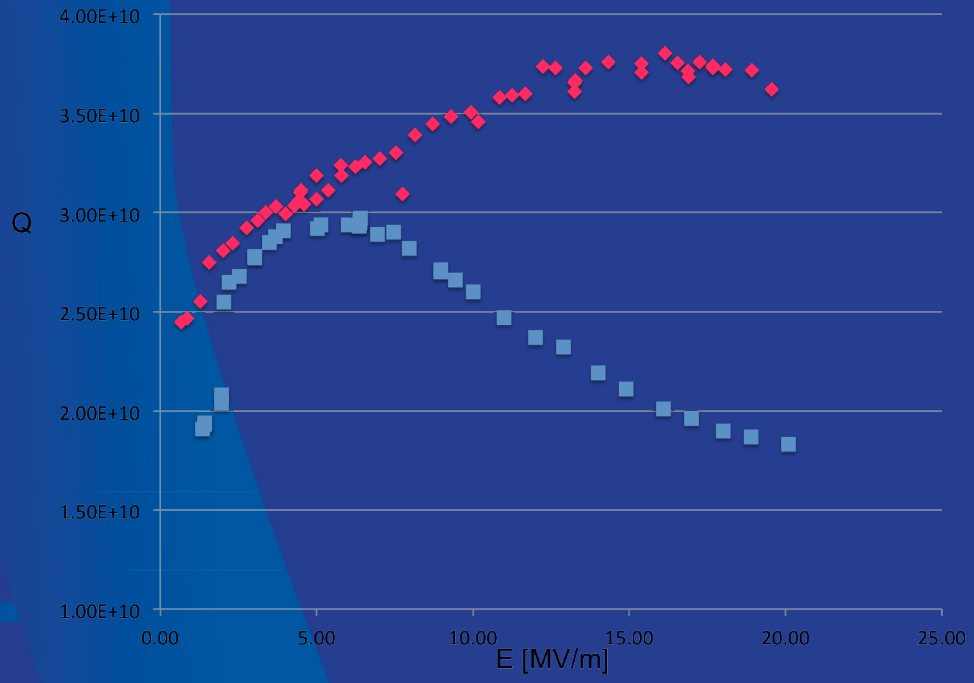
New Insights on the Physics of RF Surface Resistance and a Cure for the Medium Field Q-Slope



Anna Grassellino

SRF 2013,

Cité Universitaire, Paris

U.S. DEPARTMENT OF ENERGY

Fermilab

Outline

- How does the medium field Q-slope *emerge* from the two surface resistance components, for different surface treatments? (study at 1.3 GHz)

- A *new* surface treatment which systematically *reverses* the medium field Q-slope

What is $R_0(B)$ and $R_{BCS}(B)$ for standard surface treatments?

Field Dependence of Surface Resistance for typical treatments

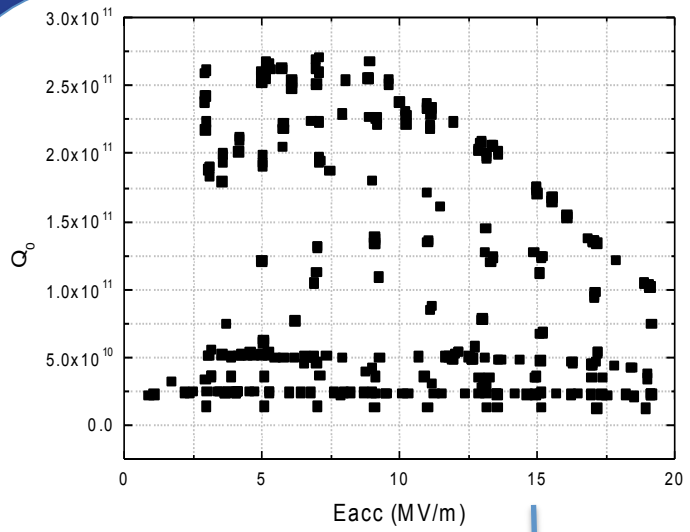
- $Q = G/R_s$, where $R_s = R_{BCS}(T) + R_0$
- Crucial question – how does *medium field Q-slope* emerge from its components R_{BCS} (B) and R_0 (B)?
- Answering allows:
  - Obtain *$R_s(B,T)$ predictions for any standard treatment* (EP, BCP, mild bake, anneal…) to design accelerators -> missing input for optimization
  - *Baseline for comparison* with new, innovative treatments
  - *Fundamental understanding* of "Q-slopes" → see talk by A. Romanenko and poster TUP038

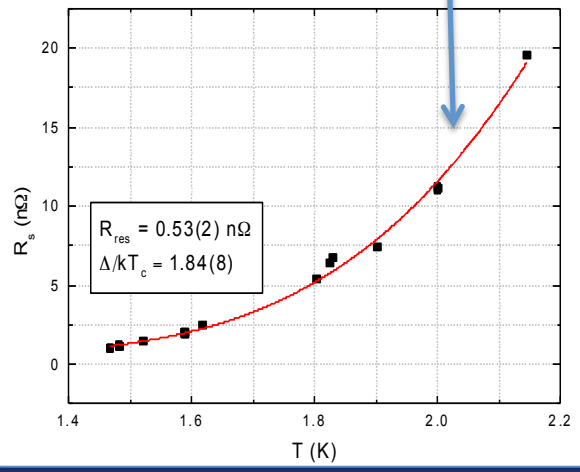
Approach

A. Romanenko and A.Grassellino
Appl. Phys. Lett. **102**, 252603 (2013)

- 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 Rres
  - Also gives Rbcs(T) = Rs(T)-Rres

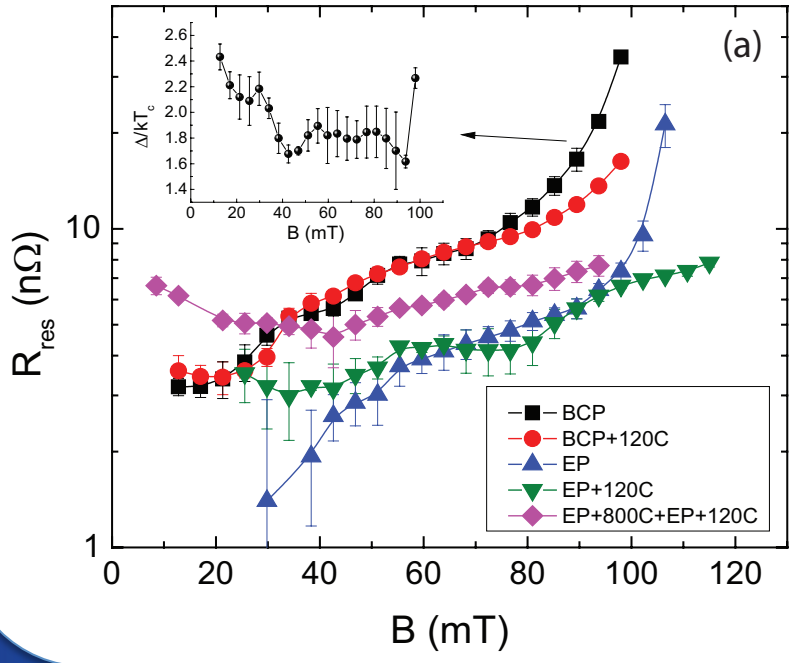


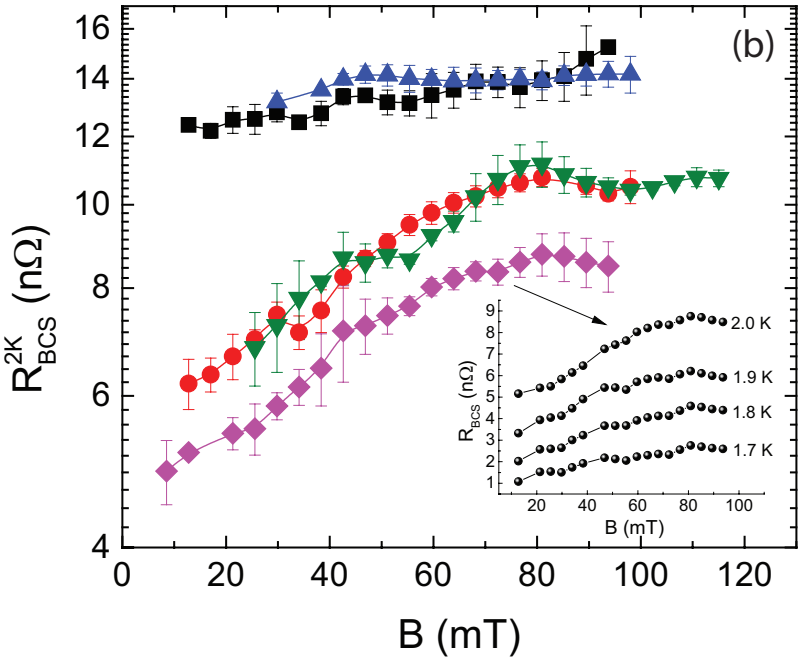


Bath temperature

A. Romanenko and A.Grassellino
Appl. Phys. Lett. **102**, 252603 (2013)

Results (1.3 GHz)



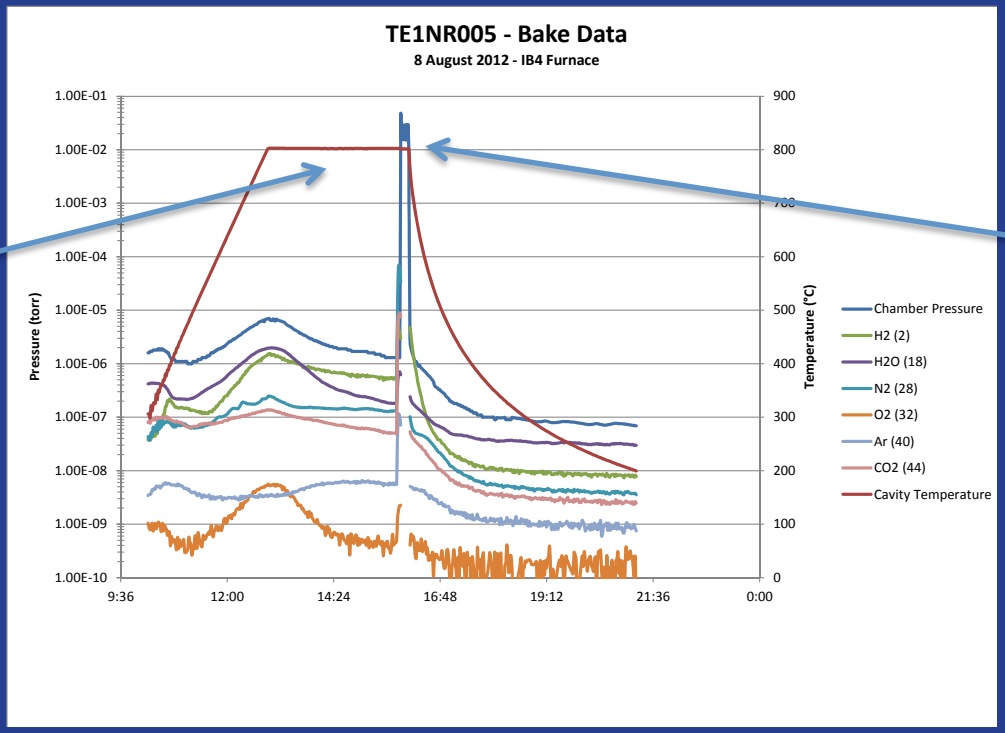


- Medium field Q slope is a combination of both $R_0(B)$ and $R_{BCS}(B)$
- R_{BCS} decreases but becomes *strongly field dependent after 120C*
- Medium field Q slope is *NOT due to thermal feedback*
- Stronger $R_0(B)$ for *BCP vs EP*

A new surface processing technique which systematically *reverses* the medium field Q-slope

High T bake in nitrogen gas

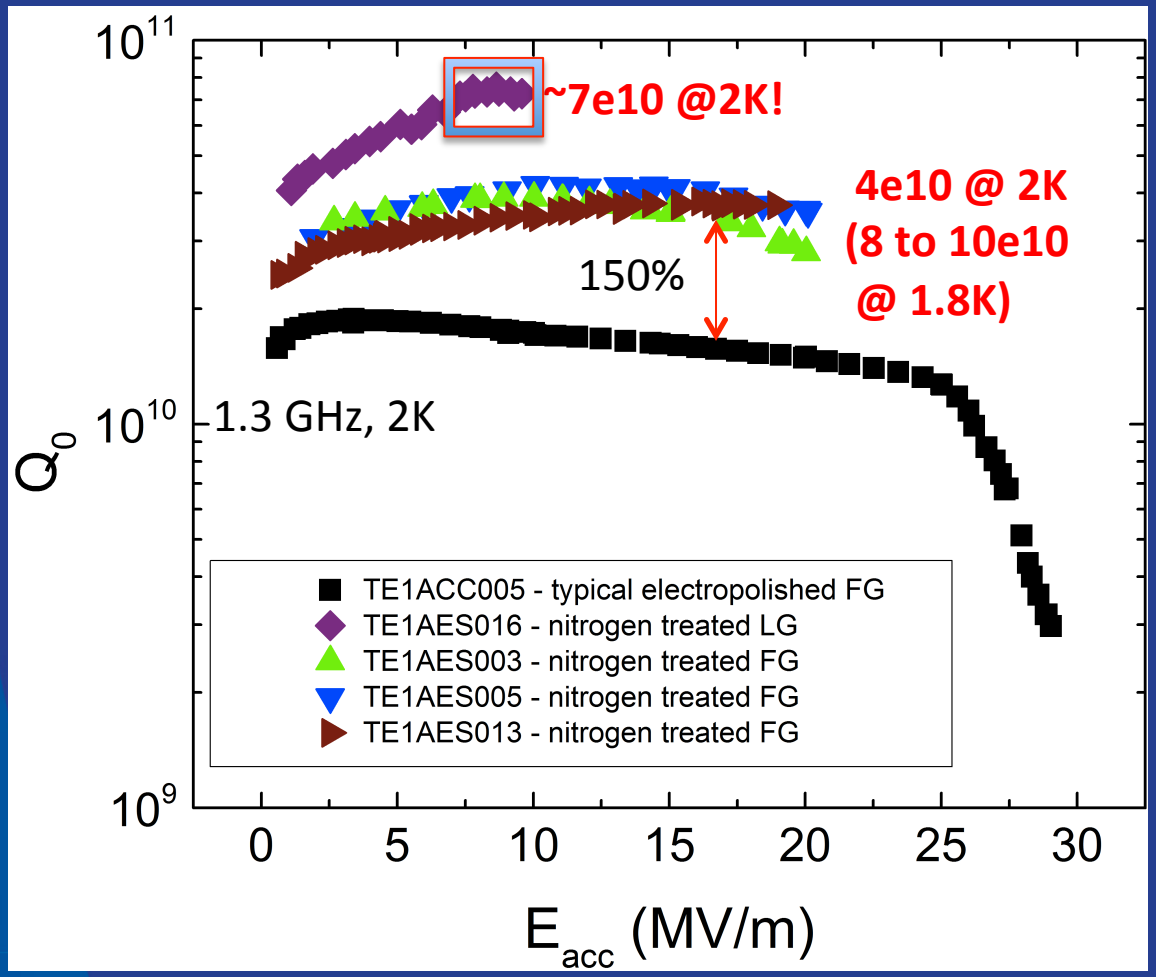
Standard 800C degassing cycle



Gas injection, ~10 min

- Several cavities treated with nitrogen at different T: 600C, 800C and 1000C for different duration
- Q all extremely poor after treatment ~ 10^7-10^9
- Then, we removed a certain amount of material via electropolishing

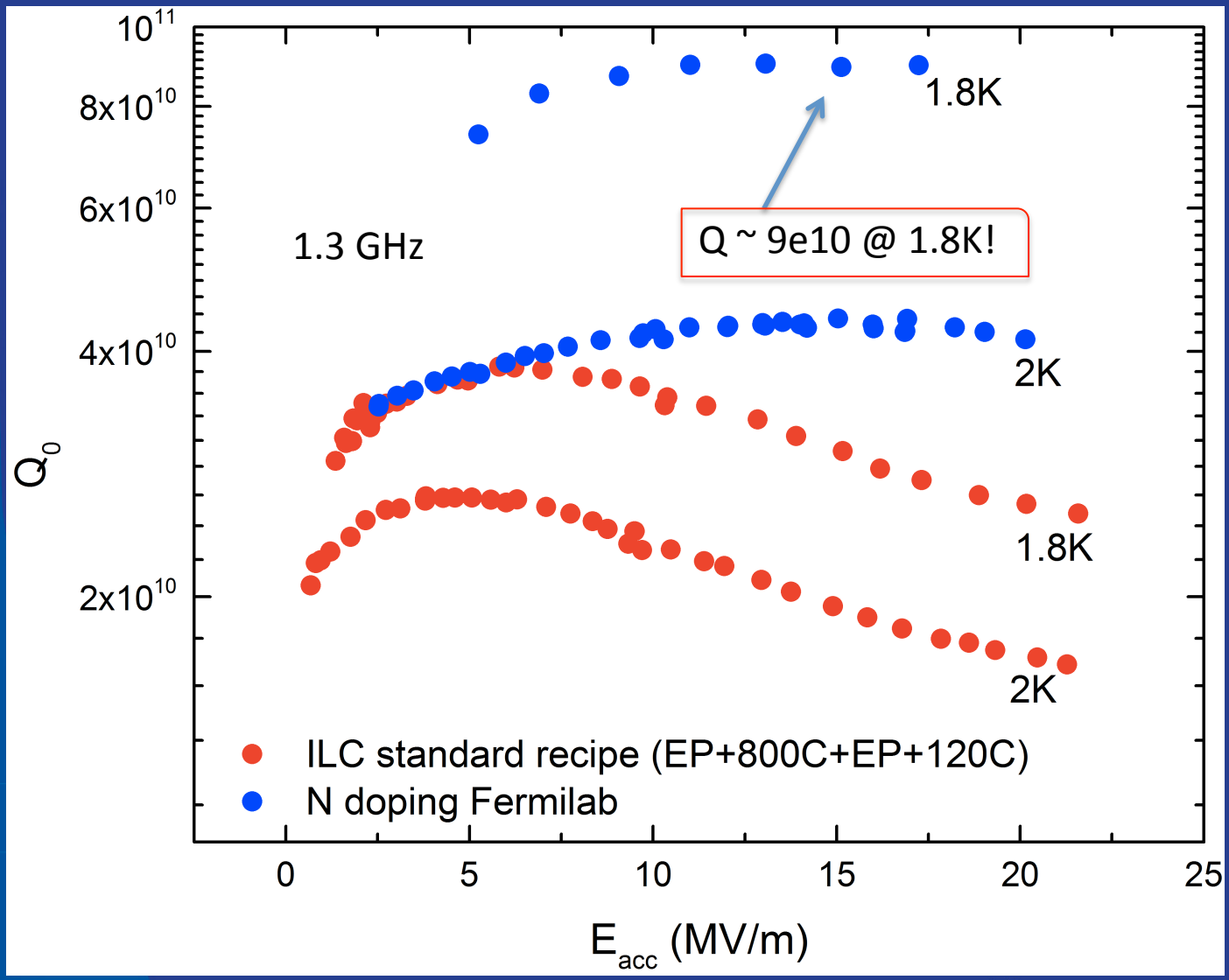
Comparing nitrogen treated cavities to standard EP



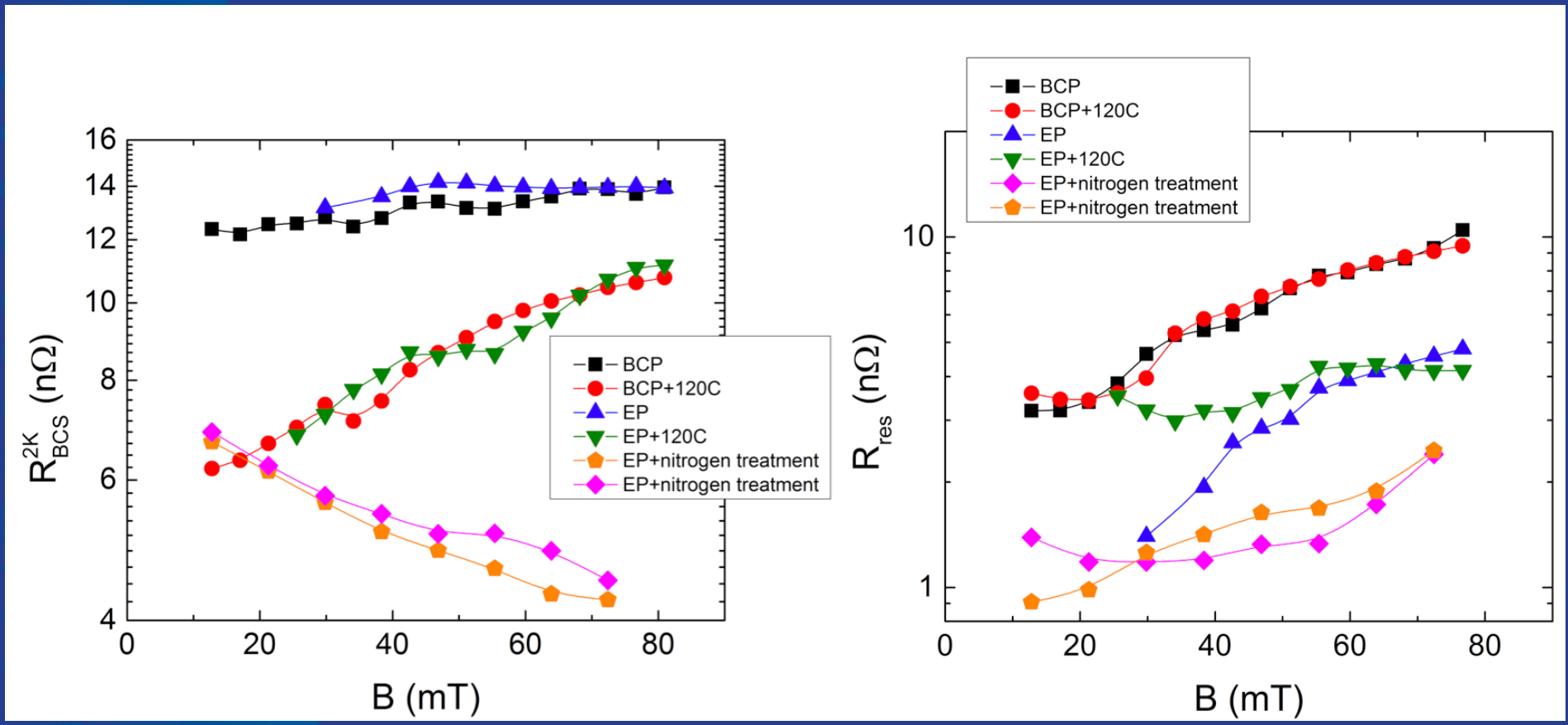
A.Grassellino et al, 2013 *Supercond. Sci. Technol.* 26 102001

Quench field systematically at 20.5 MV/m (~ 86 mT magnetic peak field) for all nitrogen treated cavities (except the LG which was limited to low quench even before treatment). This has been verified in a different geometry (650 MHz) where the quench appeared at 23MV/m, corresponding again to exactly 86 mT Bpk.

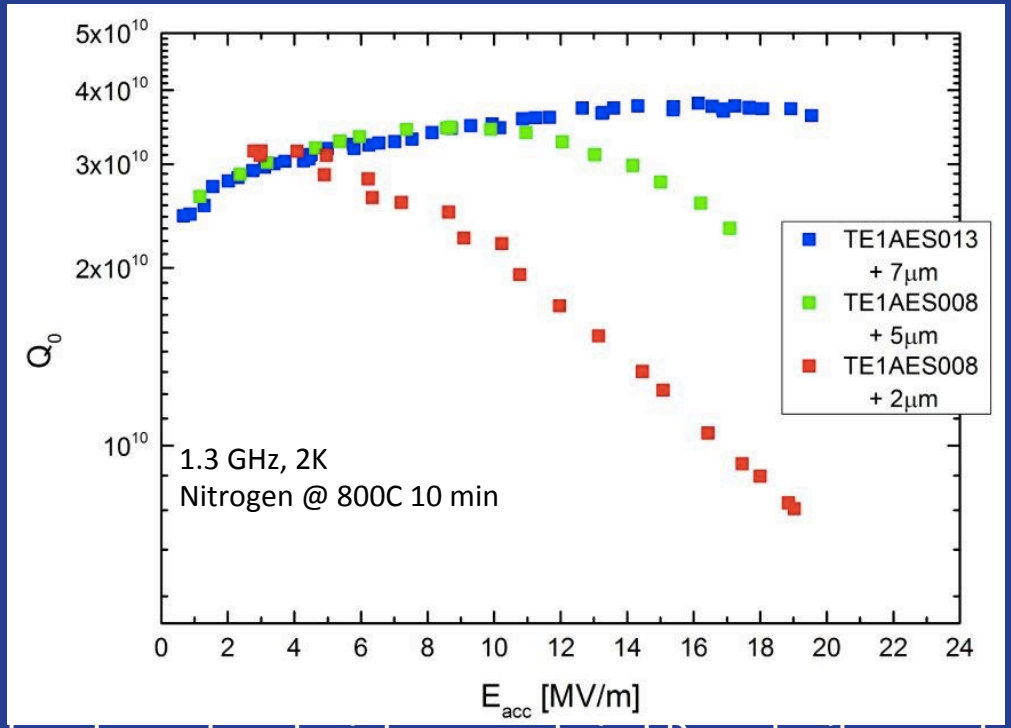
Comparing nitrogen treated to standard ILC processing at 2 and 1.8K



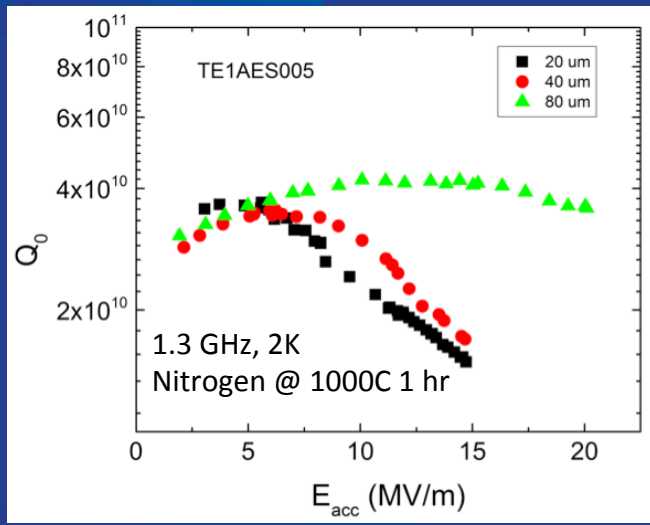
Where does the improvement originate? The reversal of $R_{BCS}(B)$

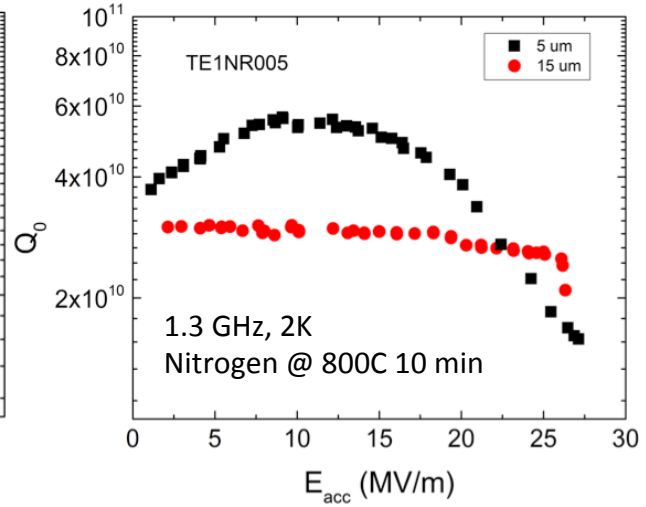


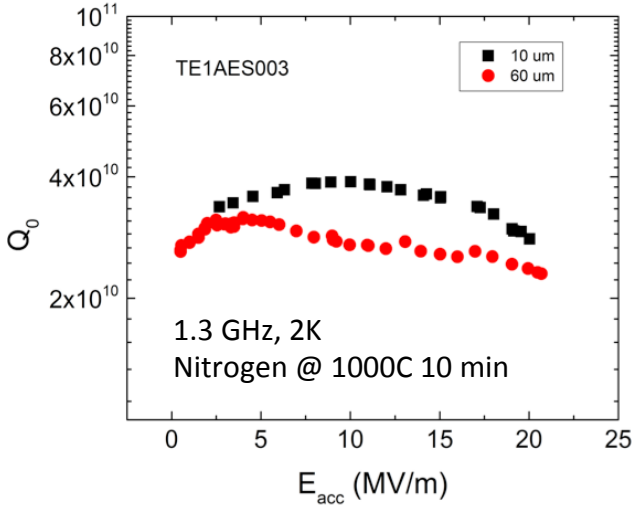
Antislope emerges after optimal amount of EP post gas treatment



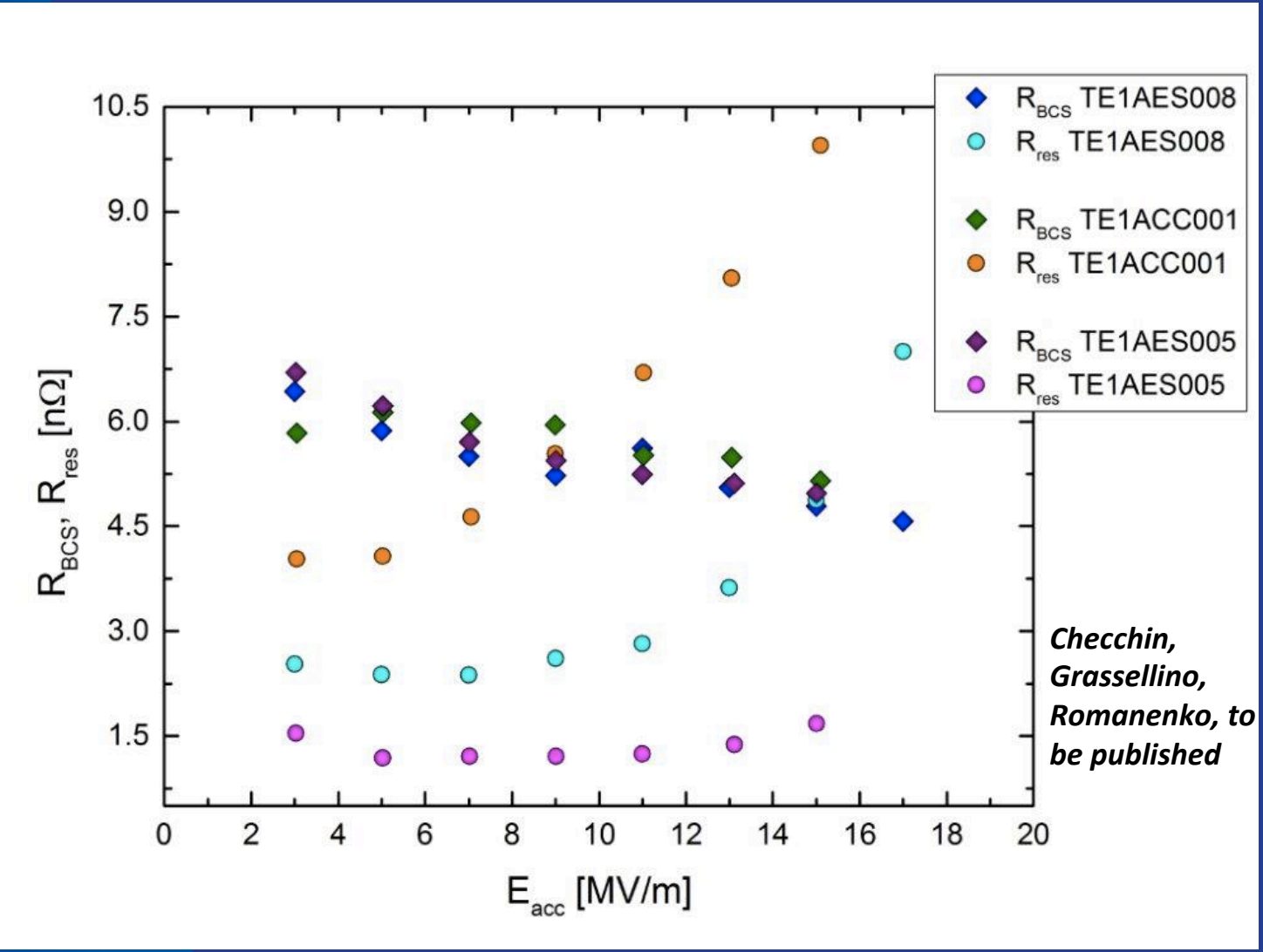
Q curves as a function of material removal via EP post-nitrogen treatment:







BCS is low for any doping above a threshold, residual lowers with concentration

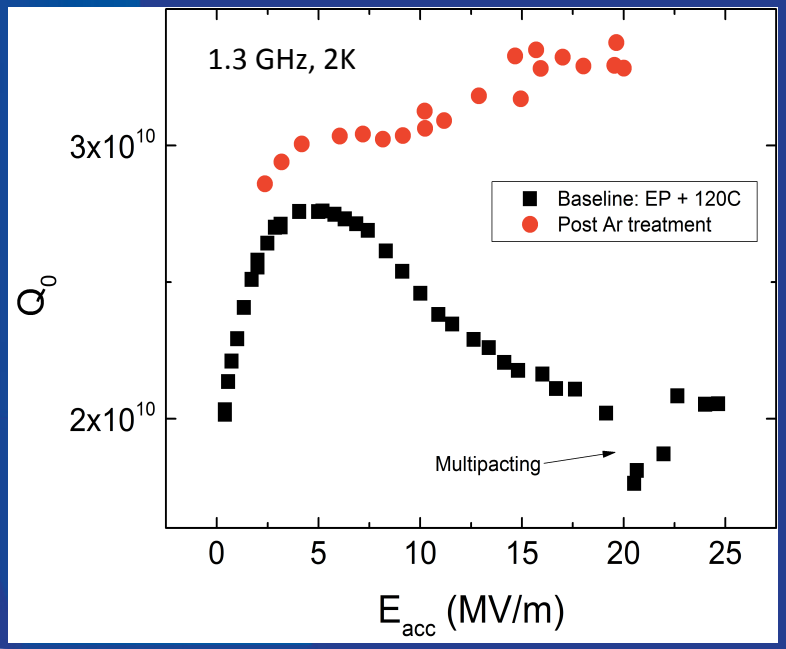


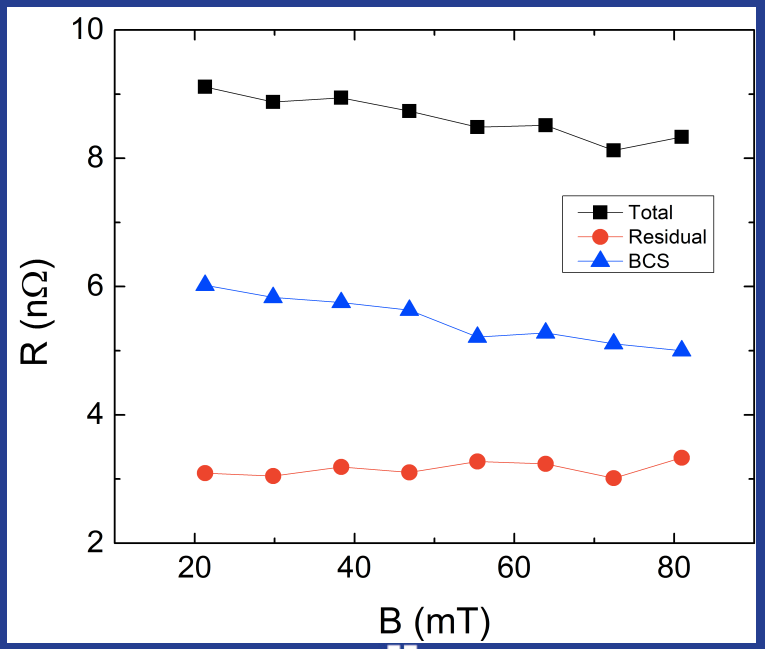
Checchin, Grassellino, Romanenko, to be published

Doping with interstitial impurities: a solution for MFQS?

The cavity baked with argon

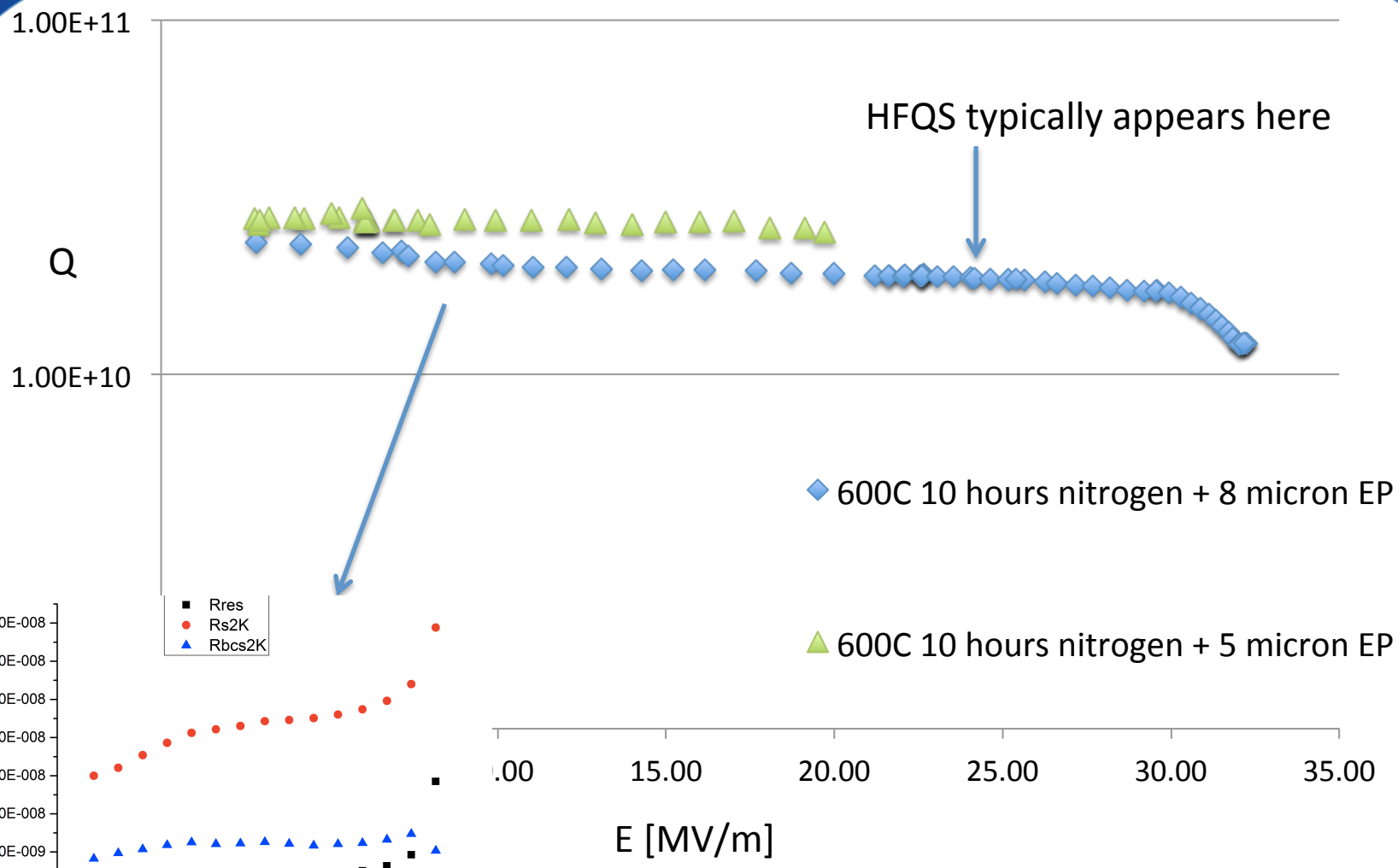
- Cavity baked at 800C for an hour in UHV, followed by an hour at 800C in partial pressure ~$2x10^{-2}$ T of Argon → *Q ~$1x10^{7}$*
- Then ~ 7 micron removal via EP → *again anti-Qslope!*
- Interesting note: anti-Q-slope result recently reported by Jlab also has argon injection at high T in the preparation steps
- Interstitial impurities doping may be the common root of the anti-slope results





A.Grassellino et al, 2013 *Supercond. Sci. Technol.* 26 102001

The cavity baked at 600C with nitrogen – no MFQS first, no HFQS then



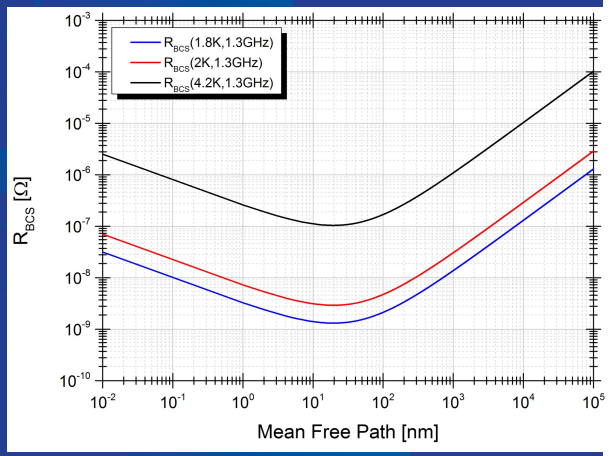
Promise for higher Q up to the highest fields

So far, our understanding of it –SIMS, XRD, XPS results – TUPO65

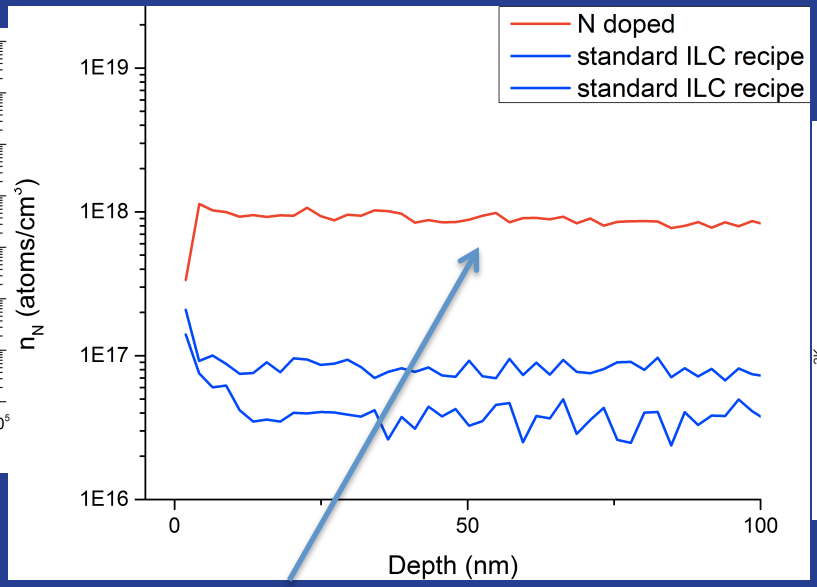
-BCS is lowered with lower mean free path:

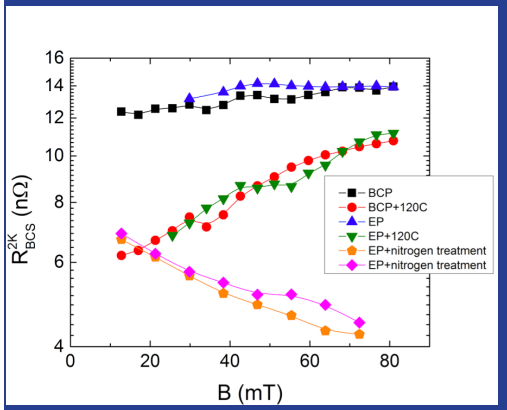
- EP, BCP → clean limit, high BCS, little to no field dependence
- In the 120C bake case mfp near surface ~ 2nm (see Romanenko's talk ad TUPO39) → lower BCS at low field, BUT dirty limit, field dependence of the gap causes slope
- Nitrogen/Argon treated: intermediate purity! Near surface ~ 40 nm → minimum of BCS at low field, but reverse field dependence unclear, maybe intrinsic? (see Xiao's talk)

-No HFQS – is doping the mechanism to eliminate HFQS? Vacancies, oxygen for 120C bake and nitrogen here? See Romanenko's talk



M. Checchin, calculated in two fluid model approx





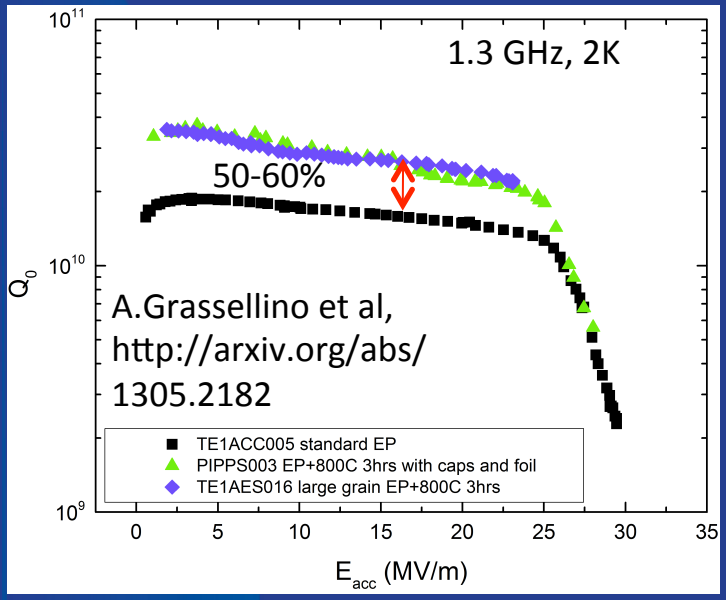
SIMS results showing 10 times higher than typical nitrogen concentration

U.S. DEPARTMENT OF ENERGY

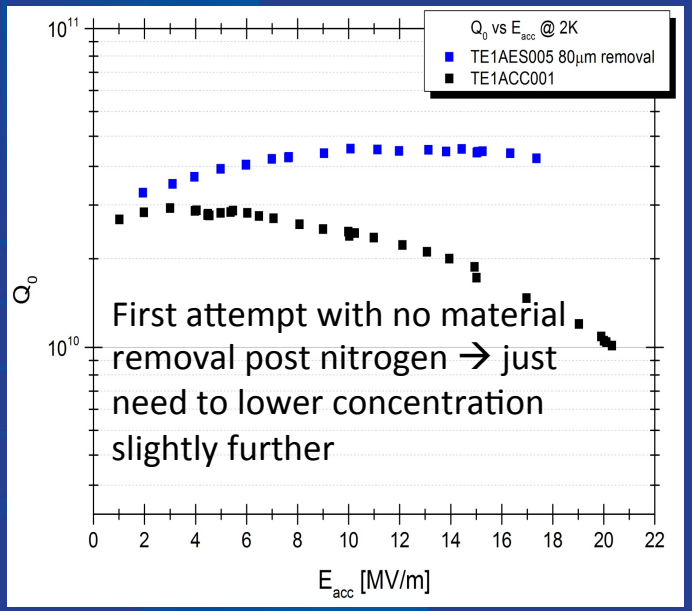
Fermilab

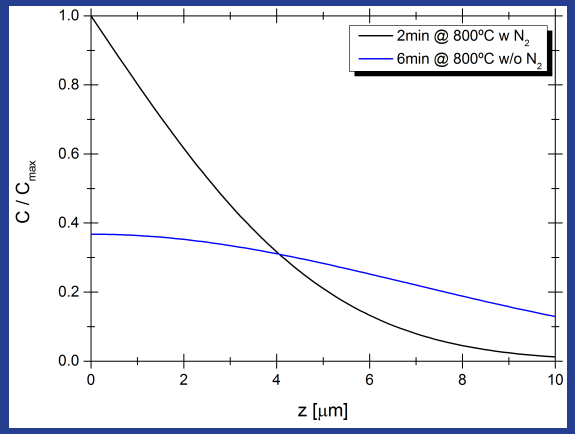
What next?

(Grassellino et al TUPO30, Gonnella, Liepe et al TUPO26)



- At FNAL, we have recently demonstrated that chemistry post annealing/degassing can be eliminated if precautions are taken during the bake (caps)
- Eliminating chemistry post annealing reduces residual resistance systematically to ~ 1 nΩ
- To increase Q further and minimize risk associated with the post treatment chemistry, we are working on eliminating the chemistry post nitrogen bake
- M.Checchin has already demonstrated it's possible! Joint effort with Cornell to adjust parameters and make the ideal concentration right at the surface
- Could become the ideal processing recipe for high Q machines





U.S. DEPARTMENT OF ENERGY

Conclusions

- Deconvolution in BCS and residual leads to deeper understanding of medium field Q- losses, due to several contributions
- A cure has been found for the medium field Q-slope! And perhaps an alternative one for HFQS, too
- Interstitial doping seems the key to improved performance
- With a little more work, we will be able to adopt it as the new standard treatment for highest Q at medium field and perhaps also at high field
- We can now dream of Q ~ 9e10 at 1.8K, 1.3 GHz !

The work presented comes from a team effort:

A.Grassellino, A.Romanenko, A.Rowe, O.Melnychuk, A.Crawford, M. Checchin, D.Sergatskov, T.Khabiboulline, A. Sukhanov, Y.Trenikhina, F.Barkov, M.Wong, D.Bice, B.Stone, C.Baker, Y. Pischalnikov

Thanks to the FNAL management for support of the high Q program: V.Yakovlev, C. Ginsburg, R. Stanek, R.D.Kephart