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Flux expulsion studies of niobium material for 650 MHz cavities for PIP-II

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Abstract

Two different vendors supplied the niobium sheet material for PIP-II 5-cell 650 MHz cavities, which was characterized by multiple different ASTM sizes. Cavities subsequently fabricated from these sheets were heat-treated at various temperatures, then the cavities' flux-expulsion performance was measured. Where the initial measurements of Vendor O materials showed that nearly all flux remained trapped despite a high thermal gradient, 900C heat treatment subsequently improved the flux expulsion to an acceptable rate. Vendor A materials expelled well without the need for 900C heat treatment, highlighting that characterizing materials in this way is key for upcoming and future projects using these suppliers.

Modeling ideal flux expulsion

Flux expulsion performance is quantified as a ratio between the magnetic field measured at the cavity equator before the superconducting transition (B_{nc}) and after (B_{sc}): B_{sc}/B_{nc}. Ideal values for this ratio can be simulated in COMSOL for different cavity geometries, and compared against the measured values.

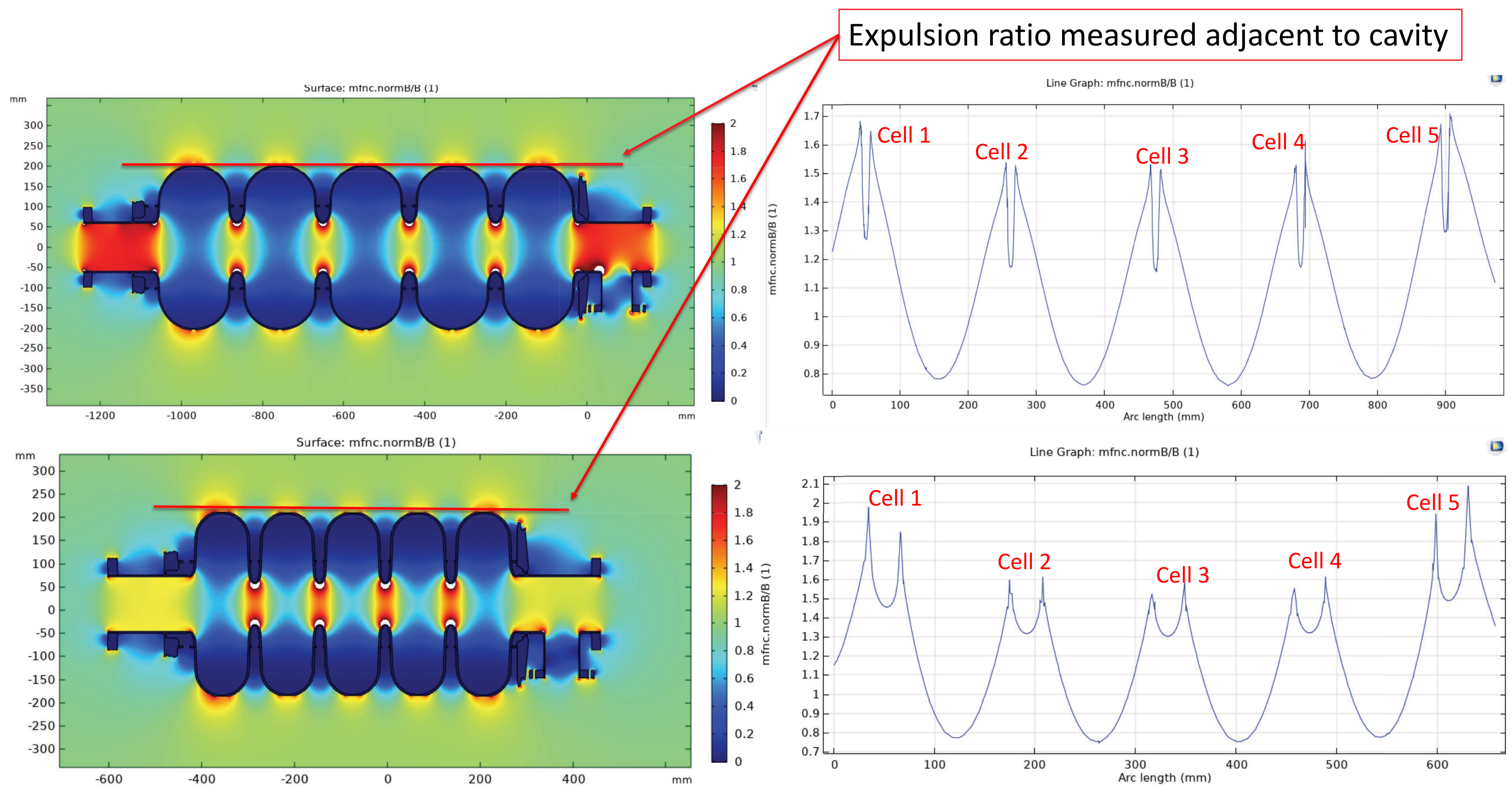
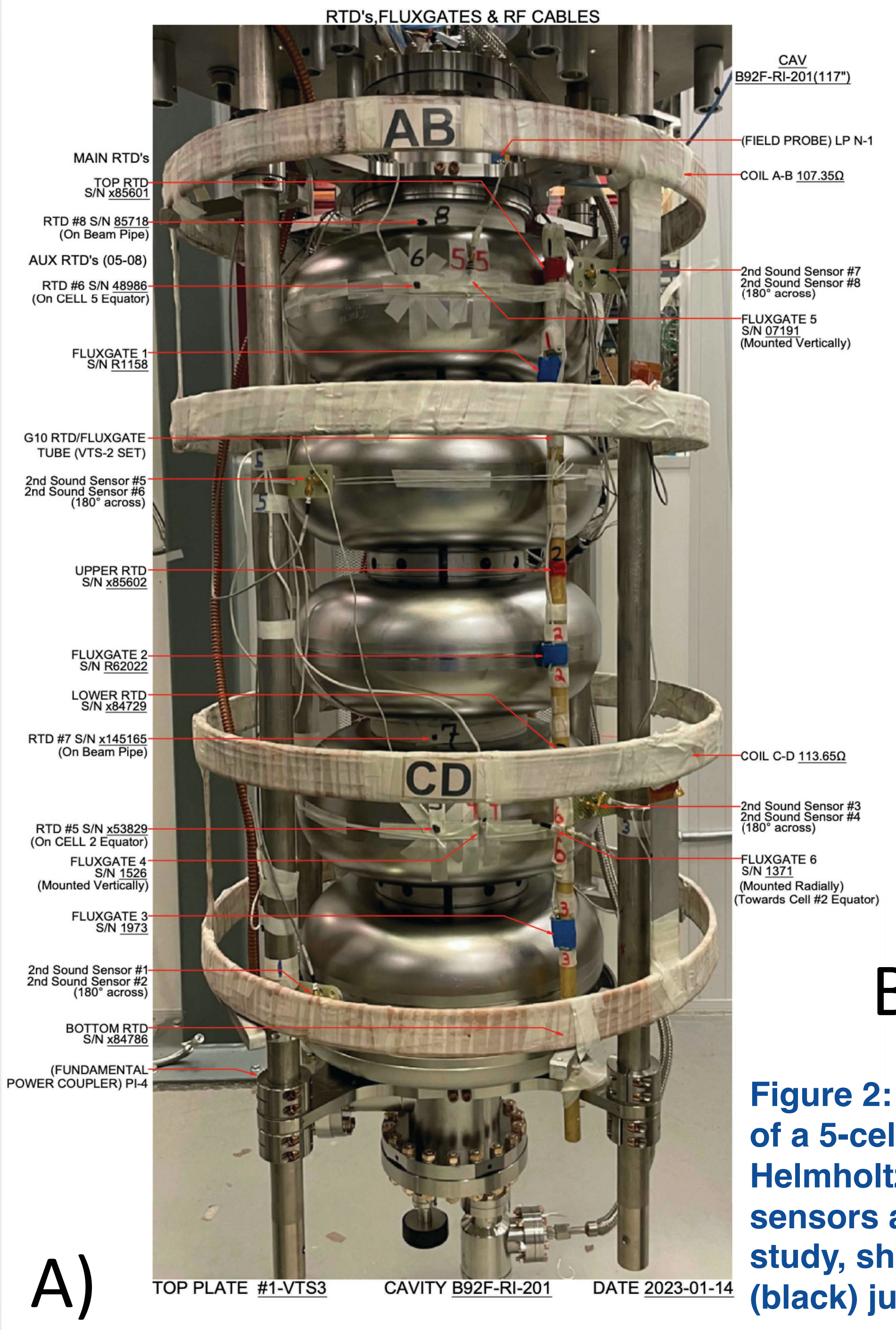

Expulsion ratio measured adjacent to cavity

Figure 1: COMSOL simulations of ideal B_{sc}/B_{nc}, for the high-β (top) and low-β (bottom) cavities, measured adjacent to the cavity. The values this ratio takes along the red lines are shown in the plots to the right.

Experimental setup

Flux expulsion studies were carried out by imposing external magnetic field with Helmholtz coils, then repeatedly warming and cooling the cavity through Tc, and measuring the flux expulsion ratio at the equator.



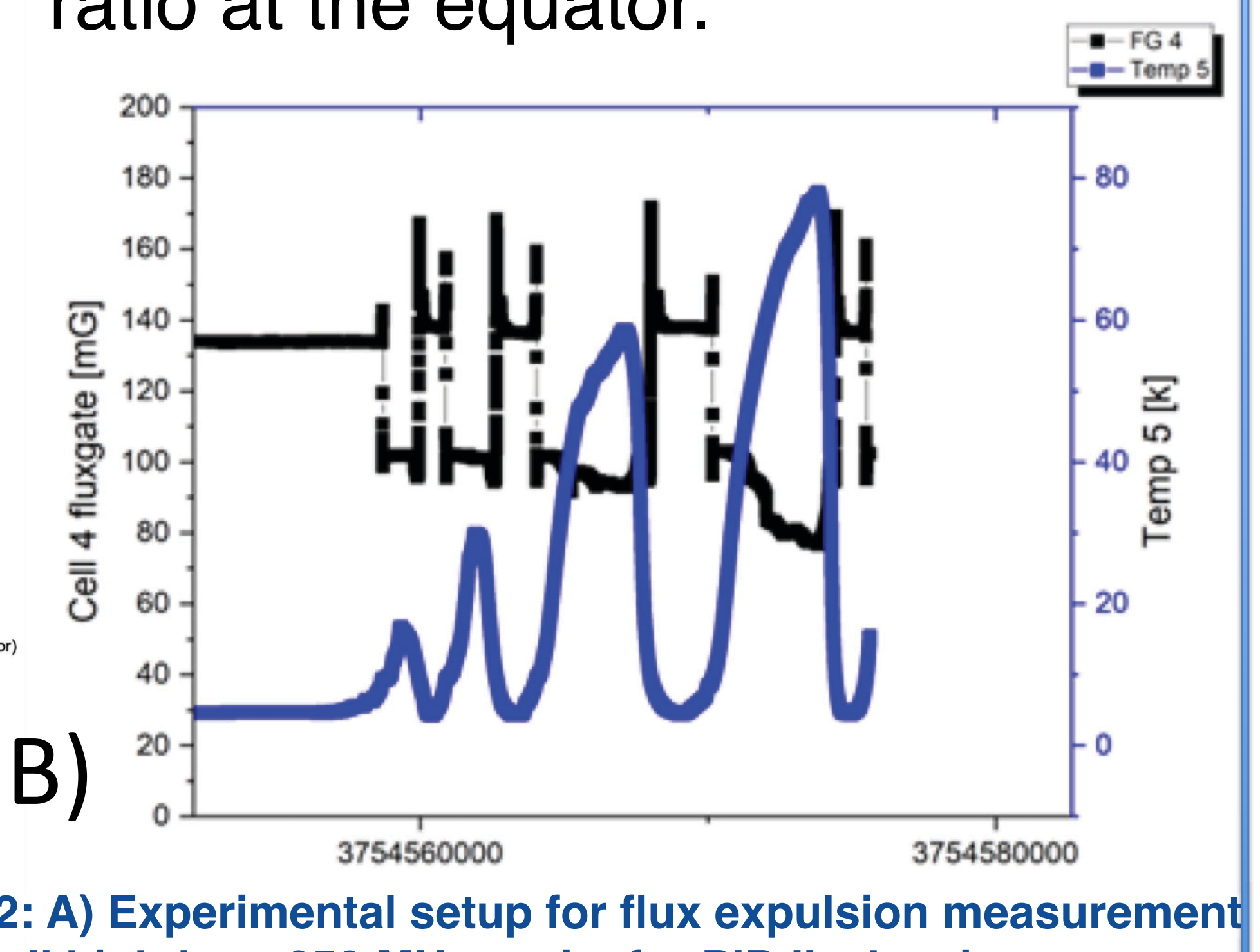


Figure 2: A) Experimental setup for flux expulsion measurement of a 5-cell high-beta 650 MHz cavity for PIP-II, showing Helmholz coils installed, and the array of fluxgate magnetic sensors and thermal (RTD) sensors. B) Example thermocycle study, showing temperature cycles (blue) and the magnetic field (black) jumping upward as the cavity cools through Tc.

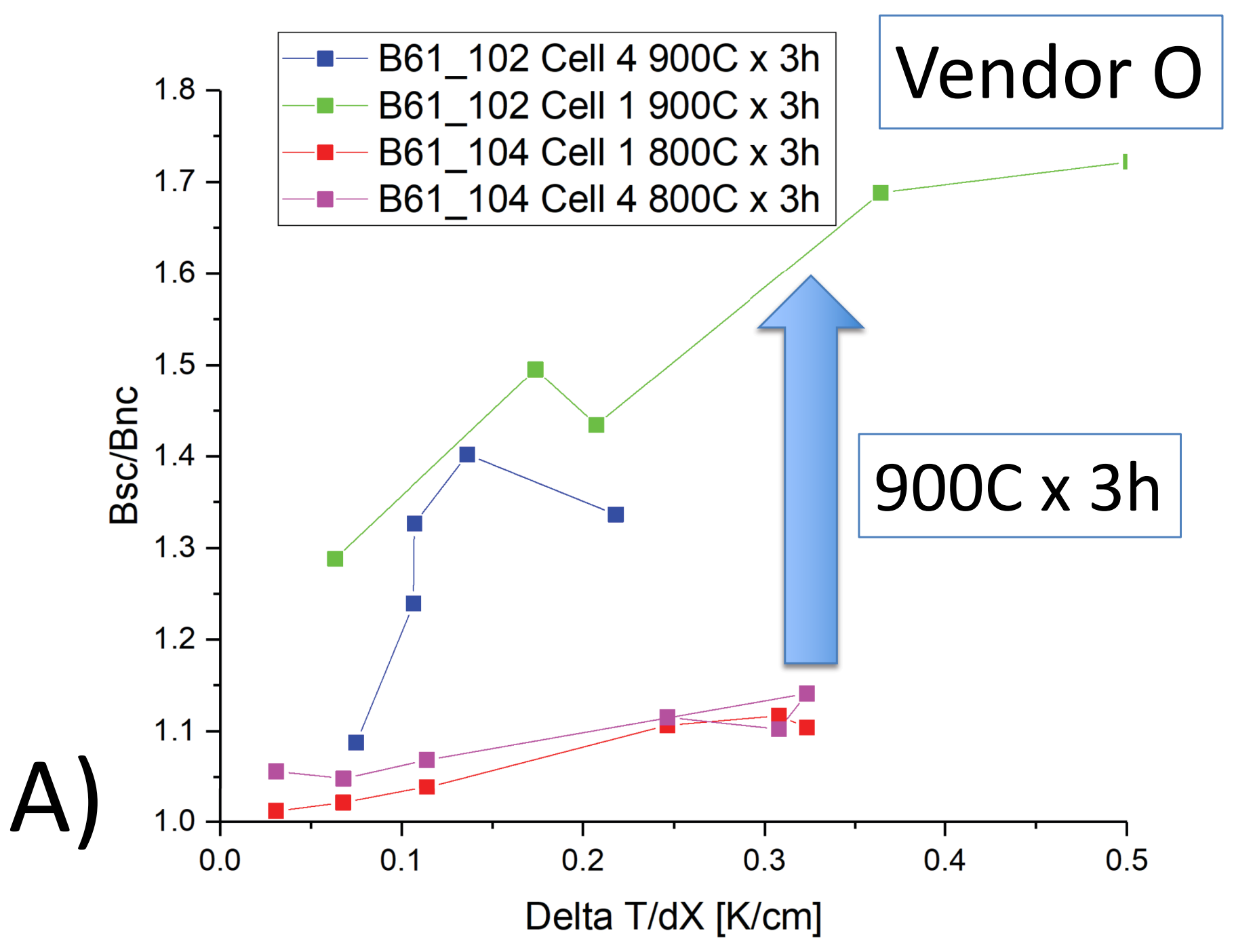
Niobium sources

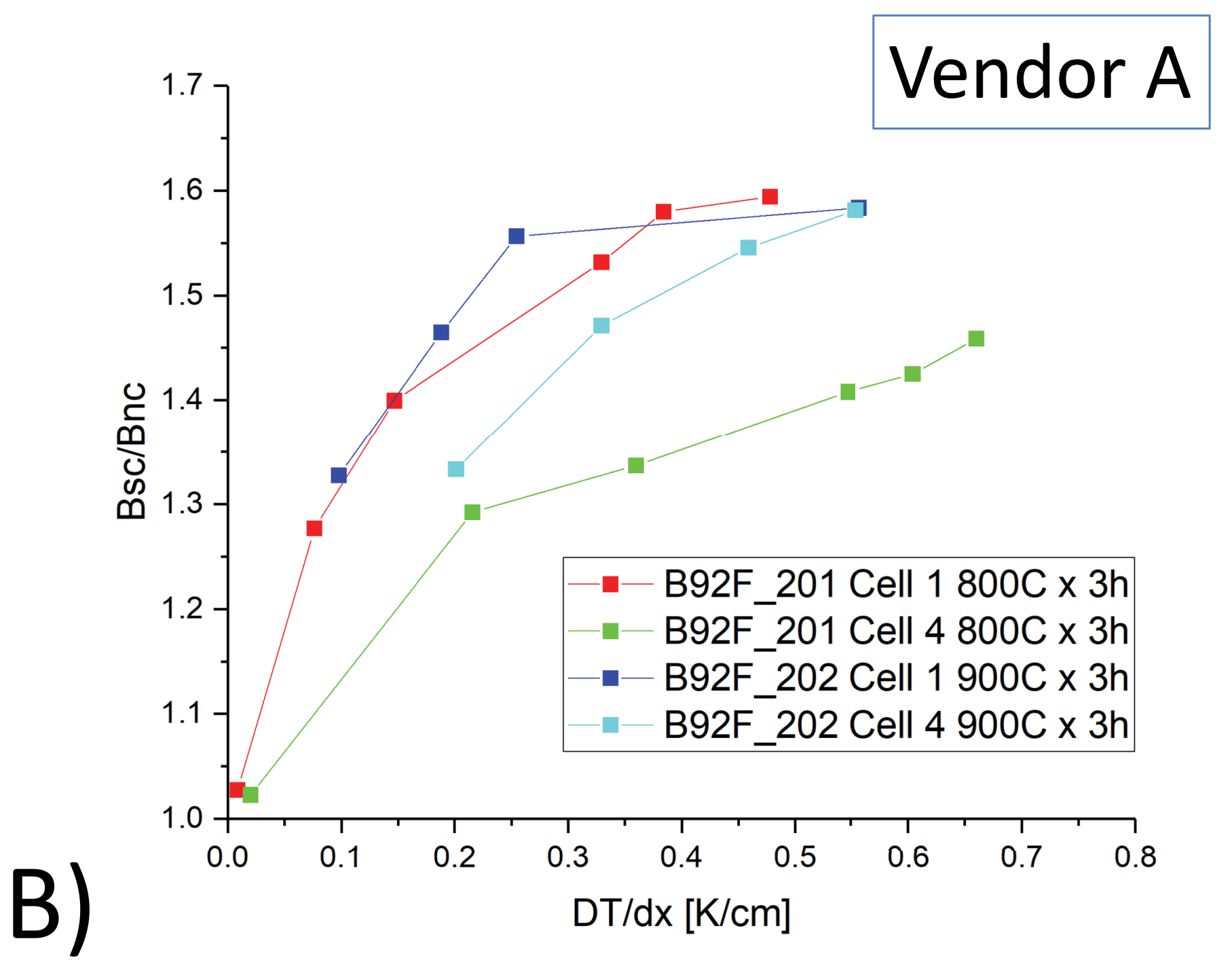
Niobium version	ASTM size	Hardness (HV10)	Elongation (%)	Specification	Note
Vendor O v1	~7	<=60	>=30	XFEL	Used in LCLS-II
Vendor O v2	~6	<=60	>=30	XFEL	Used in PIP-II LB650 prototype (EZ-001, EZ-002 and 1-cell)
Vendor O v3	~5	<=50	>=50	PIP-II	Used in PIP-II LB650 Pre-production
Vendor O v4	~4.5	<=50	>=50	PIP-II	Used in PIP-II LB650 Pre-production
Vendor A	~5	<=50	>=50	PIP-II	Used in PIP-II HB650 prototype

Vendor O and Vendor A both supplied niobium to PIP-II pre-production and prototype cavities, consisting of multiple ASTM sizes. Our subsequent goal was to determine how the flux expulsion properties of these cavities differed, and, how these properties were variously affected by annealing treatments.

Flux expulsion differs by vendor

The 5-cell "low" β = 0.61 made from Vendor O material initially expelled poorly, before 900C annealing significantly improved their performance, as shown in A). In contrast, the 5-cell "high" β = 0.92 cavities, fabricated from Vendor A material, had good expulsion performance initially, and 900C annealing did not significantly improve that performance, as shown in B). 900C annealing mechanically weakens the cavities, so it is desirable to minimize its use, especially in low-β cavity structures. An option going forward in production may be to use material that does not need annealing for the low-β cavities if possible.





Conclusions

Niobium material from Vendor A expelled flux well as-is, requiring no 900C annealing. Niobium material from Vendor O did not expel flux well initially, and only improved after 900C annealing. It is critical to understand the flux expulsion properties of niobium intended for use in cavities intended for high-Q applications using techniques such as N-doping or furnace baking, which tend to increase their sensitivity to trapped flux.

References

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