TRIUMF

SRF 2021

Results and Analysis from Multi-mode Coaxial Cavity Tests

SRF 2021

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Frequency and field resolved TEM mode cavity performance characterizations with different treatments

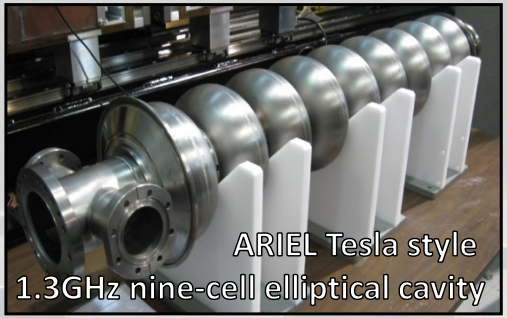
Outline

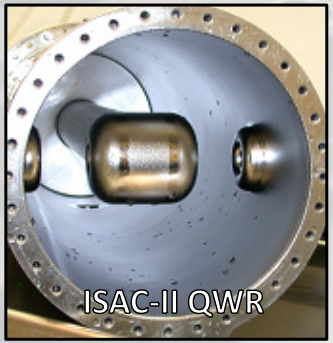
- *Motivation*
- *Cavities*
- *Performance measurement results*
  - *120C/48h low T bake vs baseline treatment*
  - *400C/3h mid-T furnace bake on QWR and HWR*
    - *Field and Frequency dependencies*
  - *Sample studies*
- *Summary & Outlook*

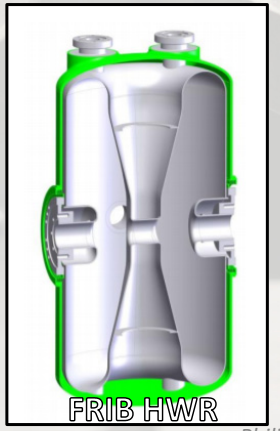
Motivation

- *Great improvements on Q_0 and E_{acc} in recent years*
  - *N2 doping & infusion, two-step baking, mid-T bakes, Nb3Sn…*
- *But research is focused on 1.3GHz, elliptical cavities for big projects like LCLS-II, SHINE, ILC… operating around 2.0K.*
- *Question: What about low frequency, TEM mode cavities like QWR & HWR, typically operating at low frequency, 4.2K, and are BCPed, not EPed?*
- *Question: Do different geometry leads to different sensitivities to magnetic fields? Does a different cooldown scheme help expel magnetic flux?*
- *Question: Do we find the origin and mitigation strategies of medium field Q slope in TEM cavities?*

TEM Cavity equivalent to single cell elliptical cavities







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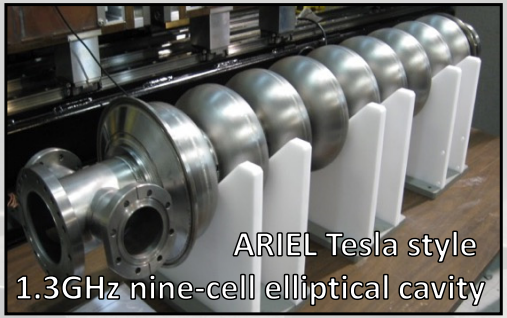
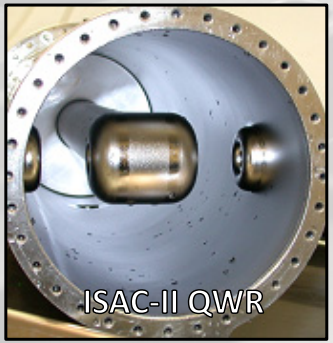
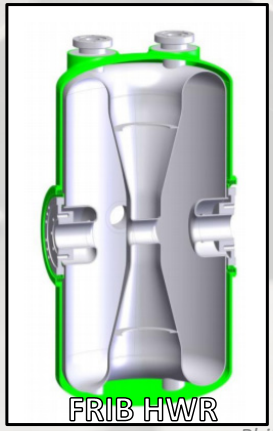
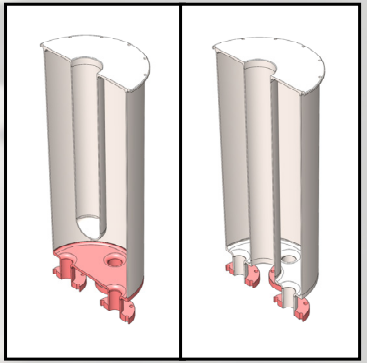




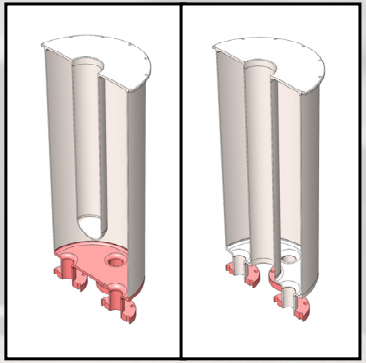


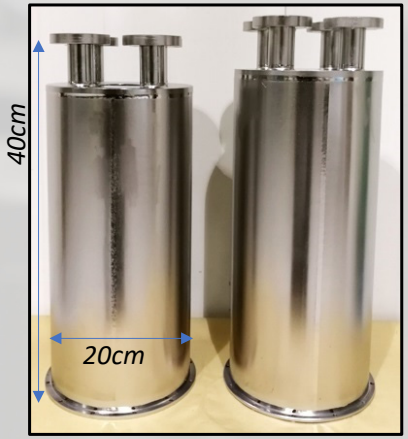


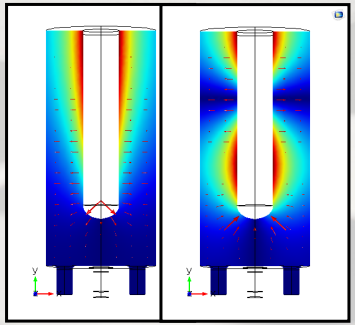
Coax Test Cavities

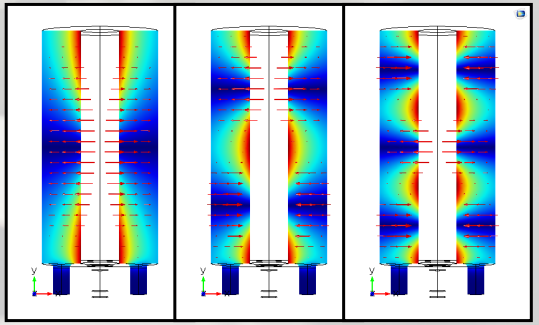
- *Designed and build two coax cavities, QWR and HWR, with a similar purpose & size as a 1.3GHz single cell cavity.*
- *No beam ports on cavity, simplifying geometry.*
- *RRR grade Nb for cavity walls, reactor grade for ports/bottom plate (QWR),*
- *No NbTi -> less sources of contamination.*
- *More details in: Phys. Rev. Accel. Beams 23, 122001*

- *Some notes:*
  - $R_s^* = \frac{G}{Q_0}$
  - $R_s\ (= R_{BCS}(T) + R_{Res})$ *is field distribution corrected (see Delayen et al.), better comparable to* $R_s = G/Q_0$ *from elliptical cavities.*
  - *All data shown is with external magnetic field compensated to* $|B_{ext}| < 0.5\mu T$*, unless otherwise stated.*







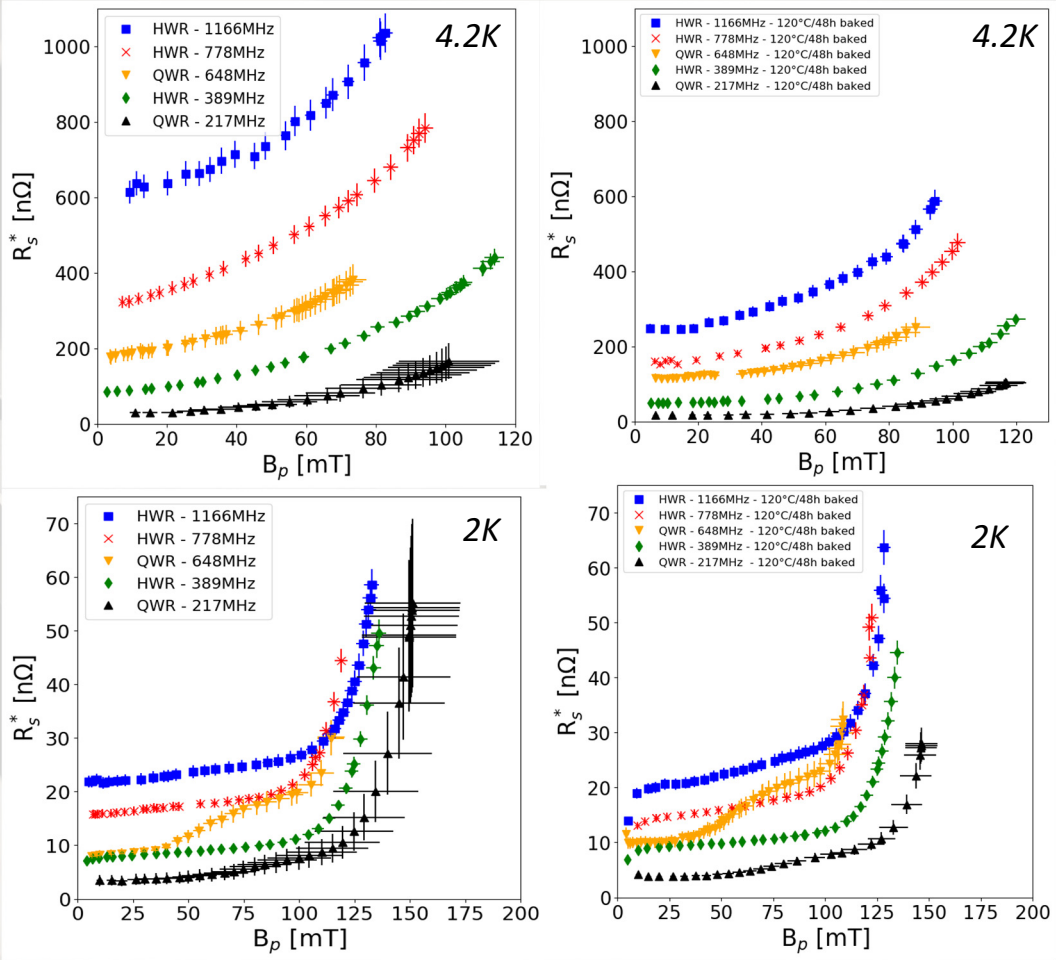


217MHz *648MHz* *389MHz* *778MHz* *1166MHz*

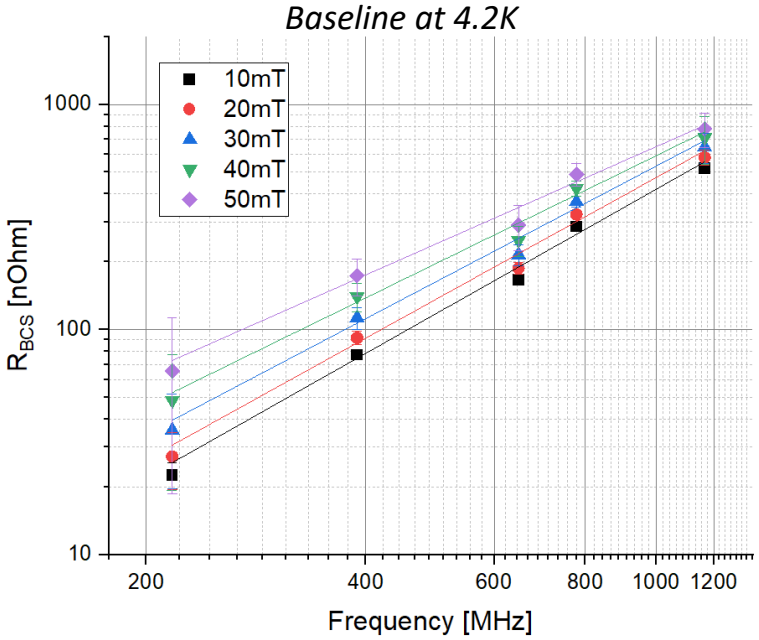
Past results:
- Baseline
- 120 °C bake

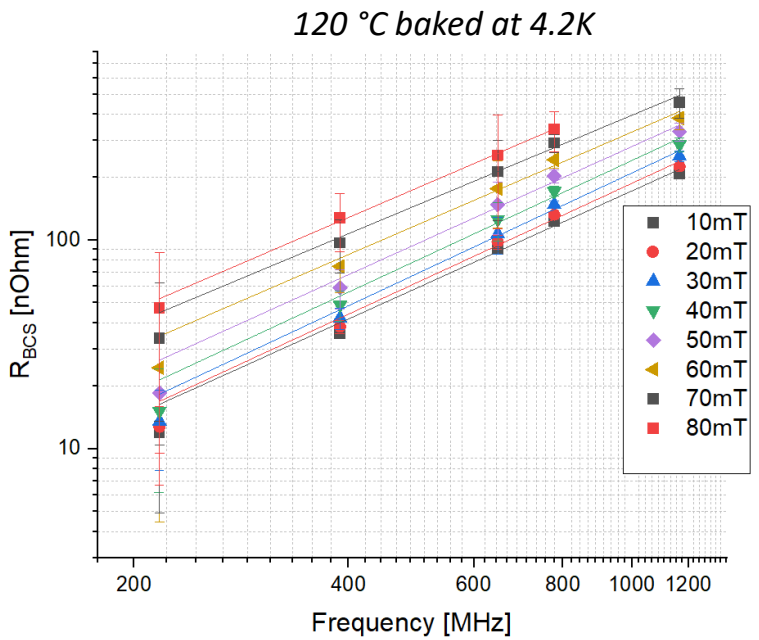
- *Baseline after 800 °C degassing and flash BCP (15µm)*
- *120 °C bake is known in the high frequency & low T world to cure HFQS and some moderate improvements in Q_0 in EP'ed cavities.*
- *Improvements in Q_0 are a result of a reduction in $R_{BCS} \rightarrow$ very effective at 4.2K.*
- *No change in high field behavior at 2K – no measurable field emissions detected.*
- *Small improvements in Quench field at 4K, but not at 2K*
- *As shown at [TTC 2021]*

Baseline *120 °C/48h baked*



Frequency dependence of R_{BCS}

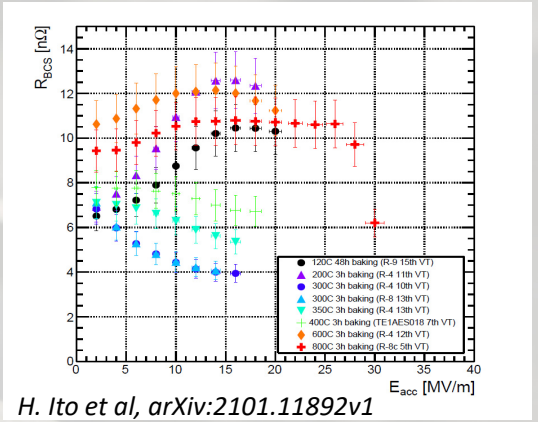




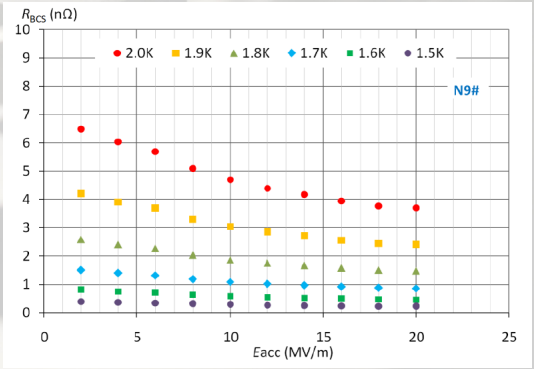
Slight changes in frequency dependence, but overall still following $R_{BCS} \propto \omega^{\sim 2}$

Mid T bake - 250 to 400°C

- *Mid T bakes between 250 and 400 °C on EP'ed elliptical 1.3GHz cavities have been shown to increase Q_0 with rising RF field.*
- *Rise in Q_0 is attributed to a decrease in R_{BCS} with low R_{Res}.*
- *Very promising heat treatment for heavy ion accelerators like the ISAC-II LINAC at TRIUMF, operating at 4K where R_{BCS} is typically dominant.*



H. Ito et al, arXiv:2101.11892v1



F. He et al, arXiv:2012.04817

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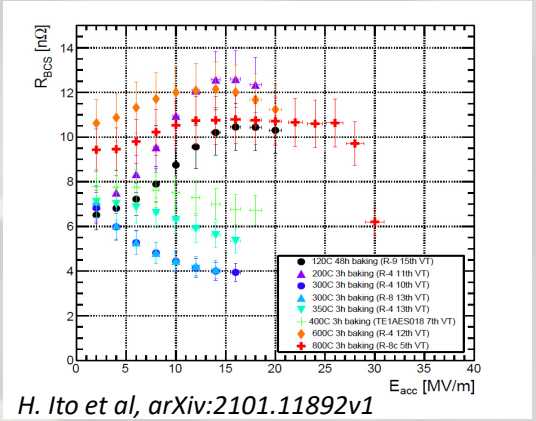
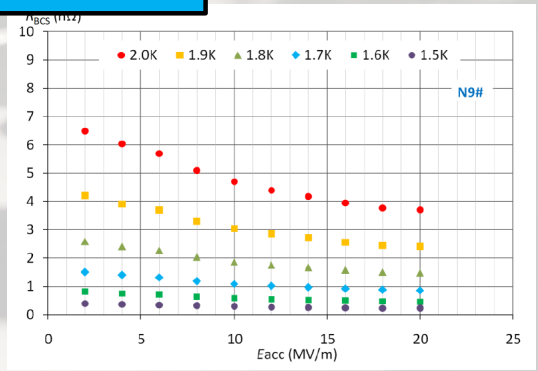


H. Ito et al, arXiv:2101.11892v1

Q: does this translate to BCP'ed cavities with low frequencies in a different geometry?



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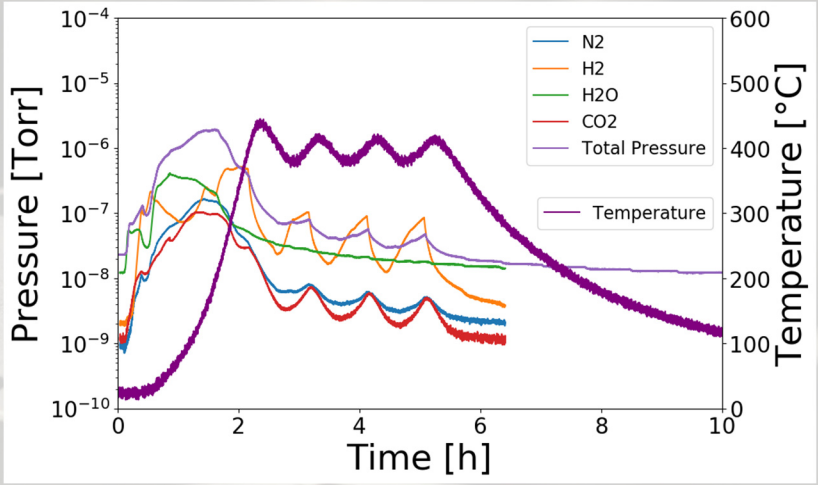
QWR: 400°C/3h treatment

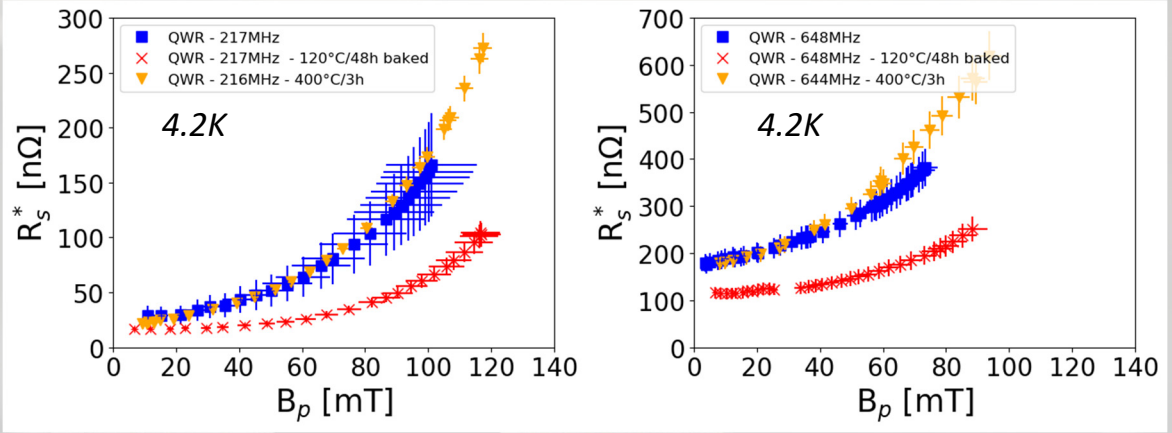


- *Heat treatment is done in TRIUMFs induction furnace. Dedicated for SRF cavities.*
- *400C/3h after a reset BCP was chosen as a first Mid-T bake.*
- *No chemistry after heat treatment (HPR before installation in furnace and afterwards for clean assembly).*
- *Witness samples for SEM/EDX/SIMS analysis accompanied the cavities.*

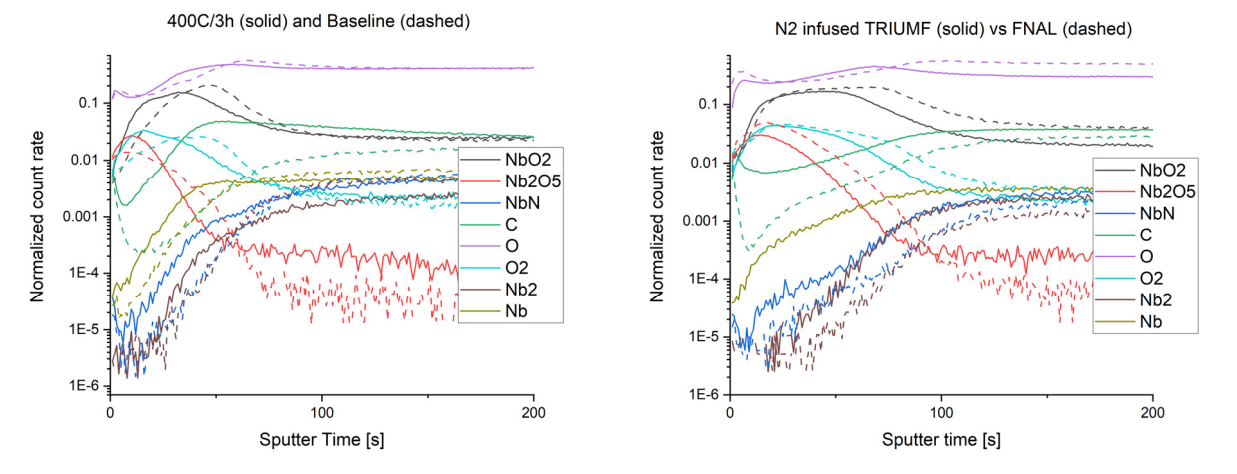
QWR results

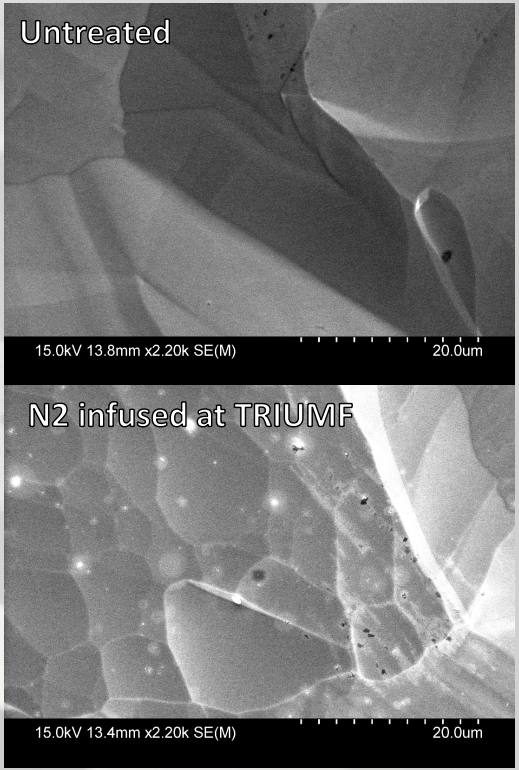
- *In general, a very similar performance compared to the baseline treatment.*
  - *At 4K identical performance.*
  - *At 2K some minor differences at low fields.*
  - *Similar R_{BCS} and R_{Res} as baseline.*
  - *Performing worse than 120 °C baked.*
- *Good result without chemistry after heat treatment (and air exposure) is encouraging.*

217MHz *648MHz*



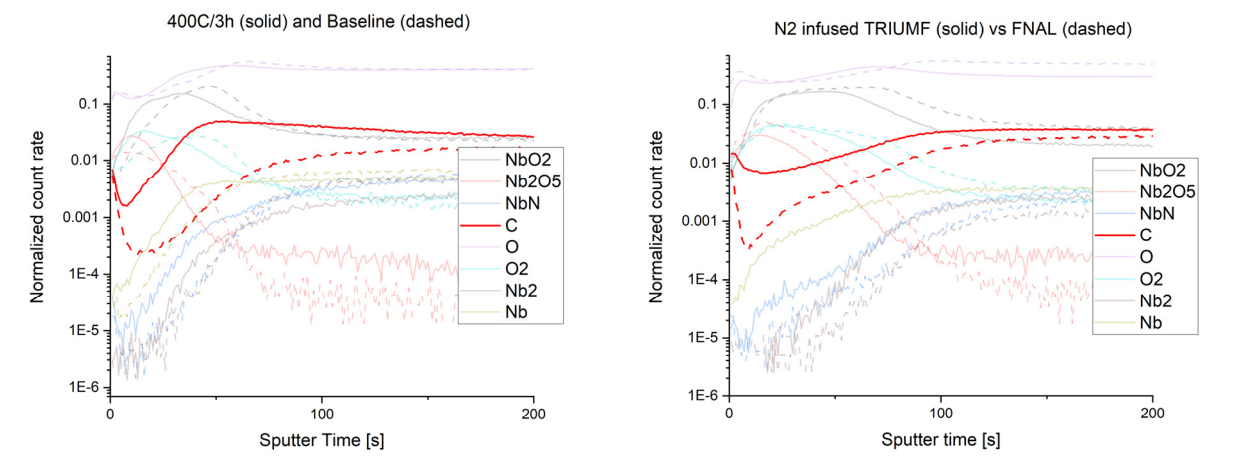
SEM, EDX and SIMS sample study

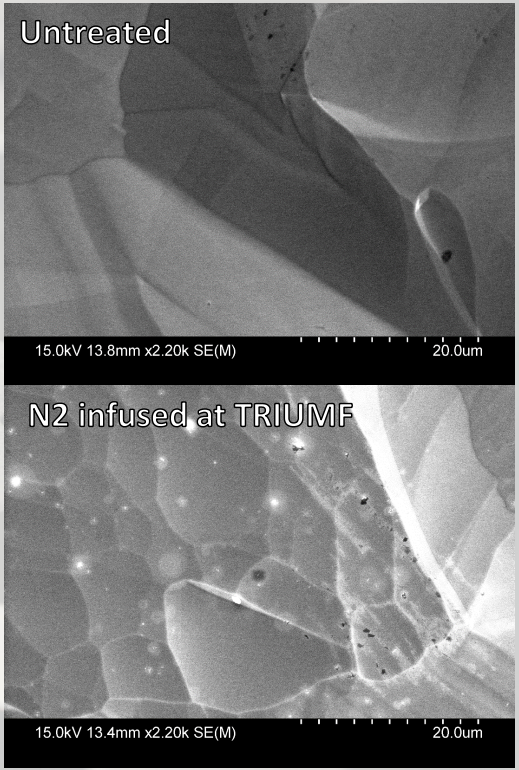




- *SIMS analysis done on witness samples / prepared samples, done at U Western Ontario, SEM & EDX at U of Victoria.*
- *Most SIMS traces are very similar, except Carbon. Potential source of poor performance?*
- *Significant peak of CO_2 was seen on RGA during furnace bake.*

SEM, EDX and SIMS sample study





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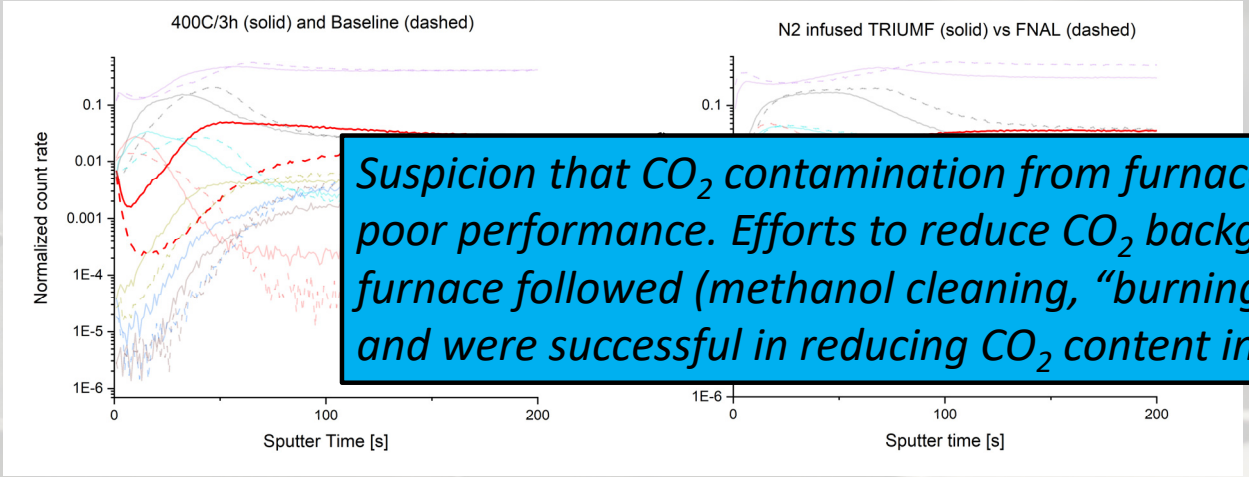
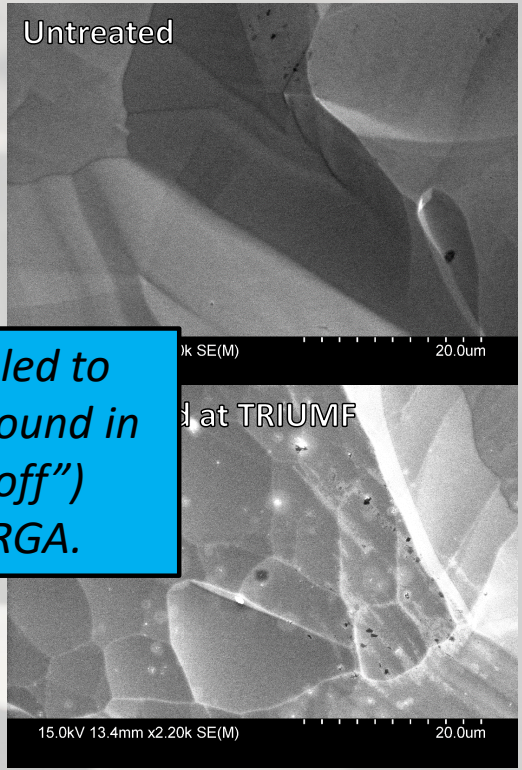


Suspicion that CO_2 contamination from furnace led to poor performance. Efforts to reduce CO_2 background in furnace followed (methanol cleaning, "burning off") and were successful in reducing CO_2 content in RGA.



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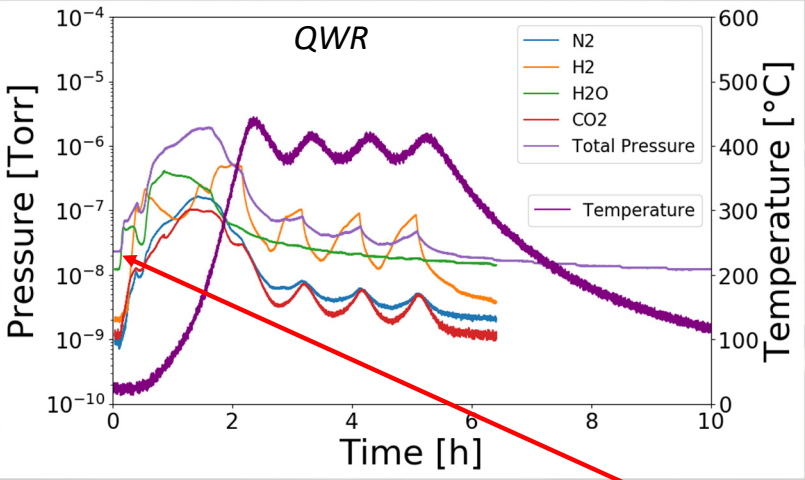
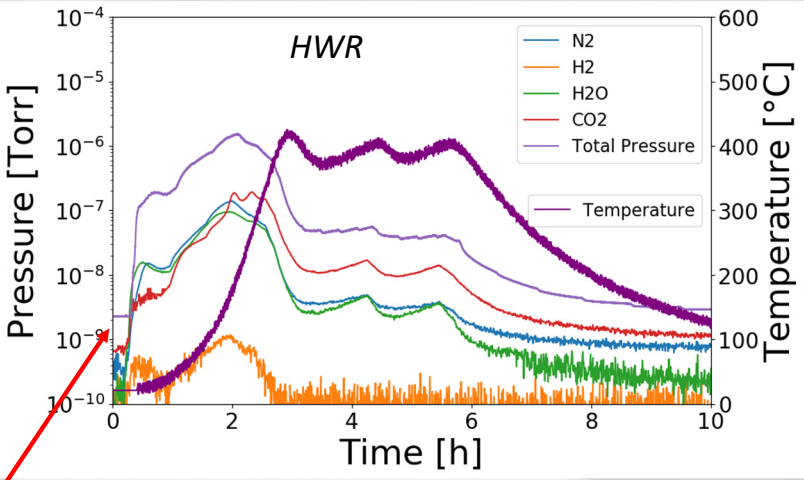
HWR: 400 °C /3h treatment

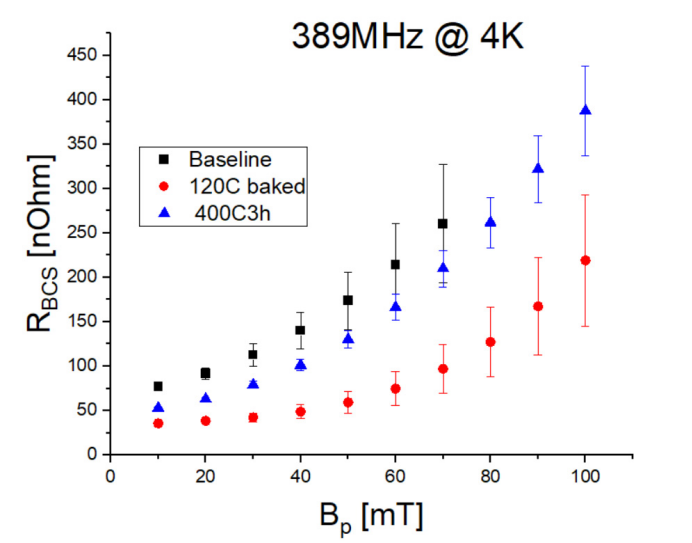


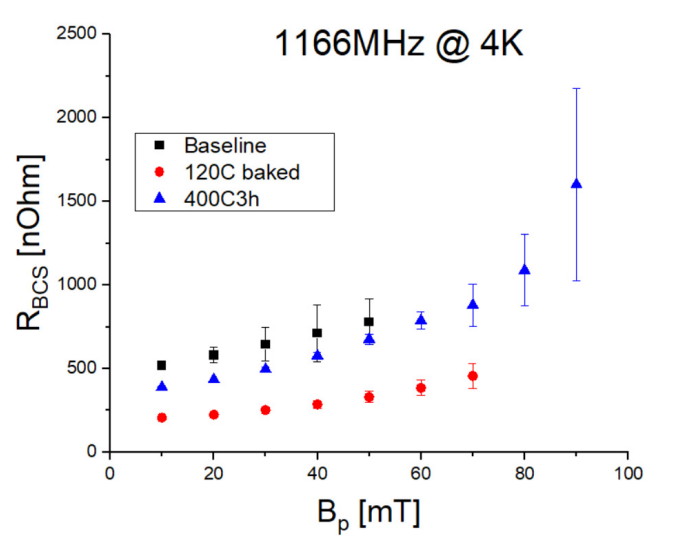


Starting pressure

- *After furnace cleaning procedures.*
- *Started with lower vacuum pressure than at the QWR heat treatment ($3 * 10^{-8}$ vs $2 * 10^{-9}$ Torr).*
- *But overall, very similar gas spectrum profile with similar heat profile.*

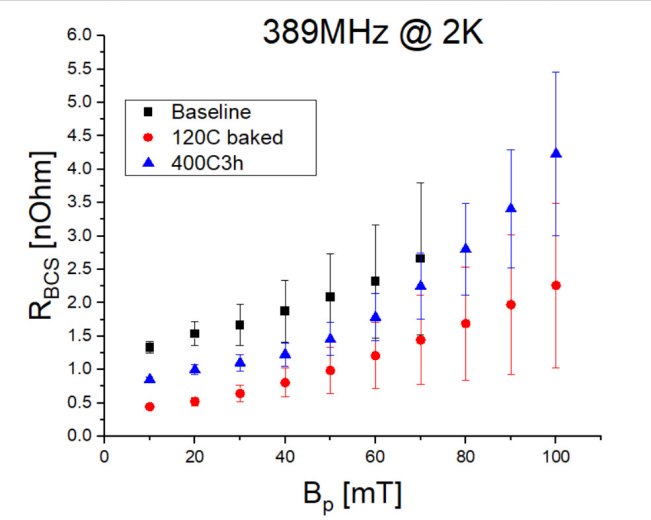
Change in R_{BCS} at 4K

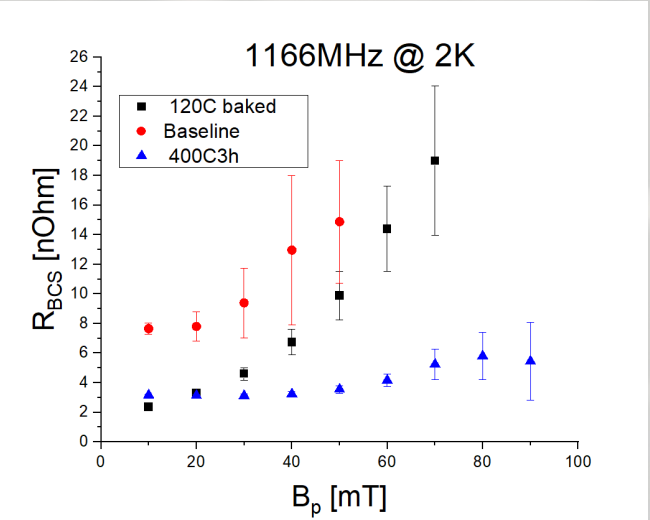




- *R_{BCS} is lowered compared to baseline.*
- *But not as much as a 120 °C /48h bake does.*
- *Still an increasing trend with field → No inversion of the field dependence*

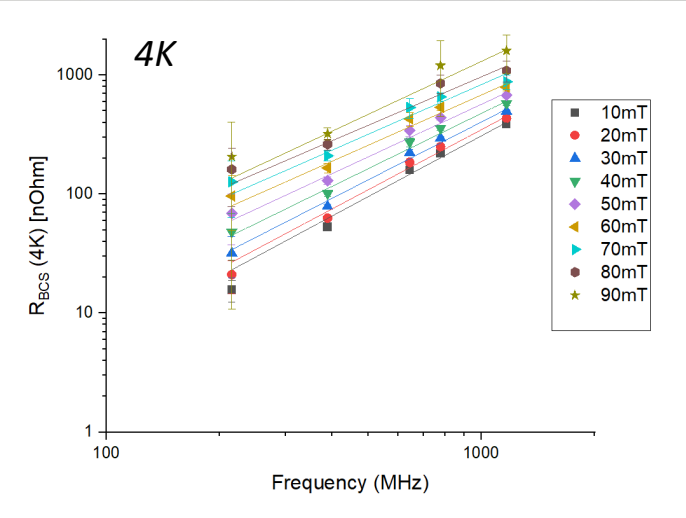
R_{BCS} at 2K

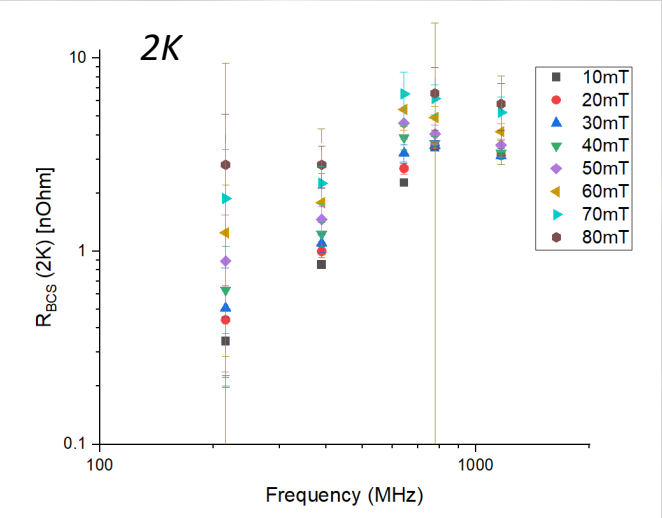




- *At high frequency: R_{BCS} with mid-T bake shows a stronger temperature dependence than 120 °C bake: lower value at 2K, higher at 4K*
- *Relatively flat field dependence at 2K*
  - *Sign towards decreasing R_{BCS} with field?*

Frequency dependence changes with T





$R_{BCS}(\omega)$ at 4K follows expected pattern.
At 2K, first 4 modes still follow a simple power law $R_s \propto \omega^{\sim 2}$, but the higher frequency mode does not fit into that pattern anymore

SEM and EDX on witness samples

- *In progress, samples send out.*
- *Will do SIMS after SEM and EDX on same sample.*

Cavity surface treatments so far explored

Treatment	QWR			HWR		
	ZFC	*FC V*	*FC H*	*ZFC*	*FC V*	*FC H*
Baseline: 800C+flash BCP	*Done*			*Done*		
Baseline + 120°C /48h LTB	*Done*			*Done*	*Done*	*Done*
N2 infusion	*Done*	*Done*				
Two step bake: 75C+120C						
400°C /3h, no chemistry after	*Done*	*Done*	*Done*	*Done*	*June 22*	*June 25*
EP						
N2 doping						
…						

ZFC = zero (external magnetic) field cooled
FC V = field cooled with ext. field in vertical direction (aligned with cavity axis)
FC H = field cooled with ext. field in horizontal direction (perpendicular to cavity axis)

Cavity surface treatments so far explored

Treatment	QWR			HWR		
	ZFC	*FC V*	*FC H*	*ZFC*	*FC V*	*FC H*
Baseline: 800C+flash BCP	*Done*			*Done*		
Baseline + 120°C /48h LTB	*Done*			*Done*	*Done*	*Done*
N2 infusion						
Two step bake: 75						
400°C /3h, no che					*June 22*	*June 25*
EP						
N2 doping						
…						

Still a lot to explore, Mid-T bake at 400 °C complete, further mid-T bakes with other temperatures and EP in planning.

ZFC = zero (external magnetic) field cooled
FC V = field cooled with ext. field in vertical direction (aligned with cavity axis)
FC H = field cooled with ext. field in horizontal direction (perpendicular to cavity axis)

Summary

- *Multimode cavities provide valuable data on frequency dependence of R_s.*
- *First data on Mid-T bake indicating improved performance on BCP'ed coaxial cavities.*
- *400 °C/3h treatment does improve BCS resistance on BCP'ed TEM mode cavities, especially at higher frequencies.*
- *Encouraging result and gives motivation to explore the parameter space of mid T bakes for further improvements.*

Outlook

- *More mid T bakes with different temperatures.*
- *Grants for EP and T-map equipment received. Detailed design in progress*
- *More surface treatment and mag. flux expulsion studies coming.*

Some references

- *Summary paper on cavities and methodology: P. Kolb et al: Phys. Rev. Accel. Beams 23, 122001 (Editor's Suggestion)*
- *Cavity design: Z. Yao, SRF2017 TUPB065, LINAC2018*
- *First QWR cold test results: P. Kolb, TTC 2019 Vancouver*
- *Further QWR test results: P. Kolb, SRF2019: TUP046*
- *Baseline results for QWR & HWR: P. Kolb, TTC@Cern 2020*
- *Results from 120C/48h low temperature bake: P. Kolb, TTC 2021*

Thanks!

Thanks go to the people who make things happen in the background:

Bhalwinder Waraich, James Keir, Devon Lang, David Kishi, Johnson Cheung, Ben Matheson…

And you for your attention!