Industry-Research Institution Collaboration in the United States

Sam Posen

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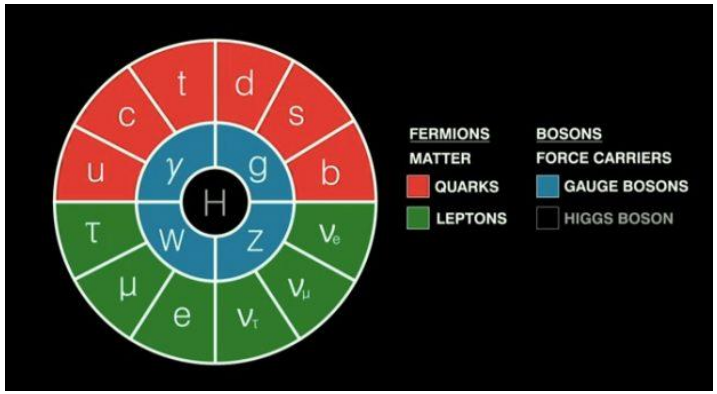
Acknowledgements

- Thanks very much to Hugh Montgomery, Dmitri Denisov, Marc Ross, Andrew Hutton, Steve Holmes, Jim Kerby, Camille Ginsburg

3 Key Factors for Success in Large Experiments:

1) Scientific motivation
2) Understanding of the technology
3) Reasonable cost



Slide based on discussion with M. Ross & A. Yamamoto. Cryomodule image courtesy Rey Hori and linearcollider.org. Video courtesy European XFEL.

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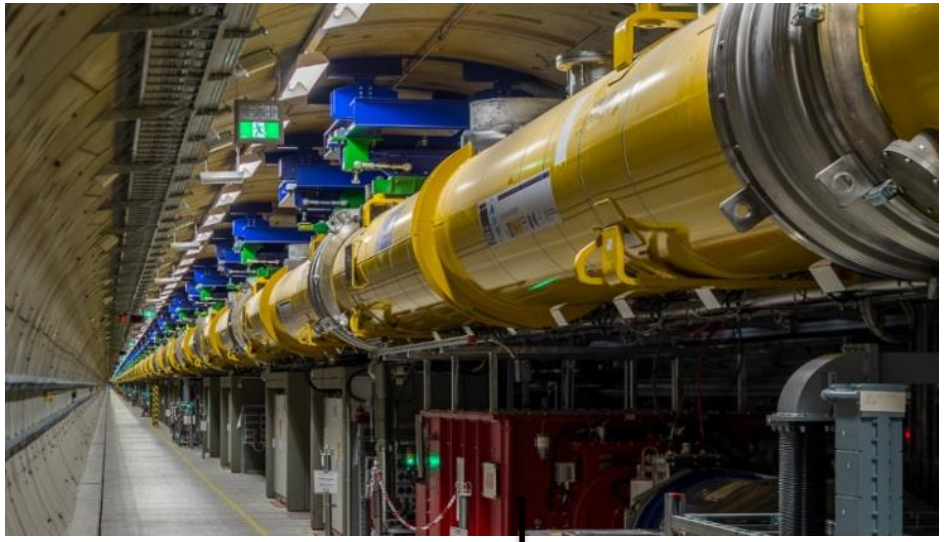
Past SRF 1.3 GHz Cryomodules: EXFEL, LCLS-II…

EXFEL: ~800 cavities



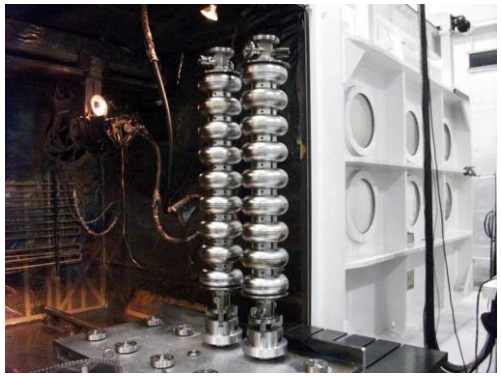
LCLS-II: ~300 cavities

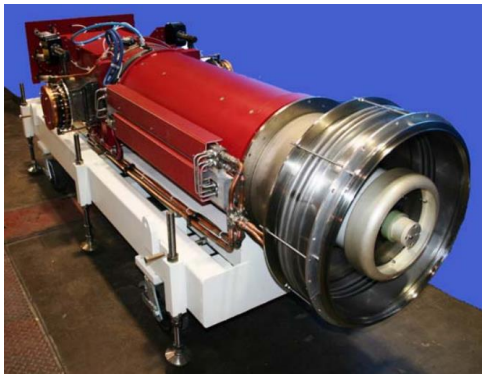
ILC: ~8000 cavities

- Substantial reduction in cost and schedule risk in production
  - Gain experience at laboratories
  - Identify and mitigate technical risks
  - **Industrialize fabrication at vendors**

Benefits of Industrialization

- Reduce costs under forces of market competition using system engineering
- Sustain expertise through contracts with multiple laboratories around the world
- Strong industry/laboratory partnerships allow technology transfer of latest techniques to production
- Increase reliability and maintainability of systems
- Develop new applications outside of science (e.g. MRI)





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Images from Roark, SLAC, HyperTech

ILC Industrialization Demonstration – E-XFEL

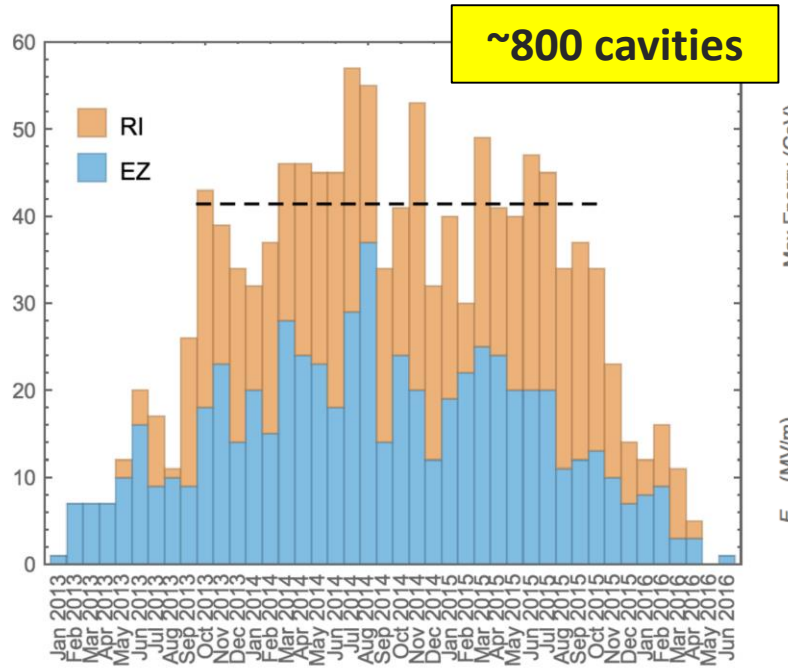
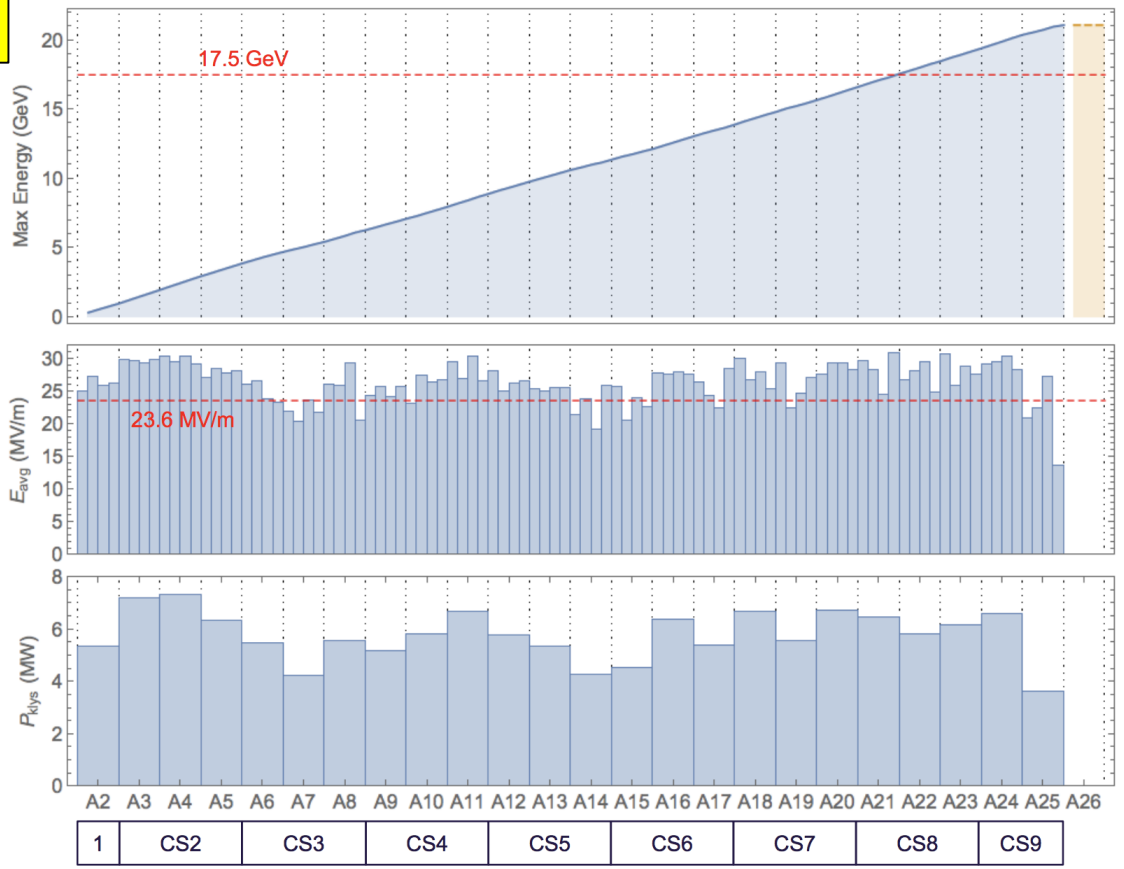


FIG. 8. Stacked bar chart showing the number of cold vertical tests by calendar month for RI (orange) and EZ (blue) cavities based on test date. The dashed line is the total average test rate taken from 1 October 2013 to 31 November 2015, which is considered the peak testing period (after ramp up and before ramp down).

D. Reschke et al. Phys Rev. Acc. & Beams, 20, 042004 (2017)



H. Weise, European XFEL Users' Meeting 2017

European XFEL

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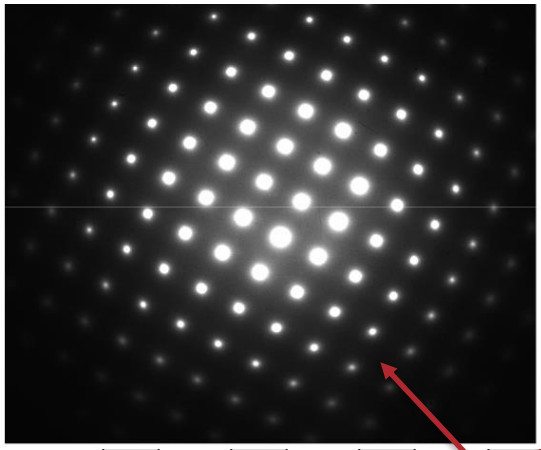
N-doping Treatment used in LCLS-II SRF Cavities

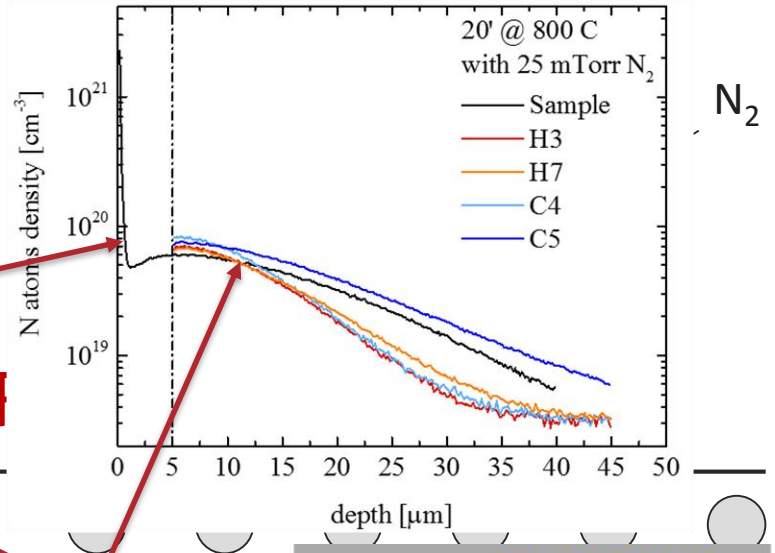
800C UHV, 3 hours → 800C N_2 p = 25 mTorr 2 minutes → 800C UHV, 6 minutes → UHV cooling → 5 um EP

Y. Trenikhina et Al, Proc. of SRF 2015



Nb

Final RF

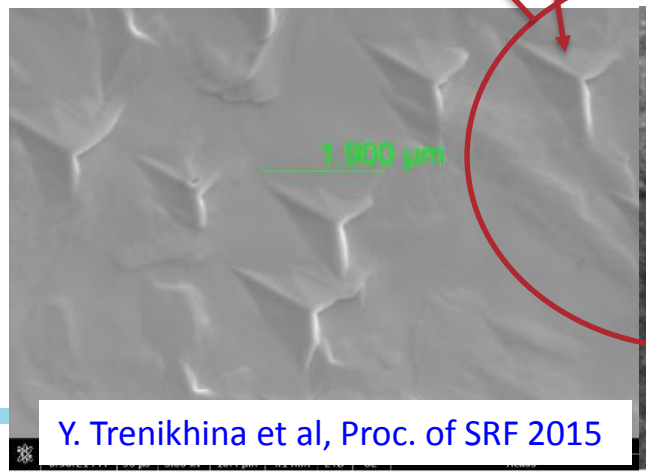


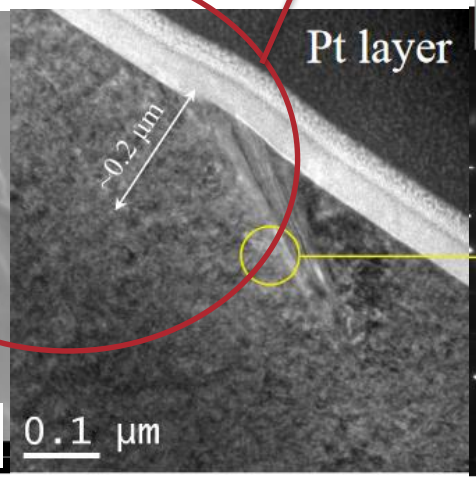
N_2

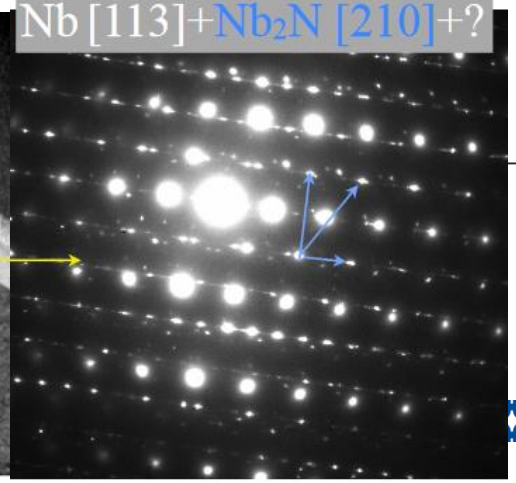
Nb_xN_y

N Interstitial

N







Y. Trenikhina et al, Proc. of SRF 2015

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Industrialization of Nitrogen Doping Process

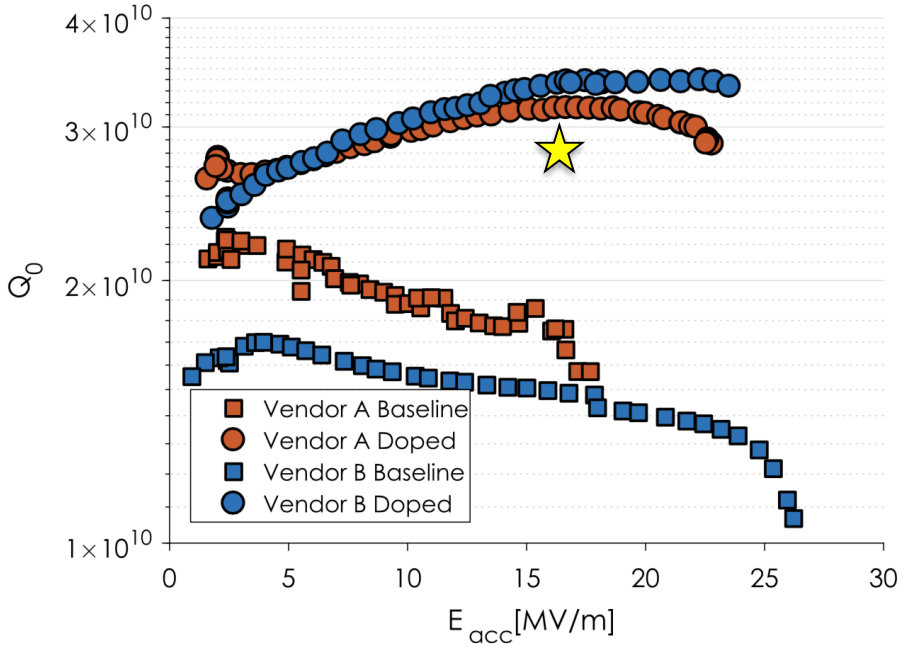

Fig. 2. Q_0 versus E_{acc} at 2.0 K for two of the vendor qualification cavities (one for each vendor, TB9AES014 for Vendor A and TB9AES023 for Vendor B). Baseline test, prior to nitrogen-doping, and final test after nitrogen-doping by the vendors is shown.

D. Gonnella et al., Nucl. Inst. Meth. A 883 (2018) 143–150

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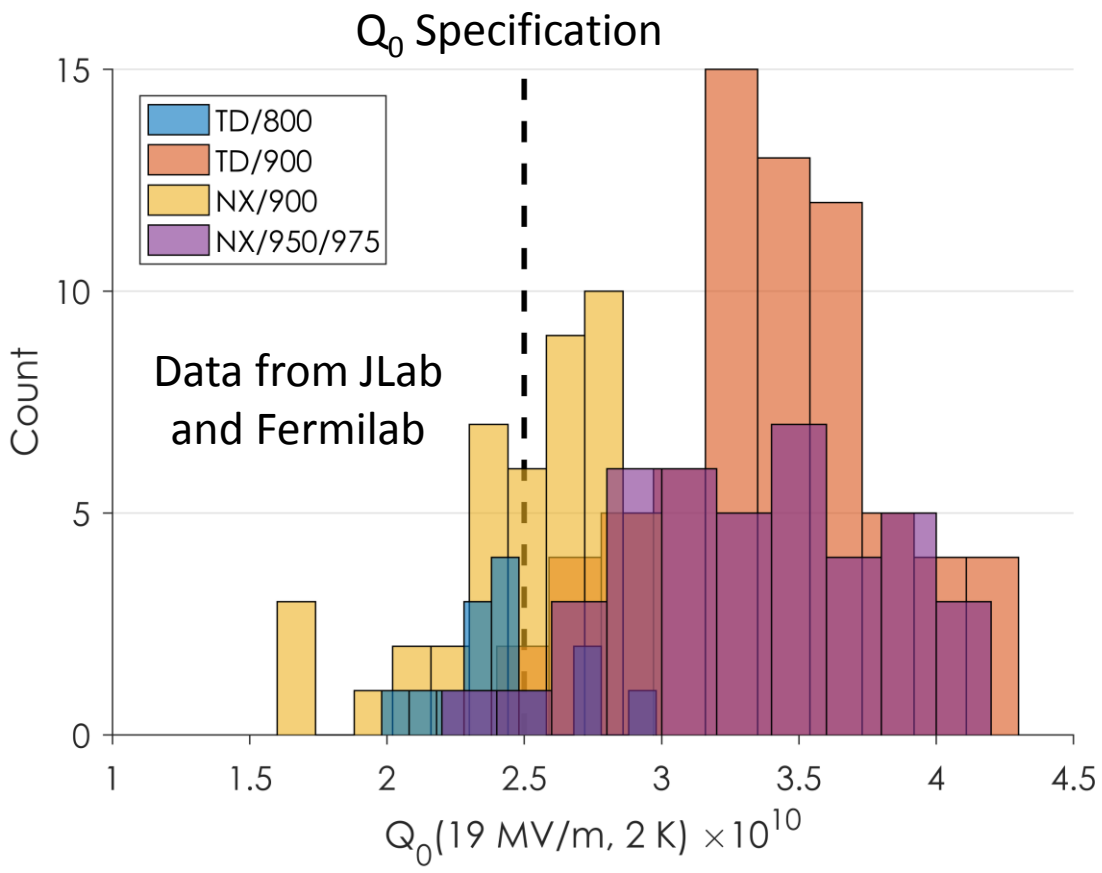
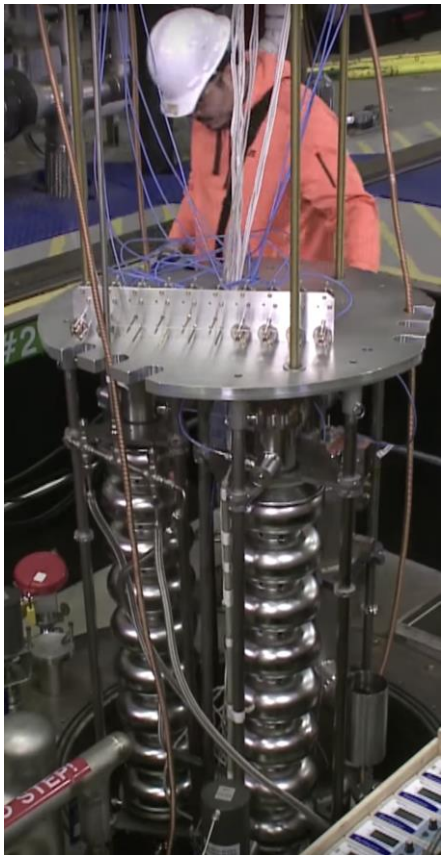
LCLS-II Production Cavities – Vertical Test

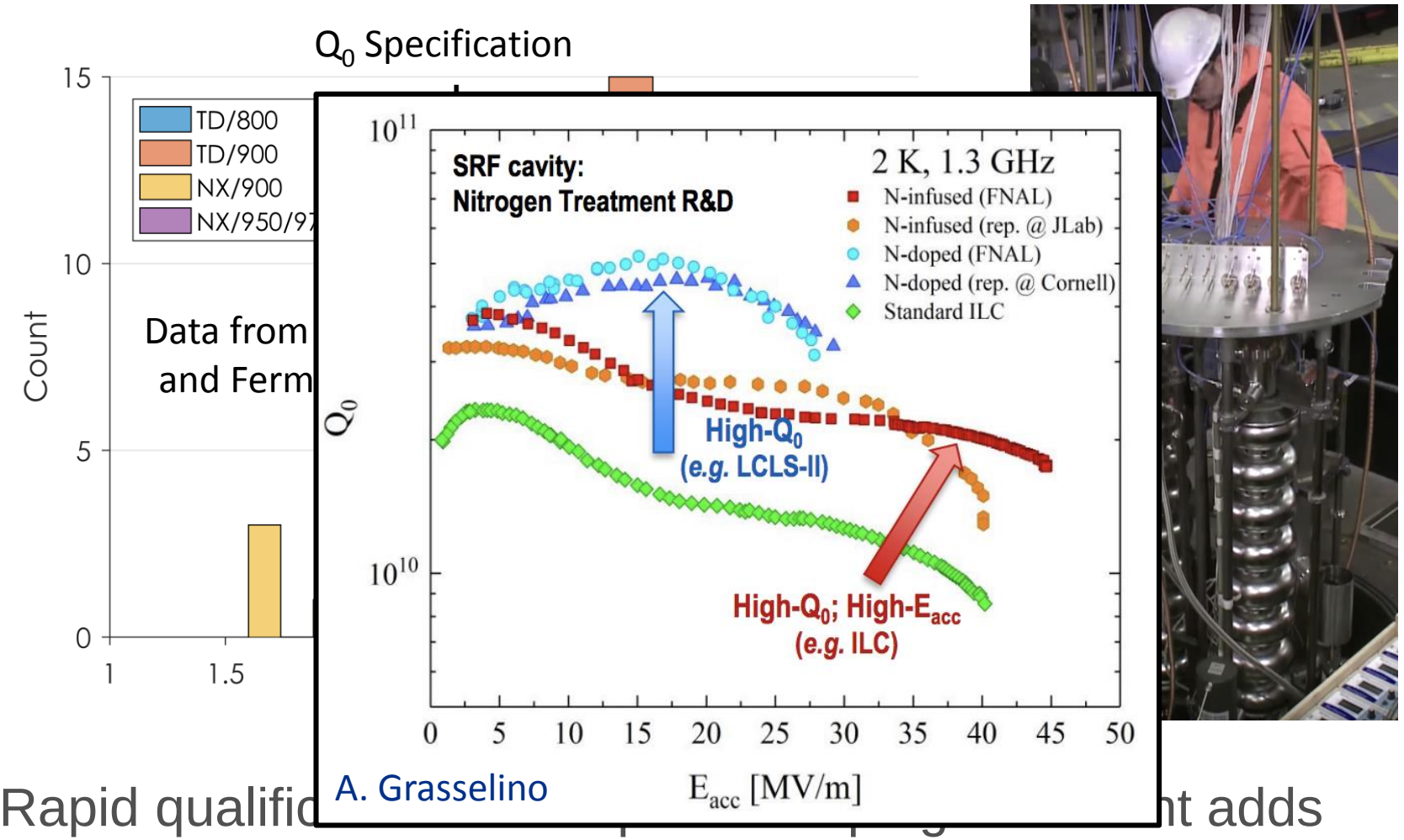




- Rapid qualification of complex N-doping treatment adds confidence in vendor capability to handle advanced cavity processing techniques, important for ILC cost reduction efforts

Plot from D. Gonnella et al., TTC Milan

LCLS-II Production Cavities – Vertical Test



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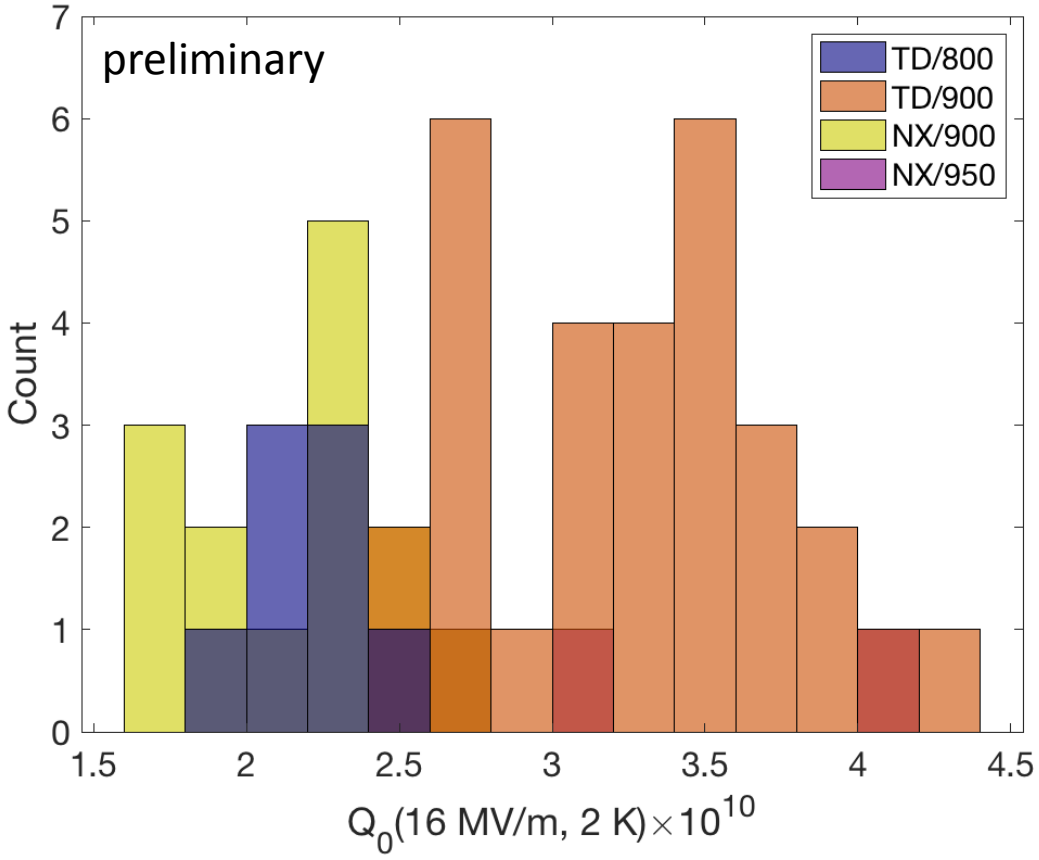
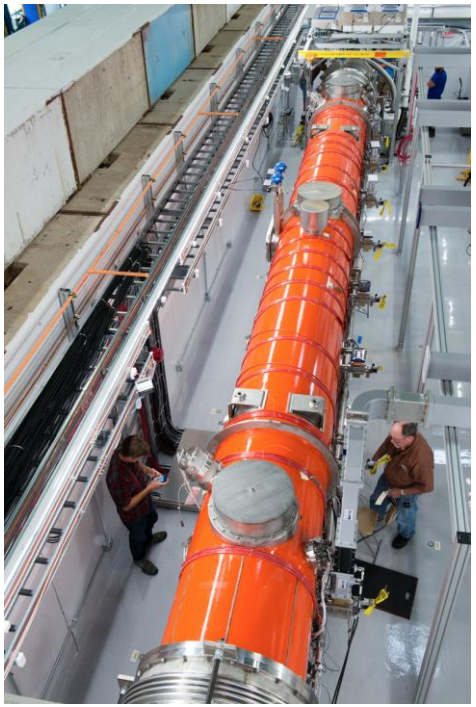
Plot from D. Gonnella et al., TTC Milan

LCLS-II Cryomodules – Fermilab





- High Q_0 performance carries over into test of full cryomodules after following new magnetic hygiene and fast cooldown protocols on high temperature baked material

LCLS-II 1.3 GHz Modules: ½ at JLab, ½ at Fermilab

Process includes vertical test qualification, string assembly, cold mass, vacuum vessel, cryomodule testing

US Industry

- There are many highly skilled US vendors for accelerator components
- I will highlight a few vendors for SRF relevant components (by no means an inclusive list)
- Many of these vendors are contributing to LCLS-II and other projects, R&D activities
- Wide range of coverage, from base metal to full components and instrumentation

Examples of US Vendors: ATI Specialty Materials

- SRF-grade niobium – used in many Fermilab cavities
- Recently treated niobium in Fermilab R&D program to understand magnetic flux expulsion

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Images courtesy Fermilab, ATI

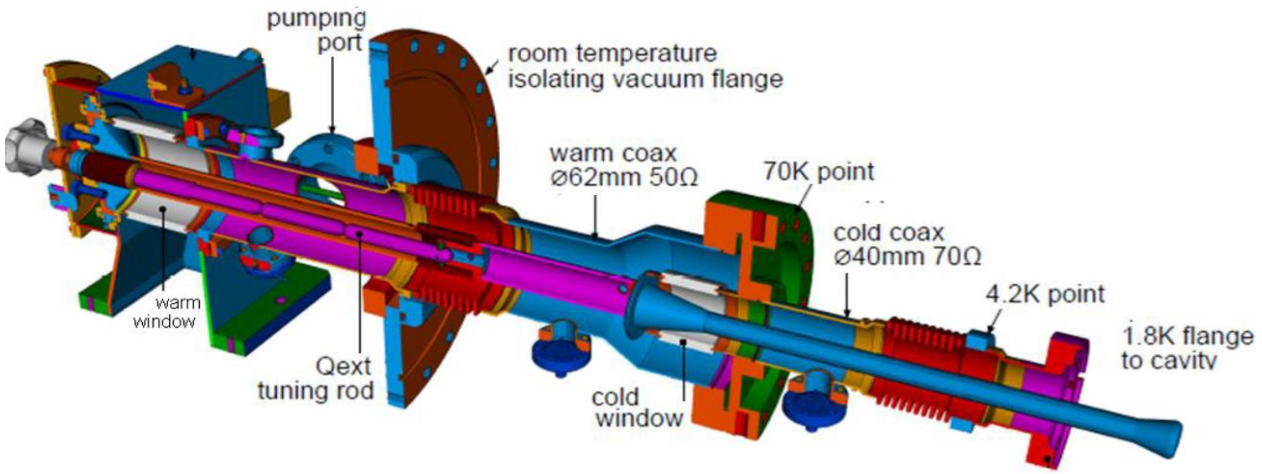
Examples of US Vendors: Roark Engineering Co.

- Complex fabrication (e.g. SRF cavities!)
- SRF accelerator customers include Fermilab's PIP-II and Michigan State University's FRIB

Images courtesy Fermilab and FRIB

Examples of US Vendors: Comm. Power Industries

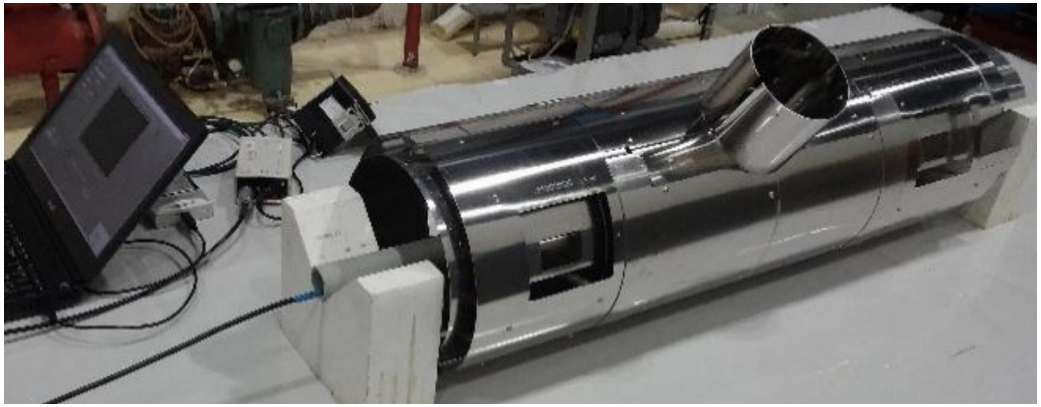
- Expertise in electron device products including RF sources
- Fabricated input power couplers for both LCLS-II and European XFEL

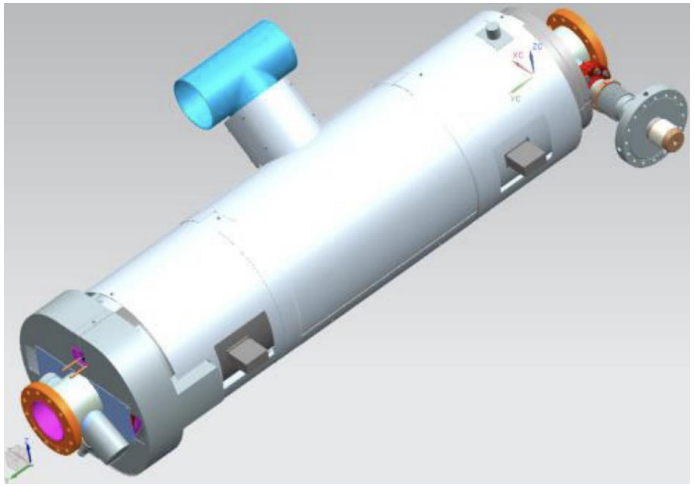


Images courtesy S. Berry, CEA Saclay/European XFEL and Fermilab

Examples of US Vendors: Magnetic Shielding

- Magnetic shielding required to minimize degradation of cavity performance due to trapping ambient fields
- Magnetic shields for cryomodules (including LCLS-II) as well as vertical and horizontal test cryostats
- Vendors include Ad-Vance Magnetics, Amuneal Manufacturing Corporation, The MuShield Company

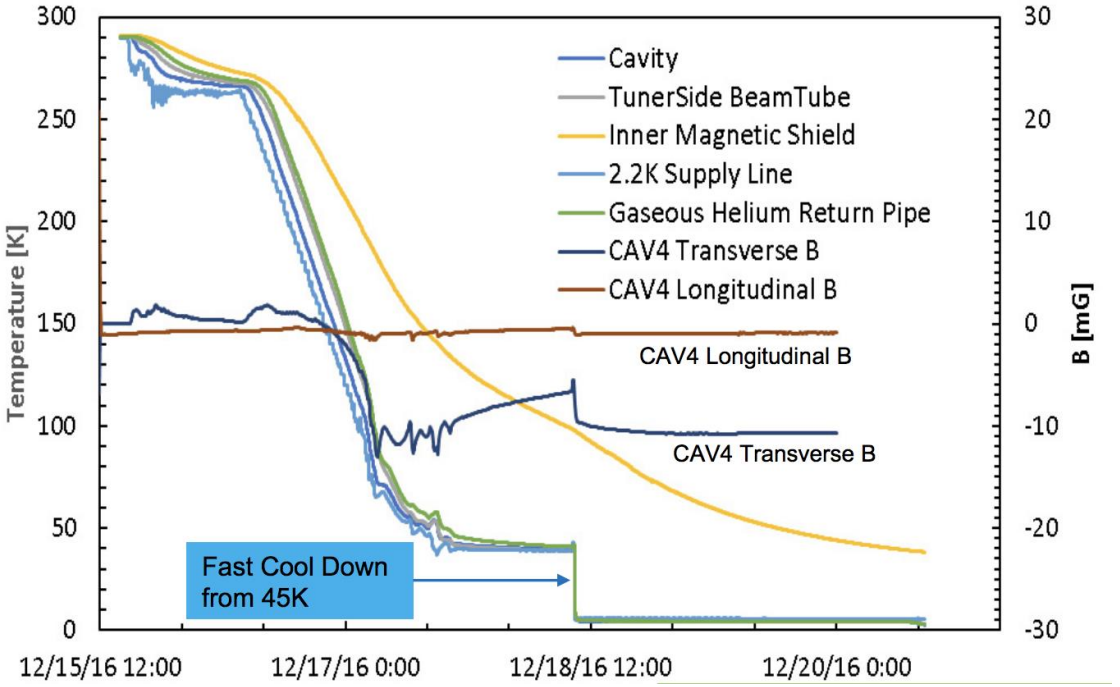




Examples of US Vendors: Lakeshore and Bartington

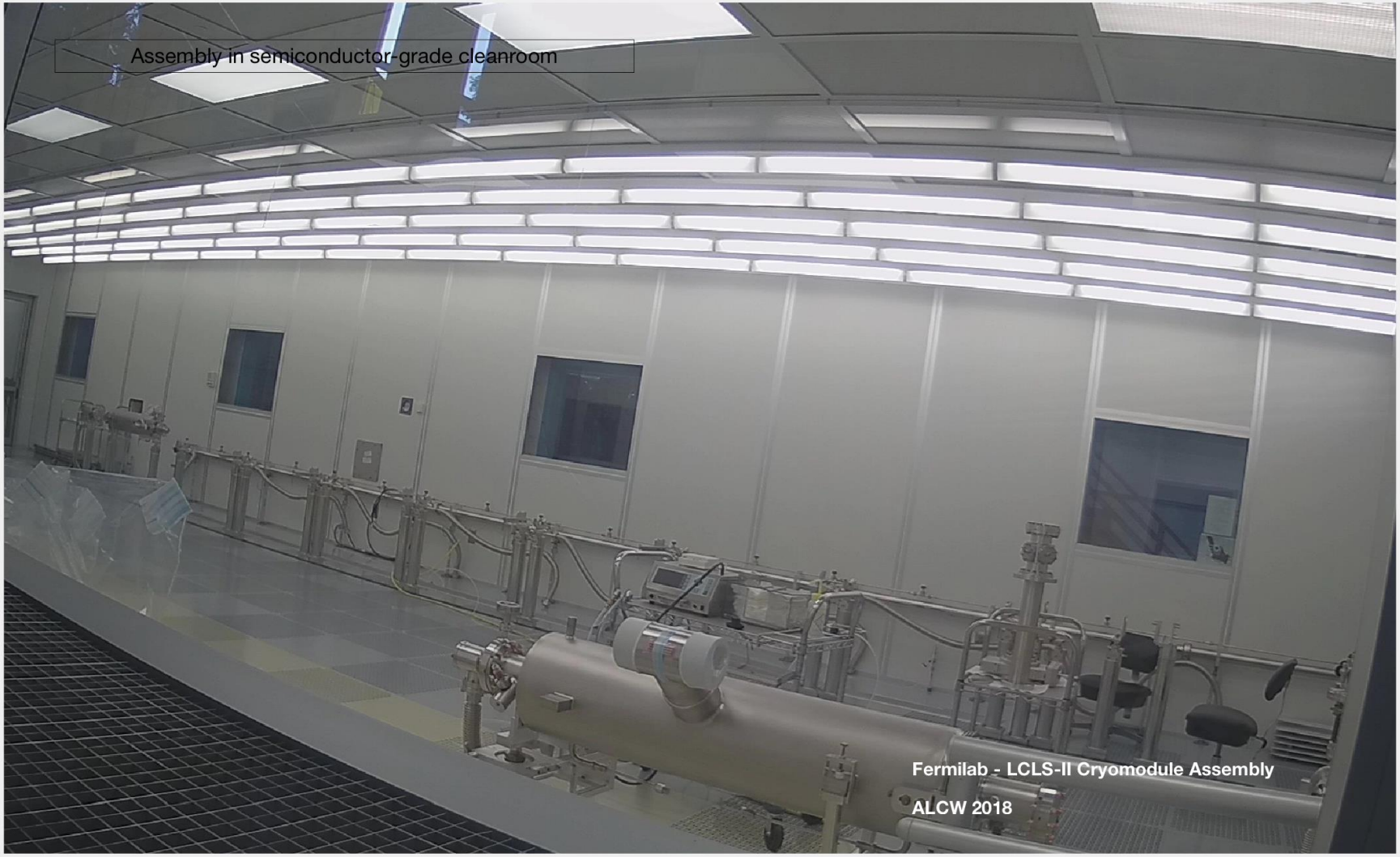
- Lakeshore Cryotronics: cryogenic temperature sensors
- Bartington Instruments: cryogenic fluxgate magnetometers

Cernox® SD package



Images courtesy Lakeshore, Bartington, Fermilab LCLS-II

Putting it all Together – Cryomodule Assembly



DOE SBIR Program – Investing in Small Businesses

- Small Business Innovation Research / Technology Transfer awards
  - Phase 1: ~$100k over 1 yr
  - Phase 2: ~$1M over 2 yrs
- Competitive proposals
- Stimulate tech innovation, encourage small businesses, increase commercialization of federally supported R&D

Selection of topics from 2018 announcement:

23. ADVANCED CONCEPTS AND TECHNOLOGY FOR PARTICLE ACCELERATORS

a. 3D Printing of Accelerator Components
b. Wakefield Acceleration
c. Beam Diagnostics Tools
d. Non-Linear Magnets for High Dynamic Aperture Lattices
e. Activation Studies and Shielding Design
f. Electron Lenses
g. Other

24. RADIO FREQUENCY ACCELERATOR TECHNOLOGY

a. Cooling Systems for High-Heat-Density RF Devices
b. High Gradient Accelerator Research and Development
c. High Efficiency High Average Power RF Sources
d. Other

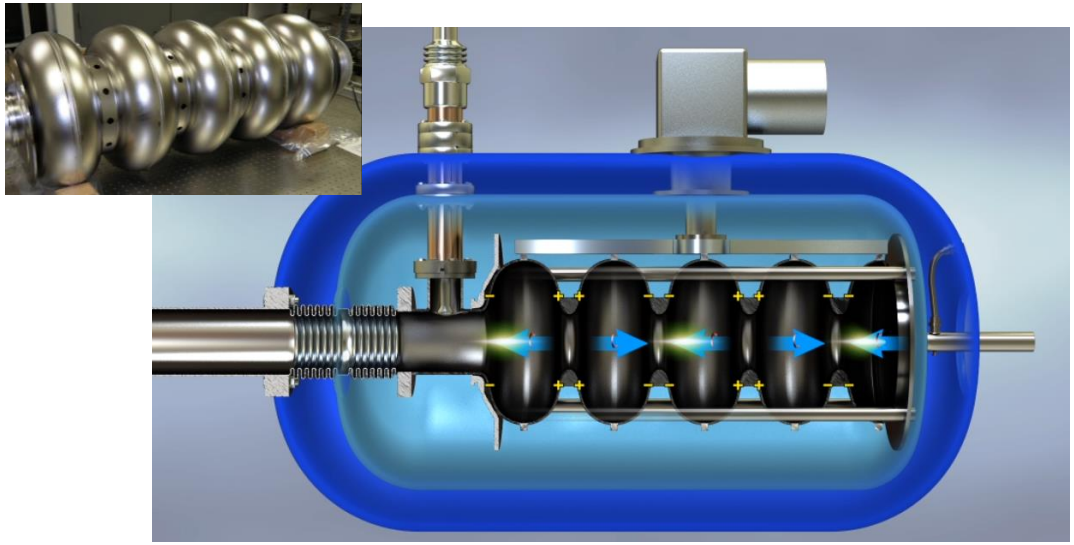
25. LASER TECHNOLOGY R&D FOR ACCELERATORS

a. Cost Reduction of Ultrafast Fiber Laser Components
b. Novel, Scalable Techniques for Carrier-Envelope Phase Locking of Multiple Fiber Lasers
c. Ceramic-Based Optical Materials
d. High Reliability Arbitrary Pulse Pattern Laser Amplifiers for H- Beam Control and Diagnostics
e. Aperture-Scalable High Performance Diffraction Gratings
f. Computer Modeling and Development of High Power Coatings for Ultrafast Optics
g. End-to-End Systems Modeling of Large Ultrafast Laser Systems
h. High Efficiency Spatial Mode Shaping and Control for High Power Ultrafast Lasers
i. Other

26. SUPERCONDUCTOR TECHNOLOGIES FOR PARTICLE ACCELERATORS

a. High-Field Superconducting Wire and Cable Technologies for Magnets
b. Superconducting Magnet Technology
c. Superconducting RF Cavities
d. Ancillary Technologies for Superconducting Magnets
e. Other

Fermilab Contributing to Development of Technology for an Industrial-Scale SRF Accelerator



- Energy: ~ 10 MeV
- Power: 250 kW
- Compact
- Simple, reliable
- Affordable

- 650 MHz cavity w/ conduction cooling via cryocooler
- Accelerator system <3000 lbs ➔ mobile applications
- Potential to enable applications in wastewater treatment, border security, compact light sources – **direct, positive impact on general public**

* FNAL patents pending

Slide courtesy Charles Thangaraj/IARC, Fermilab

Summary

- Industrialization has substantial benefits to large science projects
- Industrialization activities in previous projects like EXFEL and LCLS-II have reduced costs and cost risk for future projects like ILC and PIP-II
- Recent successes include technology transfer of nitrogen doping treatment to cavity vendors for LCLS-II
- Projects benefit from North American vendors with expertise in highly technical areas and high degree of reliability
- Laboratory relationship highlights include SBIR program, technology transfer efforts, and compact SRF accelerator development