Cornell SRF (Collider) R&D

Current Activities and Future Opportunities

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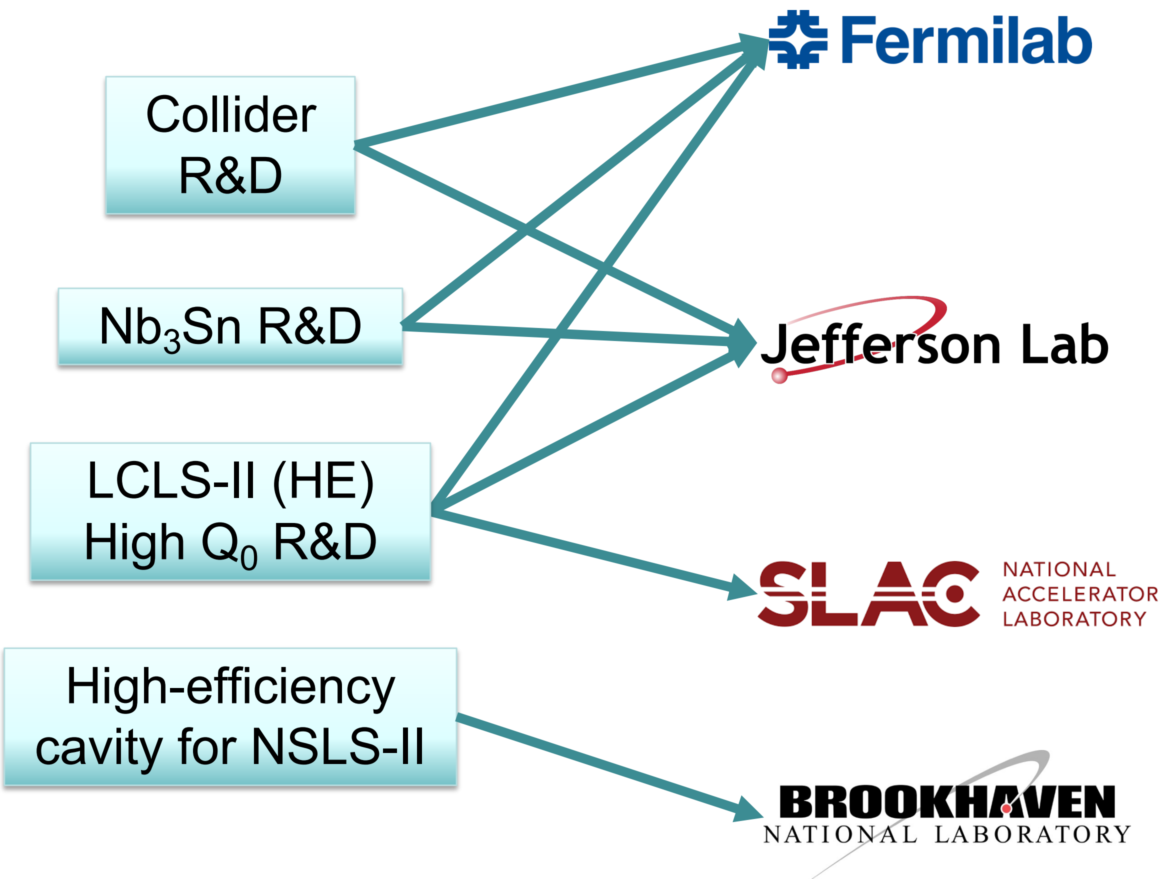
Cornell Superconducting RF Group

Cornell Superconducting RF Program

Convergence fundamental research	Energy and intensity frontier	Energy and environment	Societal impact	Workforce devolvement	Quantum materials and computing
Transformative understanding of super-conductivity and material growth	Cavities as science drivers	Enabling sustainable science via energy efficiency	Accelerators for medicine, environment, industry, national security…	Scientists prepared to join the workforce in areas of critical need	

National Lab Connections



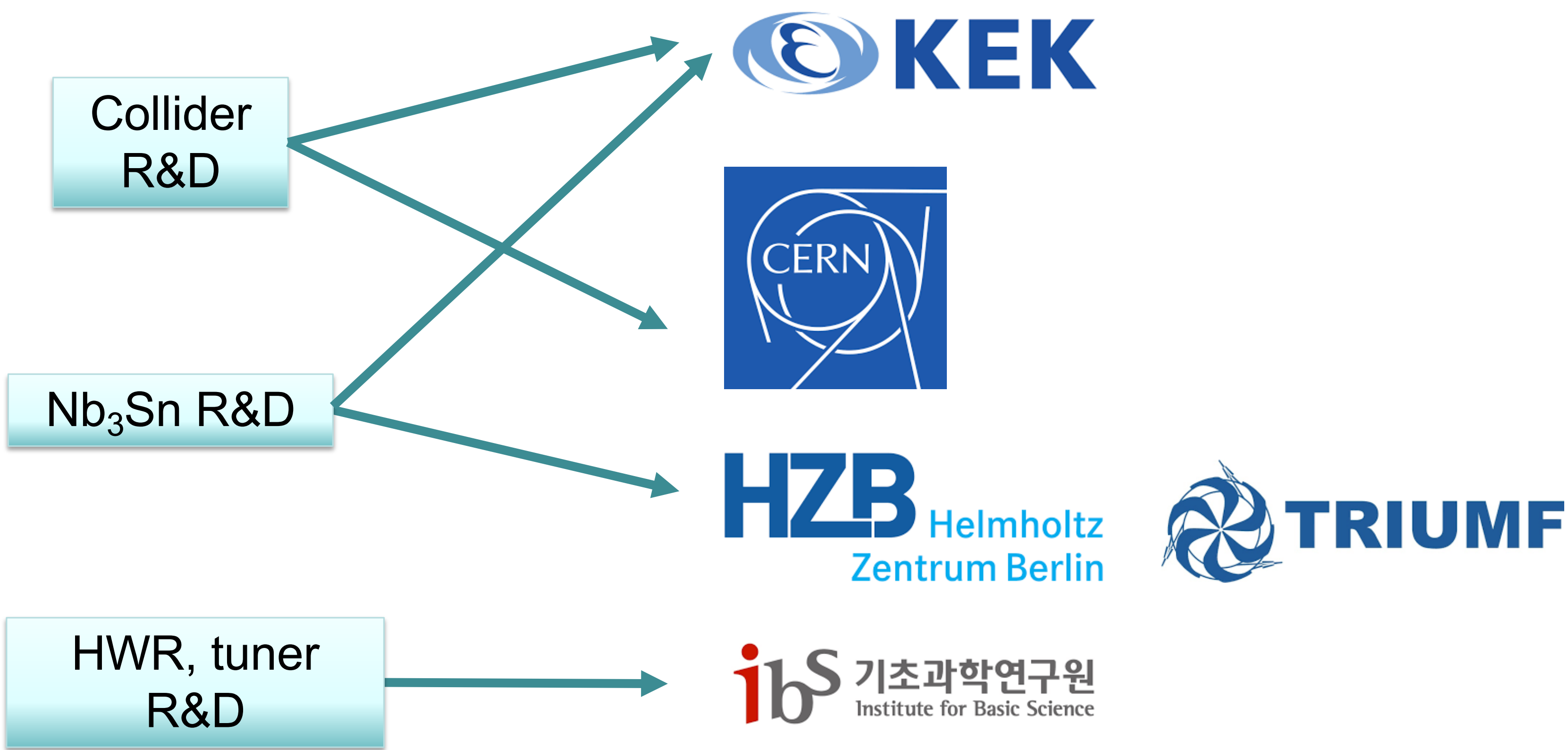
- ILC cost reduction (high Q – high field)
- N-doping development
- US – Japan accelerator R&D
- Inspired Nb3Sn program at FNAL (former Cornell student Sam Posen)
- Future: collaboration on TW structures, collider SRF R&D, quantum materials…

- US – Japan accelerator R&D
- N-doping development
- Inspired Nb3Sn program at JLab (former Cornell student Grigory Eremeev)

- First N-doped cavity in a cryomodule (Dan Gonnella, now SRF group leader at SLAC)
- Discovered importance of minimizing trapped magnetic flux in N-doped cavities

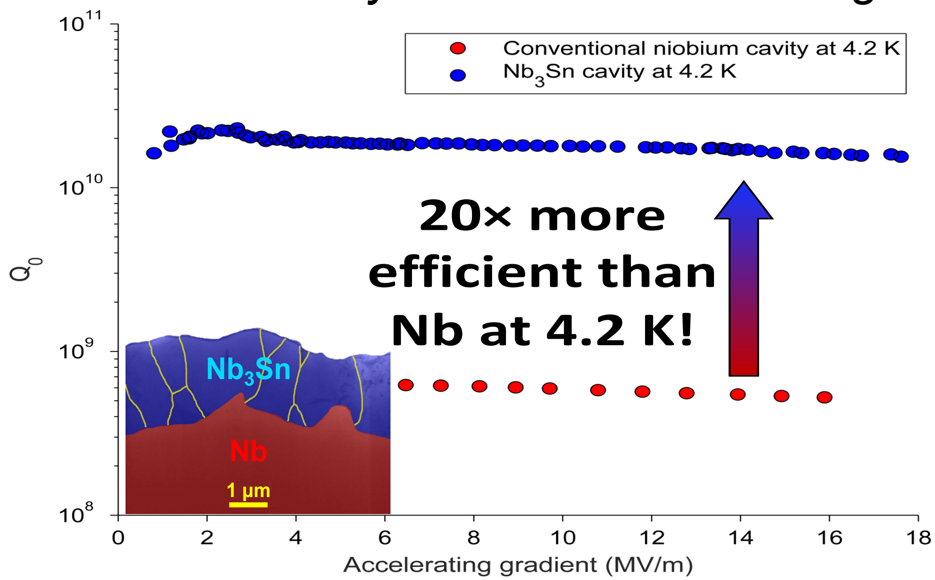
- First high-performance (electropolished and doped) 500 MHz cavity for storage rings

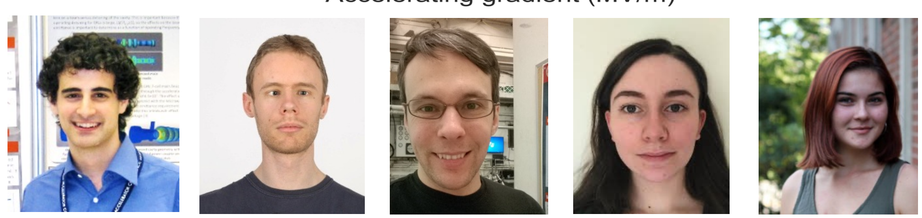
International Lab Connections



Cornell Breakthrough: Nb_3Sn SRF

- Funded and enabled by the DOE GARD Program (DE-SC0008431) -

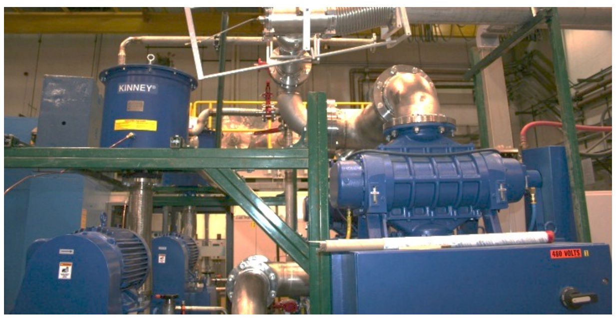


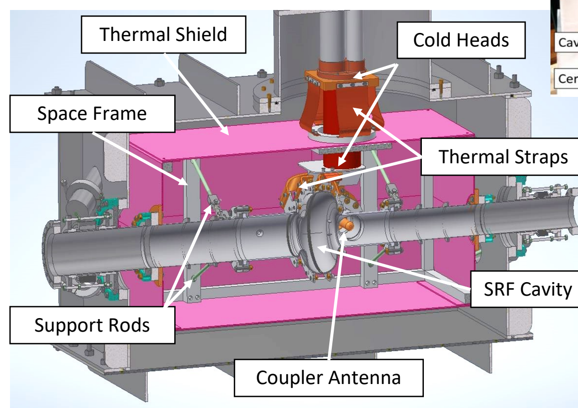


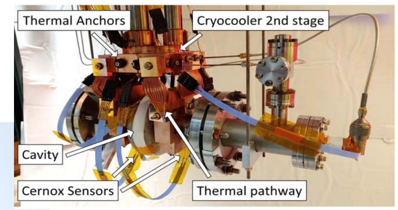
- **2x to 4x lower cooling power than Nb (sustainable CW accelerators, e.g. FCC)**
- **4.2 K cavity operation**
- **New SRF direction with worldwide activity**
- **Enabled new SRF application area: Turn-key SRF for industry, medicine, environment…**

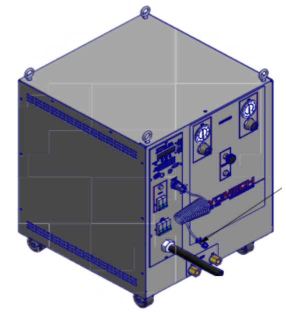
First-ever functional alternative-material (Nb_3Sn) SRF cavities that outperform traditional niobium cavities!

Cornell Breakthrough: Robust, turn-key SRF technology, e.g., for industrial, medical, security applications









Cornell Compact Cryomodule;
similar programs at FNAL and JLab

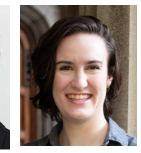
First demonstration of a Nb3Sn cavity operated at 10 MV/m with conduction cooling from a commercial cryocooler!

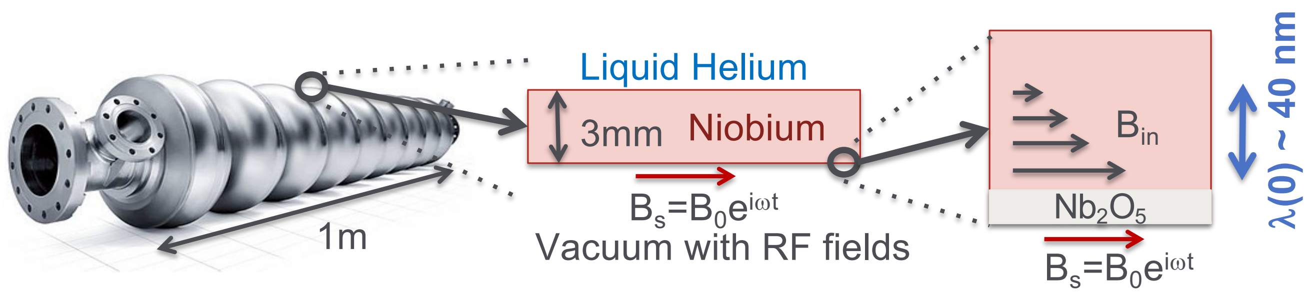
U.S. DOE award DE-SC0021038 “Next Steps in the Development of Turn-Key SRF Technology”

N A Stilin et al 2023 Eng. Res. Express 5 025078 DOI 10.1088/2631-8695/acdd51

Opportunity: Boosting Energy Efficiency (Q_0)

$$R_{BCS} \propto f^2 e^{(-const*T_C/T)}$$

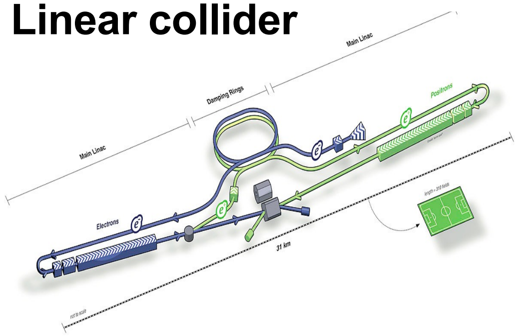


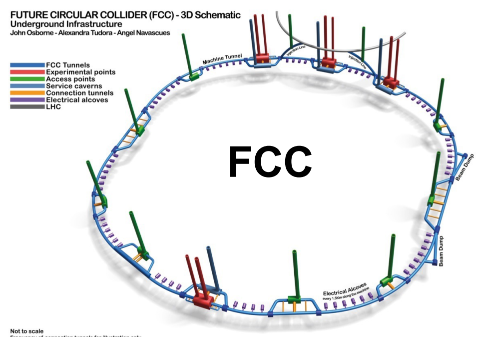


Huge potential for large gains:

- **Improved Nb**
- **Larger energy gap (higher Tc) superconductors**
- **Inhomogeneous layers:** Surfaces by design

Linear collider





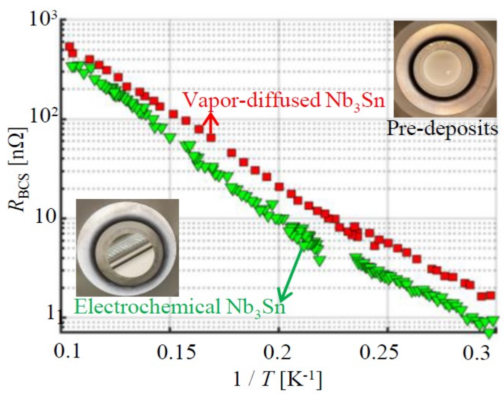
accelerator-based light source solution for a sustainable future of EUV lithography

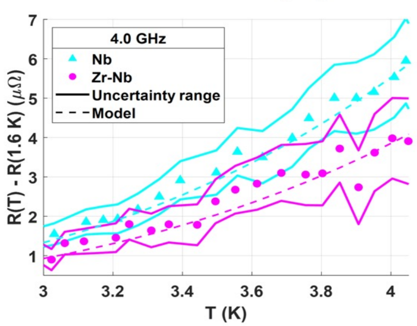
Image credit FNAL

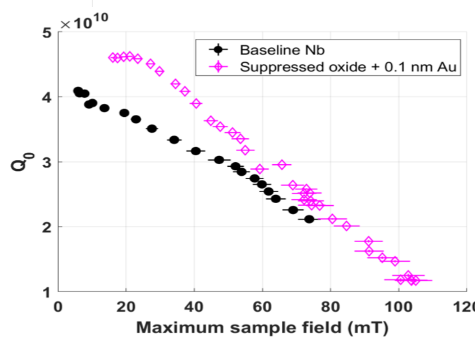
Strong synergy with superconducting quantum materials and systems R&D

Opportunity: Boosting Energy Efficiency

	Niobium	Nb_3Sn	Nb-Zr
Critical Temperature T_c	9 K	18 K	13 - 16 K
Q_0 at **4.2 K**	6 x 10^8	**6 x 10^{10}**	**?**

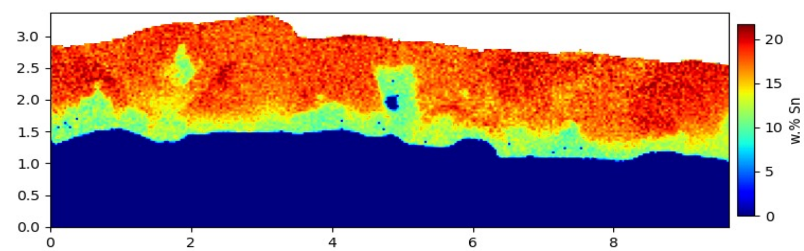






R&D directions:

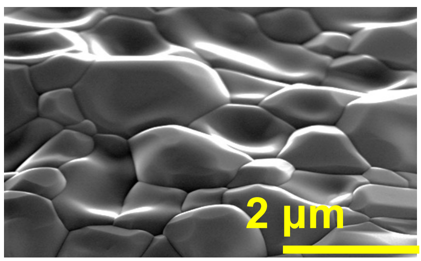
- Improved Nb treatments
- Passivating surface layers to prevent formation of lossy oxide
- Improve Nb_3Sn coatings and new growth methods (electroplating, CVD)
- Explore potential of Nb-Zr alloys and metal doping (new ARDAP award)

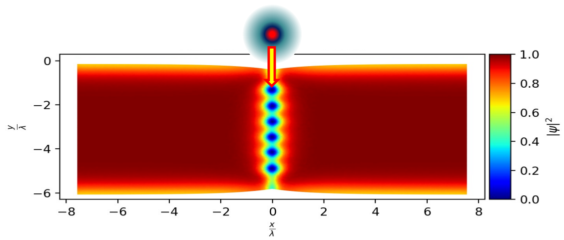


Z. Sun et al., SUST (2023); Z. Sun et al., Adv. Electron. Mater, T. Oseroff et al., arXiv:2305.12035

Opportunity: Higher Energy Gain SRF

	Niobium	Nb_3Sn theory	Nb_3Sn reached to date
Superheating field	220 mT	420 mT	-
Corresp. max. E_{acc}	55 MV/m	**100 MV/m**	**24 MV/m**



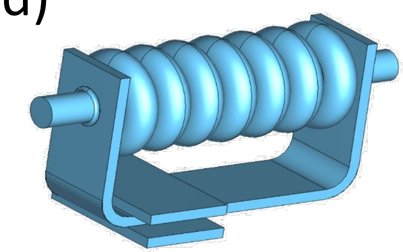


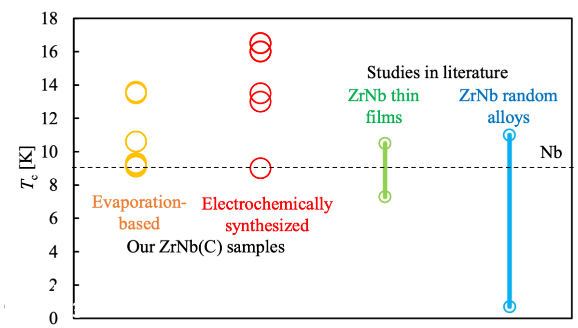
Surface roughness lowers vortex entry field (for $\xi << \lambda$ Nb_3Sn!)

	Niobium	Nb-Zr
Critical Temperature T_c	9.2 K	13 - 16 K
Predicted superheating field	220 mT	>300 mT ?
Corresponding max. E_{acc}	55 MV/m	>75 MV/m?

R&D directions:

- Improve Nb_3Sn coating methods for increased quench fields
- Explore potential of Nb-Zr alloys (new ARDAP award)
- Traveling wave structures (collab. with FNAL)





Nb-Zr alloy

Z. Sun et al., Adv. Electron. Mater

Potential Cornell SRF Contributions to ITN Work Packages

WP-prime 1: Cavity Industrial-Production Readiness

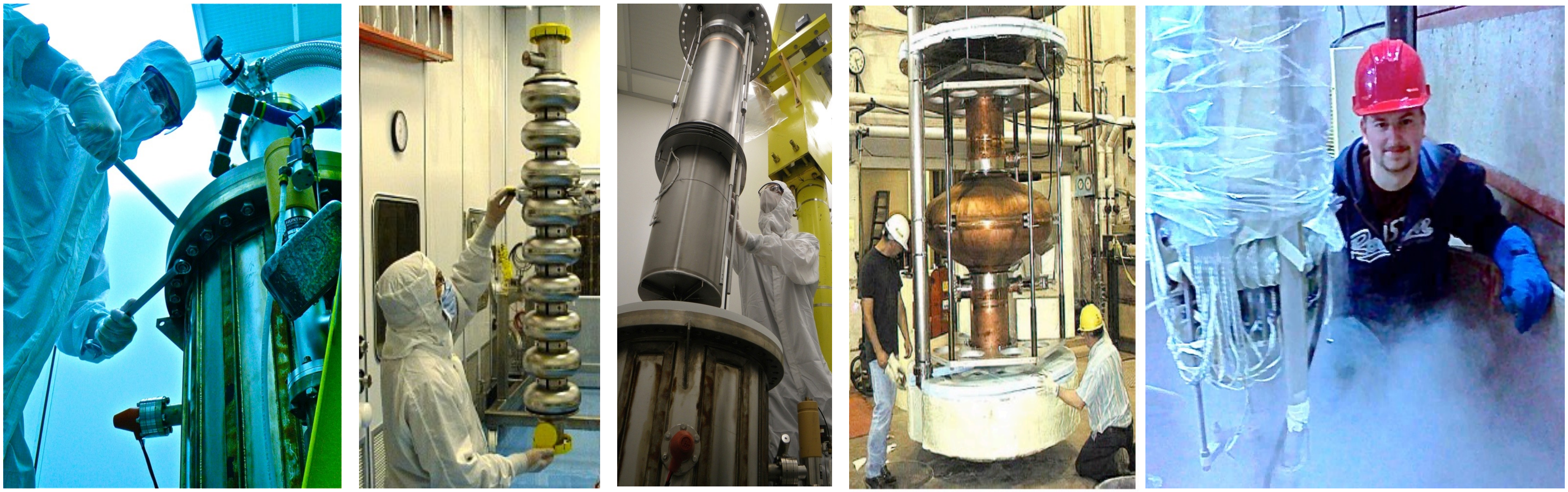
Goals of the workpackage

Parameters	*Unit*	*Design*
Baseline: Cavity gradient, E, at Q value (Q_0) (Cost-Reduction R&D goal: E, at Q value)	MV/m	35 at Q ≥0.8 E10 (38.5 at Q ≥ 1.6E10)
Cavity production yield	%	90

List of items:

Priority	*Items*	Y1	Y2	Y3	Y4
A	1-cell cavities: Fundamental research (for establishment of production/surface treatment process)	All	All (half)		
A	9-cell cavities: HPGS regulation issues to be settled	All			
A	Purchasing SC material (Nb, NbTi) contributed by JP	All			
A	Industrial production with globally shared contracts		All	All	
A	1st vertical test (VT), and further efforts (2nd and later cycle process)			All	All
A	Clean room work procedure (Robotics technology to be matured)	All	All	All	All
A	Quality control/assurance	All	All	All	All
Note: 9-cell cavity production is assumed to be continued after Y3 (totally 120 cavities in TPD)					

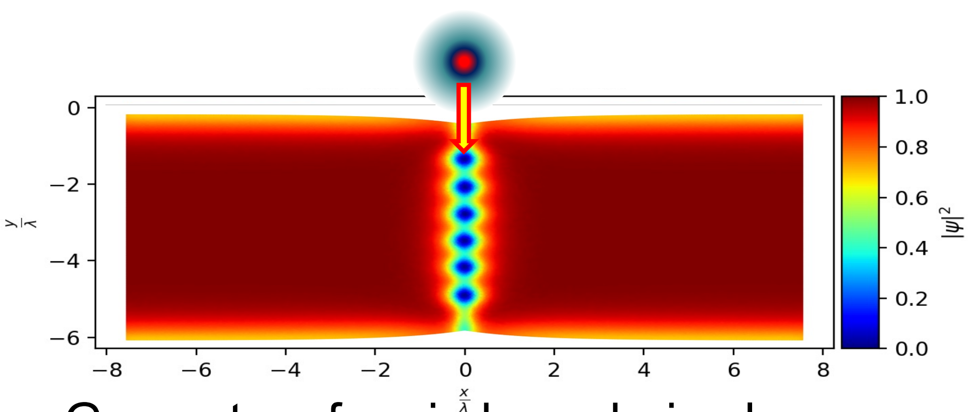
Cornell SRF Facilities



Clean room, chemical facility, UHV furnaces, coating furnaces, cryogenic RF test facility…

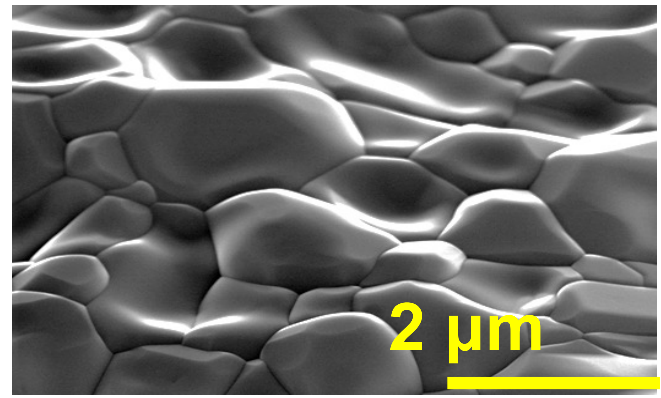
Cornell SRF Facilities: High-Field Sample Cavity

Ginzburg-Landau Simulation of Vortex Nucleation In Grain Boundaries

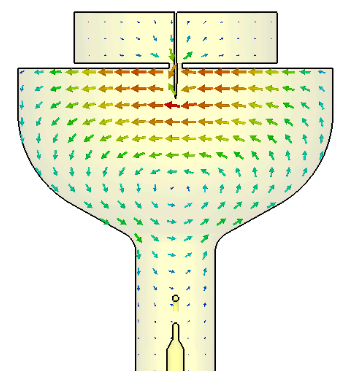


- Geometry of grain boundaries lowers vortex entry field (for ξ << λ Nb_3Sn!)

- **New setup to measure vortex entry fields of superconducting samples**

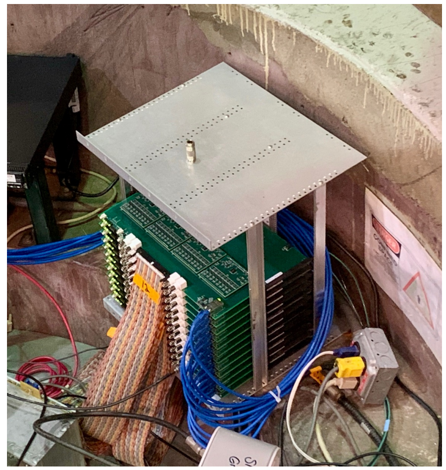


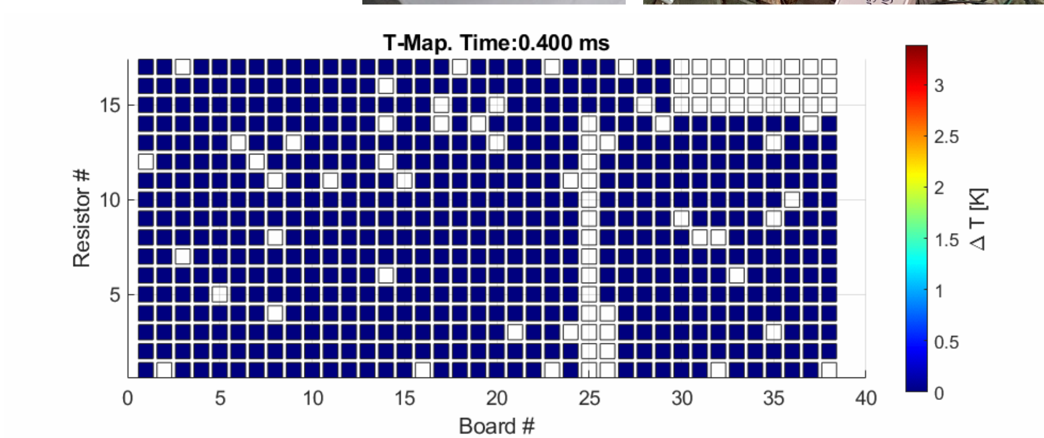
- Surface roughness enhances local surface fields

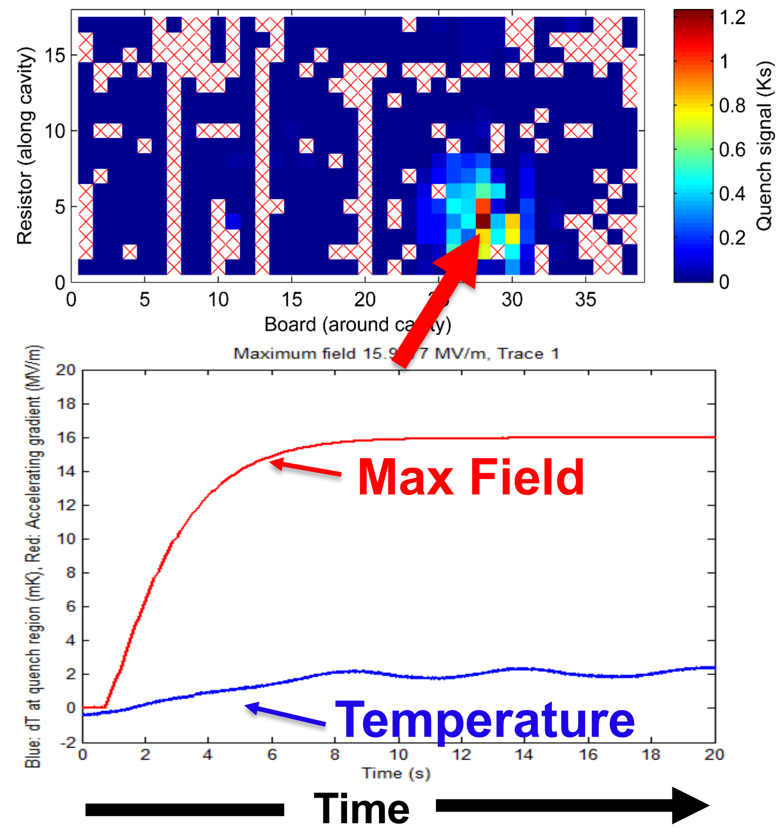


Cornell SRF Facilities: High-Speed T-Map

New time-resolved temperature mapping system to study dynamics of RF dissipation







magnetic vortex entry?

Questions?

Current and former Liepe Group graduate students at SRF'23