *Baseline for comparison* with new, innovative treatments
  - *Fundamental understanding* of "Q-slopes"

Approach

- Obtain as many Q(B,T) measurements as practical at *ALL fields* (not only at a single low field as is customary)

- At each fixed field fit corresponding Q(T) to extract $R_{residual}$
  - Also gives $R_{BCS}(T) = Rs(T) - R_{residual}$

A. Romanenko and A.Grassellino
http://arxiv.org/abs/1304.4516



Bath temperature

Results (1.3 GHz)

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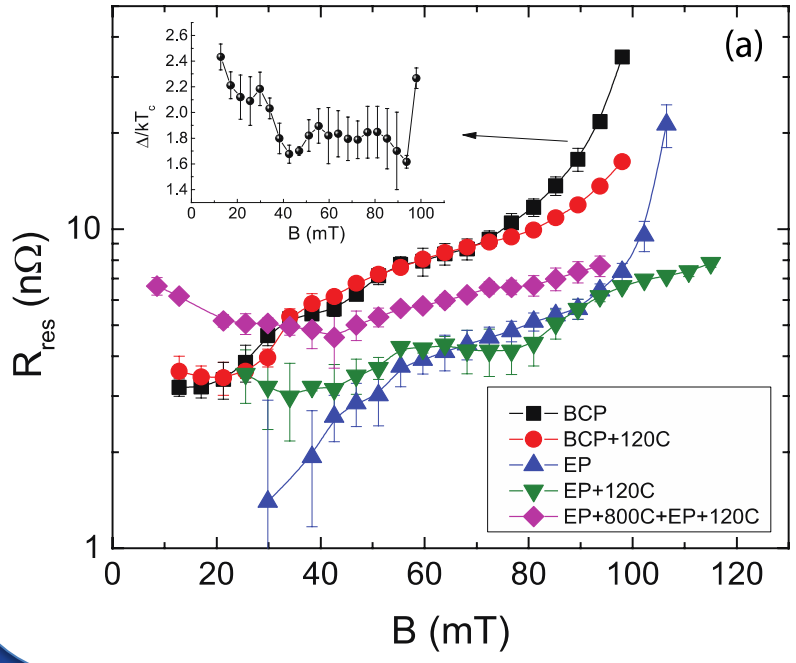
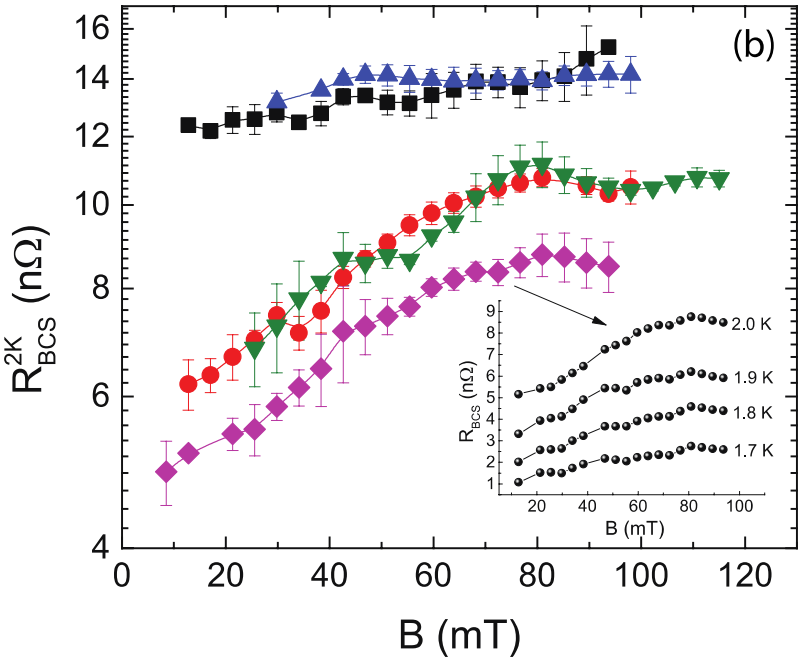
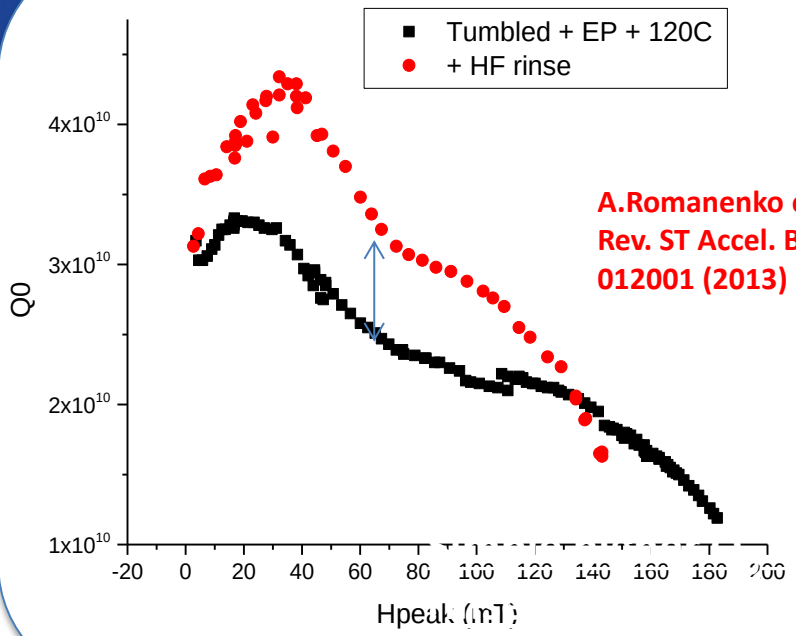




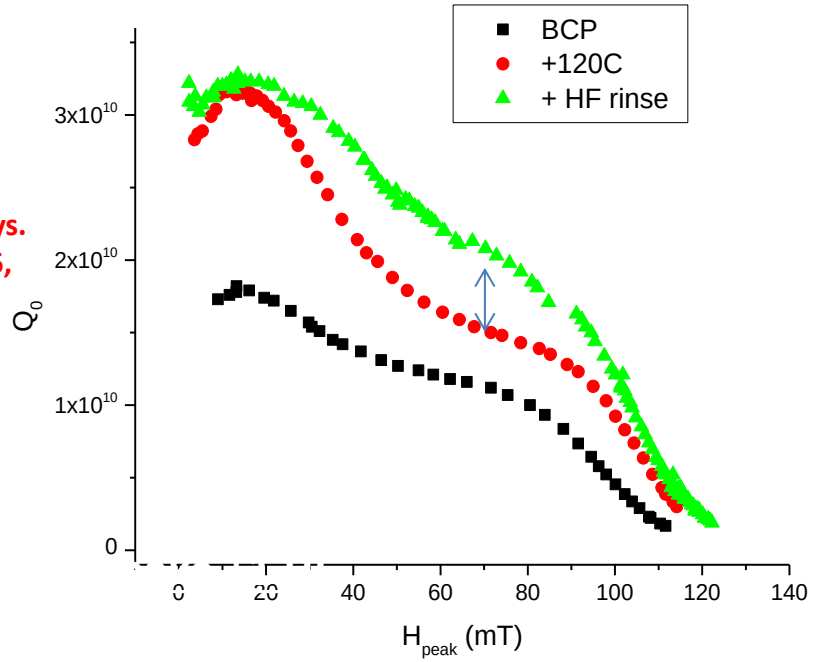
- Medium field Q slope combines both $R_{residual}(B)$ and $R_{BCS}(B)$
- R_{BCS} decreases but becomes *strongly field dependent after 120C*
- Medium field Q slope is *NOT due to thermal feedback*
- Stronger $R_{residual}(B)$ for *BCP than for EP*

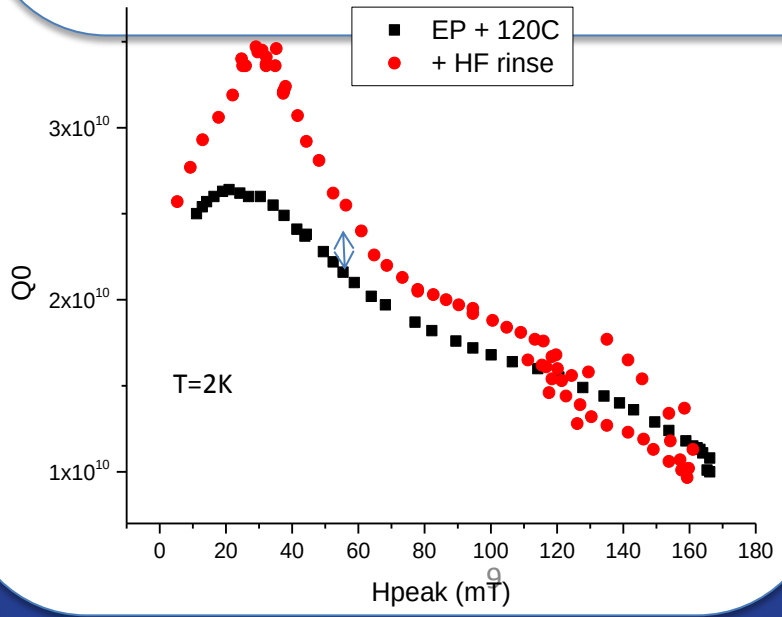
New surface processing techniques for Q maximization

Simple higher Q_0 recipe: 120C bake +1 HF rinse



A.Romanenko et al, Phys. Rev. ST Accel. Beams 16, 012001 (2013)

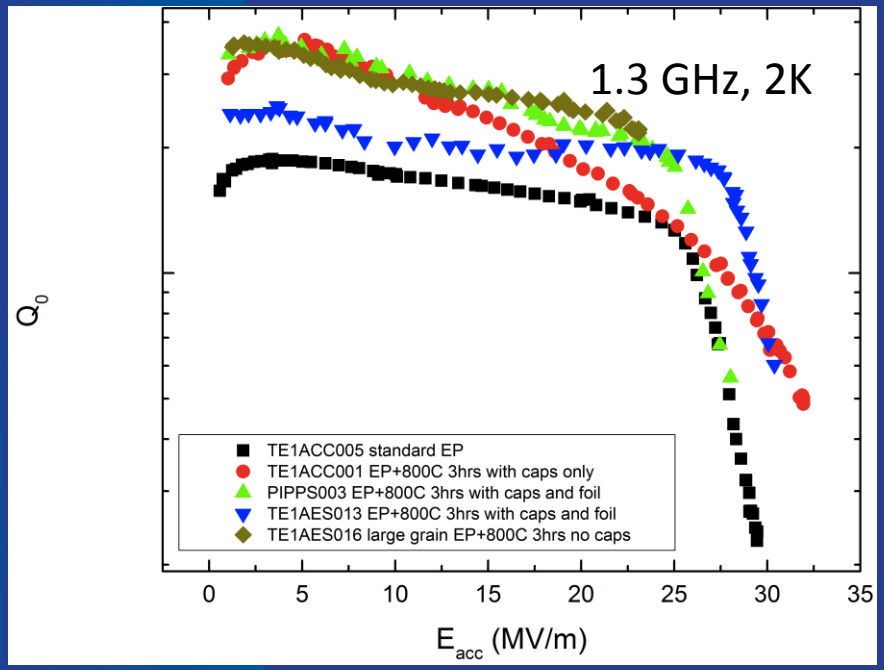




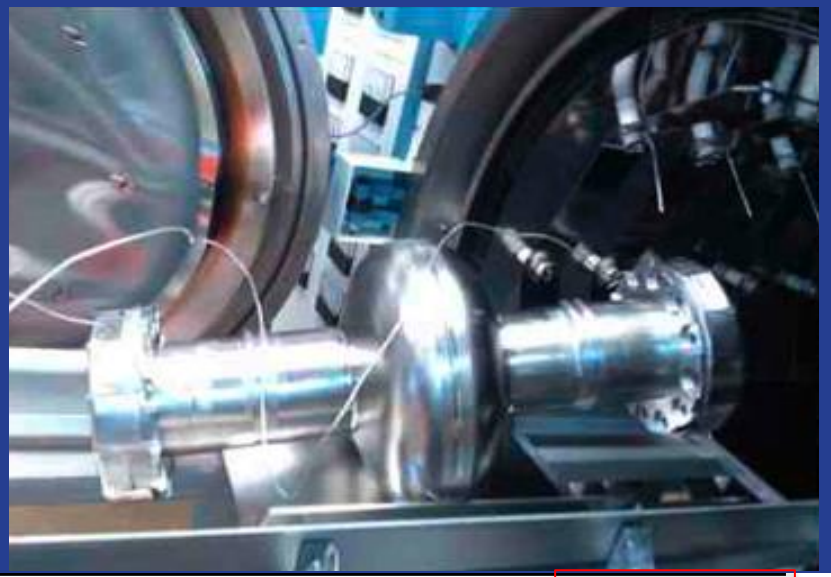
- 120C bake followed by a single HF rinse (5 min) followed by water rinse is beneficial for the medium field Q value – gains of up to 50% measured at 70 mT
- Mechanism: reverse increase in residual, preserve improved BCS due to 120C bake

Fermilab

Annealing with caps+ no chemistry produces extra-low residual resistance



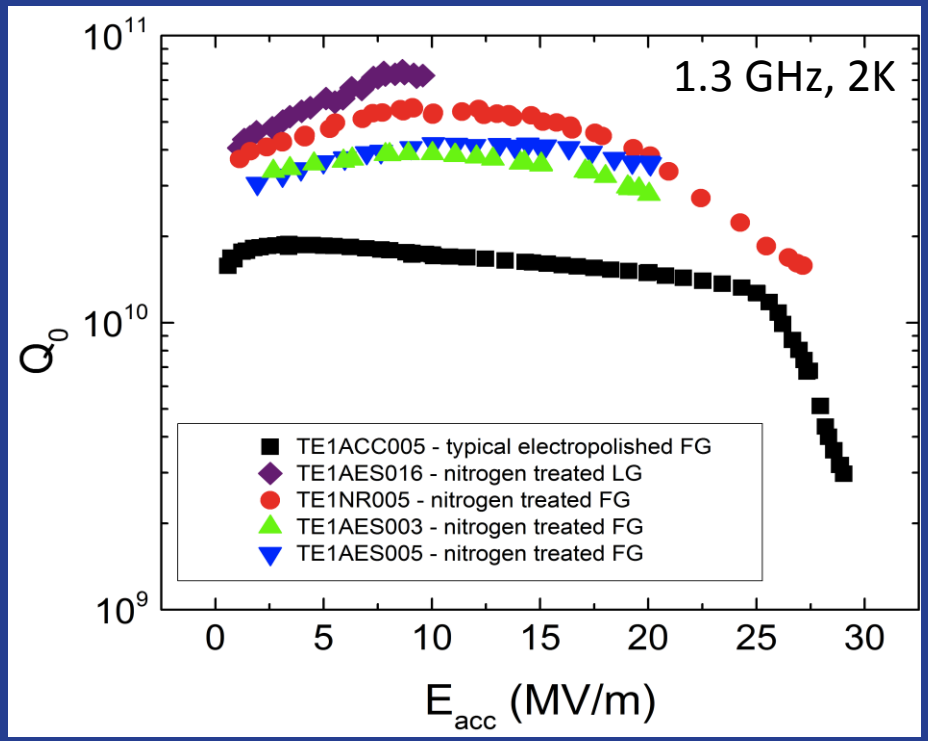
A.Grassellino et al, http://arxiv.org/abs/1305.2182



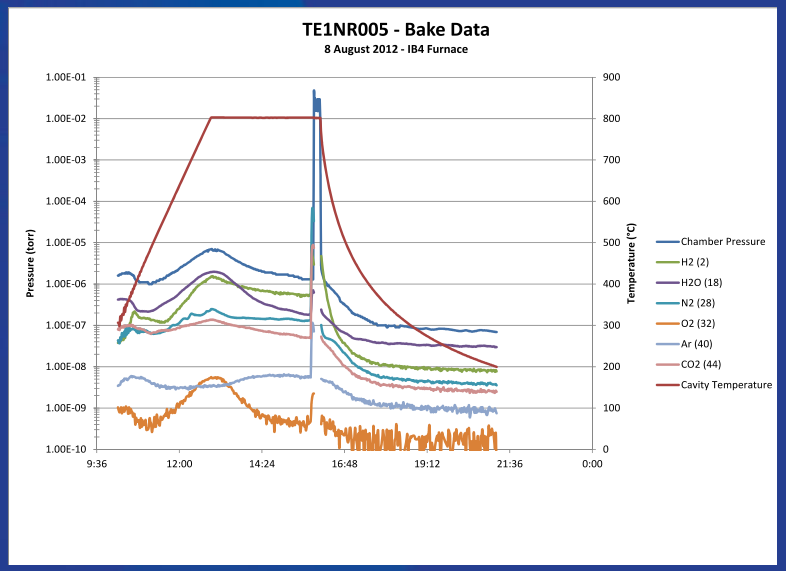
- *Systematically low R_0*
- *Extra cost savings from skipping the post furnace chemical processing*
- *See also* G. Ciovati, Phys. Rev. ST Accel. Beams 13, 022002 (2010)

CAVITY ID	Type	Treatment	Q at 5 MV/m, T = 2K	Residual Resistance at 5 MV/m (nΩ)
TE1AES016	Large grain	EP + 800°C 3 hrs no caps, argon venting	3.5e10	1.47±0.44
TE1AES013	Fine grain	EP + 800°C 3 hrs with caps plus foil, dry air venting	2.4e10	<1.09
PIPPS003	Fine grain	CBP + EP + 800°C 3 hrs with caps plus foil, nitrogen venting	3.5e10	1.45±0.84
TE1ACC001	Fine grain	EP + 800°C 3 hrs with caps only, nitrogen venting	3.5e10	0.85±0.67

Heat treatments in nitrogen produce unprecedented values of $R_{BCS}(B)$



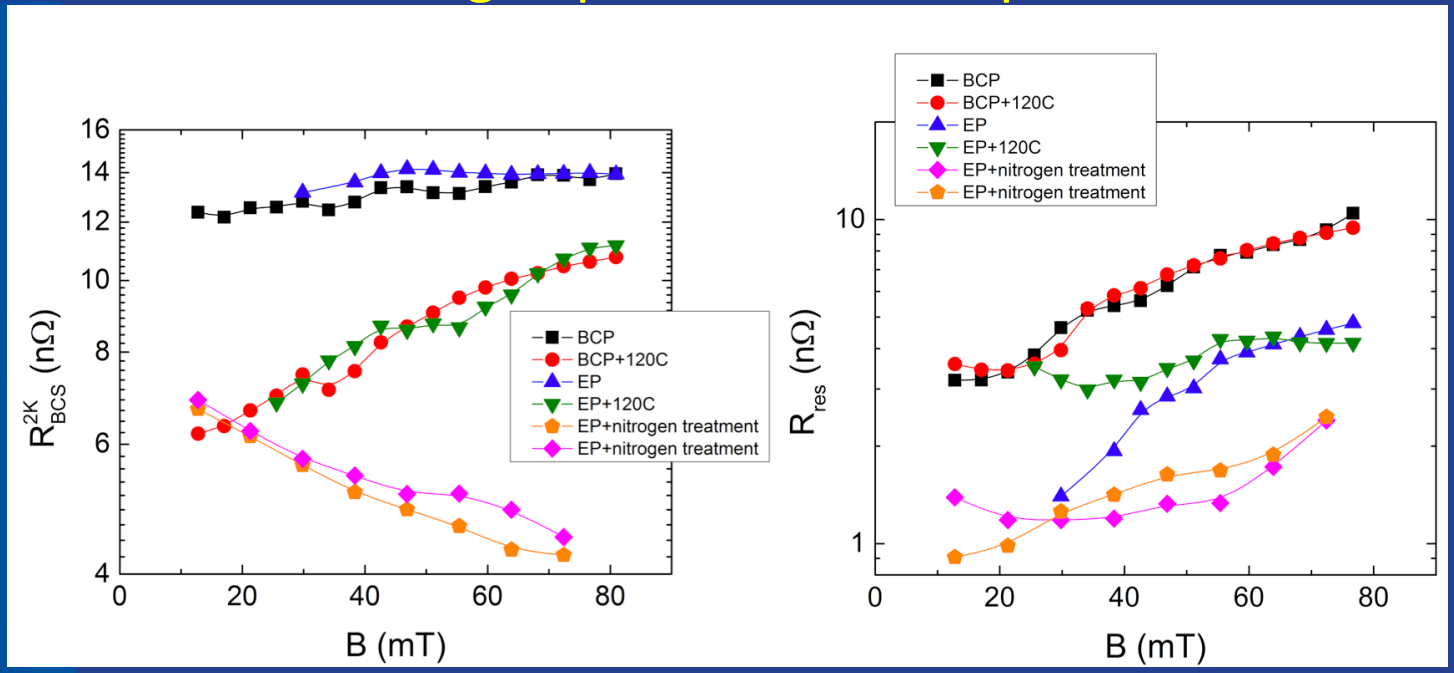
A.Grassellino et al, http://arxiv.org/abs/1306.0288



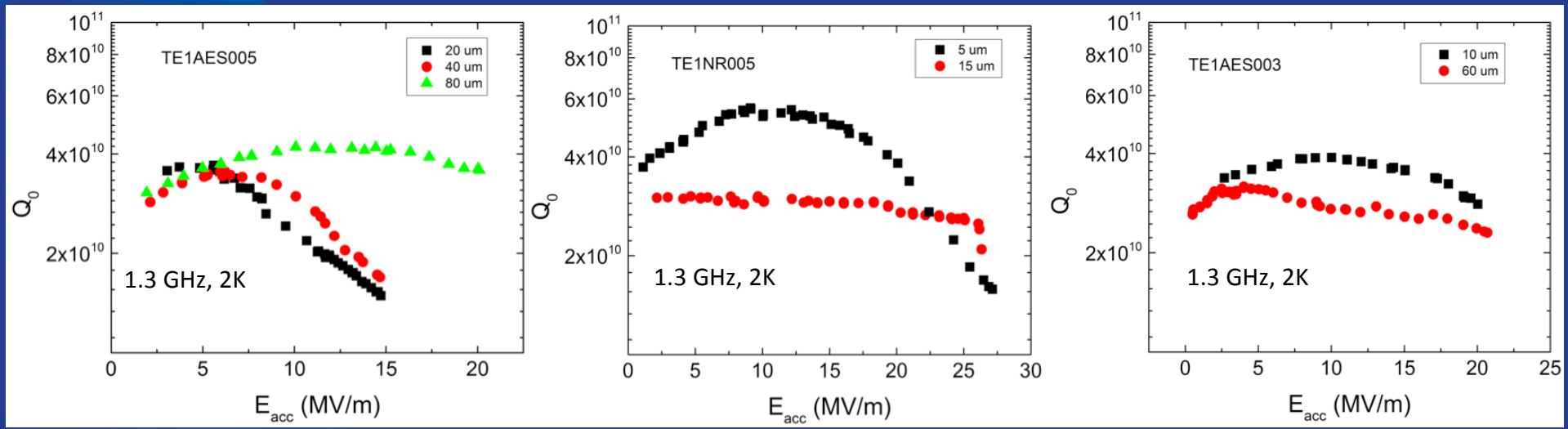
- Cavities baked at high T in partial pressure of nitrogen
- After the treatment followed by some material removal via EP, *Q improvements up to a factor of 3* compared to standard processing!

Fermilab

Heat treatments in nitrogen produce field dependence reversal of R_{BCS}



Q curves as a function of material removal via EP post-nitrogen treatment *(indicate optimal N to Nb concentration ratio)* :



Conclusions

- *Different recipes found for Q improvement*
  - Anneal before EP (see 2MOrC-05)
  - Long anneals, with care for contaminants
  - HF rinsing
  - Nitriding
    - *Reverse medium field Q-slope!*
    - Up to *150% gain in Q* in the T range of interest for CW accelerators
- Recipes are extremely simple, *can be replicated at any lab* with access to a standard hydrogen degassing furnace