R&D Towards High Gradient CW Cavities

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LINAC'22

August 30th, 2022

Overview

- Part I: Extending Microscopic Understanding of the Role of Impurities in Cavities
  - Key Material Science Findings: Oxygen Enables High G in LTB Cavities
  - Role of Diffused Oxygen in Mitigating HFQS
  - Role of Diffused Oxygen in Tuning Cavity Quench Field
- Part II: Recent SRF R&D Towards Increasing Cavity Performance
  - +50 MV/m Recipe: Cold EP + 2-Step Low-Temp Bake
  - Plasma Processing
- Part III: Potential Application of Findings to a Newly Proposed LINAC: LBNF/DUNE Booster Replacement @ Fermilab

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Quest for High Q_0 and Gradient with Impurities

- Cavity performance dictated by first ~100 nm from RF surface

<u>N impurities</u>

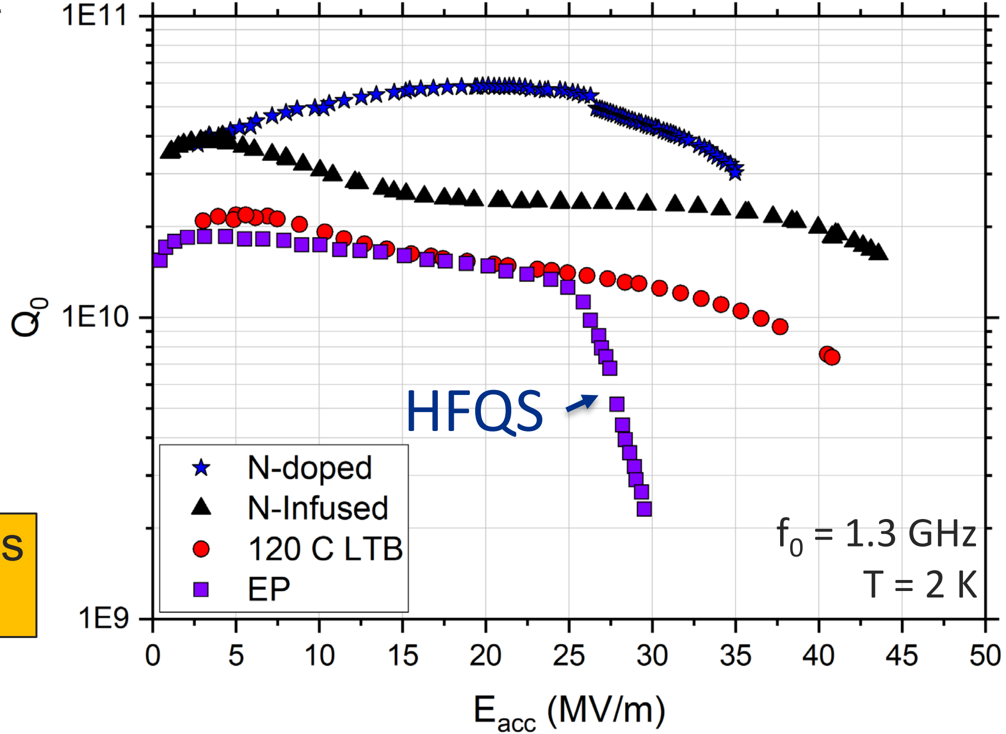
- High Q_0: N-doping
- High Gradient: N-Infusion

<u>Oxygen impurities:</u>

- High Gradient: Low Temp. Bake
- High Q_0: ?

What is the precise role of O impurities in bulk Nb cavity performance?

Nb SRF Cavities Post Various Surface Treatments



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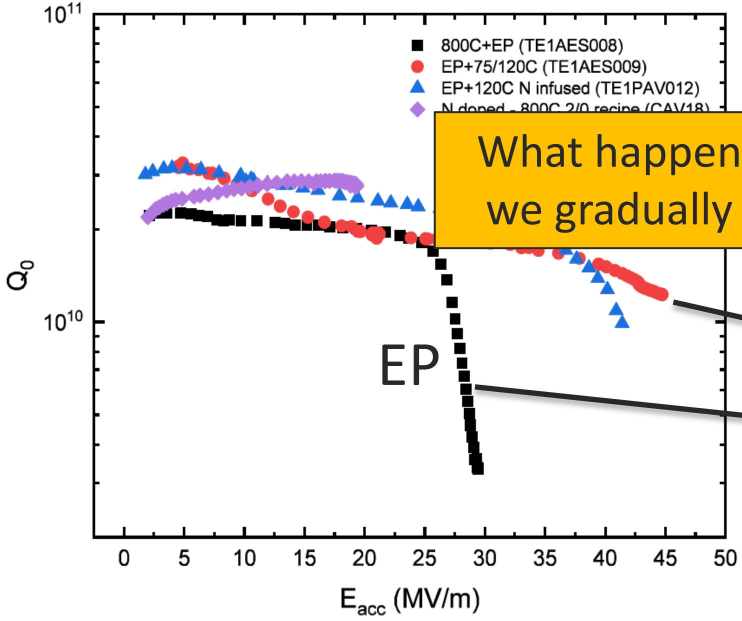
Key Material Science Findings: Diffused O Enables High G in LTB Cavities

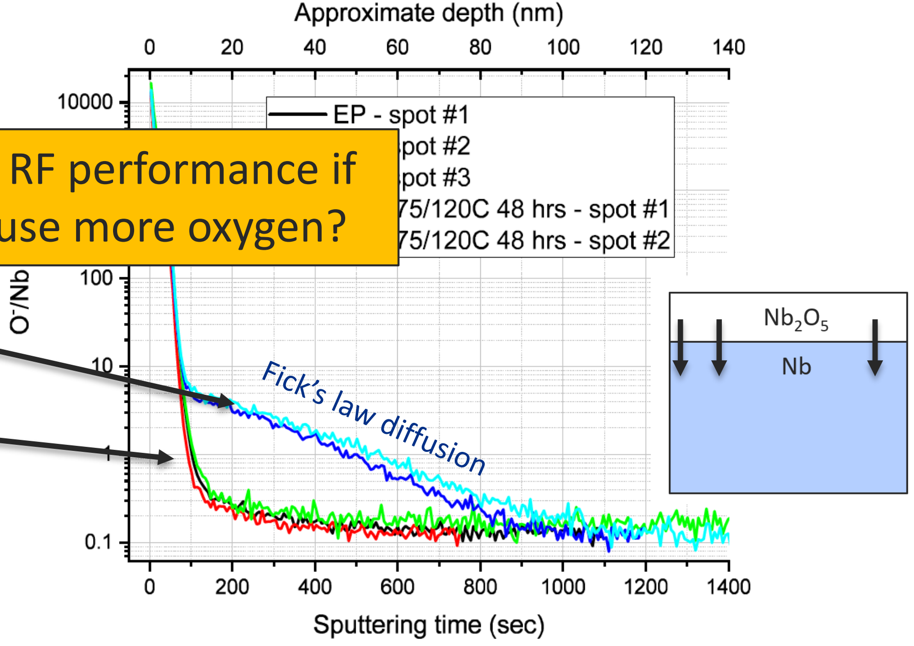
RF Data on Variously Processed Cavities to be Cut



A. Romanenko et al, SRF’2019, THP014

What happens to RF performance if we gradually diffuse more oxygen?

TOF-SIMS Data on Cavity Cutouts



A. Romanenko, TTC’2020, CERN

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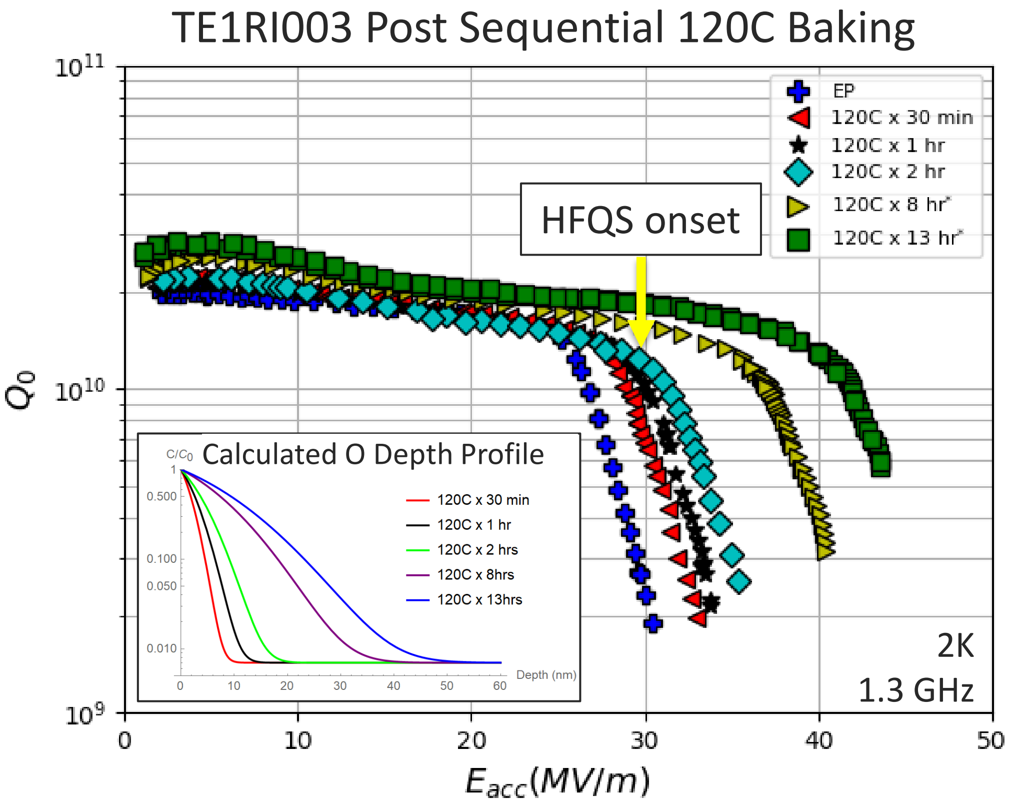
Utilizing Diffused O to Eliminate HFQS & Improve Gradient



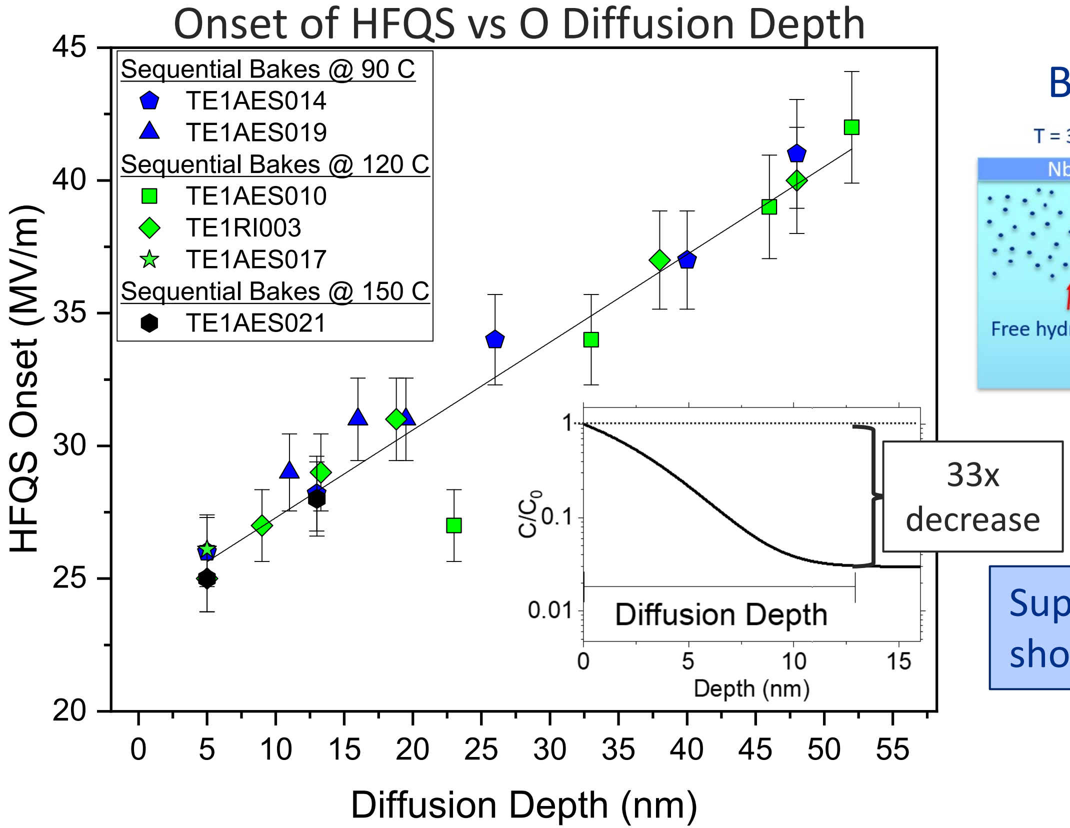
D. Bafia et al, Proceedings of SRF'2021, THPTEV016

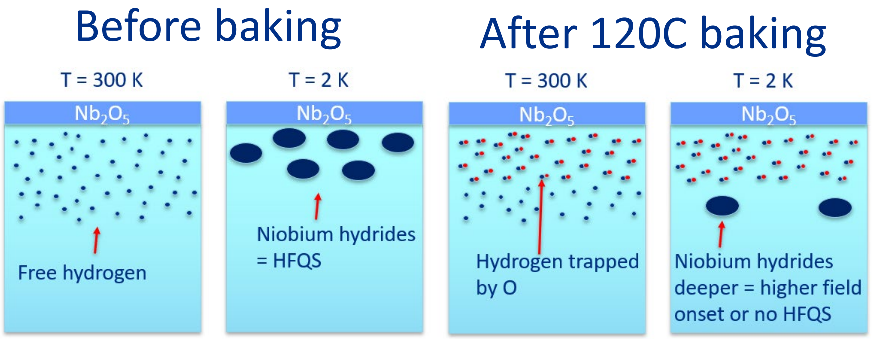
Subjected TE1RI003 to sequential rounds of 120 C vacuum baking

As O diffuses deeper:

- HFQS onset increases
- Quench field improves

Solidifying the Role of O in the Mitigation of HFQS





Supports Romanenko model of hydrides and shows that diffused oxygen mitigates HFQS

D. Bafia et al, Proceedings of SRF'2021, THPTEV016

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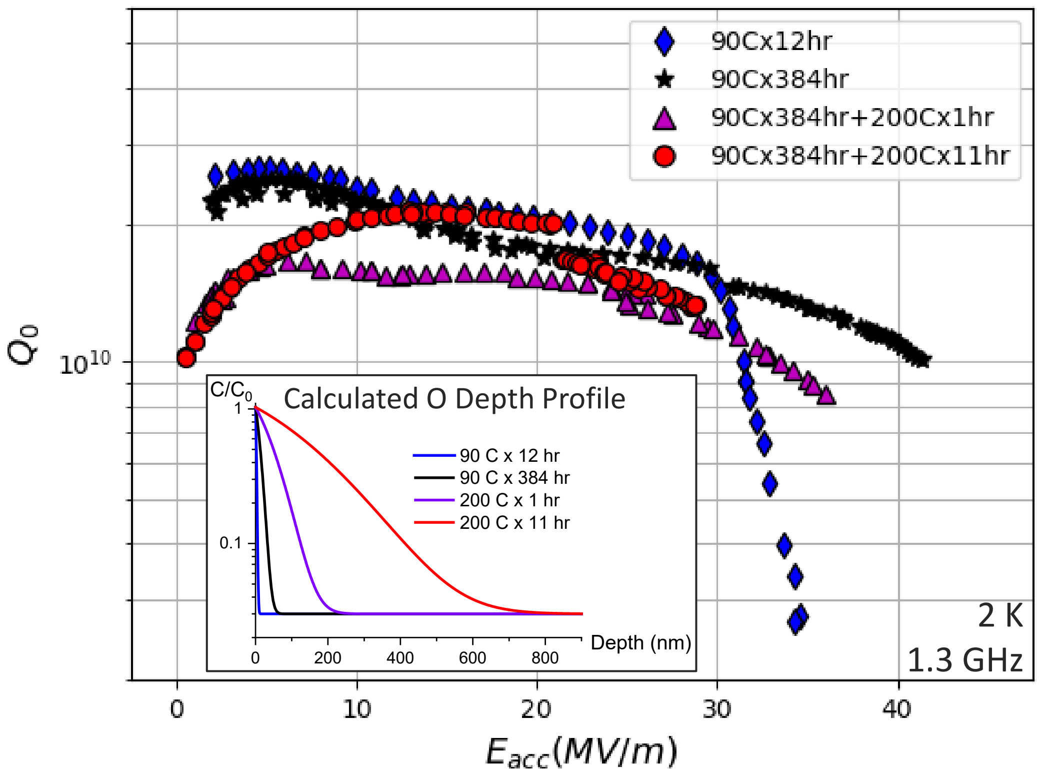
Effect of Oxygen Diffusion on Quench Field

Cavity maintained vacuum throughout entire study

- **90 C x 12 hr**
  - HFQS
- **90 C x 384 hr**
  - Diffuses oxygen ~64 nm, no HFQS up to quench
- **200 C x 1 hr**
  - Rounding of curve
  - Reduction in quench
- **200C x 11 hr → O-Doped**
  - Anti-Q slope
  - Reduction in quench

TE1AES019 Post Sequential Baking



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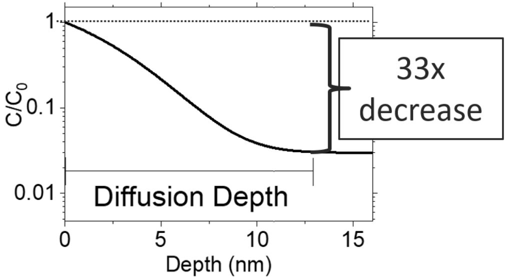
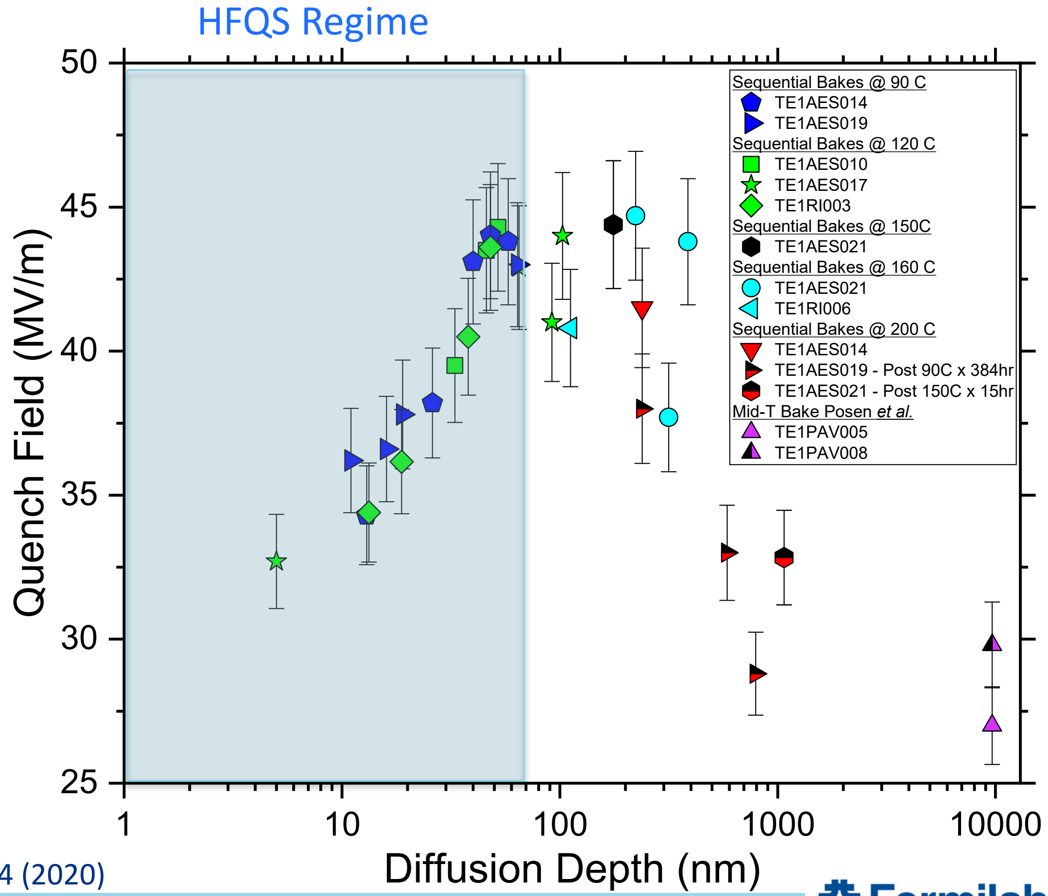
Diffusion Depth vs Quench Field



- Non-monotonic dependence of quench field on O diffusion depth
- HFQS regime: quench dominated by thermal origins

NOT ultimate quench reach of Nb cavities → single step diffusion; What about multi step diffusion?



Mid-T Bake data comes from S. Posen *et al.*, PRA **13**, 014024 (2020)

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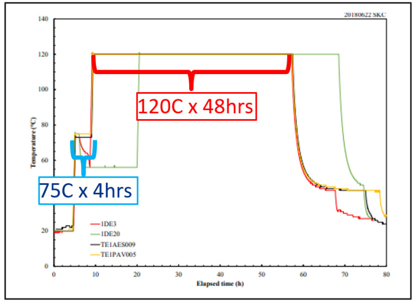
New Cold EP + 2-Step Low-Temp Bake Enabling 50 MV/m

Grassellino *et al.* https://arxiv.org/abs/1806.09824

Cold EP +



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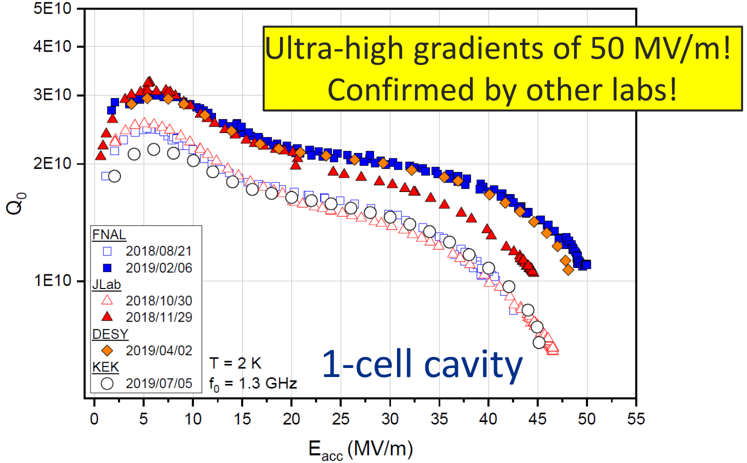
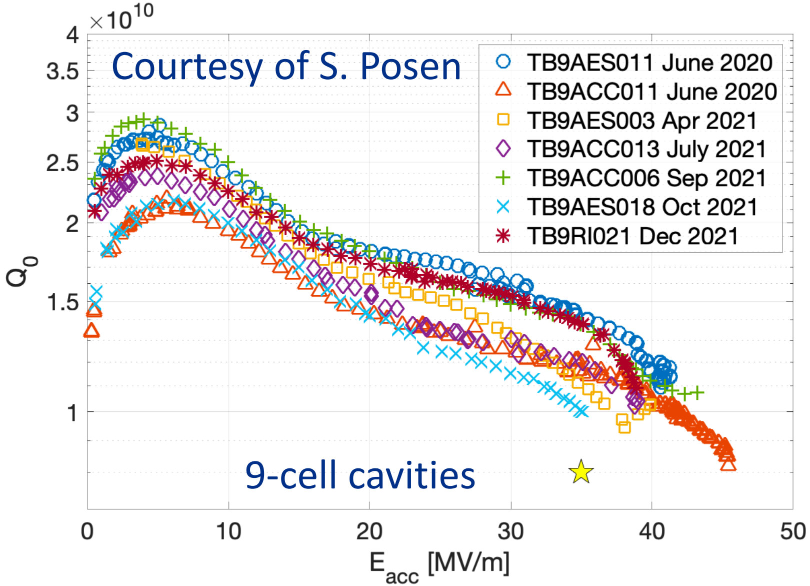


Transferred recipe to 9-cell cavities as part of ILC Cost Reduction effort

- Average E_{acc} = 40.4 MV/m!



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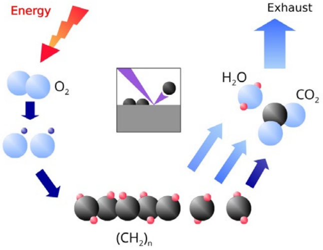
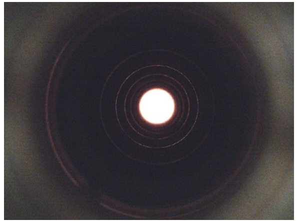
Plasma Processing Applied to LCLS-II-HE vCM





Vacuum cart – Downstream

RF system, computers

Plasma processing procedure for 1.3GHz CMs is fully validated

RF test after plasma processing demonstrated that:

- **vCM performance** is **preserved**
- Plasma processing did not introduce any contamination: vCM **still FE-free**

B. Giaccone, THPOGE21, poster and talk this Thursday

B. Giaccone, et al. arXiv:2201.09776 (2022)

S. Posen *et al.* PRAB **25**, 042001 (2022)

Plasma processing **can also eliminate multipacting:**

- Possible to **address both FE and MP in situ in CMs**, decreasing CM testing time, commissioning time, and increasing the reliability during machine operations.

	Before plasma		After Plasma
	1^{st} cooldown	2^{nd} cooldown	
1	/	**157**	**0**
2	135	106	205
3	41	44	53
4	**68**	**3**	**0**
5	**10**	**16**	**0**
6	46	7	69
7	68	33	82
8	**128**	**108**	**0**

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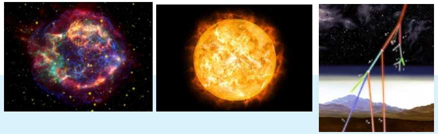
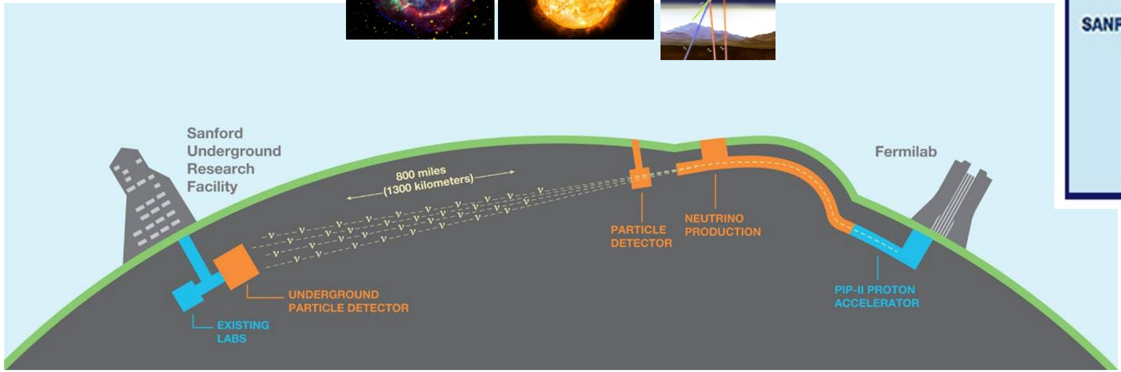
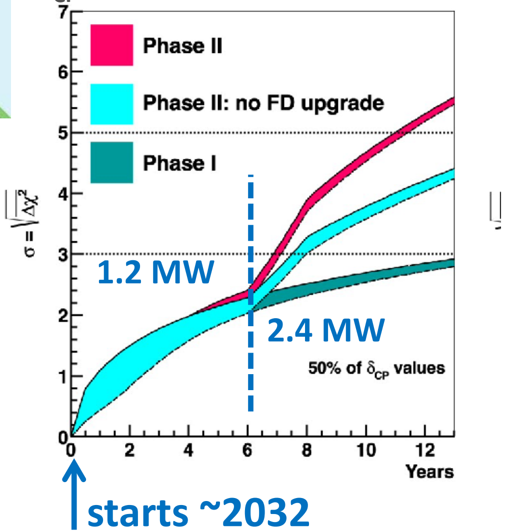
DUNE Physics Program





δ_{CP} Discovery, sigmas over time



- Unambiguous, high precision measurements:
  - Neutrino oscillations
  - Mixing angle
  - CP violation
- Sensitive to MeV-scale neutrinos – galactic supernova bursts

Slide courtesy of S. Posen

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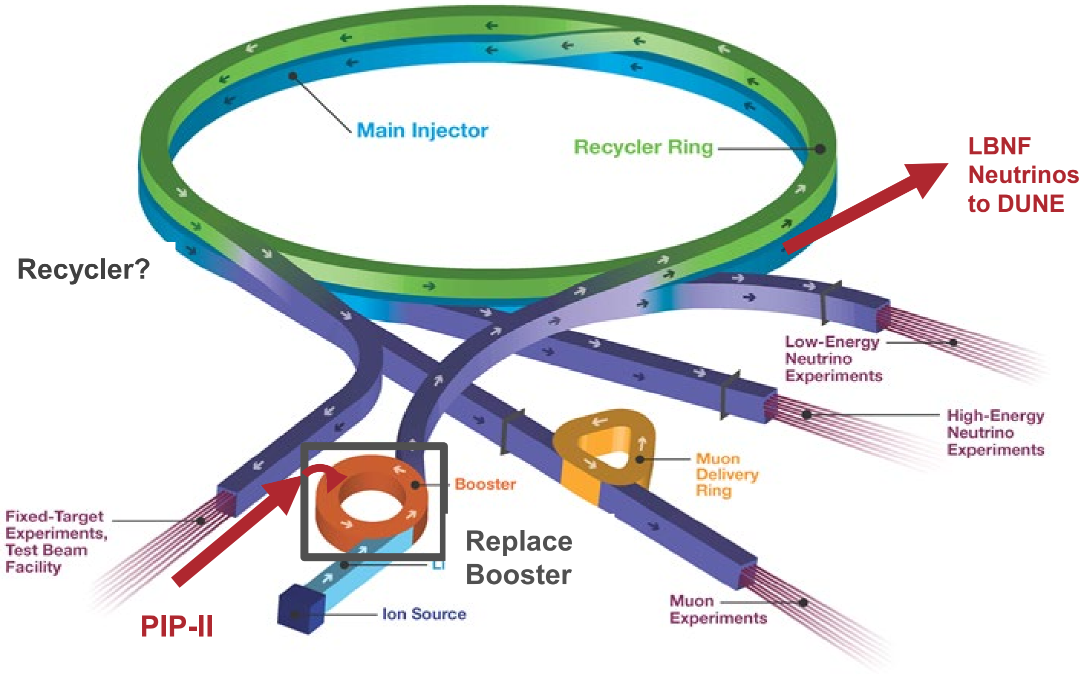
Fermilab Accelerator Complex Upgrades to reach 2.4MW

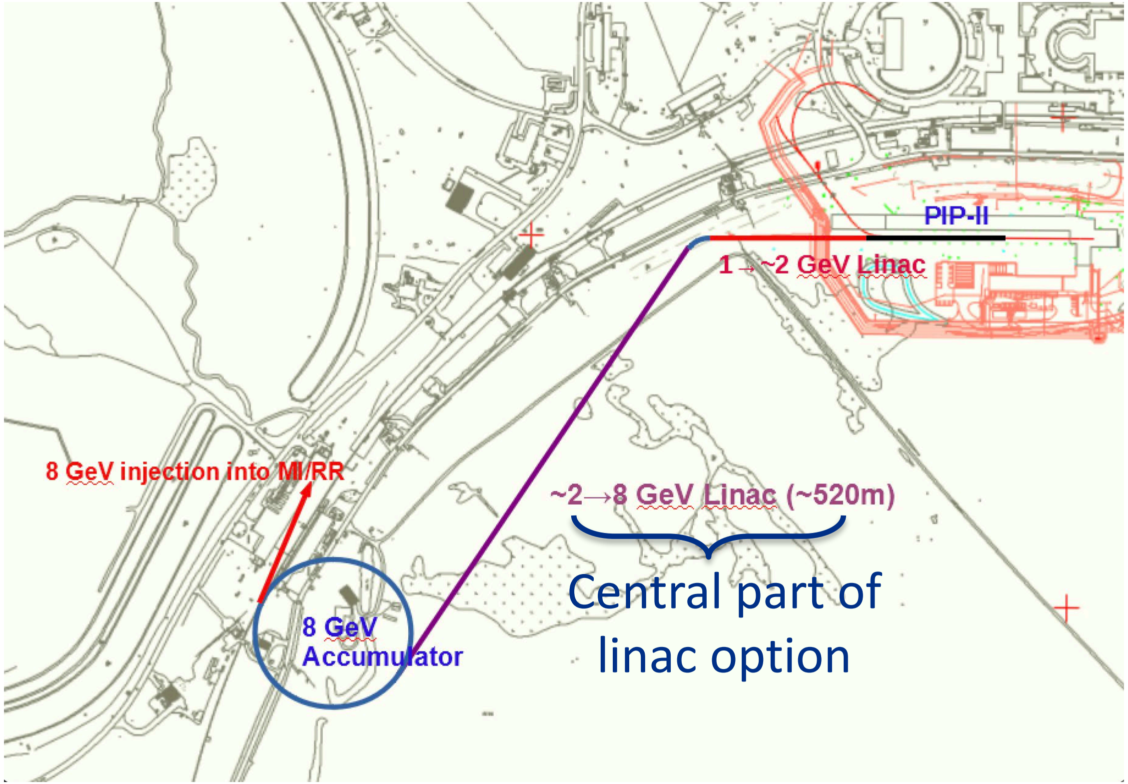


After PIP-II goes online, booster will be the bottleneck for proton power on target for LBNF/DUNE

Slide courtesy of S. Posen

Booster Replacement Linac Layout

- High gradient pulsed SRF linac to 8 GeV
- CM similar to LCLS-II design
  - 8 x 1.3 GHz 9-cells
  - Quadrupole magnet
- Q_0 = 1E10, E_{acc} = 31.5 MV/m
  - Already achieved by cold EP + 2-step bake
- Plasma processing may be used to mitigate FE and MP



Slide courtesy of S. Posen

See white paper for full details: S. Belomestnykh *et al.* arXiv:2203.05052

Conclusions

- Acquiring a deeper understanding on the role of impurities in cavity performance
- Able to tune cavity performance *via* simple low temperature baking
- Dramatic improvements in cavity performance with cold EP + 2-step bake
- Plasma processing may provide the potential for *in situ* mitigation of field emission and multi-pacting in cryomodules
- These advances in SRF cavity performance have enabled potential cost reduction for future accelerators
  - Use technology in a potential LINAC for the Fermilab booster replacement in LBNF/DUNE

Thank you for your attention!