16 May 2026

Applications of accelerators, engagement with industry, technology transfer and outreach

Sam Posen

IPAC 2026 – Normandy, France

FERMI NATIONAL ACCELERATOR LABORATORY

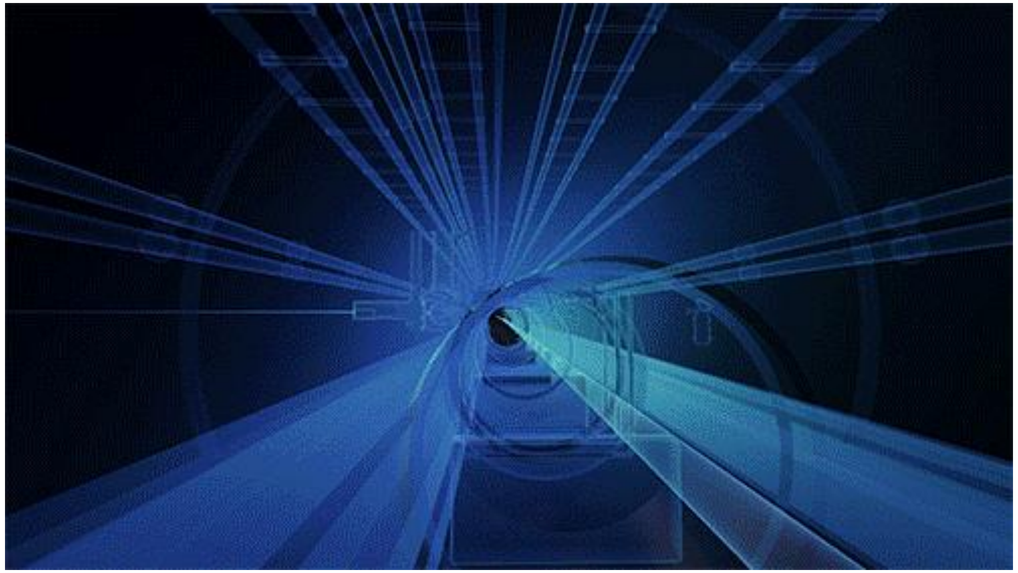
1

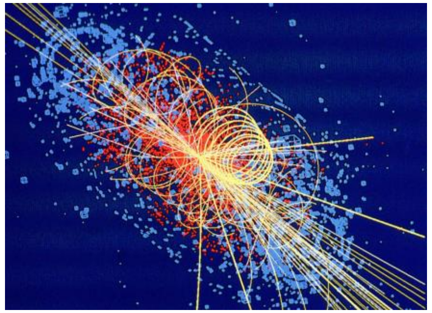
Introduction

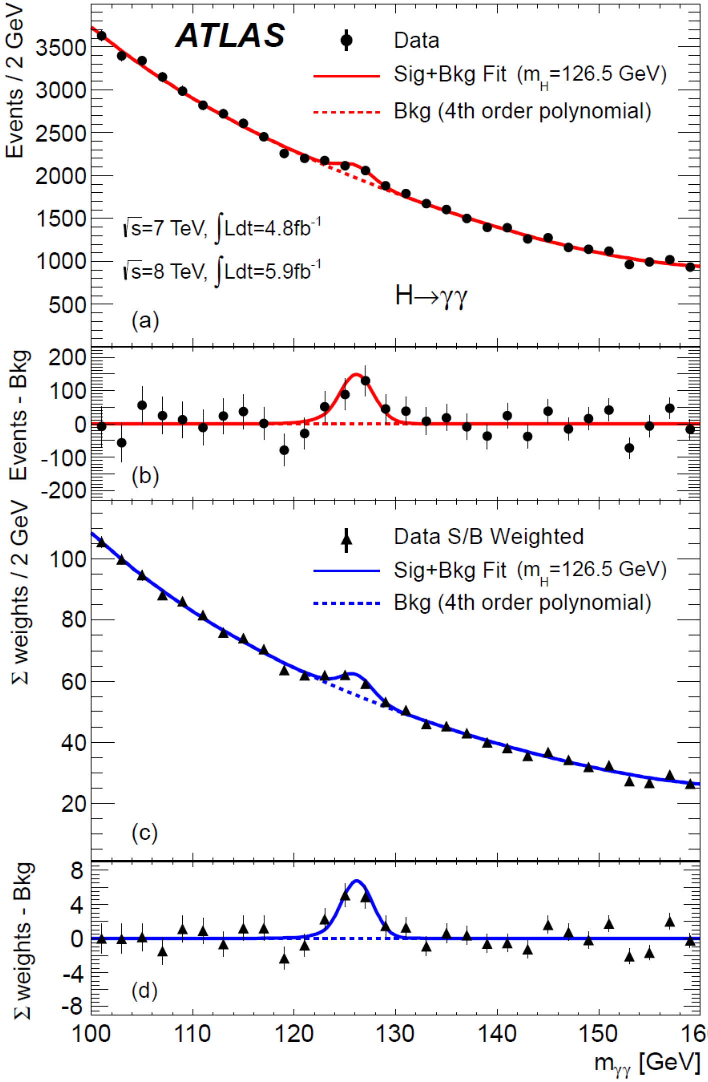
Colliders

The Large Hadron Collider (LHC)

The Large Electron-Positron Collider (LEP)





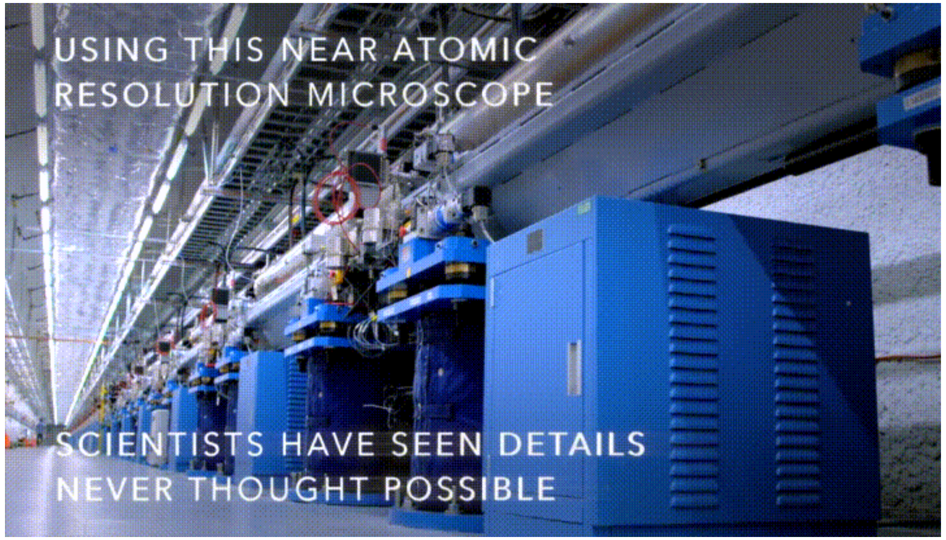


Images from CERN, google, nobelprize.org, arXiv:1207.7214v2

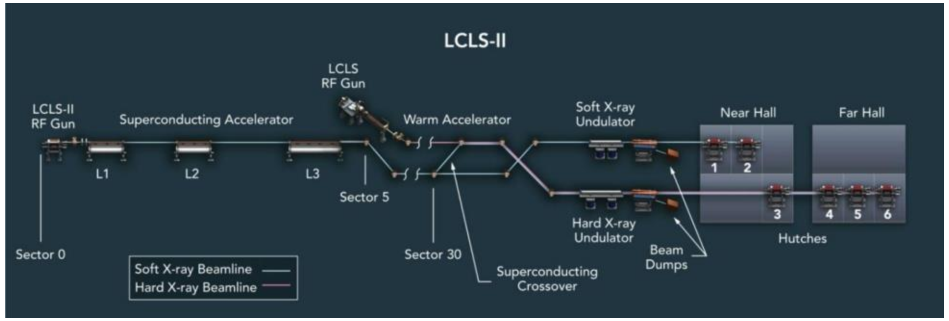
Light Sources

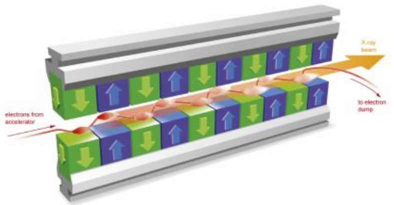
LCLS-II

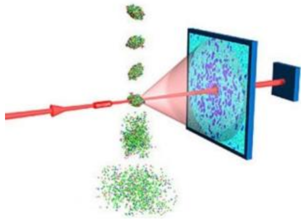
European XFEL


USING THIS NEAR ATOMIC RESOLUTION MICROSCOPE

SCIENTISTS HAVE SEEN DETAILS NEVER THOUGHT POSSIBLE



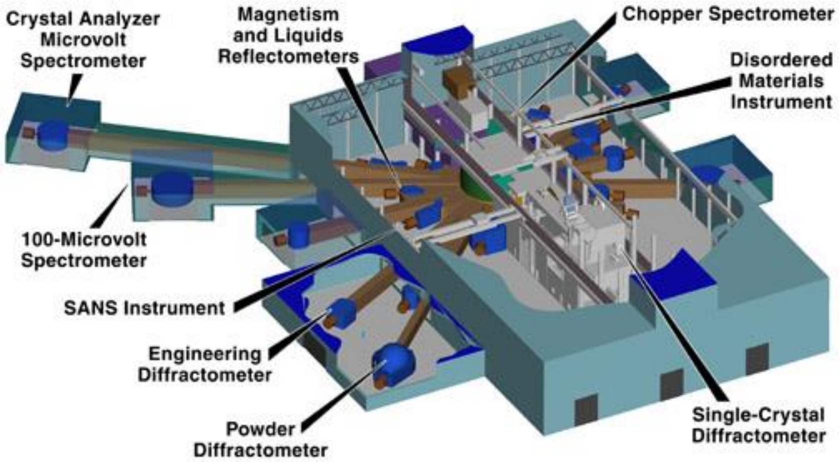


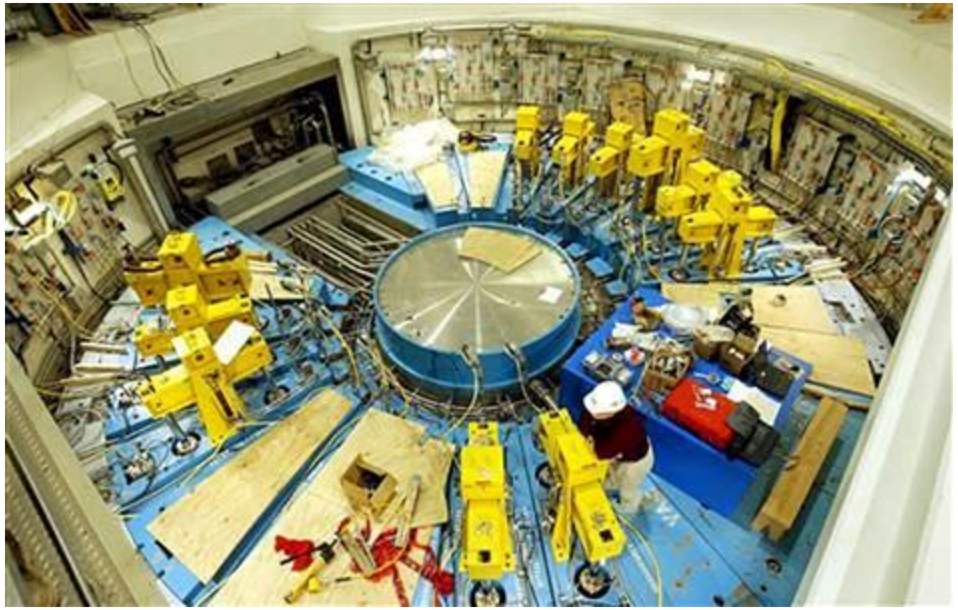


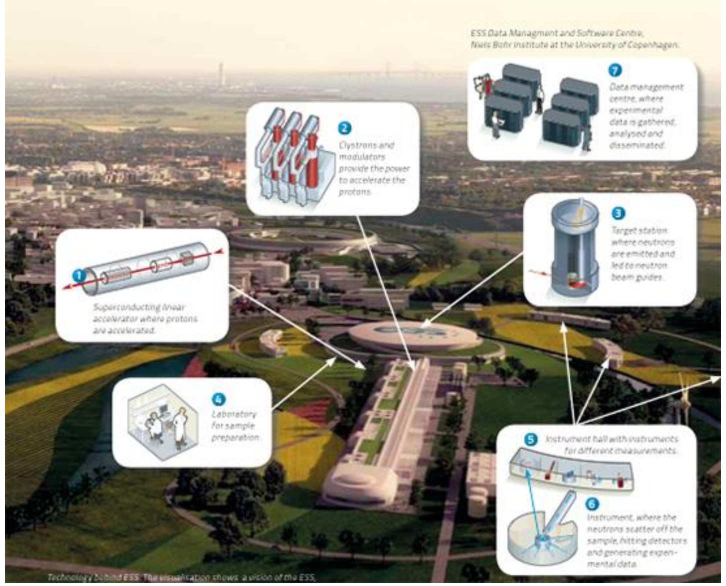
Images from LCLS-II and the European XFEL
youtu.be/t7jUZwhZdd0

Neutron Sources

EUROPEAN
SPALLATION
SOURCE

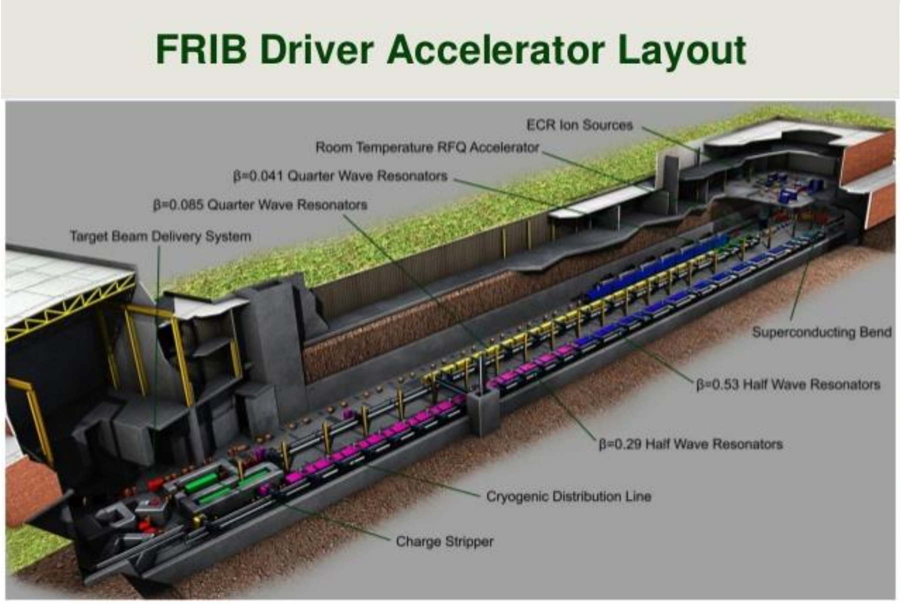


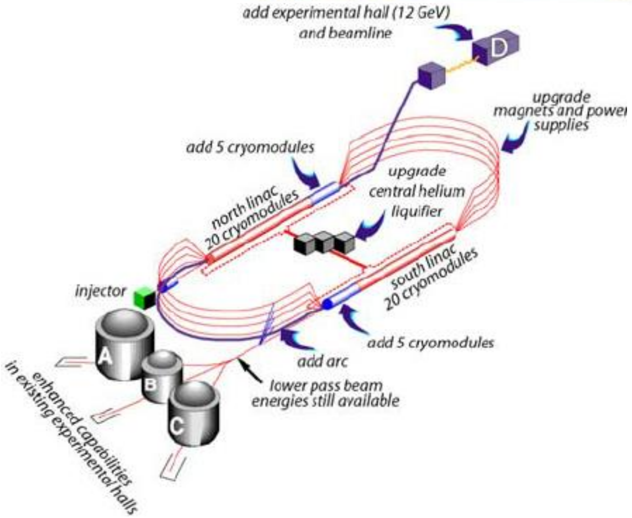


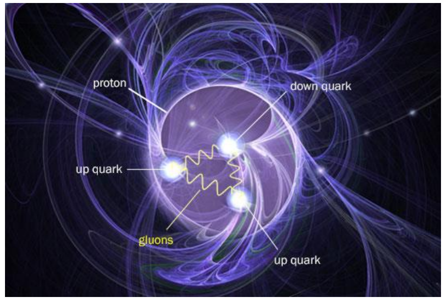


Images from Spallation Neutron Source, Oak Ridge National Laboratory and European Spallation Source

Nuclear Physics

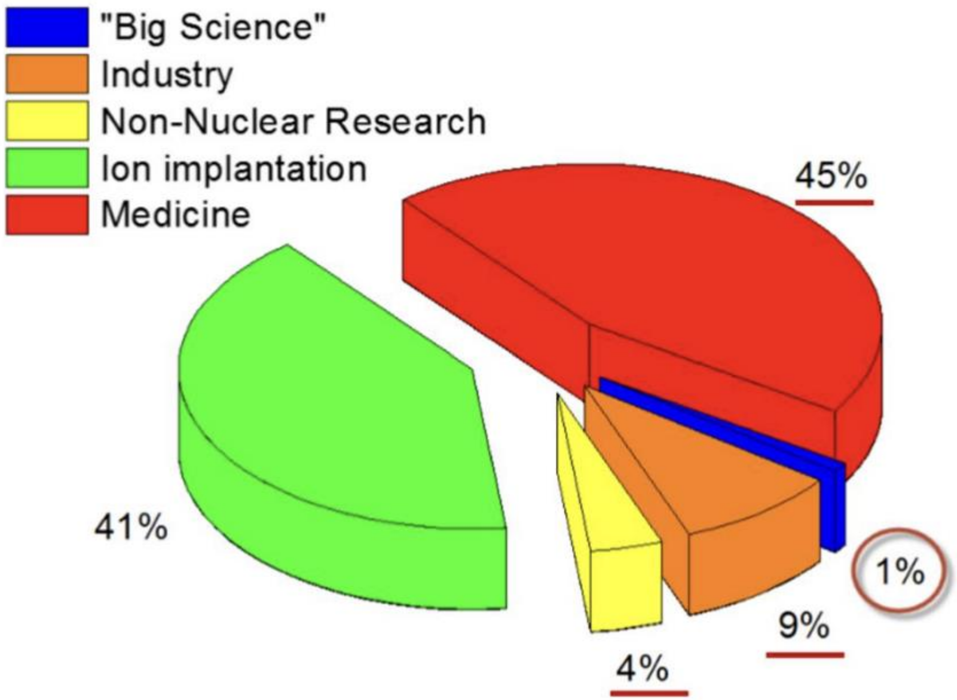




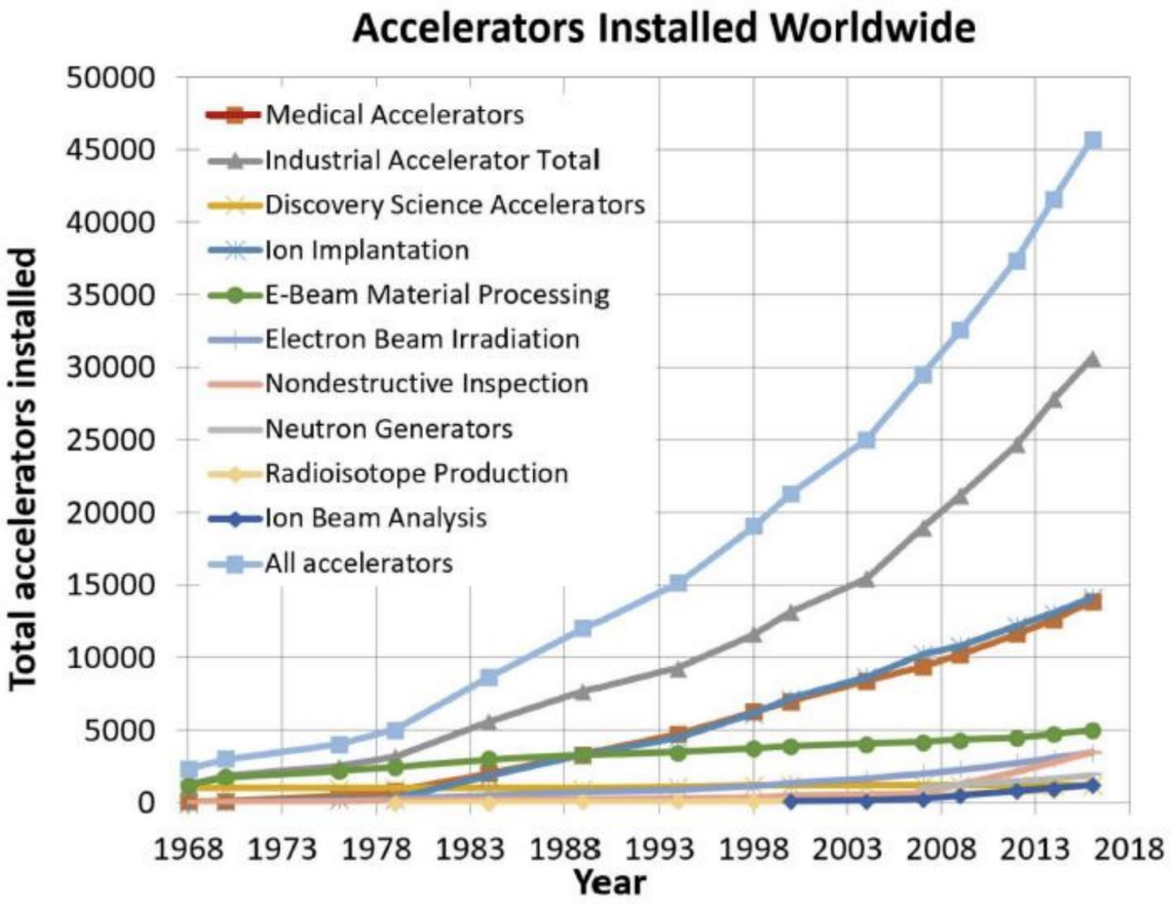


Images from FRIB (Michigan State University), RISP (RAON, Korea), CEBAF (Jefferson National Laboratory, Virginia), Brookhaven National Laboratory, New York)

Particle accelerator technology is used in many exciting applications beyond accelerator-based science



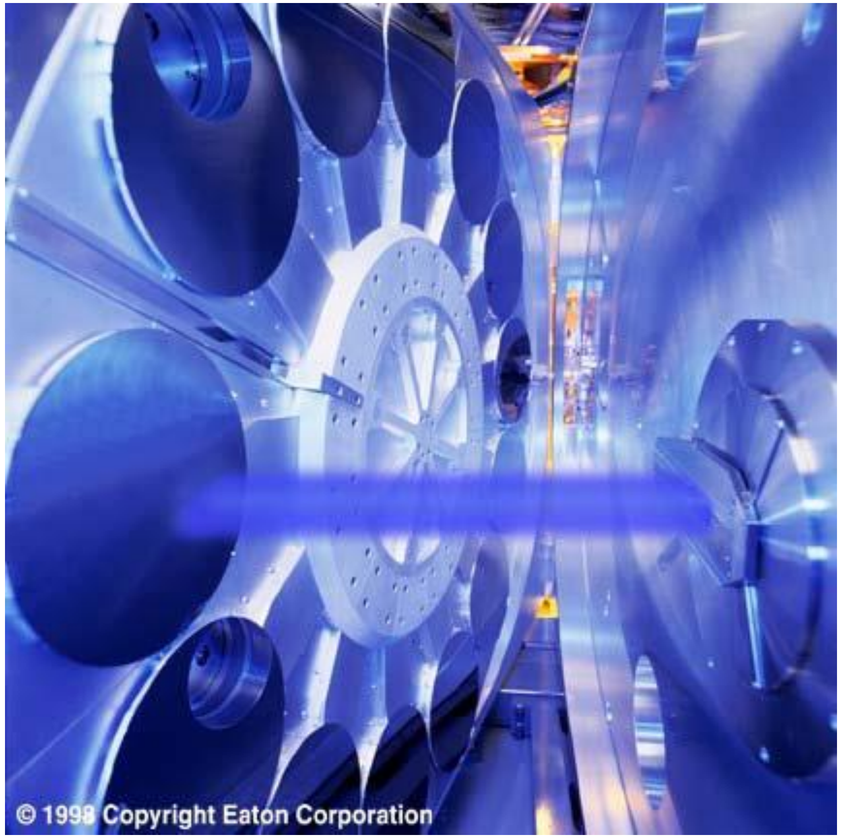
Kutsaev, S.V.. *Eur. Phys. J. Plus* **136**, 446 (2021



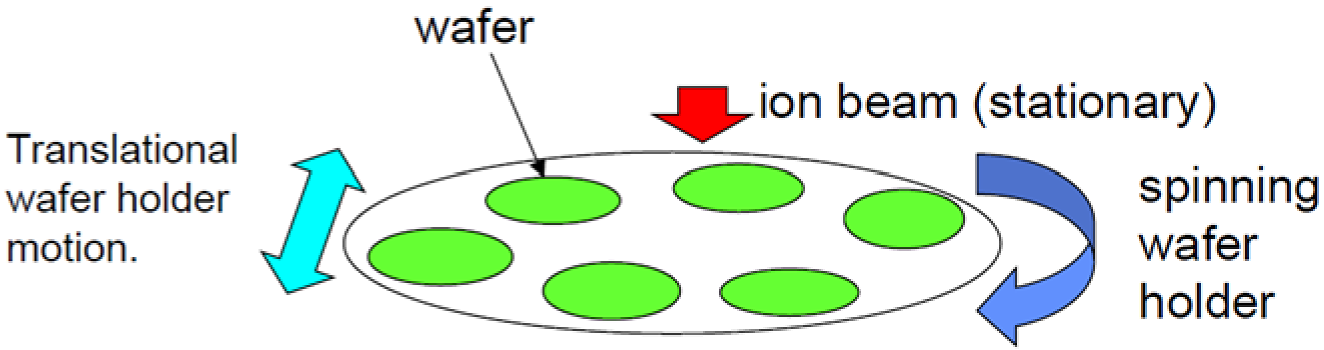
Doyle, McDaniel, Hamm, *The Future of Industrial Accelerators and Applications, SAND2018-5903B*

Slides from S. Sheehy, U. Melbourne, CERN Accelerator School and P. Buaphad

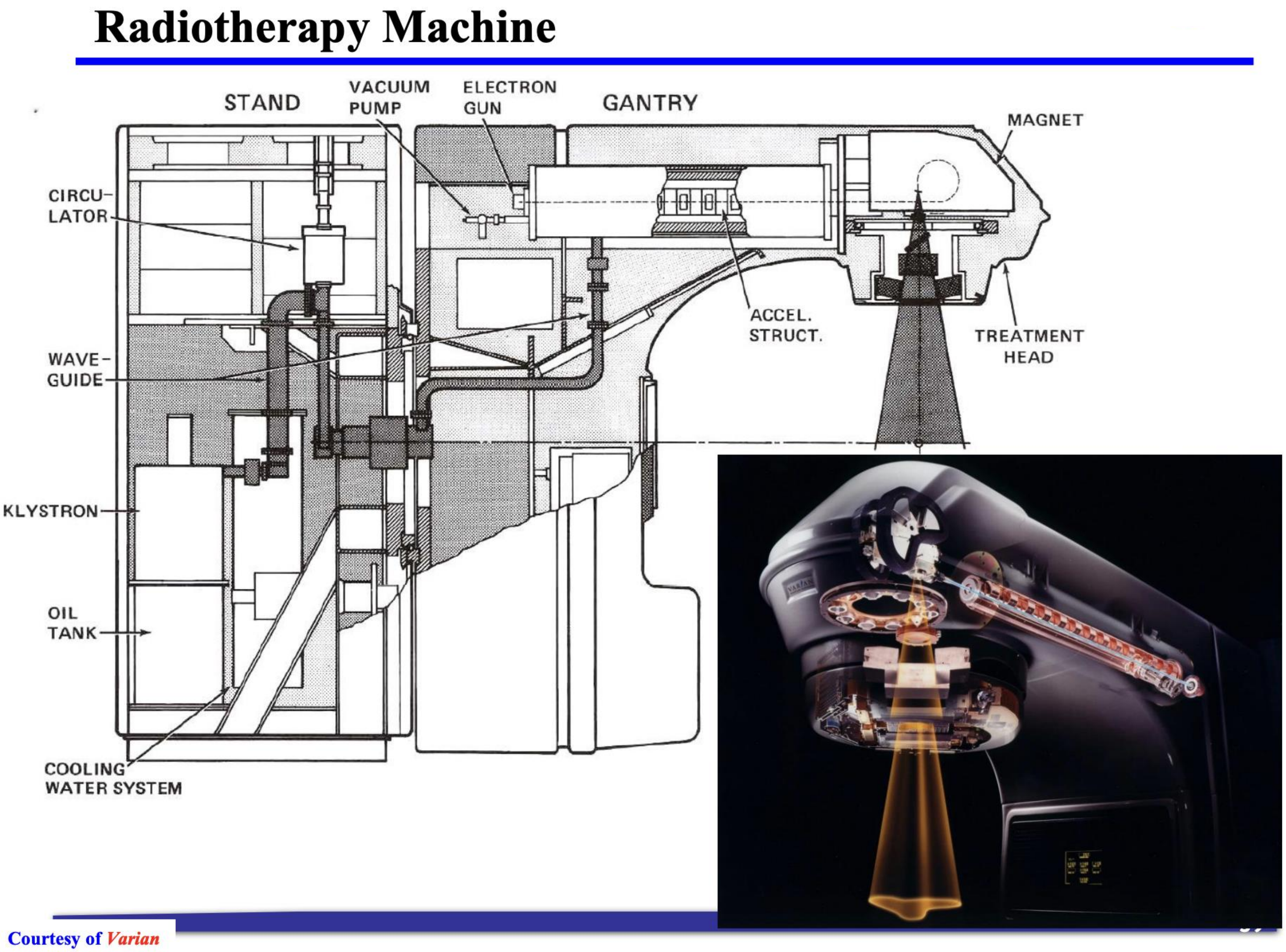
Ion Implantation


© 1998 Copyright Eaton Corporation

Eaton HE3 High Energy Implanter, showing the ion beam hitting the 300mm wafer end-station.



Slide from Bo Cui, University of Waterloo



Radiotherapy Machine

Courtesy of *Varian*

Slide from P. Buaphad, Chiang Mai University, ISBA24

Outline

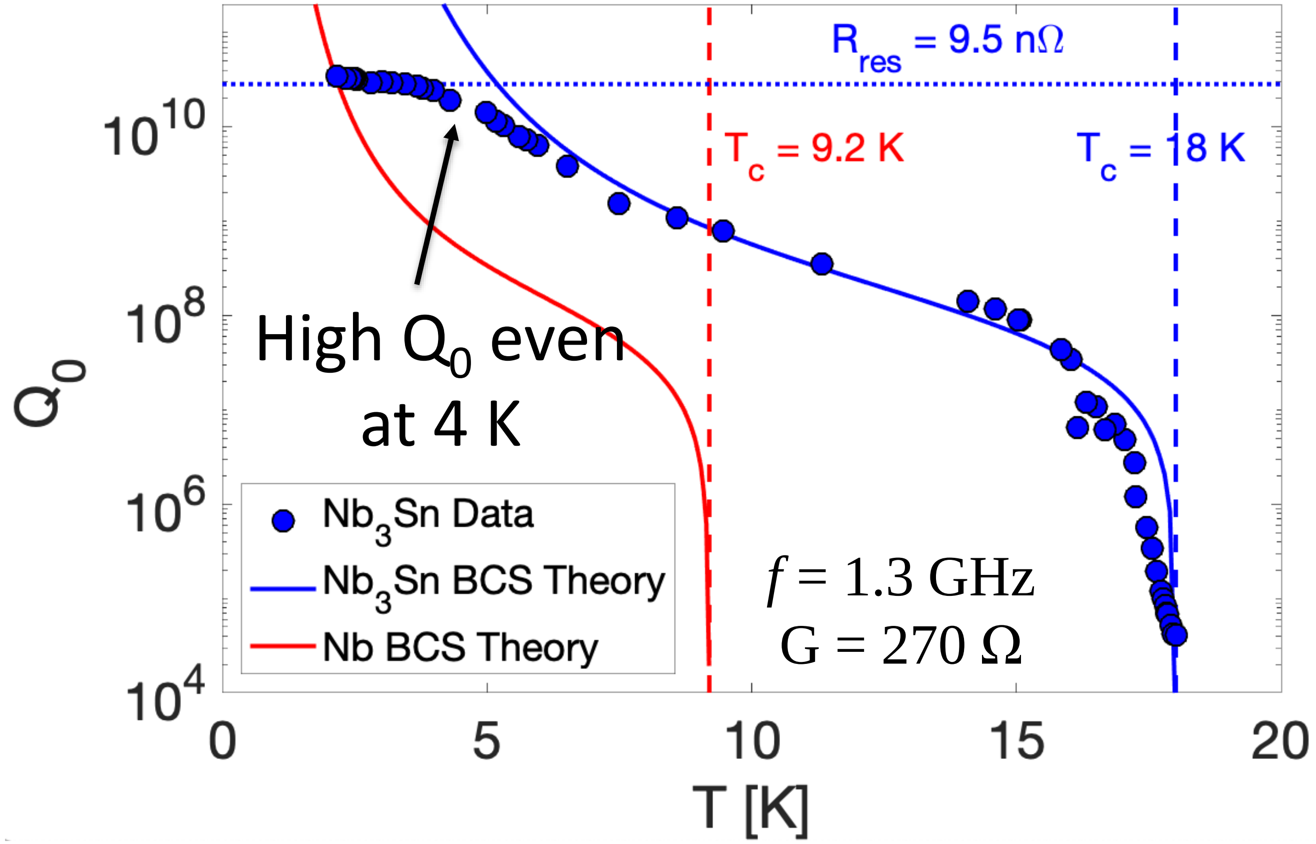
01	Introduction
02	Compact SRF Accelerators
03	Quantum Computing
04	“Beyond-the-Standard-Model” Physics with Accelerator Technology
05	Technology Transfer
06	Summary

2

Compact SRF Accelerators

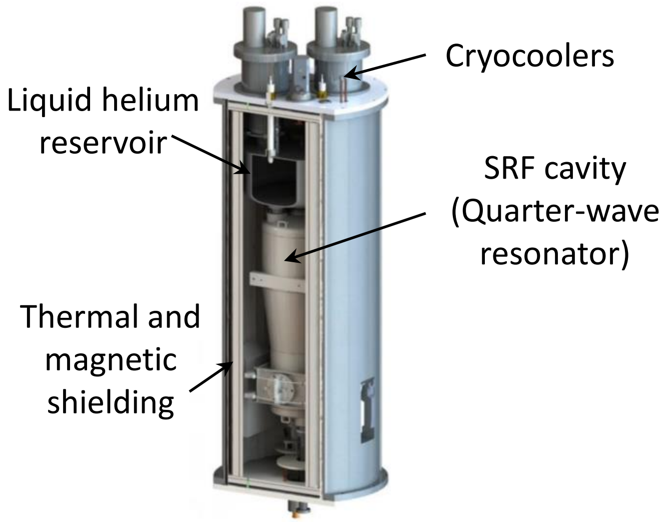
Advantages of Nb_3Sn Cavities: Higher Q_0 at High Temperature

- Nb_3Sn has substantially higher T_c than Nb (18 K vs 9 K)
- High Q_0 at relatively high temperatures
  - Potential for high $Q_0 > 10^{10}$ in ~4.5 K operation in liquid helium
  - Potential for replacing cryoplant with cryocoolers
  - Even eliminating liquid helium via conduction cooling
- Impacts for high duty factor applications, especially small and medium-scale

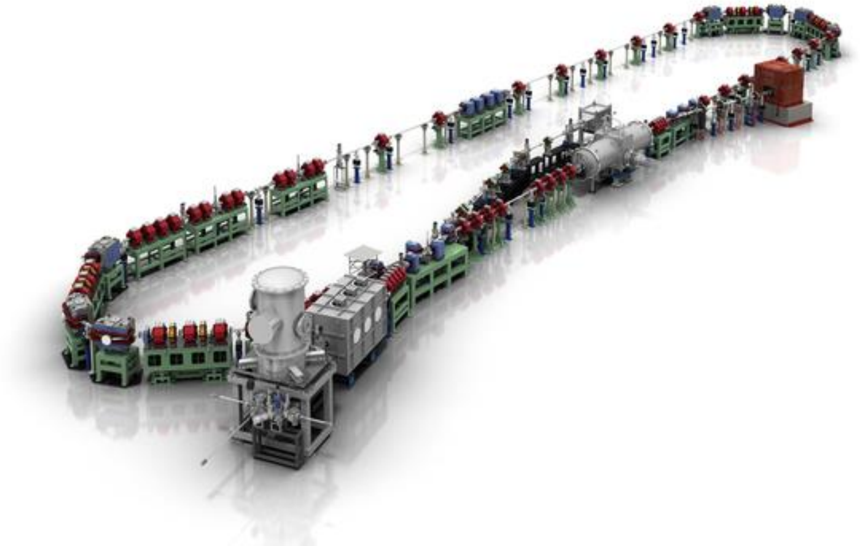


Potential Near-Term Applications of Nb_3Sn Cavities

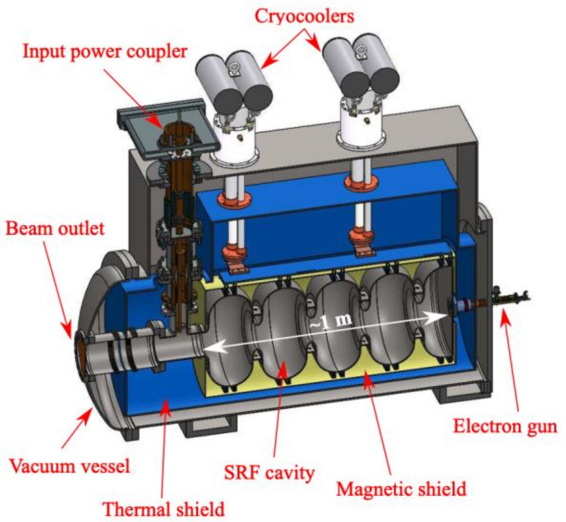
- Nb_3Sn is a potentially enabling technology for CW accelerator applications that could be realized in the near future:
  - Stand-alone cryomodules (e.g. isotope separator, harmonic cavities)
  - Turnkey/high MTBF energy recovery linacs (e.g. isotope production, EUV sources)
  - Compact high power accelerators (e.g. water treatment)



S. Kutsaev et al, *IEEE Trans. App. Superc.* 30, 8, 2020

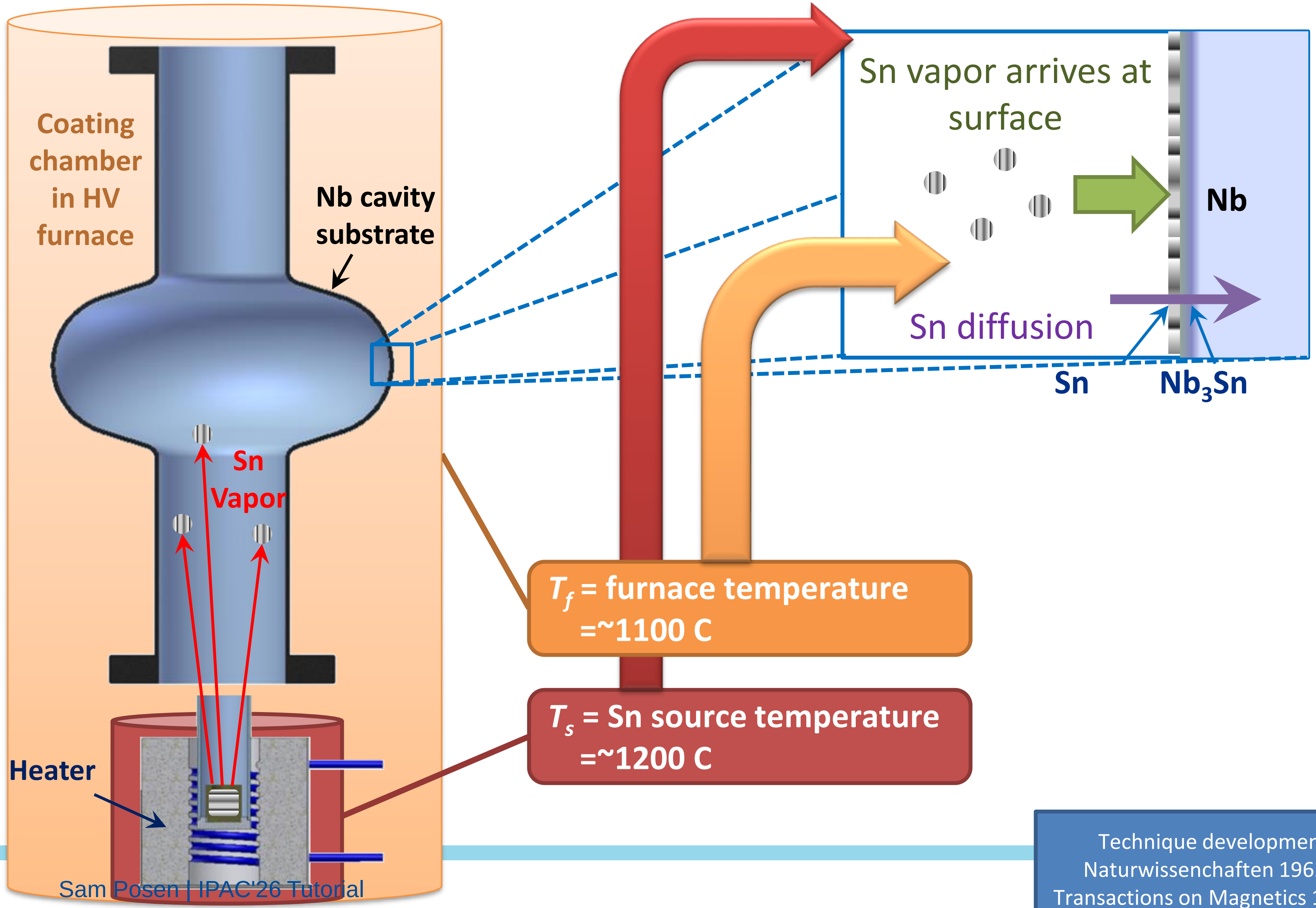


Y. Morikawa et al, New industrial application beamline for the cERL in KEK, IPAC’19, THPMP012



R.C. Dhuley et al, *Phys. Rev. Accel. Beams.* 25, 041601 (2022).

Coating Mechanism: Vapor Diffusion



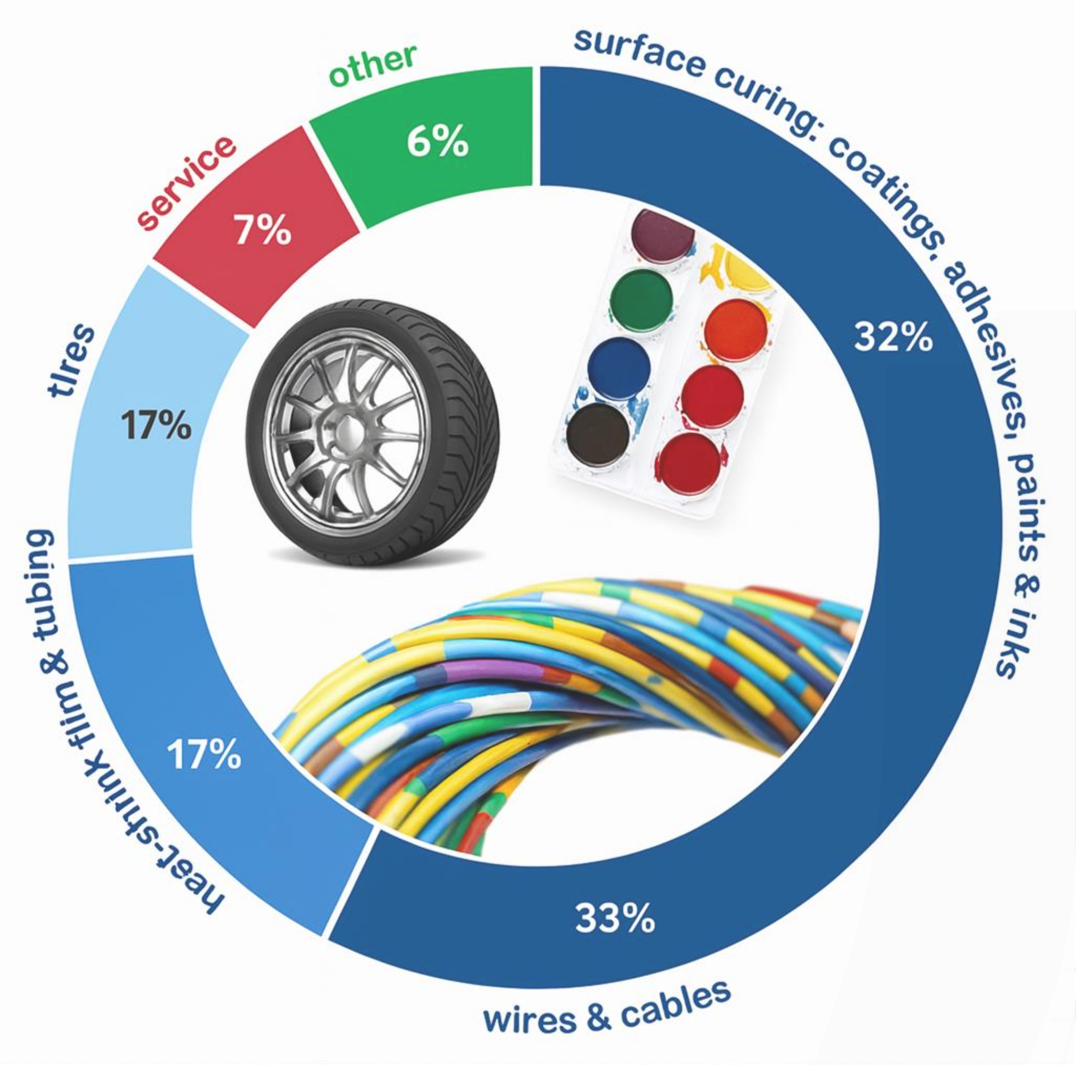
T_f = furnace temperature =~1100 C

T_s = Sn source temperature =~1200 C

Technique development: Saur and Wurm, Die Naturwissenchaften 1962, Hillenbrand et al. IEEE Transactions on Magnetics 1977, Peiniger et al, SRF'88.

Electron Beams for Industrial Applications

Slide courtesy C. Thangaraj, FNAL



Current End-use Market Distribution of Electron Beam Industrial Applications

87% of these e-beam processes involve crosslinking, represented by the applications in blue segments

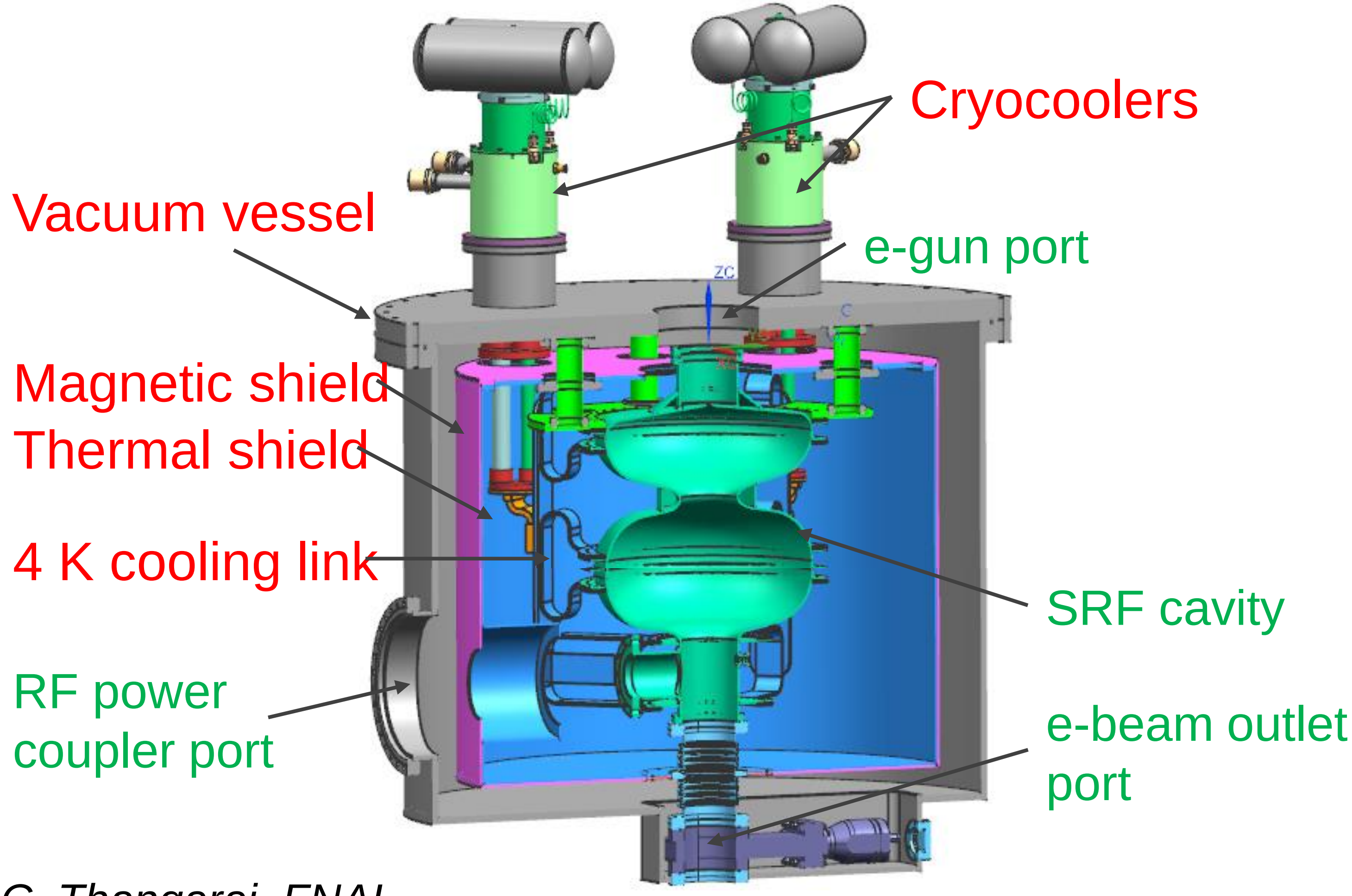
High power compact SRF accelerators based on Nb_3Sn can open *new* applications in the near future

Grdanovska, S., and Cooper, C, "Electron Beam Driven Industrial Chemistries". *Fermi National Accelerator Laboratory, U.S. DOE Office of Science,* ***2018***
https://inspirehep.net/files/ebe712e944f15ba044ed86b93556aa33

Compact SRF Accelerators – an Emerging Tool for Industrial Applications

- Because of Nb_3Sn and cryocooler technology, there is an emerging opportunity to build industrial accelerators with:
  - The advantages of SRF: high wall-plug **efficiency**, simultaneous **high energy** and high **duty factor**, high **power**
  - But now with: small **footprint**, **turnkey** operation, low **operating costs**

Section view of a FNAL Conduction Cooled SRF Accelerator prototype



Slide courtesy C. Thangaraj, FNAL

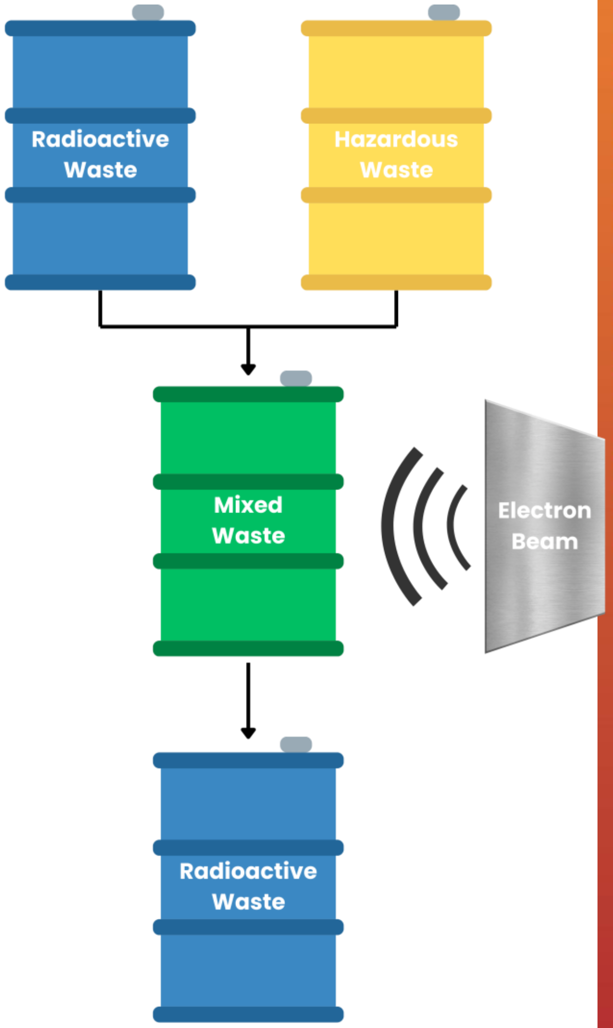
Application: Remediation of Mixed Waste

E-beam can break down:

- Toxic chemicals to allow for safer handling and easier transportation;
- Volatile substances to help prevent build-up of explosive gas mixtures over time;
- Corrosive substances that can breakdown containers and allow leaching.

E-beam treatment can potentially remediate the hazardous component of mixed waste, leaving it only radioactive.

- Could reduce overall cost and regulation, hence, simplify transport.
- Could improve safety of handling mixed waste.

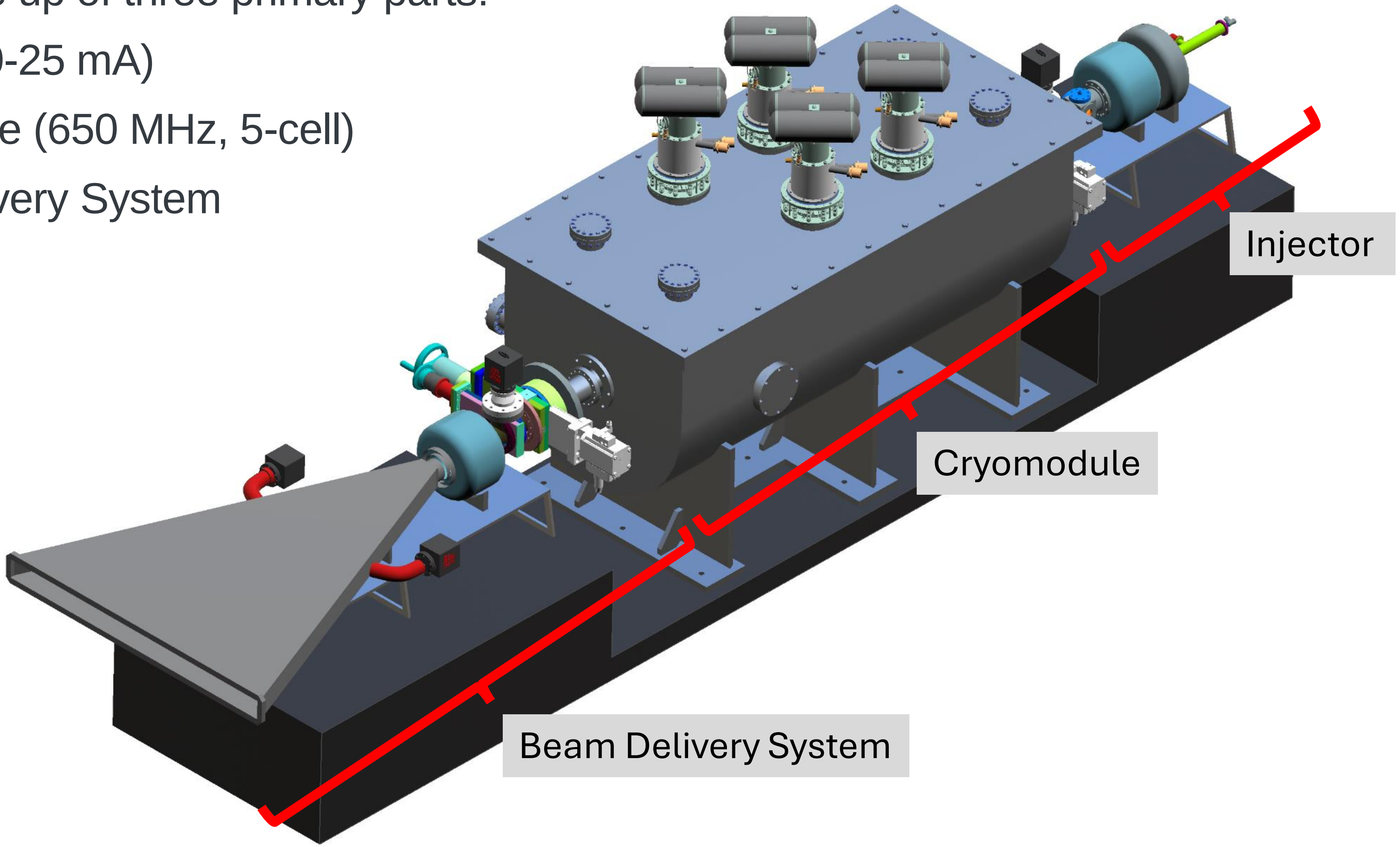


Slide courtesy C. Thangaraj, FNAL

Remediation of Mixed Waste: Modular system at 100+ kW

System is made up of three primary parts:

1. Injector (10-25 mA)
2. Cryomodule (650 MHz, 5-cell)
3. Beam Delivery System



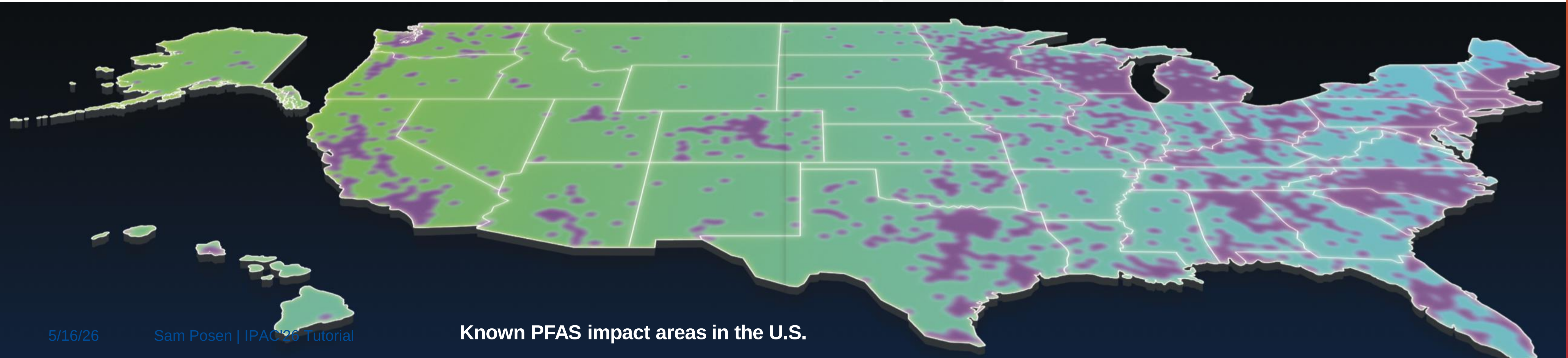
Slide courtesy C. Thangaraj, FNAL

Application: PFAS Destruction

Slide courtesy C. Thangaraj, FNAL

- **Persistent:** C–F bond energy > 480 kJ/mol → resists thermal, chemical, biological degradation.
- **Ubiquitous:** Detected in > 98 % of U.S. population and global water sources.
- **Toxic:** Associated with immune and developmental effects.
- **Opportunity:** High-energy electrons = direct molecular-bond cleavage → true destruction.

Some popular products that contain PFAS



Known PFAS impact areas in the U.S.

What are “Forever Chemicals”? – *PFAS*

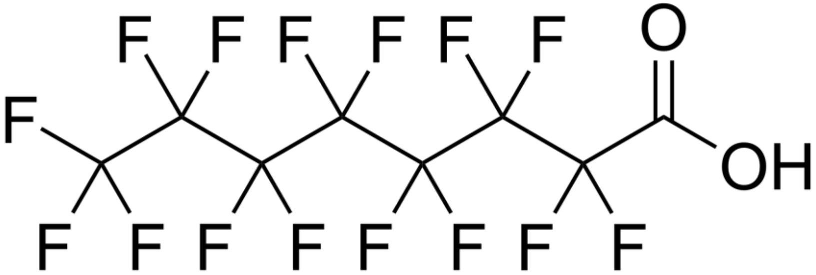
- these days used synonymously with forever chemicals
- per- and polyfluoroalkyl substances

  ↪ de facto (long) chains of C atoms, many F’s & a functional group

- recent proposed drinking water restrictions by EPA (*US*)
  - PFOA, PFOS, PFNA, PFHxS, PFBS, HFPO-DA (GenX)
  - proposed limits basically as low as detection limits
- big challenge for wastewater treatment plants

  ↪ current approach often filter & concentrate (GAC) → deal with filter (incinerate …?)

  ↪ cost & energy intensive



https://www.youtube.com/watch?v=9W74aeuqsiU

©HBO

Slide courtesy J. Vennekate, JLab

How does ebeam treatment of water work?

- don’t attack contaminants directly

→ “activate” water with beam

$$e^- \Rightarrow \quad H_2O \rightarrow e^-_{aq} + HO^\cdot + H^\cdot + HO_2 + H_3O^+ + OH^- + H_2O_2 + H_2$$

↪ create oxidants **and** reductants (*not just any, some of the strongest*)

→ those react with contaminants

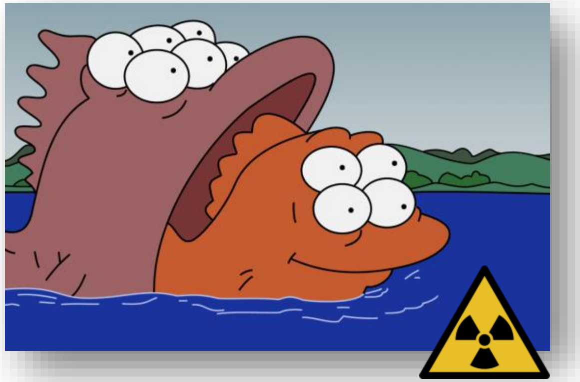
- big benefit → no addition of further chemicals required

↪ very cost-effective generation of free radicals

- And no, we don’t (radio)activate your water!

↪ stay below 10 MeV ↔ neutron activation threshold

\- *Yet, public acceptance oft an issue – “**treatment**” vs “irradiation”*



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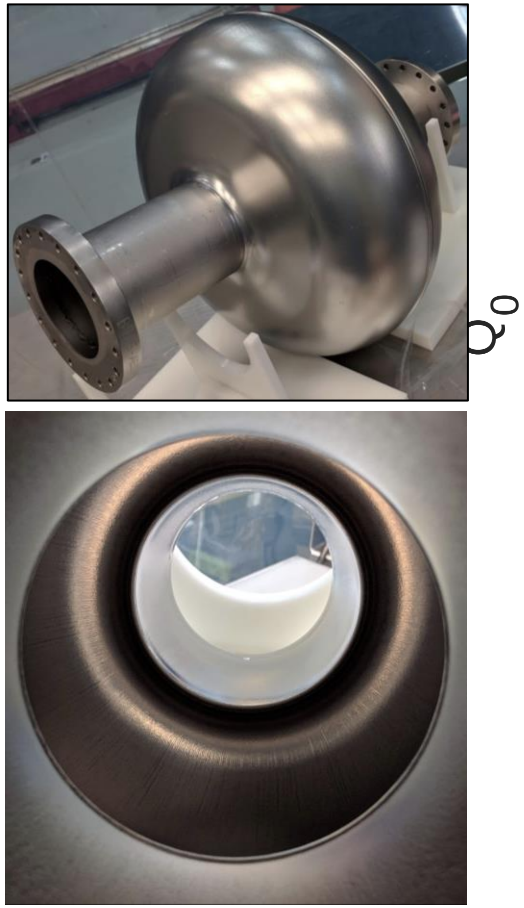
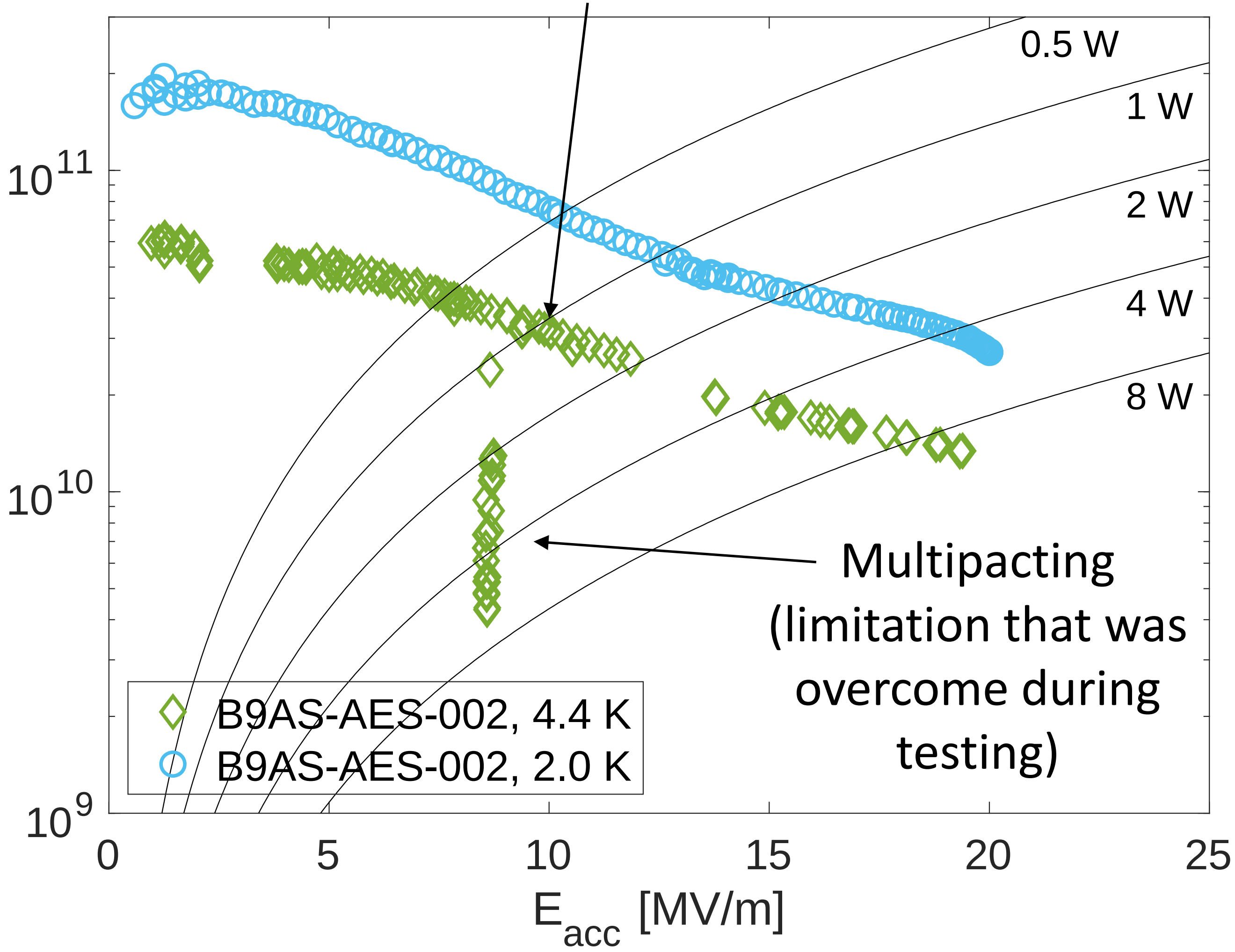
Slide courtesy J. Vennekate, JLab

Low Frequency Cavity – 650 MHz Single Cell

650 MHz cavity
B9AS-AES-002



~1 W dissipation at 10 MV/m, 4.4 K



Multipacting (limitation that was overcome during testing)

PAPER • OPEN ACCESS

Advances in Nb$_3$Sn superconducting radiofrequency cavities towards first practical accelerator applications

S Posen[1], J Lee[1,2], D N Seidman[2,3], A Romanenko[1], B Tennis[1], O S Melnychuk[1] and D A Sergatskov[1]

Published 11 January 2021 • © 2021 The Author(s). Published by IOP Publishing Ltd

Superconductor Science and Technology, Volume 34, Number 2

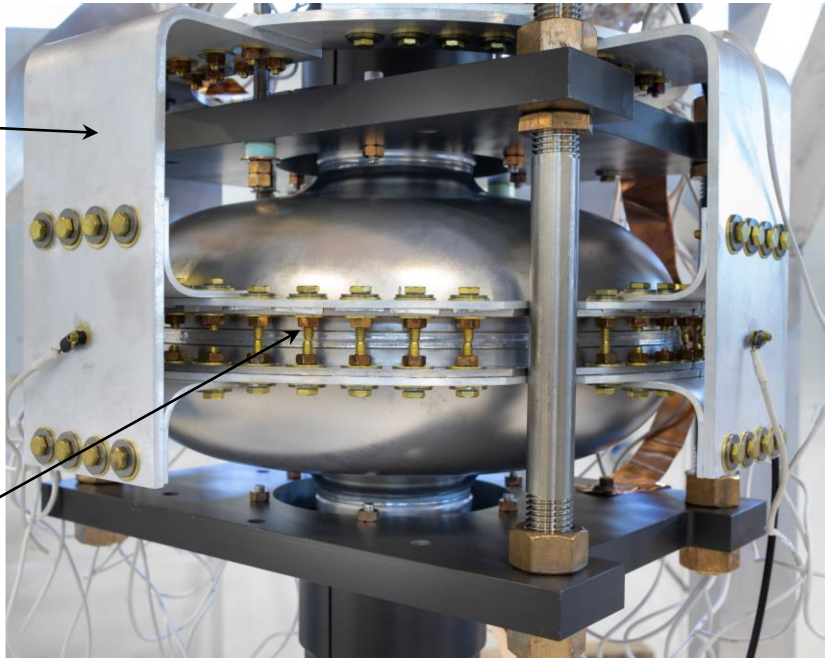
Citation S Posen *et al* 2021 *Supercond. Sci. Technol.* **34** 025007

e.g. Cryomech PT420 has cooling capacity of 2.0 W at 4.2 K

Cryocooler-Based Cooling

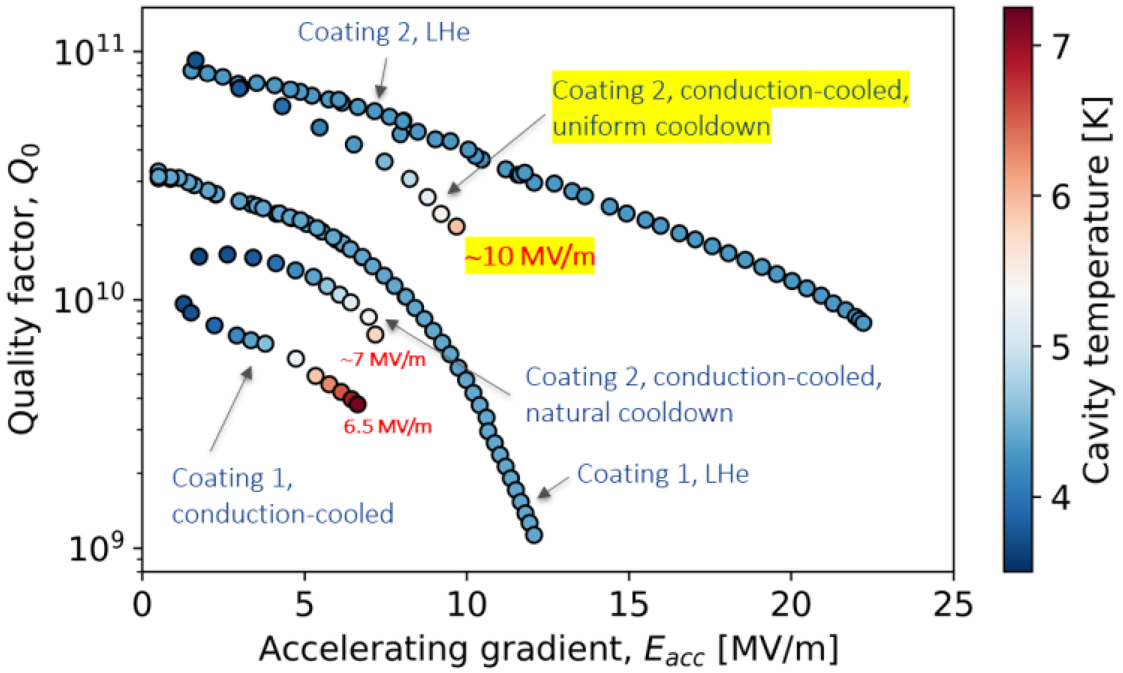
- Nb_3Sn-coated 650 MHz single cell cavity reaches gradient ~10 MV/m with a single cryocooler
- No liquid helium – conduction cooling only

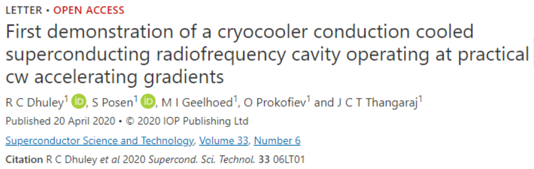
R. Dhuley



High purity aluminum cooling links between cavity and cryocooler

Nb_3Sn-coated cavity with welded Nb rings for attaching cooling links





LETTER • OPEN ACCESS

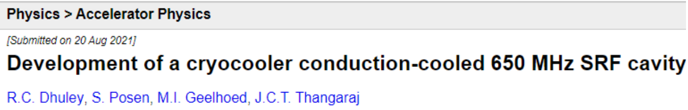
First demonstration of a cryocooler conduction cooled superconducting radiofrequency cavity operating at practical cw accelerating gradients

R C Dhuley[1], S Posen[1], M I Geelhoed[1], O Prokofiev[1] and J C T Thangaraj[1]

Published 20 April 2020 • © 2020 IOP Publishing Ltd

Superconductor Science and Technology, Volume 33, Number 6

Citation R C Dhuley *et al* 2020 *Supercond. Sci. Technol.* 33 06LT01



Physics > Accelerator Physics

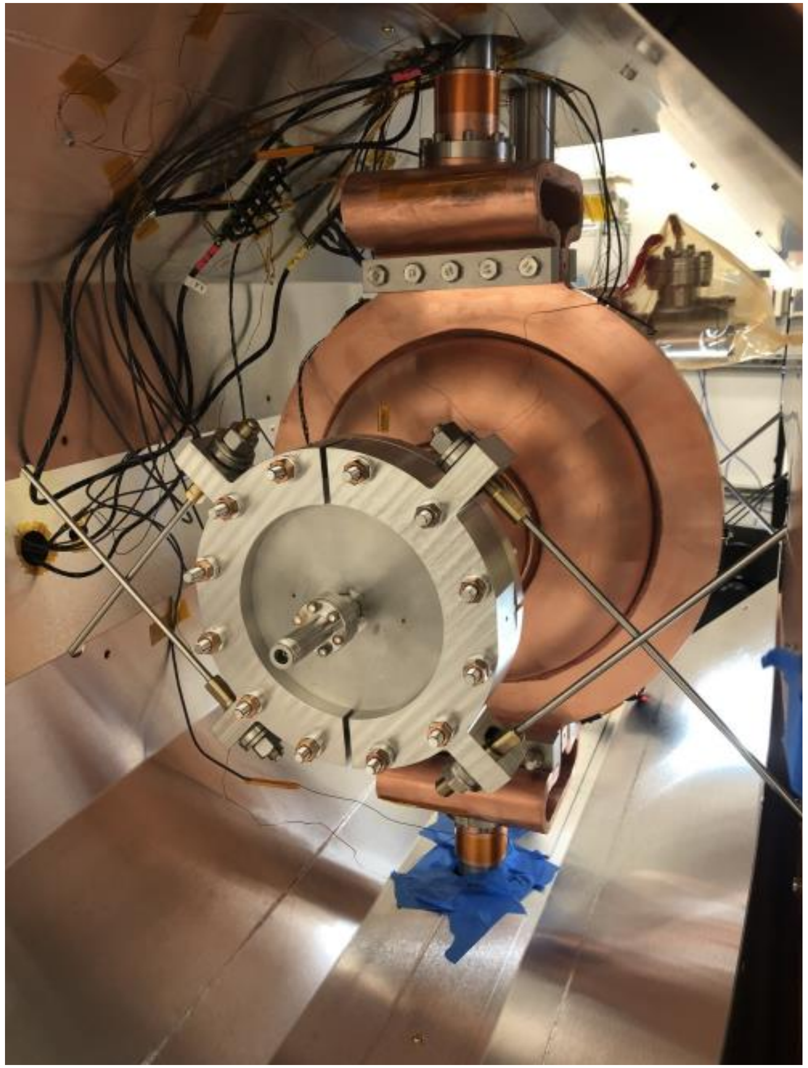
[Submitted on 20 Aug 2021]

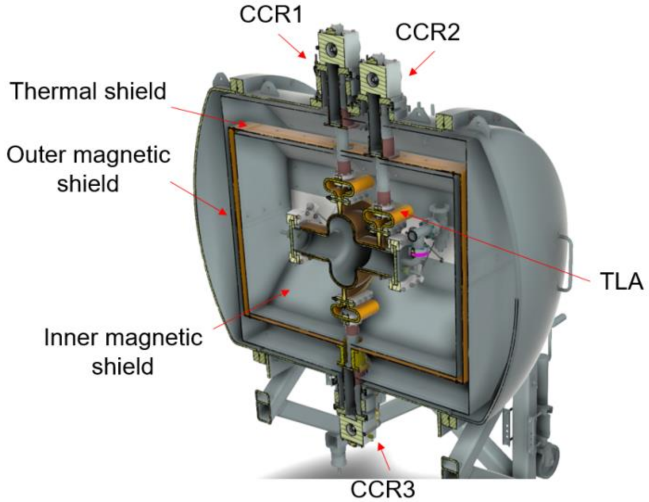
Development of a cryocooler conduction-cooled 650 MHz SRF cavity

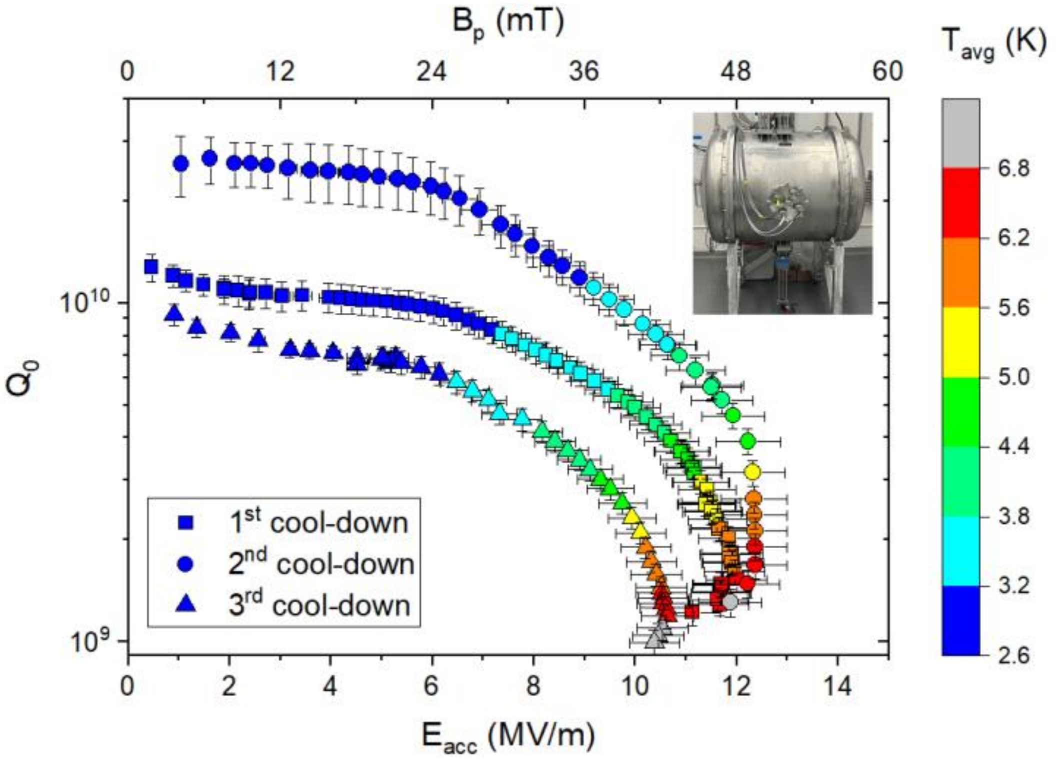
R.C. Dhuley, S. Posen, M.I. Geelhoed, J.C.T. Thangaraj

Jlab+GA Cryomodule Demonstration

- Different approach, using thick copper coating on outside of Nb cavity instead of welded Nb rings
- G. Ciovati et al., arXiv: 2302.07201 (2023)





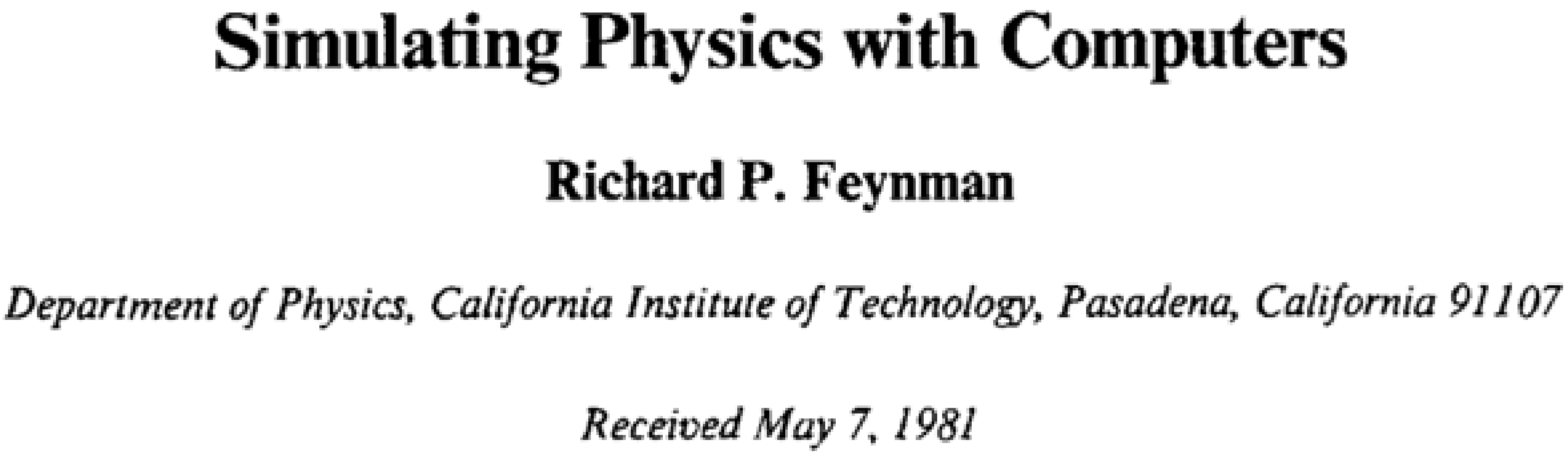


Status and Next Steps

- Recent demonstrations include high performance practical multicell cavities and low beta geometries, beam operation with Nb_3Sn
- Soon, expect first demonstrations where compact SRF accelerators provide advantage – making possible applications that didn't exist before
- Engineering challenges, not fundamental science problems

3

Quantum Computing



Simulating Physics with Computers

Richard P. Feynman

Department of Physics, California Institute of Technology, Pasadena, California 91107

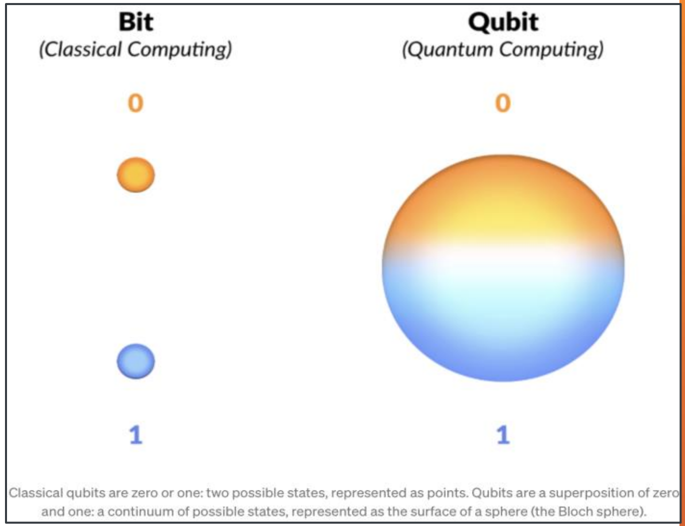
Received May 7, 1981

“Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy”

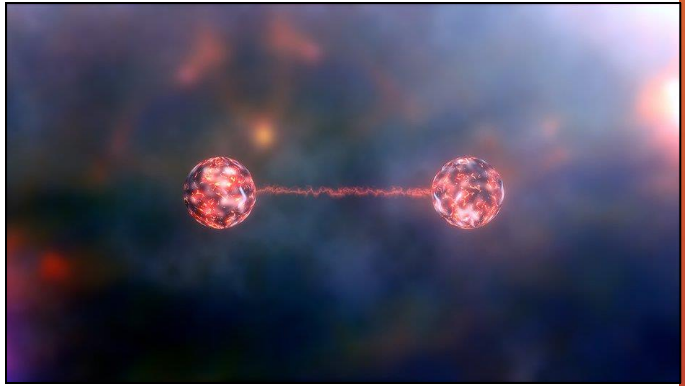
Slide courtesy A. Grassellino, FNAL

Quantum Information Science

- Growing field of science and technology, combining and drawing on the disciplines of physics, mathematics, computer science, and engineering
- Its aim is to understand how certain **fundamental laws of quantum physics** – **superposition, entanglement** - can be harnessed to dramatically improve the acquisition, transmission, and processing of information
- The exciting scientific opportunities offered by QIS are attracting the interest of a growing community of scientists and technologists, and are promoting **unprecedented interactions across traditional disciplinary boundaries**

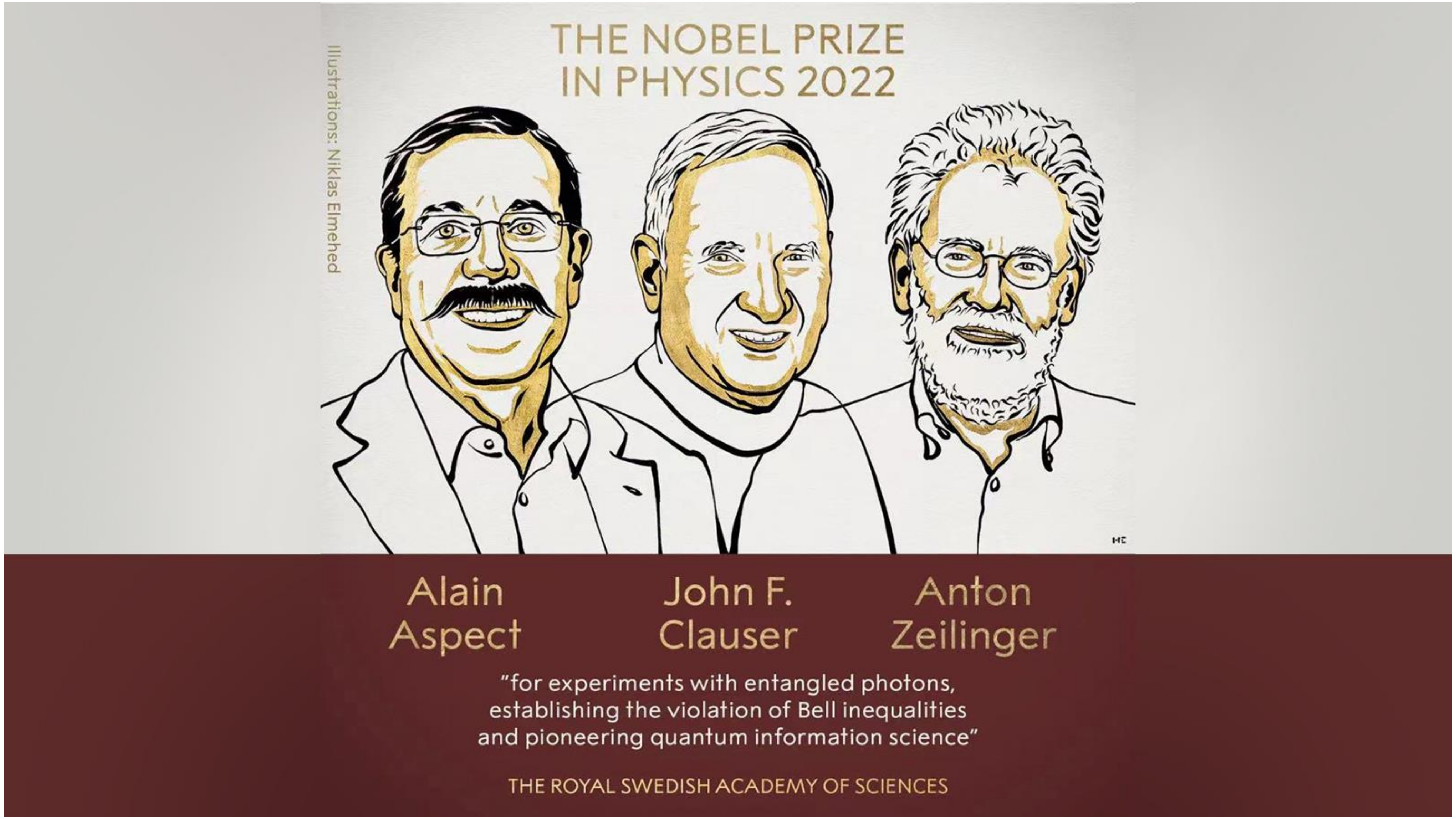


Classical qubits are zero or one: two possible states, represented as points. Qubits are a superposition of zero and one: a continuum of possible states, represented as the surface of a sphere (the Bloch sphere).



Slide courtesy A. Grassellino, FNAL

The world is excited about Quantum



THE NOBEL PRIZE
IN PHYSICS 2022

Illustrations: Niklas Elmehed

Alain Aspect

John F. Clauser

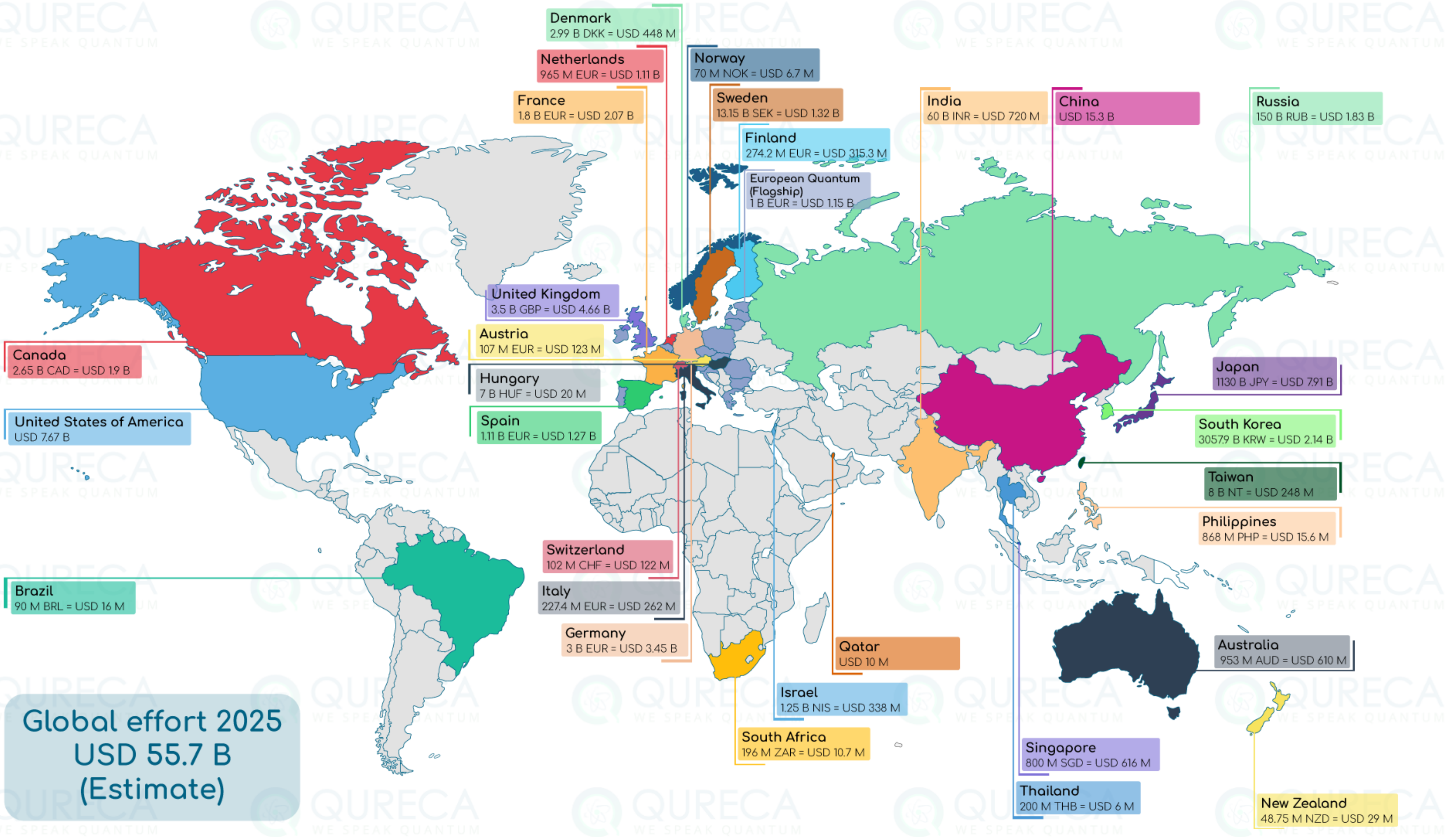
Anton Zeilinger

"for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science"

THE ROYAL SWEDISH ACADEMY OF SCIENCES

Slide courtesy A. Grassellino, FNAL

Quantum Efforts Worldwide 2025

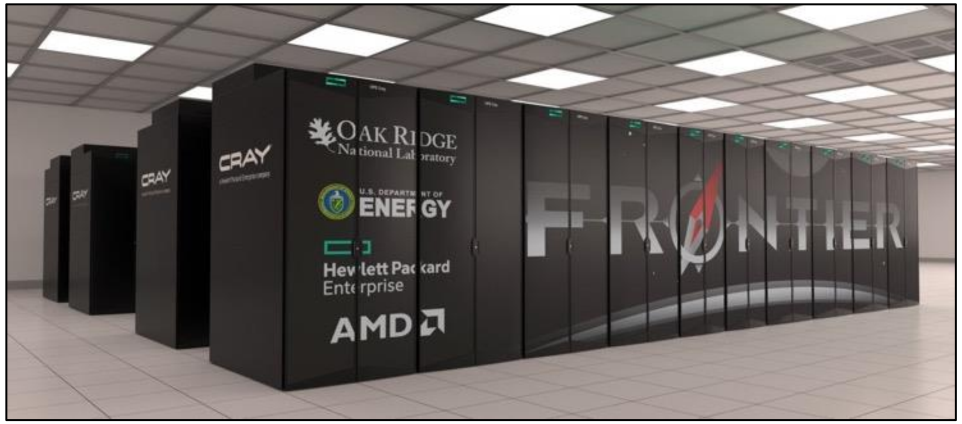


Slide courtesy A. Grasselino, FNAL

Classical Computer vs Quantum Computer

- Classical Computer

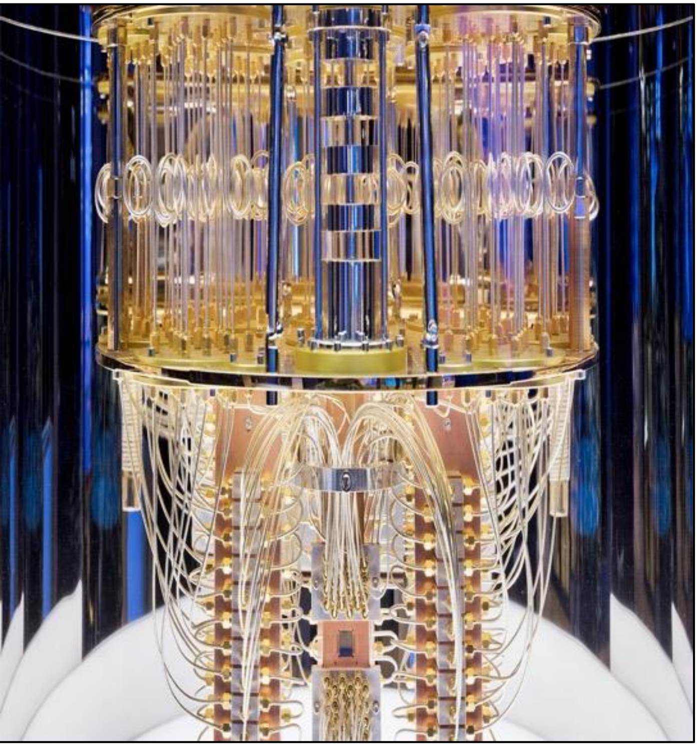
- Supercomputer

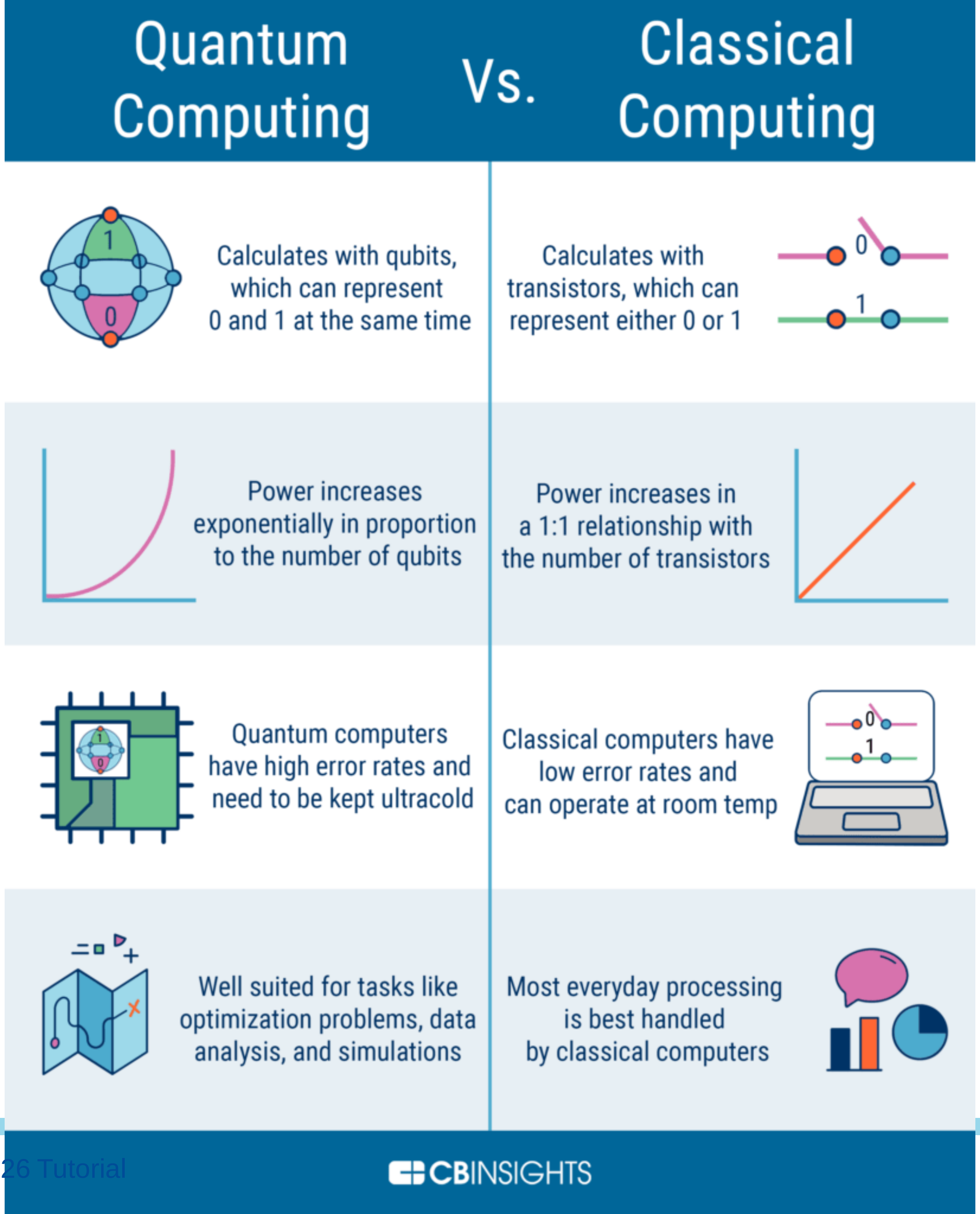


- Quantum Computer

Slide courtesy A. Grassellino, FNAL

Slide courtesy
A. Grassellino, FNAL

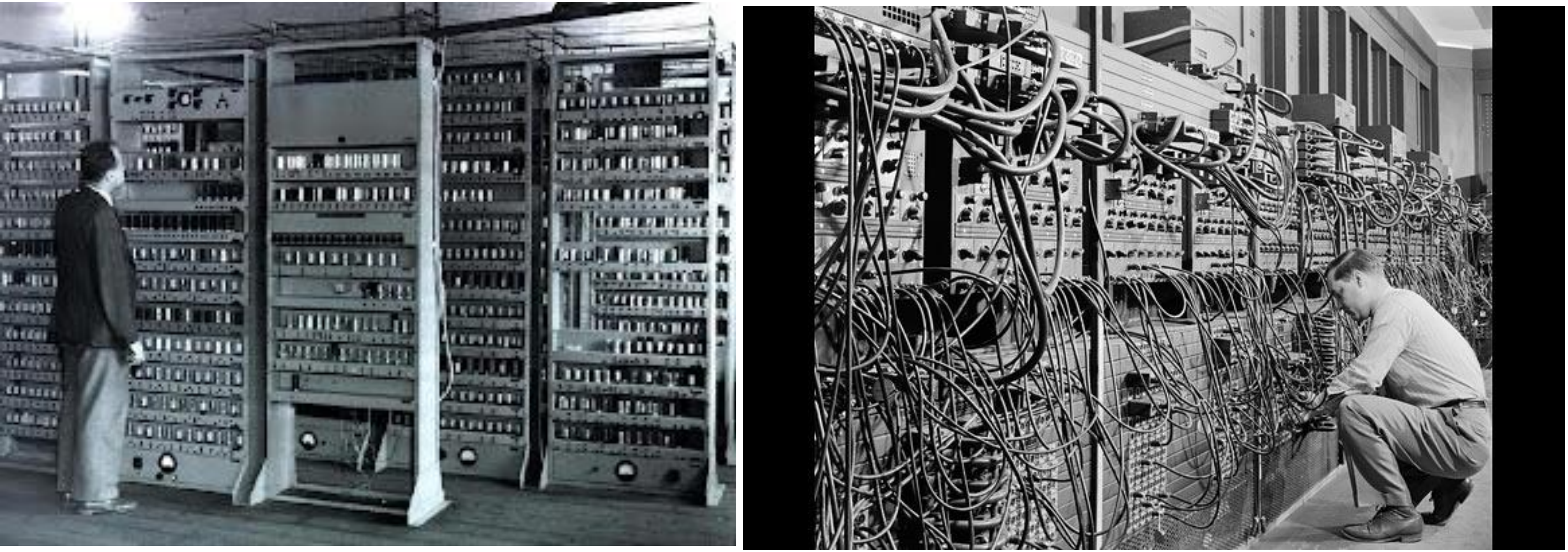




Quantum Computing	Vs.	Classical Computing
Calculates with qubits, which can represent 0 and 1 at the same time		Calculates with transistors, which can represent either 0 or 1
Power increases exponentially in proportion to the number of qubits		Power increases in a 1:1 relationship with the number of transistors
Quantum computers have high error rates and need to be kept ultracold		Classical computers have low error rates and can operate at room temp
Well suited for tasks like optimization problems, data analysis, and simulations		Most everyday processing is best handled by classical computers

CB INSIGHTS

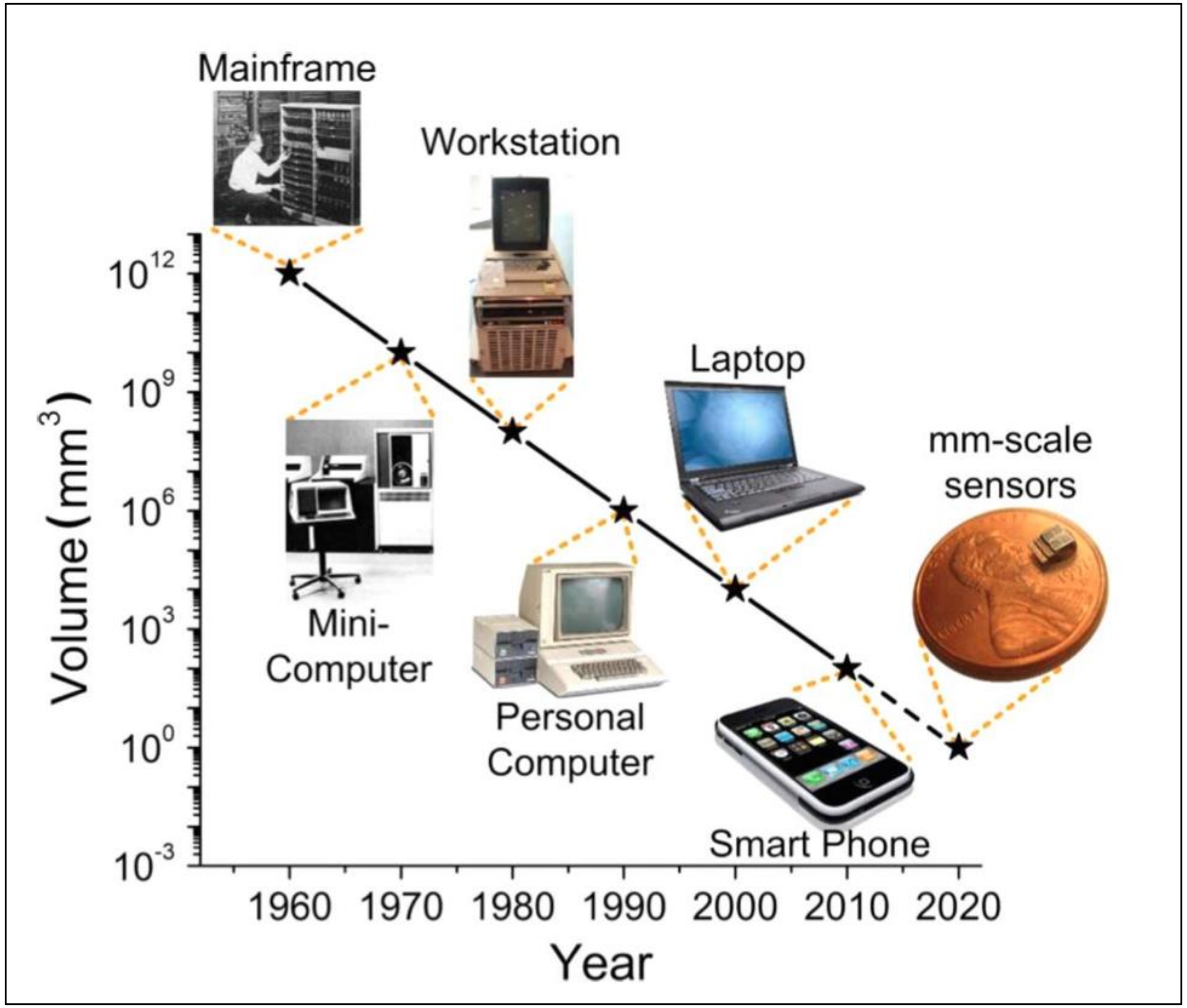
The First Classical Computers



The first vacuum tube computer, ENIAC, was developed by US army to calculate artillery firing tables in 1945

Slide courtesy A. Grassellino, FNAL

Evolution of the Classical Computer



Slide courtesy A. Grassellino, FNAL

Exponential Computational Advantage

- Exponential speed advantage for certain applications – minutes vs millions of years!

3 bits vs 3 qubits:

010 vs a|000> + b|001> + c|010> + d|011> + e|100> + f|101> + g|110> + h|111>

300 bits vs 300 qubits:

010001010110101001001110100010100101110100101001001010
100100000001010111101001010100101010101110100101010010
010100101011101001010101010010010101001010101110100100
100101001010101001001010010100100101000001001010100101
000101010110101001000100100010000100010101111010100100
10100101101001010010010101010111

vs $2^{300} = 2\text{x}10^{90}$

More than the estimated 10^{78} to 1082 atoms in the observable universe!
Physically impossible to simulate with classical computers

Slide courtesy A. Grassellino, FNAL

Shor’s Algorithm

- In 1994 Peter Shor showed that factorization of a product of large prime numbers can be done on a quantum computer exponentially faster than a classical computer
- This will eventually be the doom of RSA encryption – expect quantum encryption to grow in the future

How a quantum computer could break 2048-bit RSA encryption in 8 hours

A new study shows that quantum technology will catch up with today’s encryption standards much sooner than expected. That should worry anybody who needs to store data securely for 25 years or so.

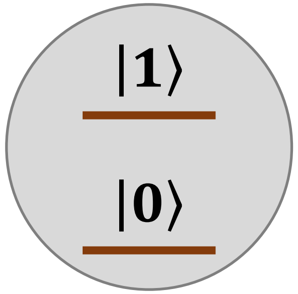
by **Emerging Technology from the arXiv** May 30, 2019

Many people worry that quantum computers will be able to crack certain codes used to send secure messages. The codes in question encrypt data using “trapdoor” mathematical functions that work easily in one direction but not in the other. That makes encrypting data easy but decoding it hugely difficult without the help of a special key.

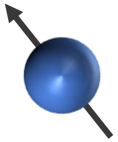
These encryption systems have never been unbreakable. Instead, their security is based on the huge amount of time it would take for a classical computer to do the job. Modern encryption methods are specifically designed so that decoding them would take so long they are practically unbreakable.

Slide courtesy A. Grassellino, FNAL

Basic Requirements for a Quantum Computer

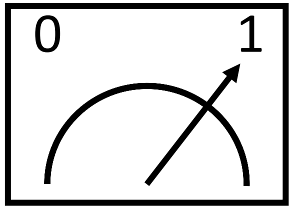


Quantum two level systems

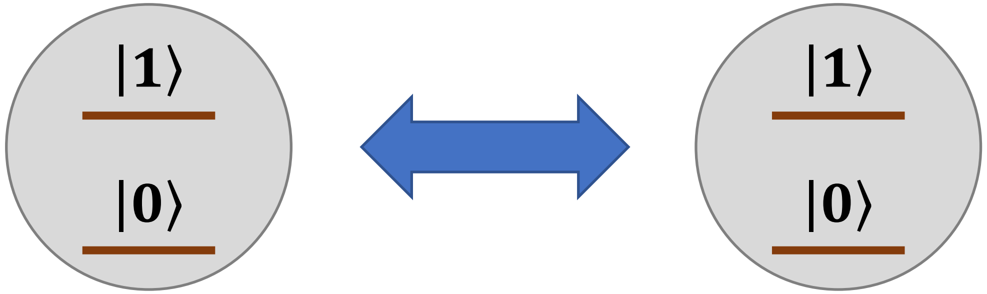


$\alpha|0\rangle + \beta|1\rangle$

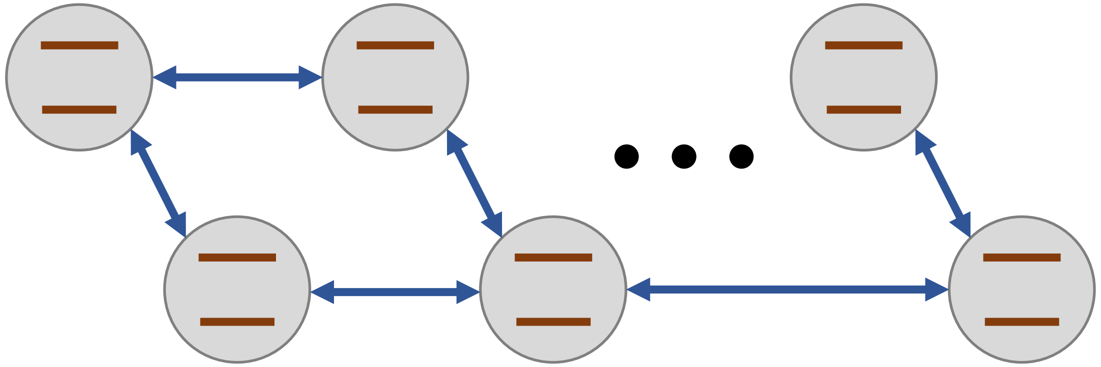
Create arbitrary states



Measure quantum states



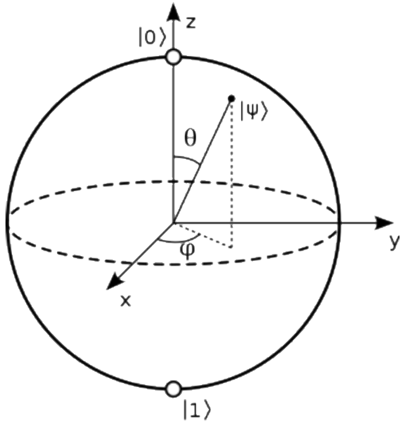
Couple multiple qubits



Scalable architecture

Slide courtesy A. Grassellino, FNAL

Challenges: Decoherence

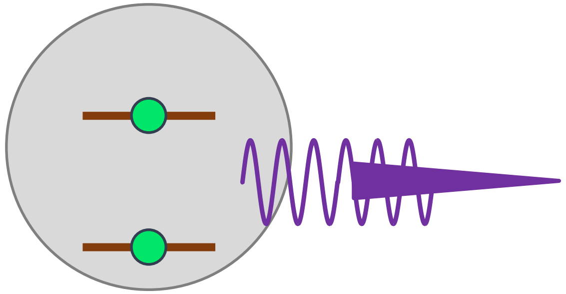


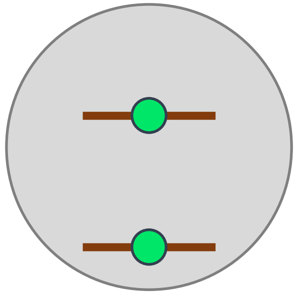
Noise

Decoherence

Relaxation (T_1)

Dephasing (T_ϕ)





$\alpha|0\rangle + \beta|1\rangle$

$|0\rangle + e^{i\phi}|1\rangle$

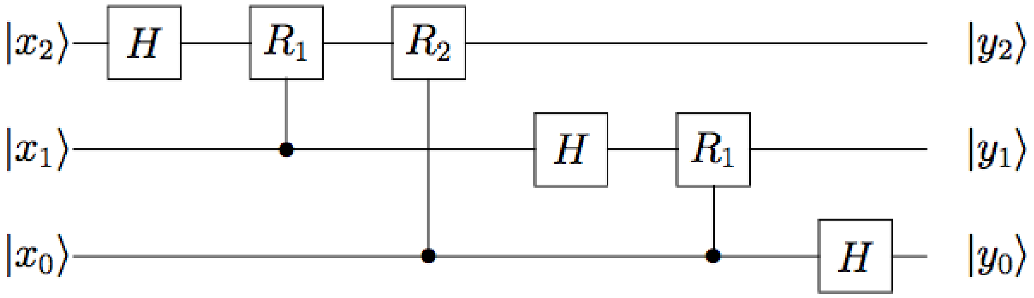
$|0\rangle$

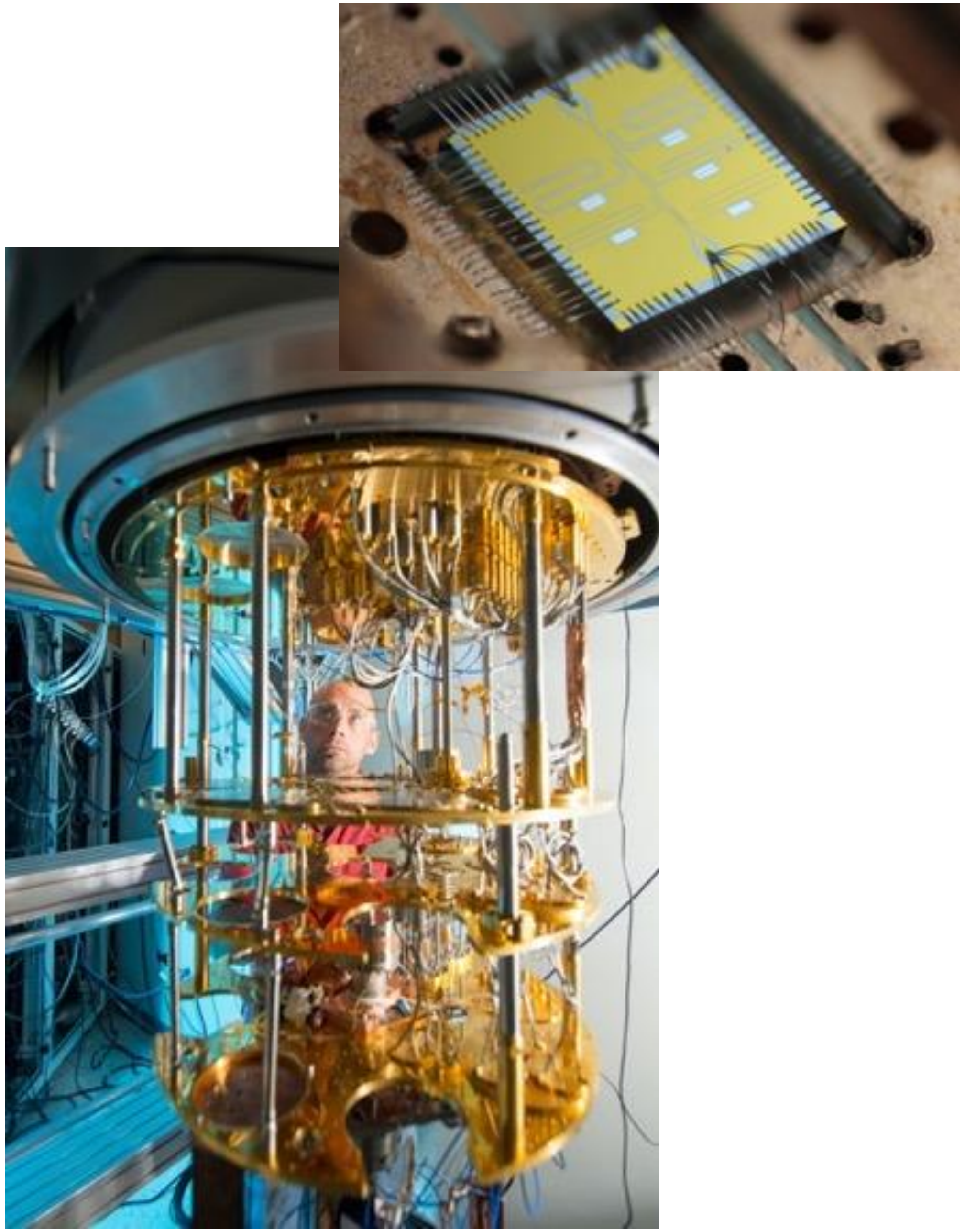
Incoherent mix of $|0\rangle$ and $|1\rangle$

Slide courtesy A. Grassellino, FNAL

Qubit challenges

- Need a qubit that you can manipulate and not confuse with other possible states of the system
- Maintain the **quantum coherence** of superpositions long enough to perform a large number of gate operations

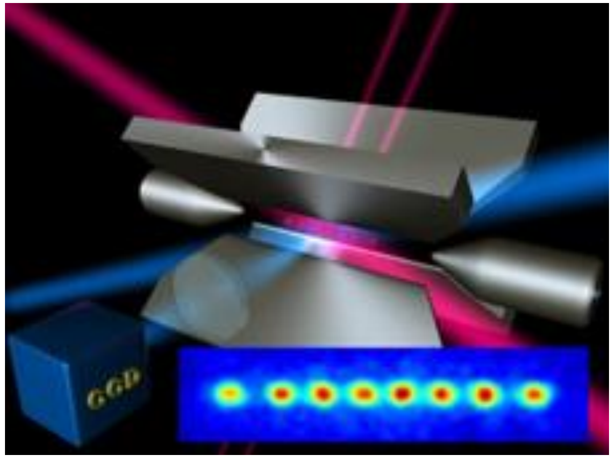




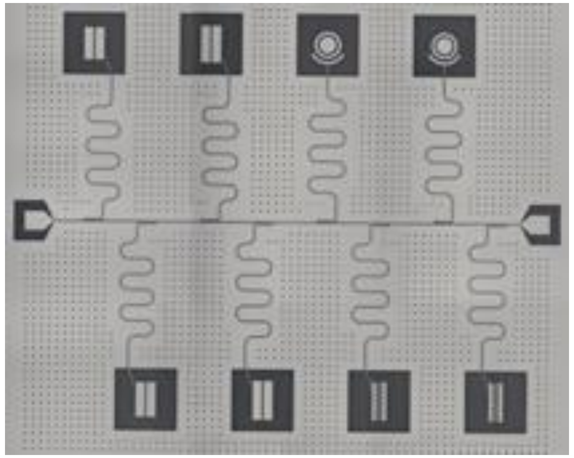
Slide courtesy A. Grassellino, FNAL

Different Platforms

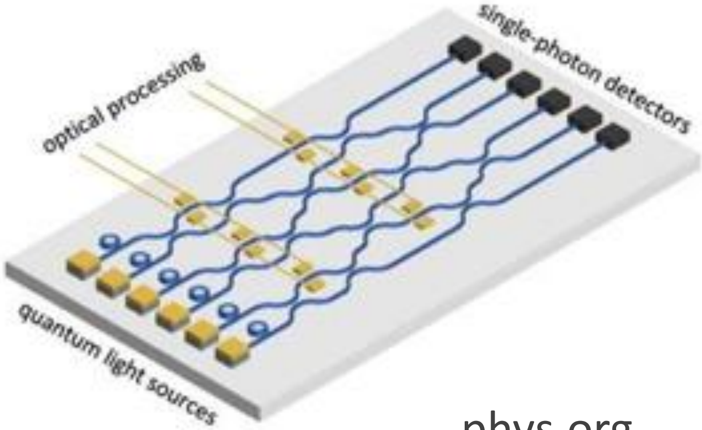
Trapped ions


laserfocusworld.com

Superconducting circuits

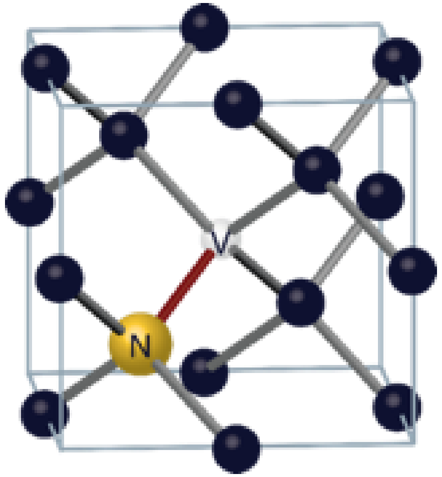

SQMS

Photonic crystals



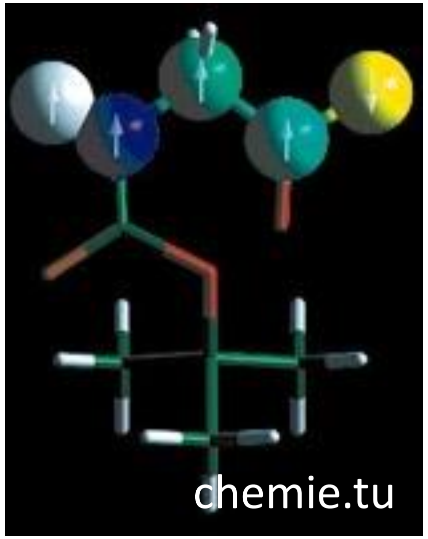
phys.org

NV centers

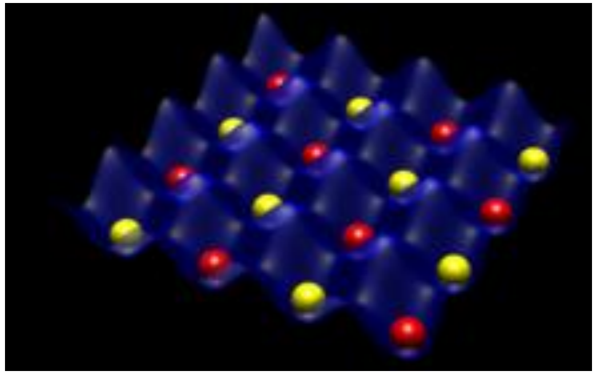


phys.org

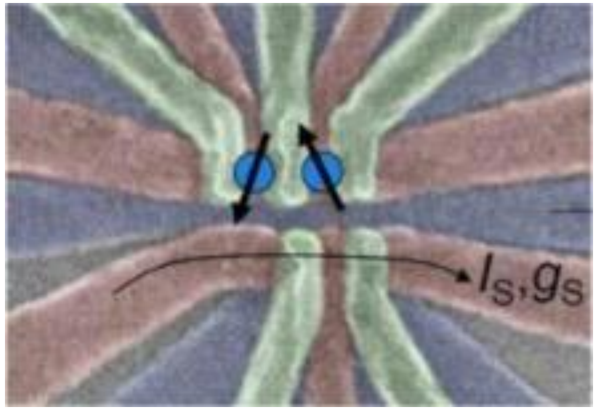
NMR


chemie.tu

Neutral atoms


NIST

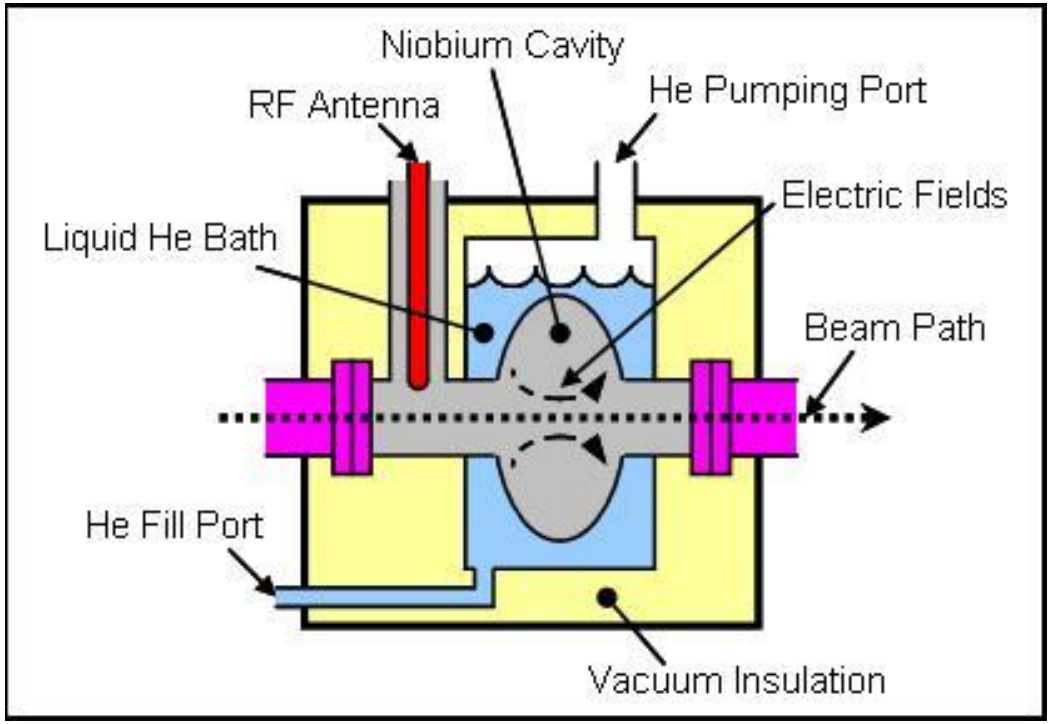
Quantum dots



sciencemag.org

Slide courtesy A. Grassellino, FNAL

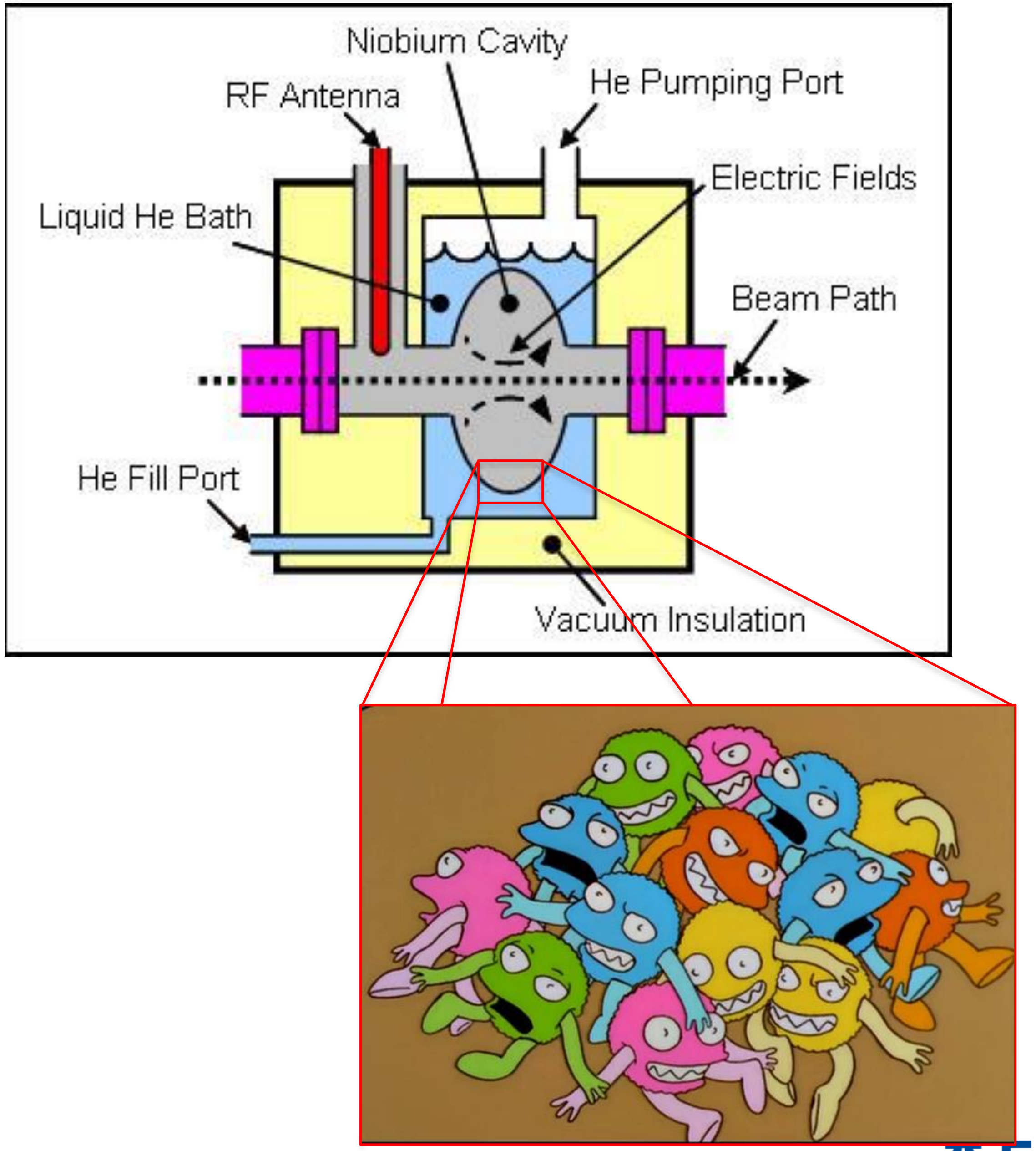
SRF Cavity in Liquid Helium



- Can this be the basis for a qubit?

SRF Cavity in Liquid Helium

- Can this be the basis for a qubit?
- Well, there’s a problem – the cavity might seem cold at 4 K or 2 K, but it’s still teeming with thermal photons

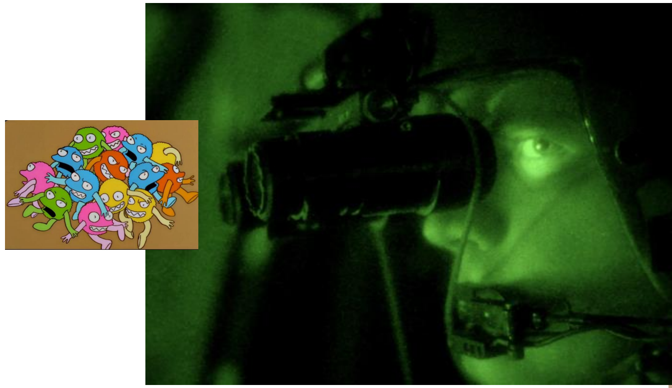


T ~ 400 C

n_T ~ 1x10^4

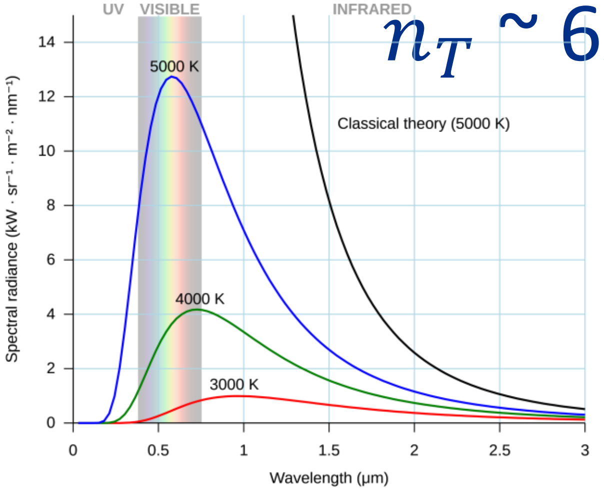
How many photons of added thermal noise at f = 1 GHz?

$$\bar{n} = \frac{1}{\exp\left(\frac{\hbar\omega}{k_B T}\right) - 1}$$



T = 20 C

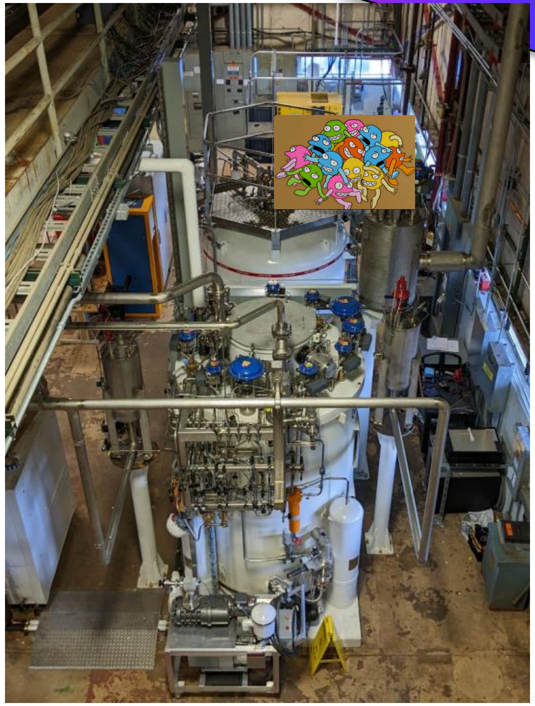
n_T ~ 6x10^3



$$B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{h\nu/kT} - 1},$$

T ~ 77 K

n_T ~ 2x10^3



T = 2 K n_T ~ 41

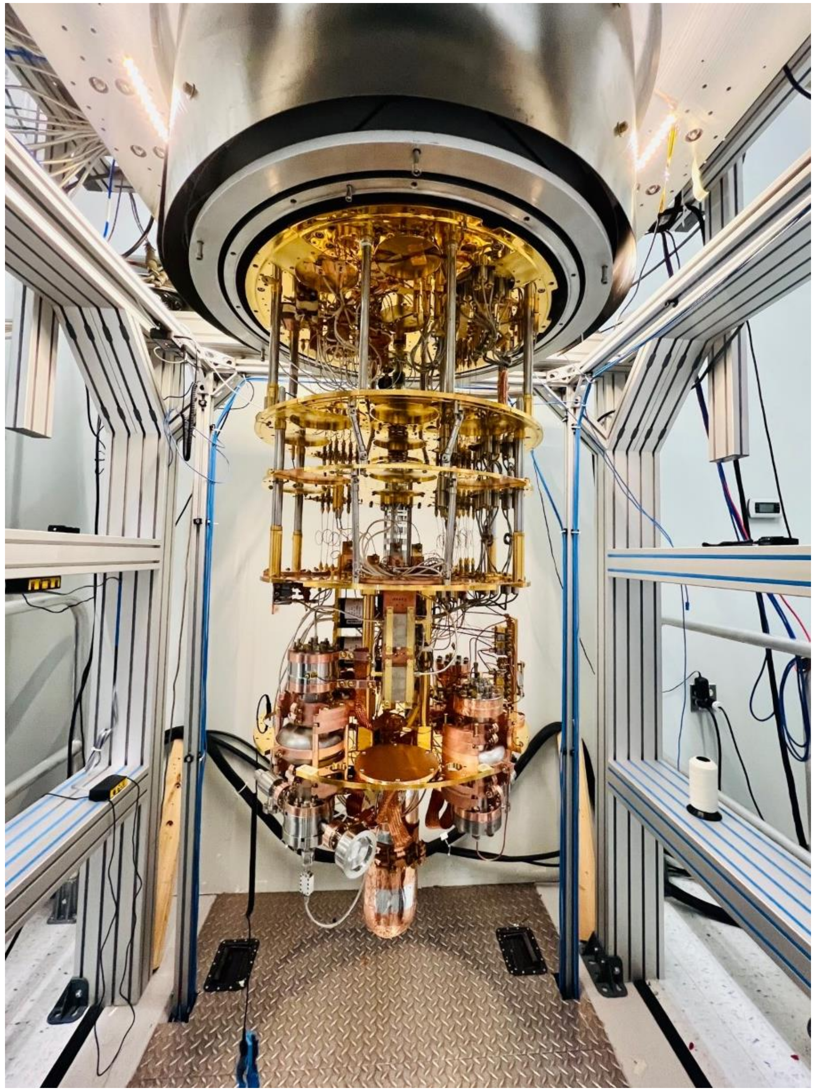
T = 20 mK

n_T ~ 0.1

Photos from: Wikipedia, freefoodphotos.com

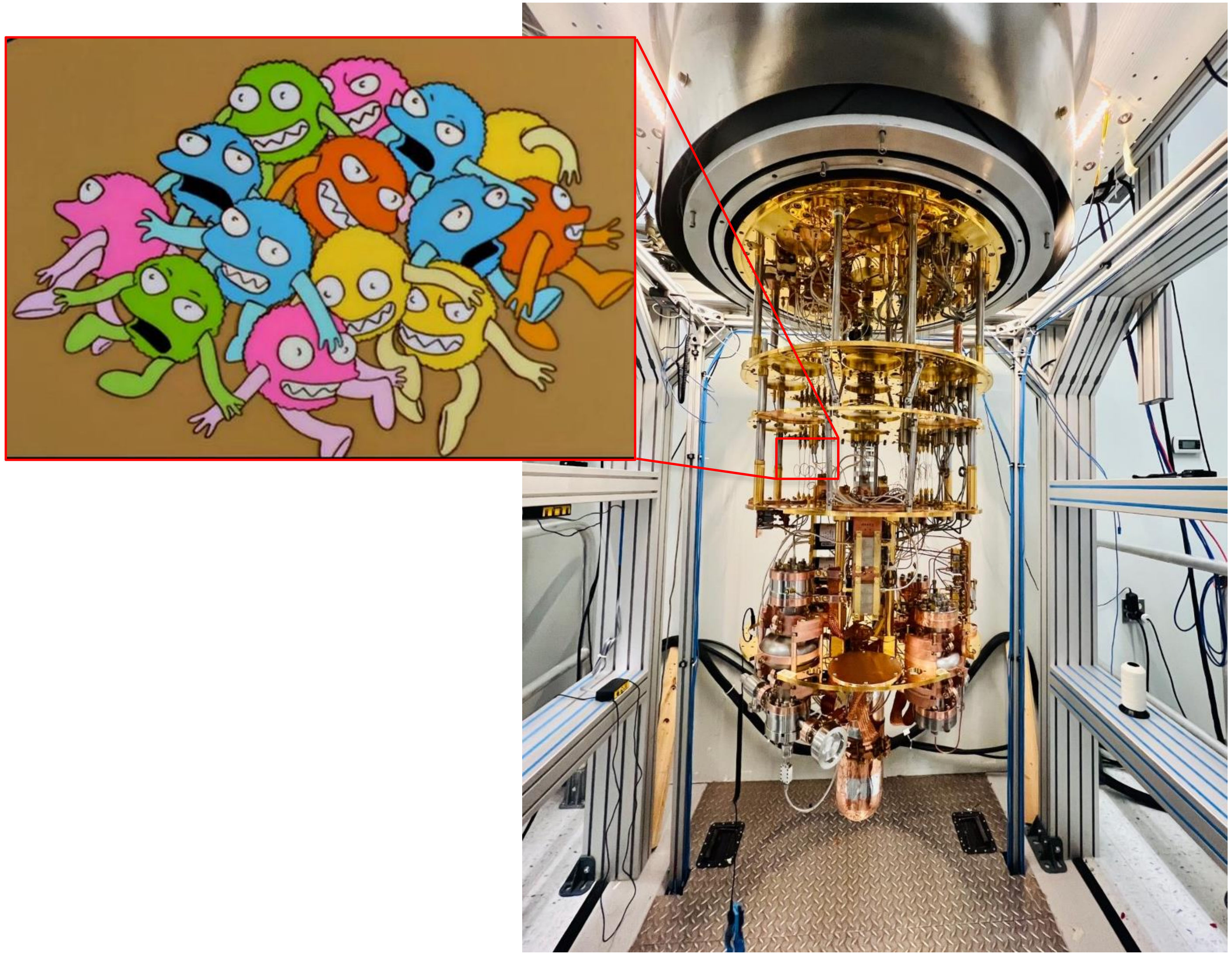
SRF Cavity in ~~Liquid Helium~~ Dilution Refrigerator

- Are our SRF-based qubits protected from thermal photons in a dilution refrigerator at 20 mK?



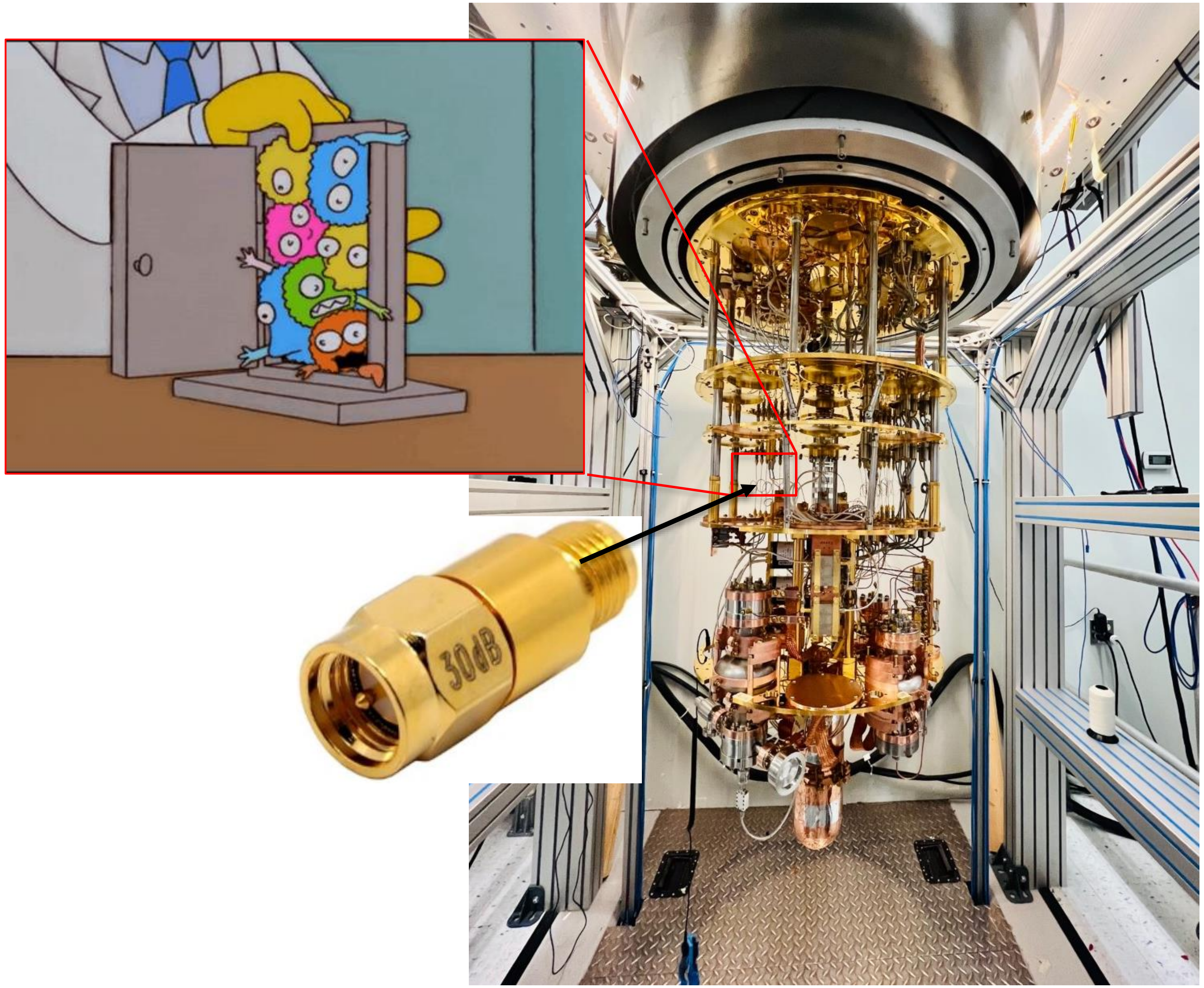
SRF Cavity in ~~Liquid Helium~~ Dilution Refrigerator

- Are our SRF-based qubits protected from thermal photons in a dilution refrigerator at 20 mK?
- We still need to be very careful – for example, the RF input lines can be low impedance connection to room temperature that can transport thermal photons into our nice cold cavity



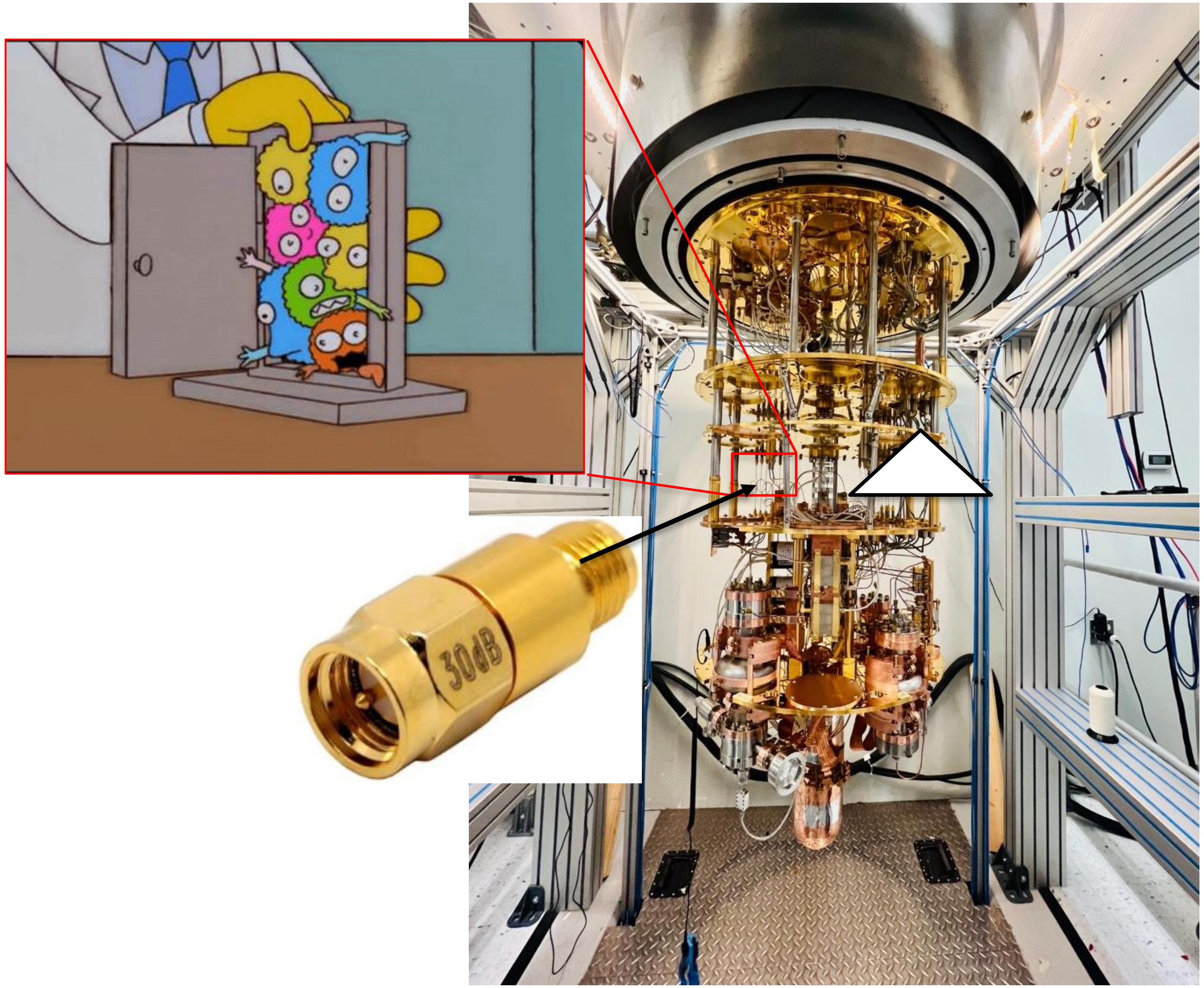
SRF Cavity in ~~Liquid Helium~~ Dilution Refrigerator

- Are our SRF-based qubits protected from thermal photons in a dilution refrigerator at 20 mK?
- We still need to be very careful – for example, the RF input lines can be low impedance connection to room temperature that can transport thermal photons into our nice cold cavity
- Cold attenuators on the input line will help block thermal photon
- We can increase the input power to still have a strong signal at the cavity even with the attenuation



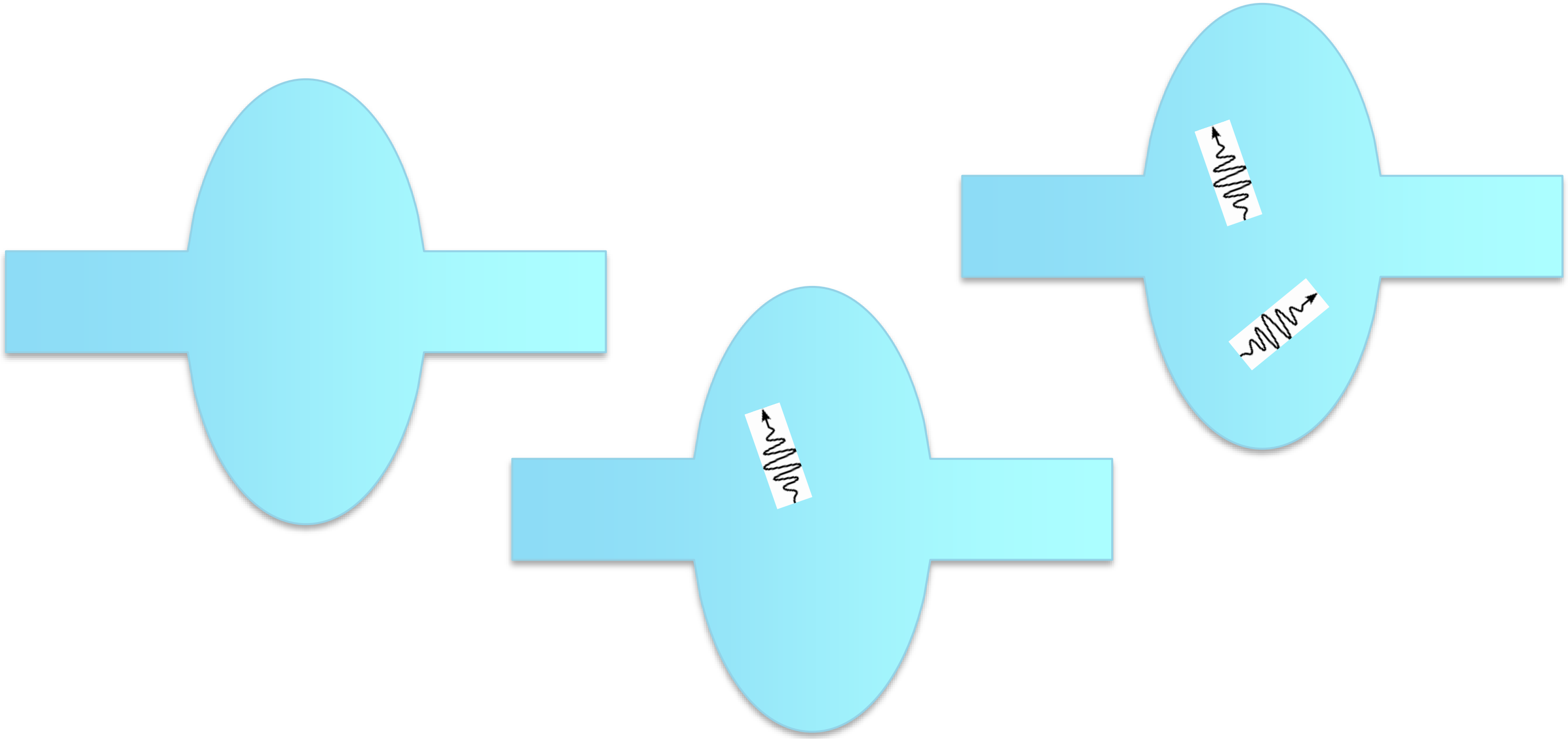
SRF Cavity in ~~Liquid Helium~~ Dilution Refrigerator

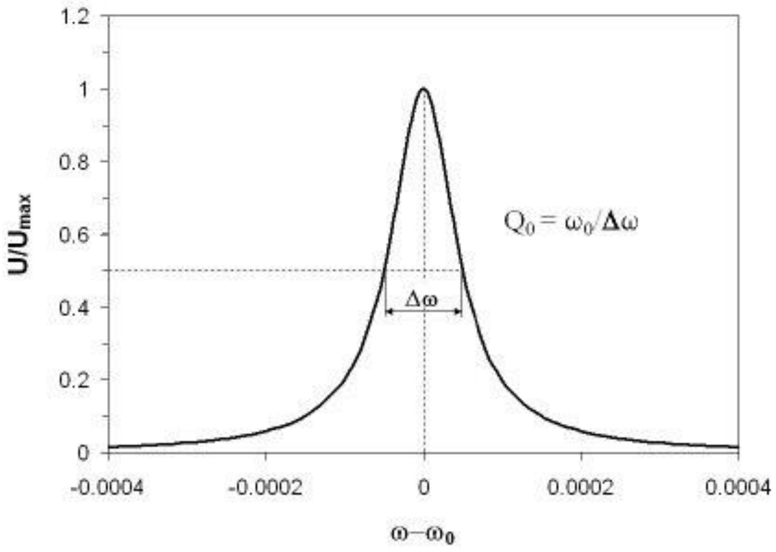
- We also have to be careful with the transmitted power line
- If we send a few photons to room temperature, they’ll get washed out by thermal photons
- Cold amplifiers will raise the transmitted power signal above the thermal background



Nonlinearity

- We still don’t have a qubit yet
- Need to distinguish different quantum states
- E.g. having 0, 1, or 2 photons in the cavity looks really similar to our diagnostics

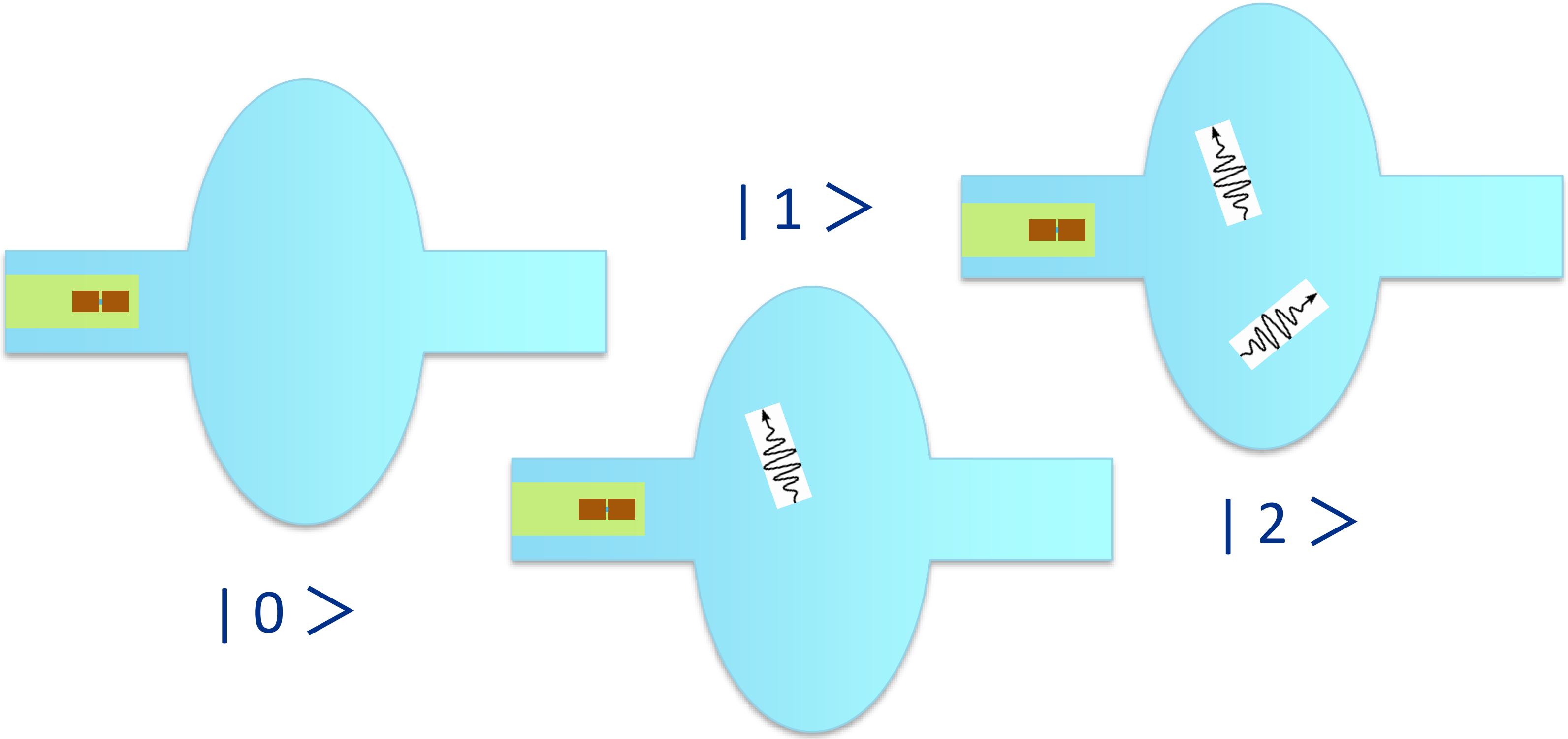


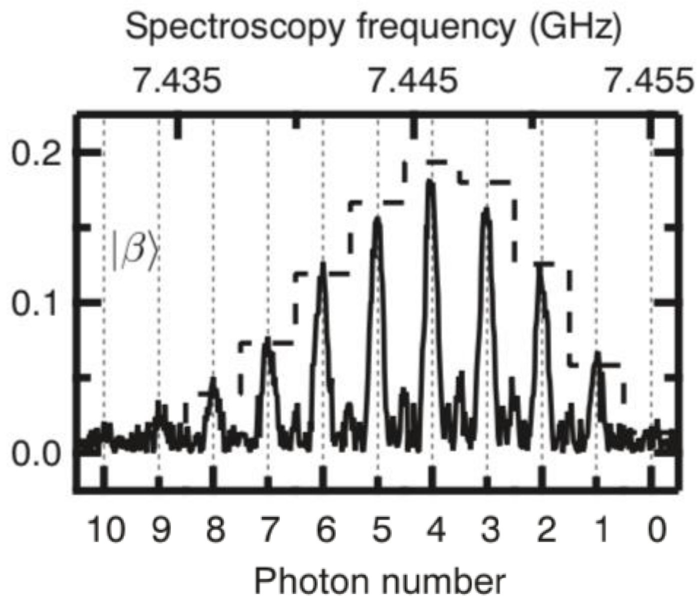


Slide courtesy A. Grassellino, FNAL

Nonlinearity

- Now let's add a nonlinear element: a Josephson junction! (aka JJ)
- Frequency of readout mode is now dependent photons in storage mode
- Even better: it's a quantum non-demolition (QND) measurement
- Can use multiple modes as multiple qubits, and entangle their states

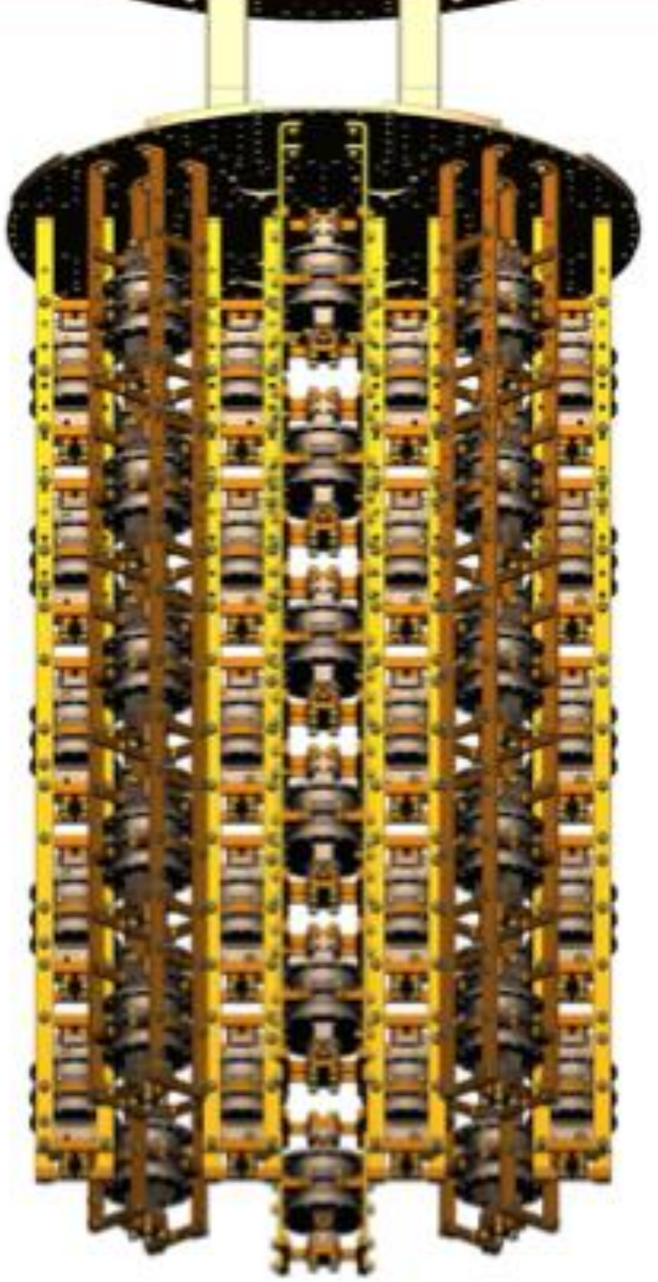




B. Vlastikas, *Science*, Vol 342, Iss 6158, pp. 607-610 (2013).

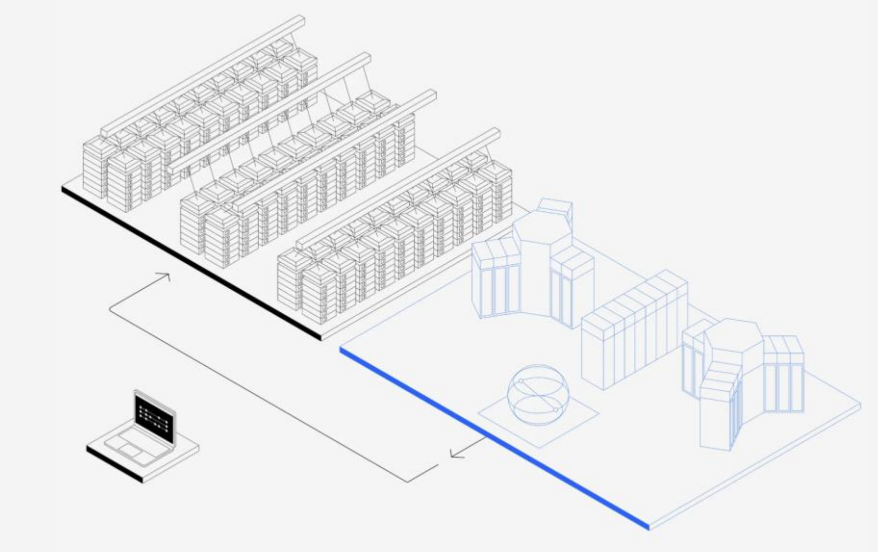
Scaling up…

- What could a large-scale quantum computer implementation look like?



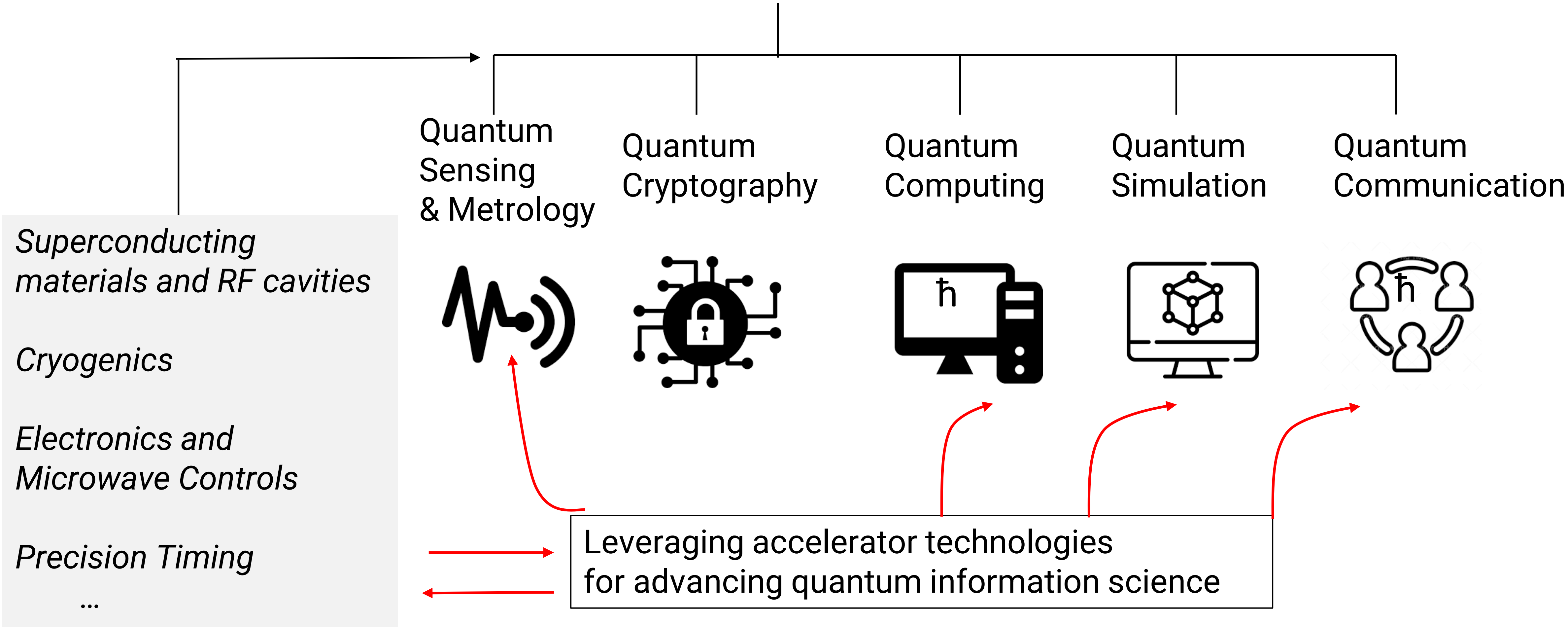
Example of 3D architecture – SQMS Center @ Fermilab

Example of 2D architecture - IBM



Slide courtesy A. Grassellino, FNAL

Quantum Information Science



Quantum Sensing & Metrology

Quantum Cryptography

Quantum Computing

Quantum Simulation

Quantum Communication

Superconducting materials and RF cavities

Cryogenics

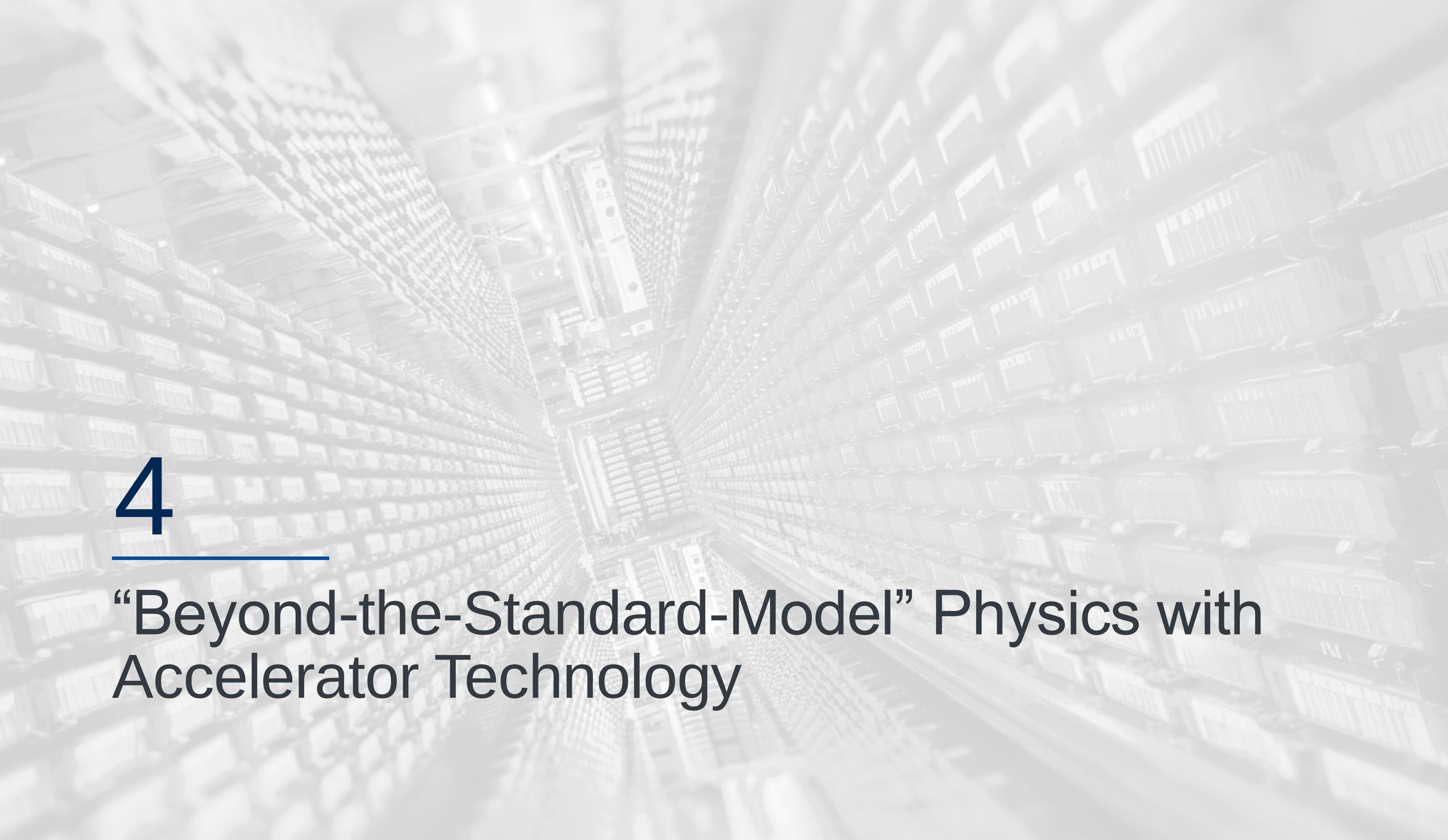
Electronics and Microwave Controls

Precision Timing

…

Leveraging accelerator technologies
for advancing quantum information science

Slide courtesy A. Grassellino, FNAL



4

“Beyond-the-Standard-Model” Physics with Accelerator Technology

Searching for Tiny Signals with RF Cavities

- We’ve done a lot of work relevant to studying tiny signals
  - Suppressed thermal photons, achieved high Q at mK temperatures and small photon numbers, developed quantum tools for studying single photon signals
- It turns out that this is useful for more than just quantum computing
- High energy physics wants this type of thing for detectors
- That’s right! RF cavities have long been a means of accelerating particles so that people with detectors can do science with the beams – but we can use the cavities themselves as high sensitivity detectors
- What high energy physics motivation is there to look for small microwave signals?

Image from: BestClipArt

Searching for Tiny Signals with RF Cavities

- The Standard Model of Physics describes our best understanding of the universe based on experimental evidence (e.g. from colliders)
- Beyond-the-standard-model (BSM) physics theories address questions not addressed by the Standard Model, like what is the origin of dark matter, and why is there so much more matter than antimatter in the universe?
- Theorists have developed a number of ideas for BSM physics that would result in a signal that is detectable but still small enough that it wouldn't have yet been observed

Image from: BestClipArt

Searching for Tiny Signals with RF Cavities

- Theories of BSM physics are designed to solve key problems (they aim to be "well-motivated") but there is so little information to base theories on that many possibilities can fit the data
- BSM theories sometimes involve many orders of magnitude of parameter space to search through (e.g. axions)
- High value experiments in BSM physics **exclude** a wide range of parameter space with high sensitivity (they "search wide and deep")
- Exclusion is a good result! Don't expect to find something, and in fact expect NOT to! If you see something, your first instinct should be that it's probably a false signal

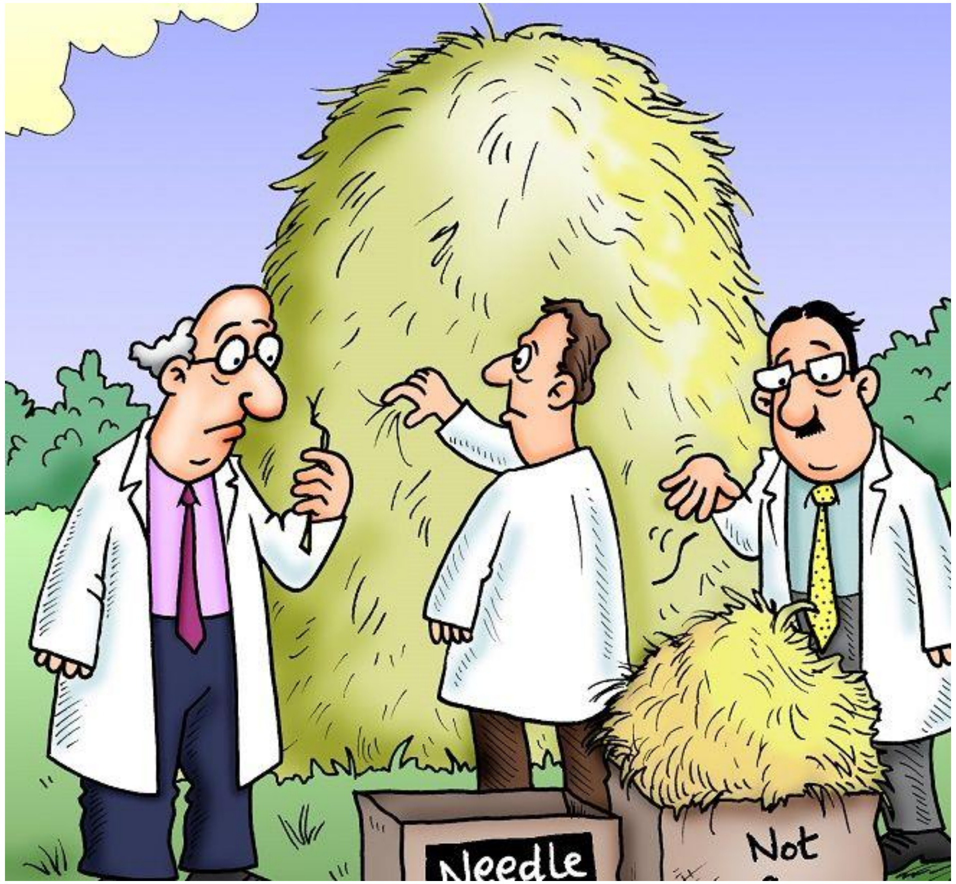
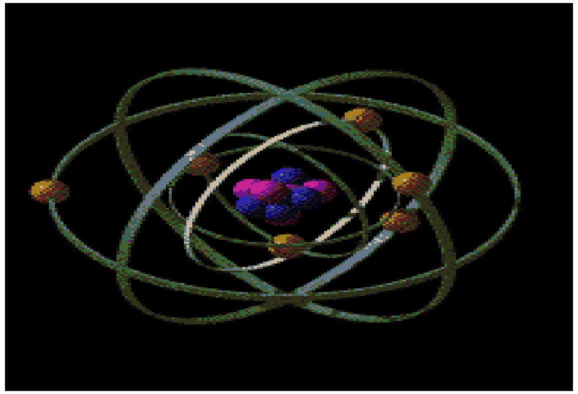


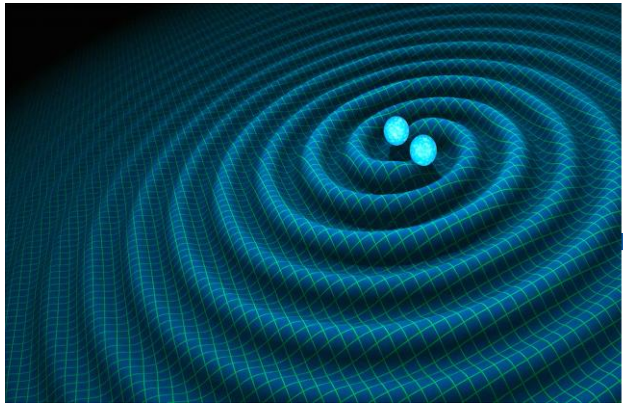
Image from: triz.co.uk

Quantum Sensing: new windows into fundamental physics

Dark Matter



Precision Measurements



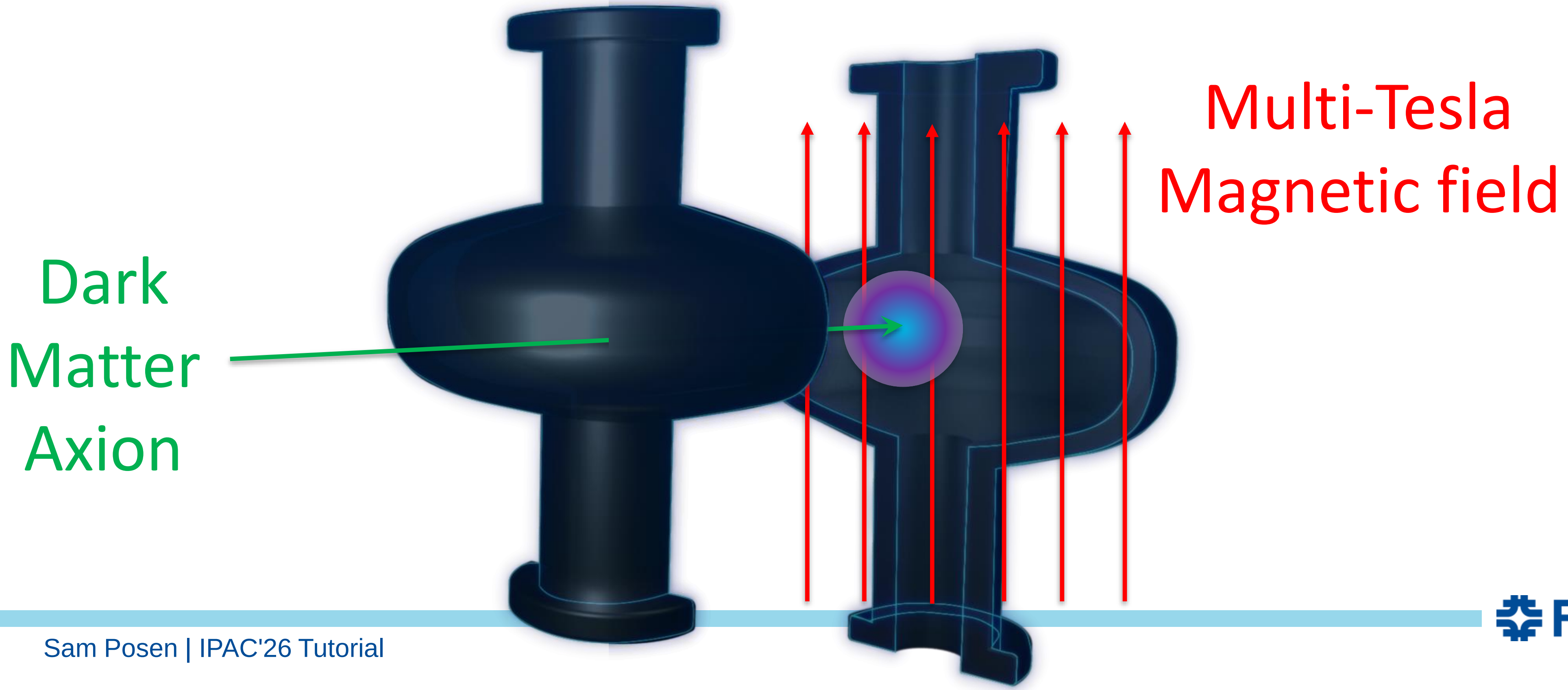
Gravitational Waves

Quantum Physics

Quantum devices are extremely sensitive to small effects – sensors!
New ways to search for dark matter?
Searches for new BSM particles?
Precision tests of the SM or of QM?
New ways to look for gravitational waves?

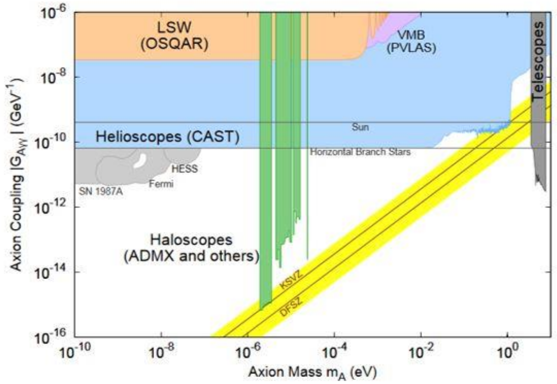
Conversion of Axion in Magnetic Field to Microwave Photon

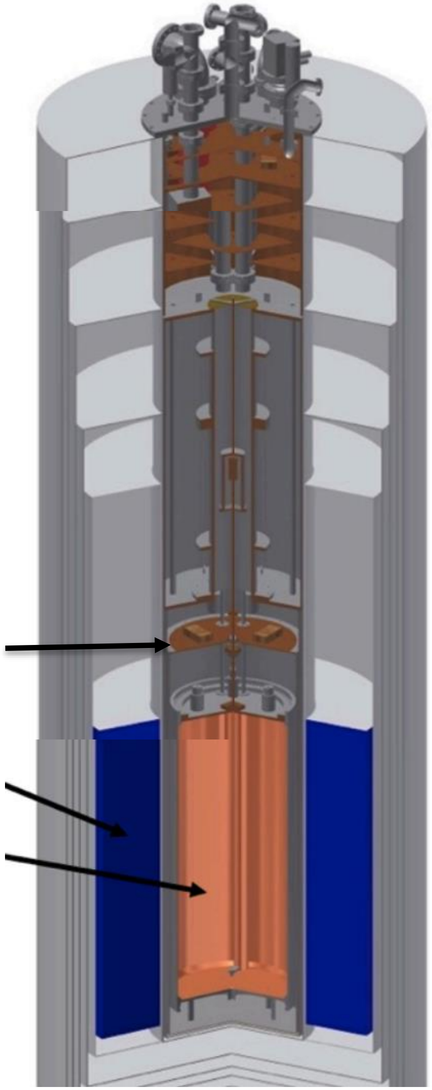
- Axion haloscope: axion converts to photon in magnetic field; if cavity frequency matches axion mass it can detect it
- Sensitivity improves with higher magnetic field, higher cavity Q_0
  - **Need a multi-tesla magnetic field and cavity that maintains high Q_0 in magnetic field**



Current State of the Art Axion Searches

- Operating haloscopes like ADMX (axion dark matter experiment) use normal conducting cavities (e.g. copper)
- They have reached desired exclusion limit for a small range of masses, but a very wide mass range remains
- Scan rate scales as $d\nu/dt \propto B^4V^2Q/2T_{sys}$
  - B (magnetic field), V (cavity volume), Q (cavity quality factor), T_{sys} (system noise temperature)
- Q improvement is promising path to improving rate of scanning substantially
- **Superconductors with very high upper critical field can help** (e.g. Nb_3Sn, REBCO)





Dilution fridge

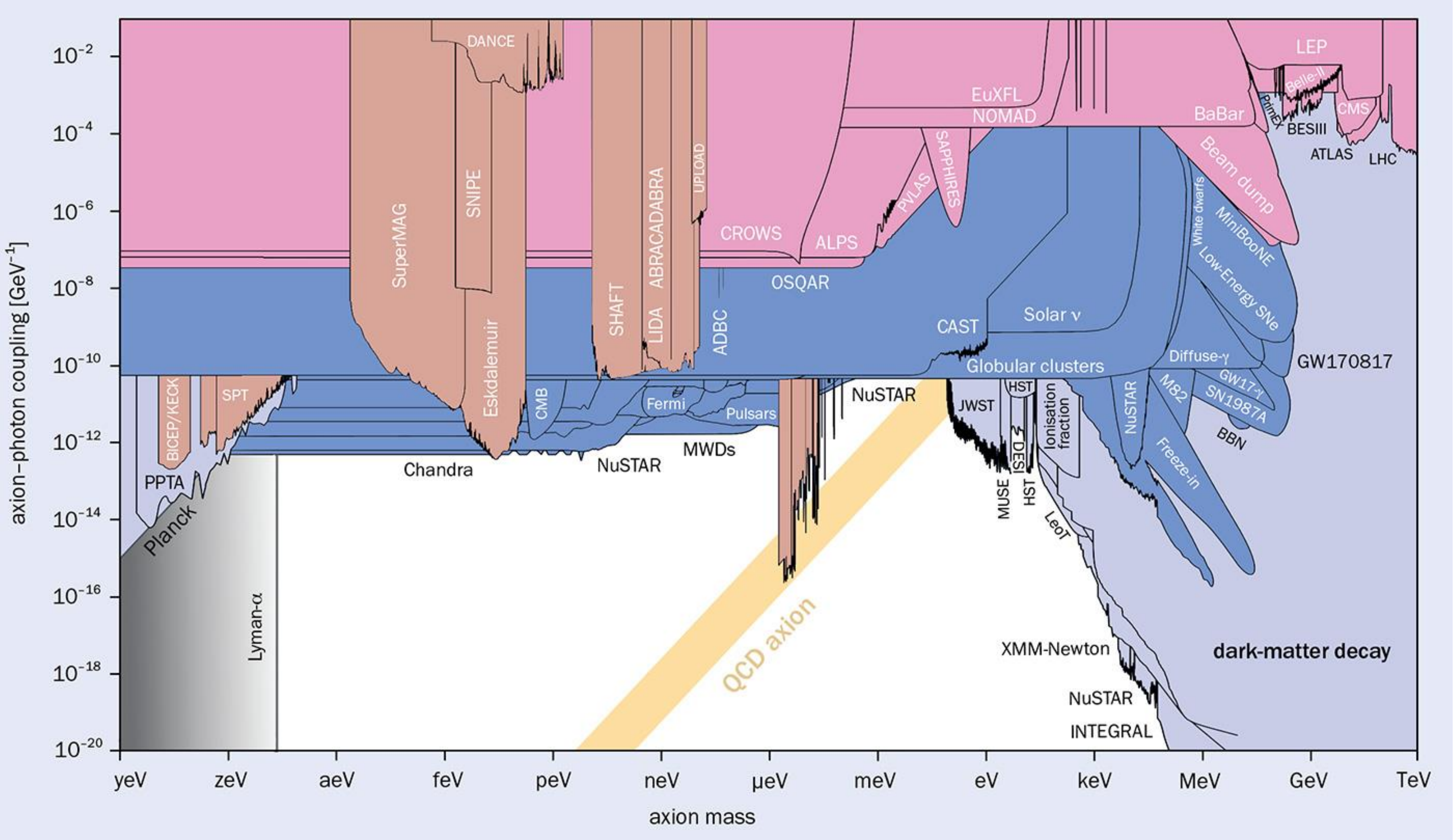
8 T magnet

Copper cavity

From ADMX

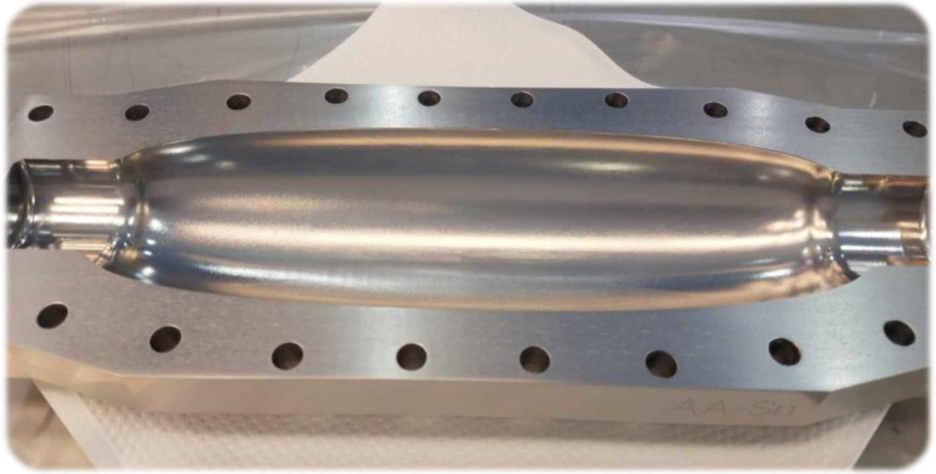
https://arxiv.org/pdf/1405.3685.pdf & https://indico.cern.ch/event/606690/contributions/2655459/attachments/1498473/2332791/Axion_Overview_TAUP_2017_Final.pdf

Exclusion Plot for the Axion



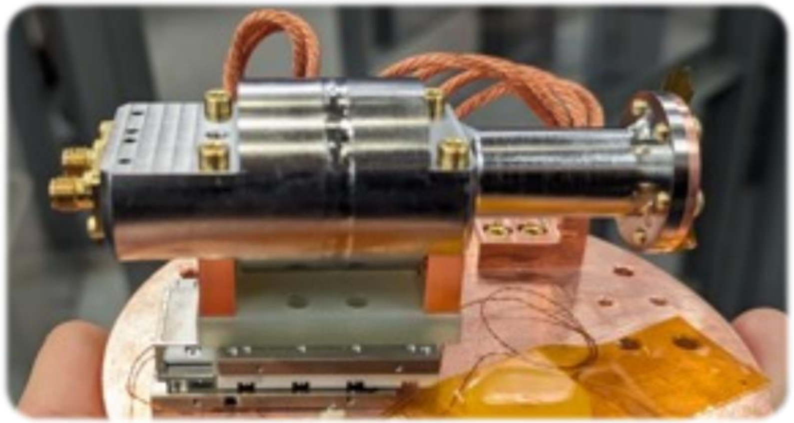
https://cerncourier.com/introducing-the-axion/

New Cavities built and deployed as novel physics tools at Fermilab SQMS

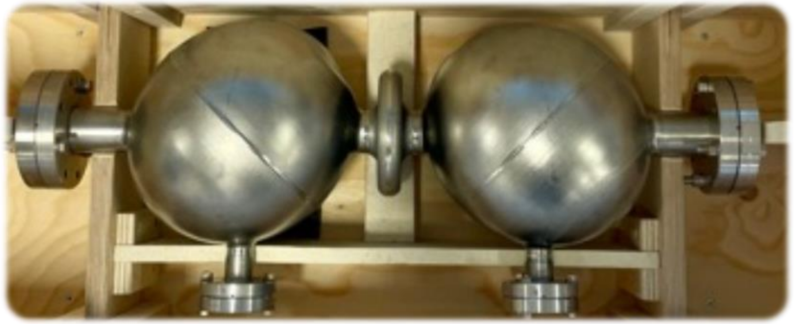


Nb_3Sn B-field cavity
Axion dark matter studies

SHADE (Superconducting Heterodyne Axion Dark matter Experiment)



SERAPH Plunger Cavity
Dark photon dark matter search



MAGO – built by INFN
Gravitational Wave Search

Slide courtesy B. Giaccone, FNAL

5

Technology Transfer

Technology Transfer

Example: Cornell University's 500 MHz cavity licensed to Accel/RI, installed in Taiwan Light Source, Canadian Light Source, and more

- What is Technology Transfer?
  - Technology transfer moves innovations from research labs to vendors, which can lead to commercial and societal benefits
- Intellectual Property (IP) Protection
  - IP products include patents, copyrights, and trademarks. These protect inventions developed in research institutions. If you invent something exciting, consider your IP options.
- Licensing Agreements
  - An inventor can license IP to a company, which defines terms for their use of the IP, including specifications for rights, royalties, and milestones.
- Institutional Support
  - Your institution may have a dedicated office to guide patent filings and licensing to foster IP protection and partnerships with industry

Image from https://proceedings.jacow.org/SRF2003/papers/mop37.pdf

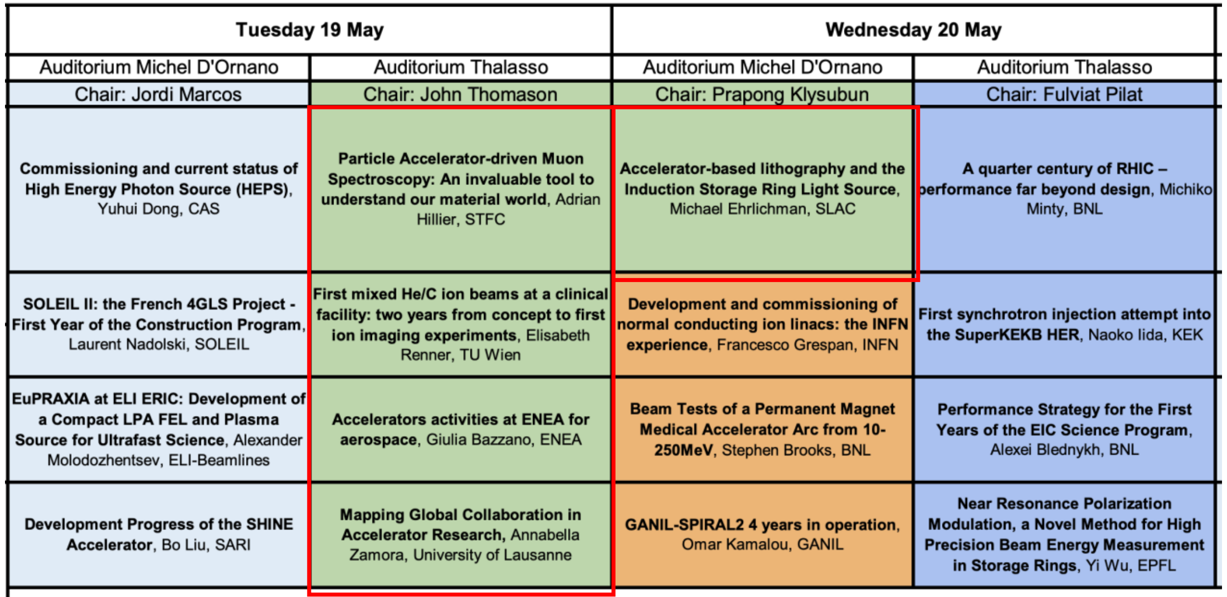
6

Summary

Final Notes

- There are brilliant and wonderful vendors here at IPAC that support accelerators at all our labs – vacuum, RF, magnets instrumentation, and a million other technologies – **go visit the vendors around the conference** – they will happily give you swag and chat with you about careers in the accelerator industry
- There are exciting and relatively new startups in large-accelerator-based industrial applications (semiconductor lithography, isotopes, subcritical reactors) – keep an eye on these – potential to grow in the coming years

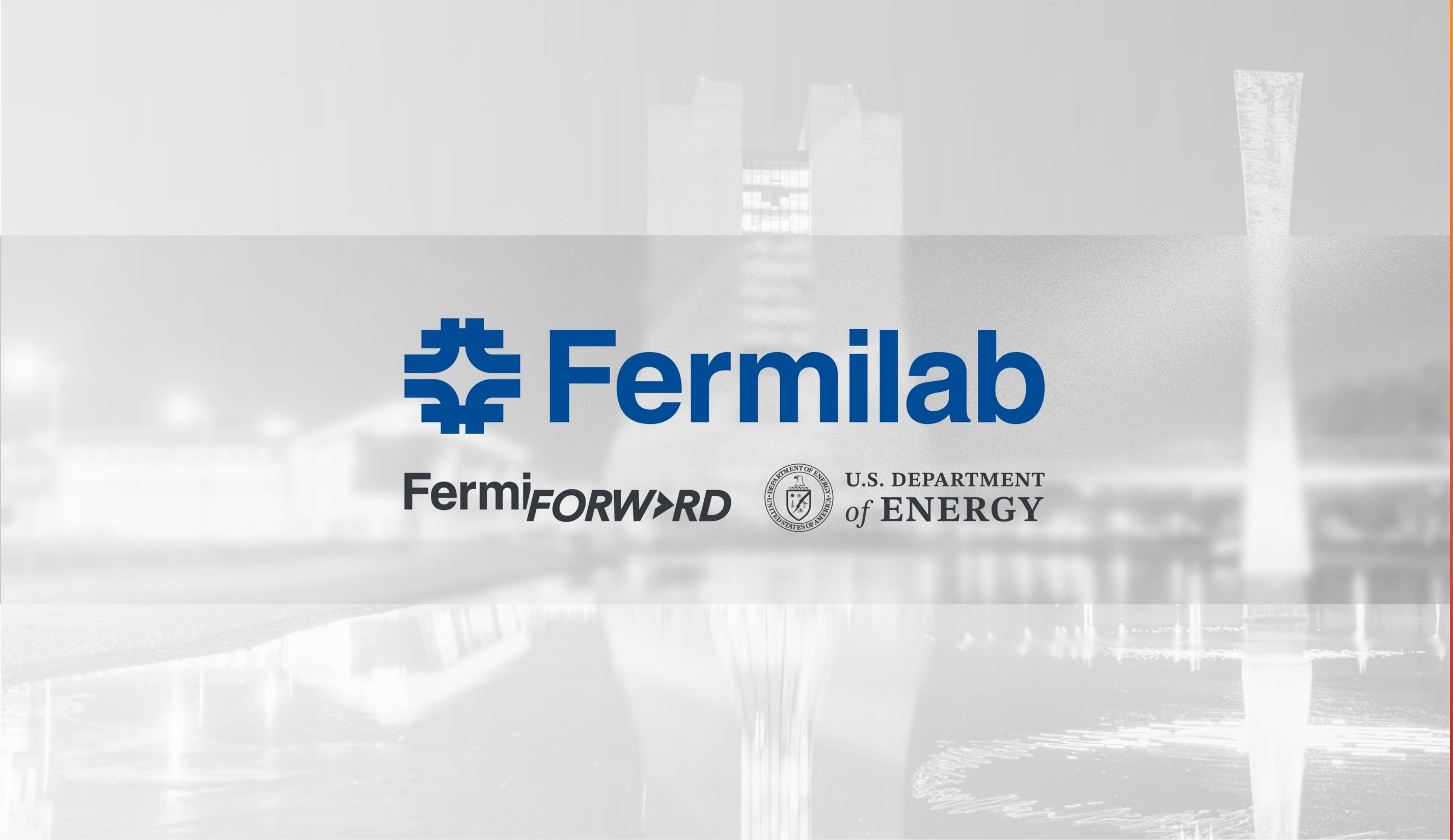
MC8 Applications of Accelerators, Engagement with Industry, Technology Transfer and Outreach



Tuesday 19 May		Wednesday 20 May	
Auditorium Michel D'Ornano	Auditorium Thalasso	Auditorium Michel D'Ornano	Auditorium Thalasso
Chair: Jordi Marcos	Chair: John Thomason	Chair: Prapong Klysubun	Chair: Fulviat Pilat
Commissioning and current status of High Energy Photon Source (HEPS), Yuhui Dong, CAS	**Particle Accelerator-driven Muon Spectroscopy: An invaluable tool to understand our material world**, Adrian Hillier, STFC	**Accelerator-based lithography and the Induction Storage Ring Light Source**, Michael Ehrlichman, SLAC	**A quarter century of RHIC – performance far beyond design**, Michiko Minty, BNL
SOLEIL II: the French 4GLS Project - First Year of the Construction Program, Laurent Nadolski, SOLEIL	**First mixed He/C ion beams at a clinical facility: two years from concept to first ion imaging experiments**, Elisabeth Renner, TU Wien	**Development and commissioning of normal conducting ion linacs: the INFN experience**, Francesco Grespan, INFN	**First synchrotron injection attempt into the SuperKEKB HER**, Naoko Iida, KEK
EuPRAXIA at ELI ERIC: Development of a Compact LPA FEL and Plasma Source for Ultrafast Science, Alexander Molodozhentsev, ELI-Beamlines	**Accelerators activities at ENEA for aerospace**, Giulia Bazzano, ENEA	**Beam Tests of a Permanent Magnet Medical Accelerator Arc from 10-250MeV**, Stephen Brooks, BNL	**Performance Strategy for the First Years of the EIC Science Program**, Alexei Blednykh, BNL
Development Progress of the SHINE Accelerator, Bo Liu, SARI	**Mapping Global Collaboration in Accelerator Research**, Annabella Zamora, University of Lausanne	**GANIL-SPIRAL2 4 years in operation**, Omar Kamalou, GANIL	**Near Resonance Polarization Modulation, a Novel Method for High Precision Beam Energy Measurement in Storage Rings**, Yi Wu, EPFL

Summary

- **What are some exciting uses of particle accelerator technology other than accelerator-based science?**
- Existing
  - Industrial accelerators for medical applications
  - Industrial accelerators for ion implantation and cross-linking polymers
  - Many more
- Emerging
  - Industrial accelerators for treating mixed low-level radioactive waste, PFAS
  - Quantum computing, sensing for fundamental physics
  - Many more
- If these are interesting topics to you, consider seeking opportunities in universities, labs, & industry!



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