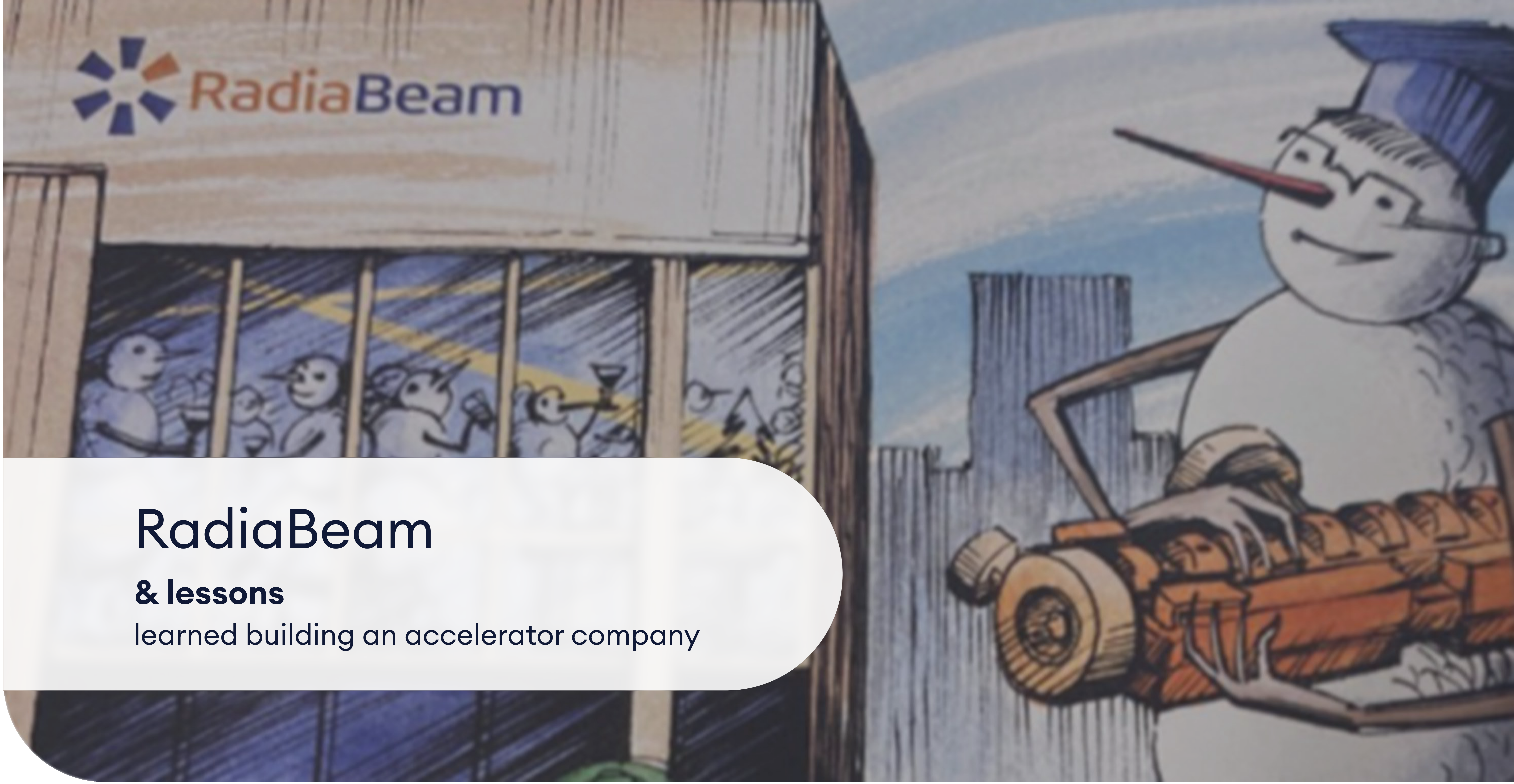
AAC’22, Long Island, NY, USA — November 09



RadiaBeam

& lessons

learned building an accelerator company

speaker Sergey V. Kutsaev —— & co-authors S. Boucher, A. Murokh

Contents and Authors

Dr. Sergey V. Kutsaev
received his Ph.D. in accelerator physics at MEPhI, Russia in 2011 for his work on accelerators for novel cargo inspection systems. Since 2014 he has worked at RadiaBeam Technologies as the RF Group Leader. IEEE Senior Member since 2020. His research interests include industrial accelerators, microwave and terahertz systems, RF superconducting and quantum technologies

Dr. Alex Murokh
received his Ph.D. at UCLA in 2002 for his work on the VISA Free Electron Laser, and is co-founder and Chief Technical Officer of RadiaBeam. Dr. Murokh's research interests include coherent radiation processes, beam diagnostic techniques, advanced acceleration methods, and novel light sources

Mr. Salime Boucher
is the CEO of RadiaBeam and an expert in the design, fabrication and applications of industrial accelerator systems. He previously worked as an engineer at SureBeam, a manufacturer of linacs for food irradiation. He has led the company since its inception in 2004 through many years of consistent growth and expanding capabilities. He also currently serves as CEO of Celestial Oncology Inc., which is developing a robotic radiation therapy system, and has guided it from founding through Series A in 2020

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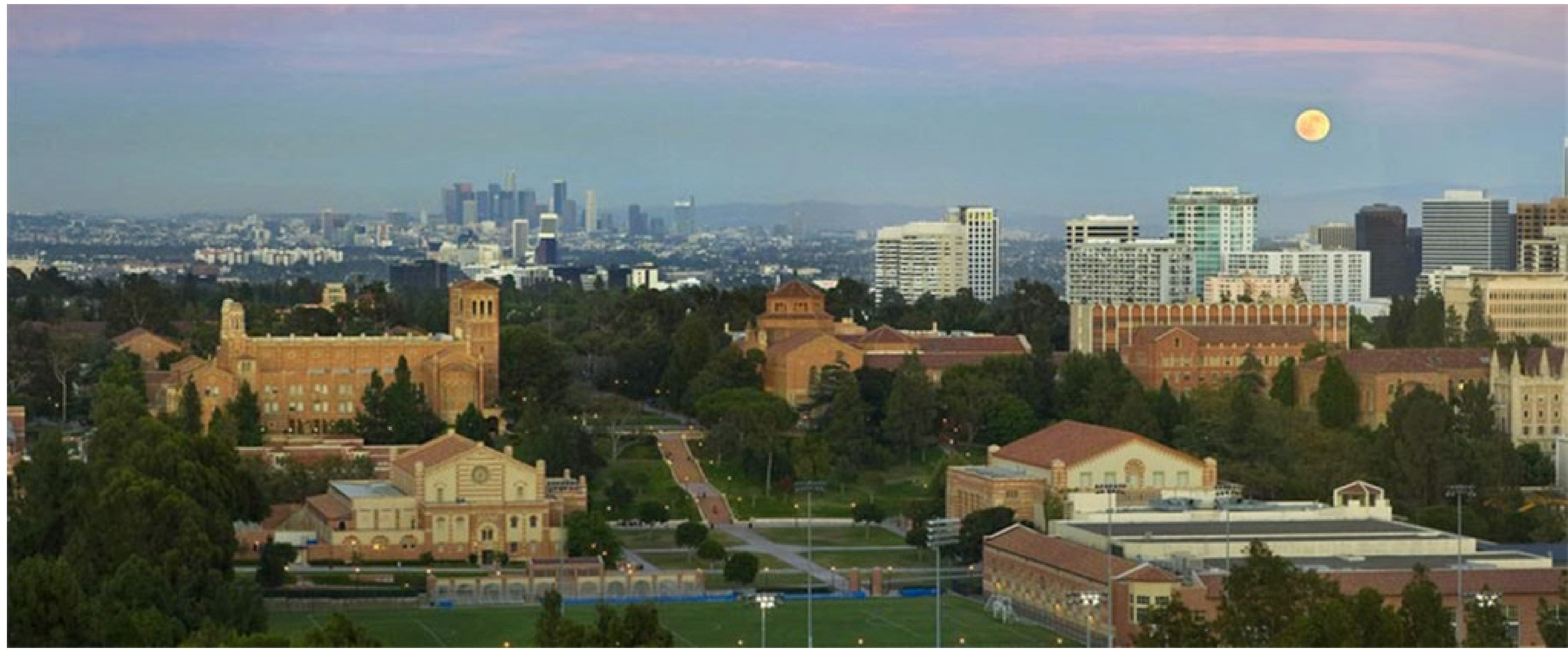
RadiaBeam company:

overview, products and capabilities

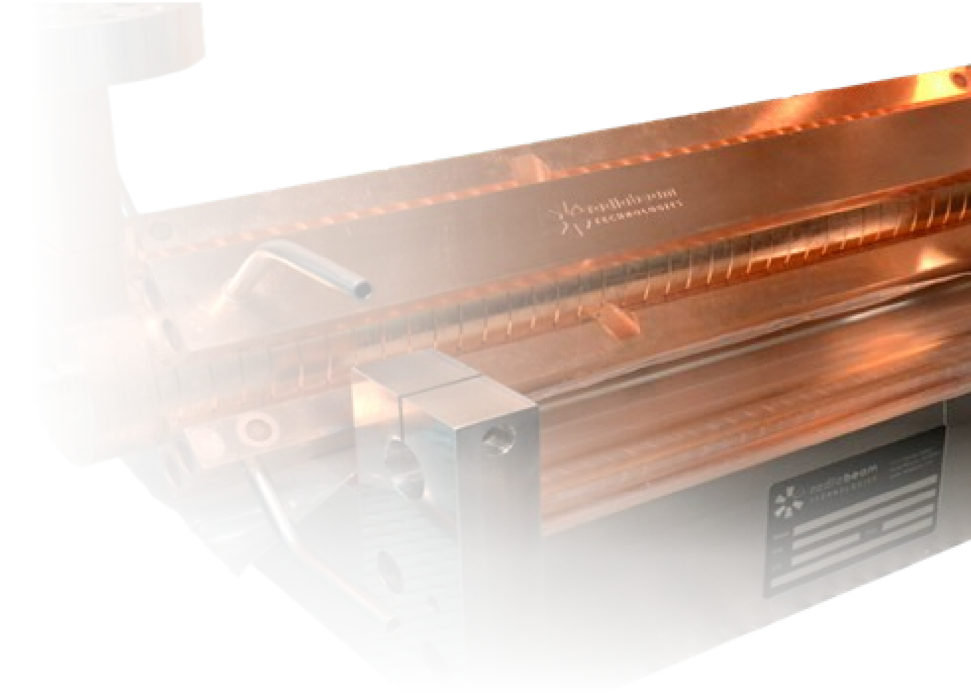
RadiaBeam

Origins of RadiaBeam

- Dual mandate from the start: serving both R&D and industrial markets
- Spin-off from UCLA particle beam physics laboratory (PBPL), mostly engaged in advanced accelerators R&D (photoinjectors, free electron lasers, plasma wakefield accelerators, etc.)
- One founder worked at SureBeam, which made linacs for food irradiation
- Dr. Kutsaev joined in 2014 with a dual industrial (ScanTech Sciences and MEPHI) and research (ANL) background with a goal to provide an impact to industrial linac development and bring new capabilities to RadiaBeam: SRF, ion accelerators etc.



Milestones

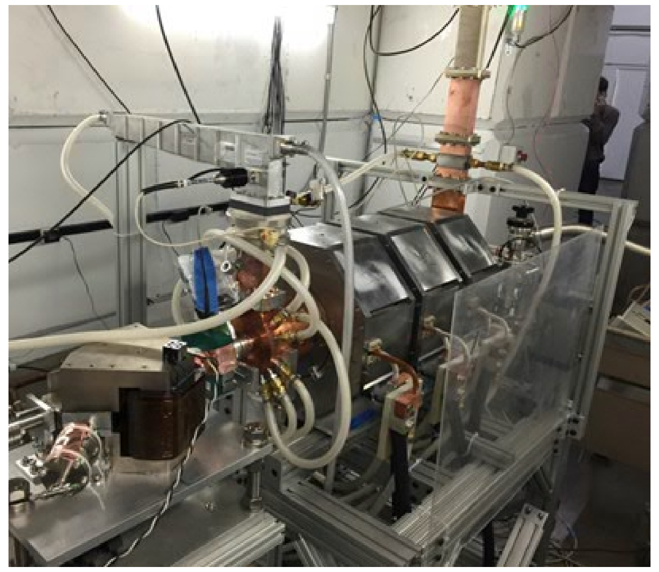


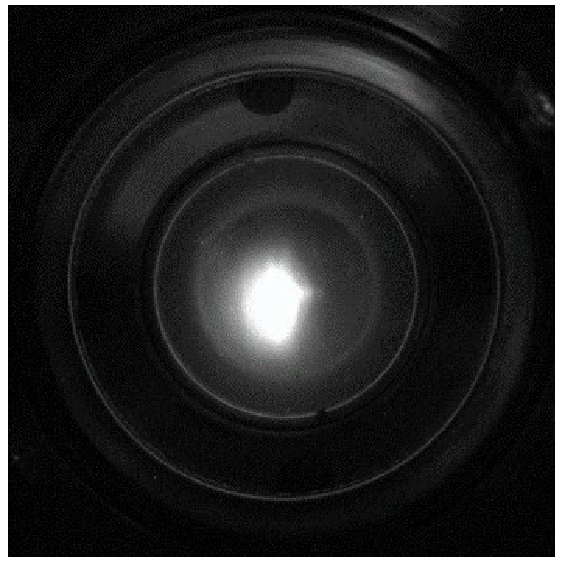
2/10/2004

RadiaBeam Technologies, LLC was born

S. Kutsaev joins RadiaBeam

- **2004** — first sales and SBIR project, got a small office in Marina del Rey
- **2007** — built first machine shop
- **2008** — first accelerating structure completed
- **2011** — first photoinjector gun delivered (Trieste FEL gun)
- **2013** — first complete accelerator sold
- **2014** — first bunker built
- **2016** — first beam in TW high power accelerator
- **2017** — first medical linacs sold
- **2020** — first food irradiation linacs sold
- **2021** — RF gun installed at APS (DOE small business of the year)
- **2022** — first sales to IAEA, Phase IIC, and Phase III
- **2022** — first stage of in-house ICS source commissioned at RadiaBeam



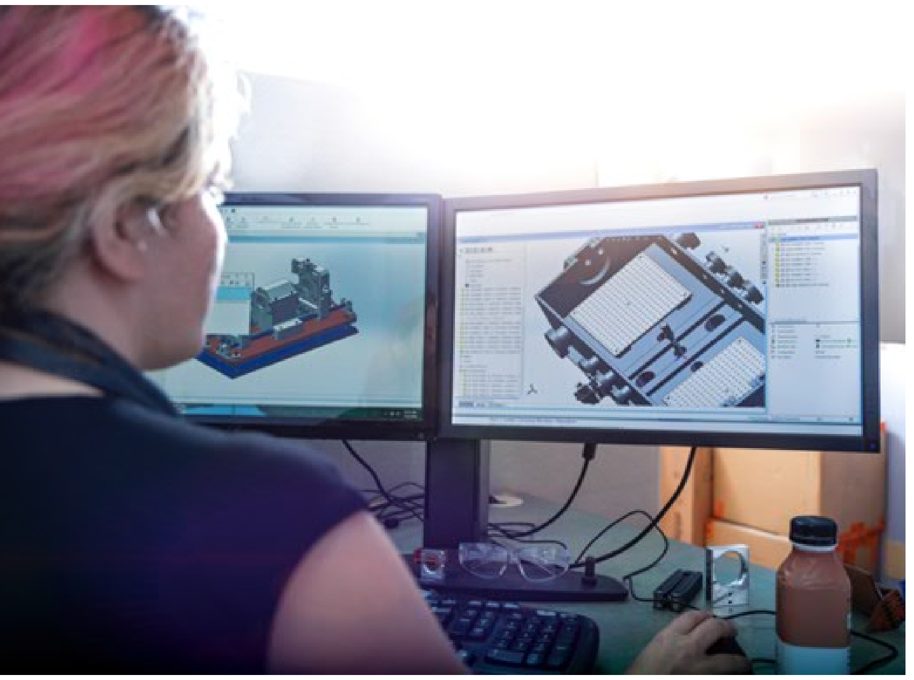
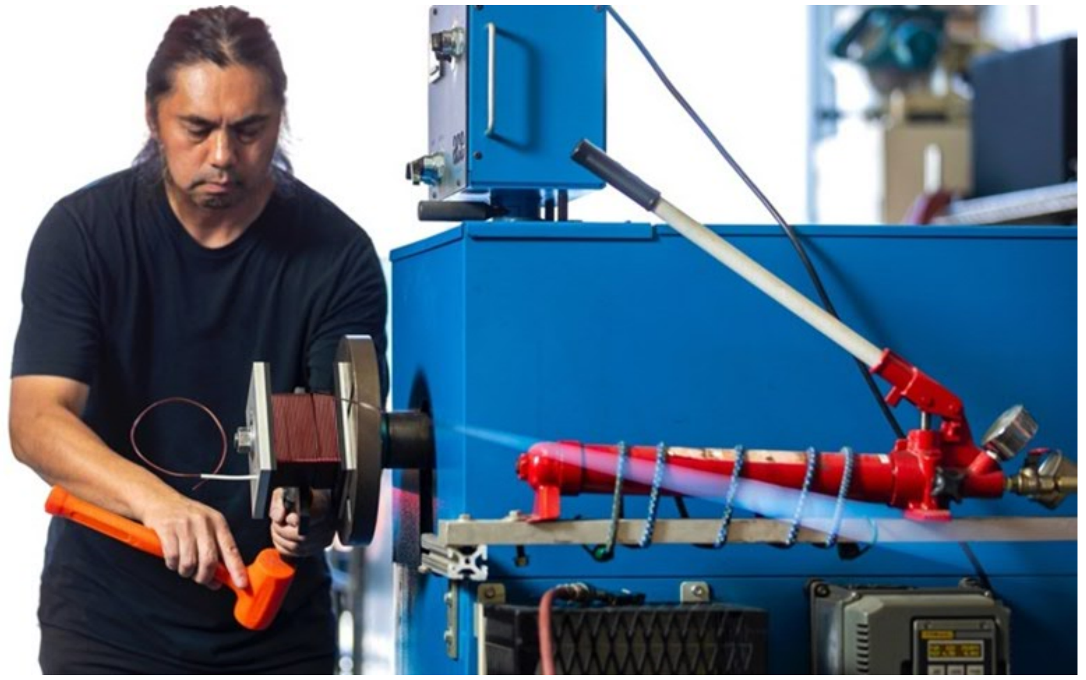


RadiaBeam Now

- 55 employees
  ~30 engineers, 10 scientists, 15 machinists/technicians
- 35,000 ft2 headquarters in Santa Monica, CA
- Accelerator R&D, design, engineering, manufacturing and testing under one roof in a dynamic, small-business setting
- Products: accelerator components (RF structures, magnets, diagnostics), medical/industrial accelerator systems

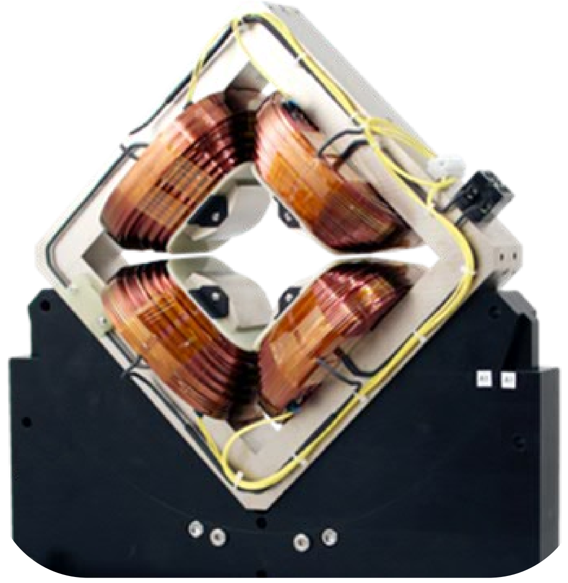
Our capabilities

- Physics design and beam dynamics simulations
- RF and mechanical design/engineering
- Manufacturing/in-house machine shop
- Coil winding and epoxy encapsulation
- Precision magnetic testing
- Low-power and high-power RF testing
- Radiation bunkers with RF stations
- E-beam and X-ray measurement equipment

Our products

Thousands of products delivered since 2004 with new products every year



Magnets

Diagnostics

Medical Linacs

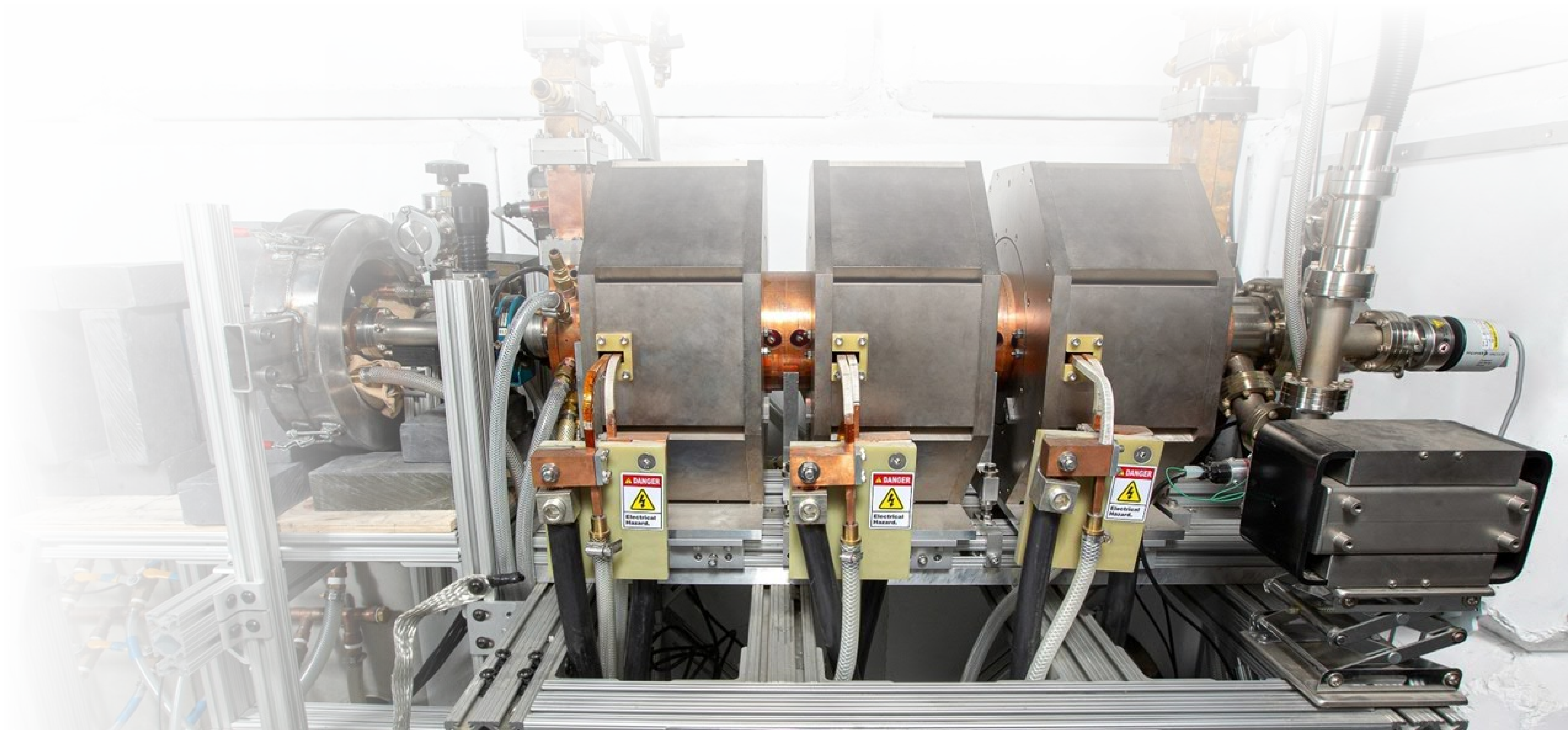
Linac Systems

Beamlines

RF Structures

Services

- Electron beam services: materials testing for sterilization, radiation biology, FLASH, etc.
- X-ray inspection services: Radiography and CT of high-value parts (e.g. aerospace)
- In-house variable-energy 2 – 9 MeV linac, X-ray imaging detectors and other tools



Components of success

Strong connection with lab and university experts
- Colleagues, not customers or consultants
- Many grants and sales result directly from our deep connections with our colleagues

DOE SBIR and other agencies consistent financial support

Focus on successful results
- We would prefer to invest our own money if needed to deliver a good device

Great team of professionals
- We always seek talented people
- Treat employees as family

Long-term investment vs immediate profit
- Equipment, technology, know-how, relationships with vendors

2

Challenges

of building an accelerator company

Means of existence

DOE SBIR/STTR grants

- Most development funds came from DOE SBIR
- Allows RBT to stay part of the broader accelerator community
- Includes BES, HEP, NP, and NNSA programs

Other grants

- Many exciting opportunities, but rarely centered on the accelerator technology
- We had good success with DNDO, NIH, and DARPA

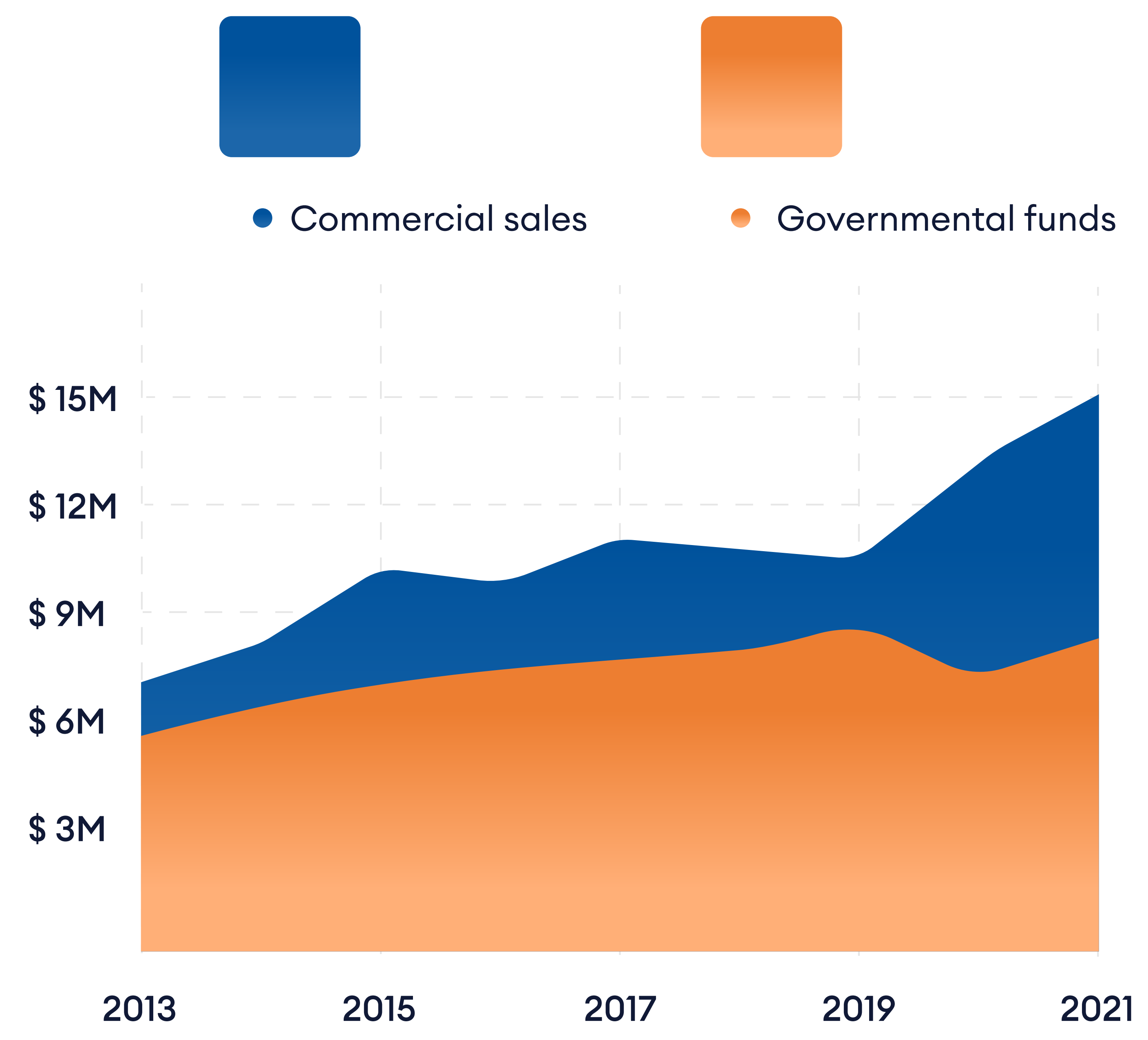
Sales to National Labs and Universities

- Highly customized, risky, and unpredictable profit (often loss)
- Procurement procedures greatly reduces the potential sales

Sales to Industrial Customers

- Mature market limits potential investments
- Strong preference for reliability vs innovation or performance

RadiaBeam Group



2 Challenges

of building an accelerator company

DOE SBIR Grants: Typical challenges and success stories

DOE SBIR Program Challenges

Topics are often disconnected from a near-term procurement or wider market need

- Focus on formal innovation, instead of building useful things with commercial potential
- Example: "Technology for Muon Colliders and Muon Beams" in 2009 HEP topics
- Ironically, the Stewardship program, directed at the labs, focuses on commercial applications

Also scattered widely and too specific, yet limited budget to fund them all

- To win 2-3 grants we need to submit 10+ proposals in all topics with random outcome
- Little freedom for company to pursue what it sees as a real market need

  e.g. it is nearly impossible to get funding for medical linac development
  even if it is synergistic with AAC efforts

Limited budgets and long timelines

- Hardware development is expensive; ~$1 million is often not enough to get to a working prototype
- While there are opportunities for a sequential Phase II, that stretches the project to ~5 years

The result is that, while the SBIR program keeps the lights on and helps us stay engaged with the community, commercially-successful outcomes are less frequent than they should be.

Misunderstanding of SBIR program

Some reviewers treat SBIR proposals as peer-reviewed papers

- If there are no criticism = the reviewer did a bad job
- Lower marks = grant declination
- No differentiation between SBIR and STTR

Some lab scientists:

- Think that SBIR grant is a procurement project (as if they paid us the money and we committed to deliver an operational device no matter what)
- Think that SBIR companies have an unlimited internal budget (and should spend all of it on their project)
- Treat SBIR as a free resource for their R&D work (no real need neither for lab nor for commercial sales)

Not very common!

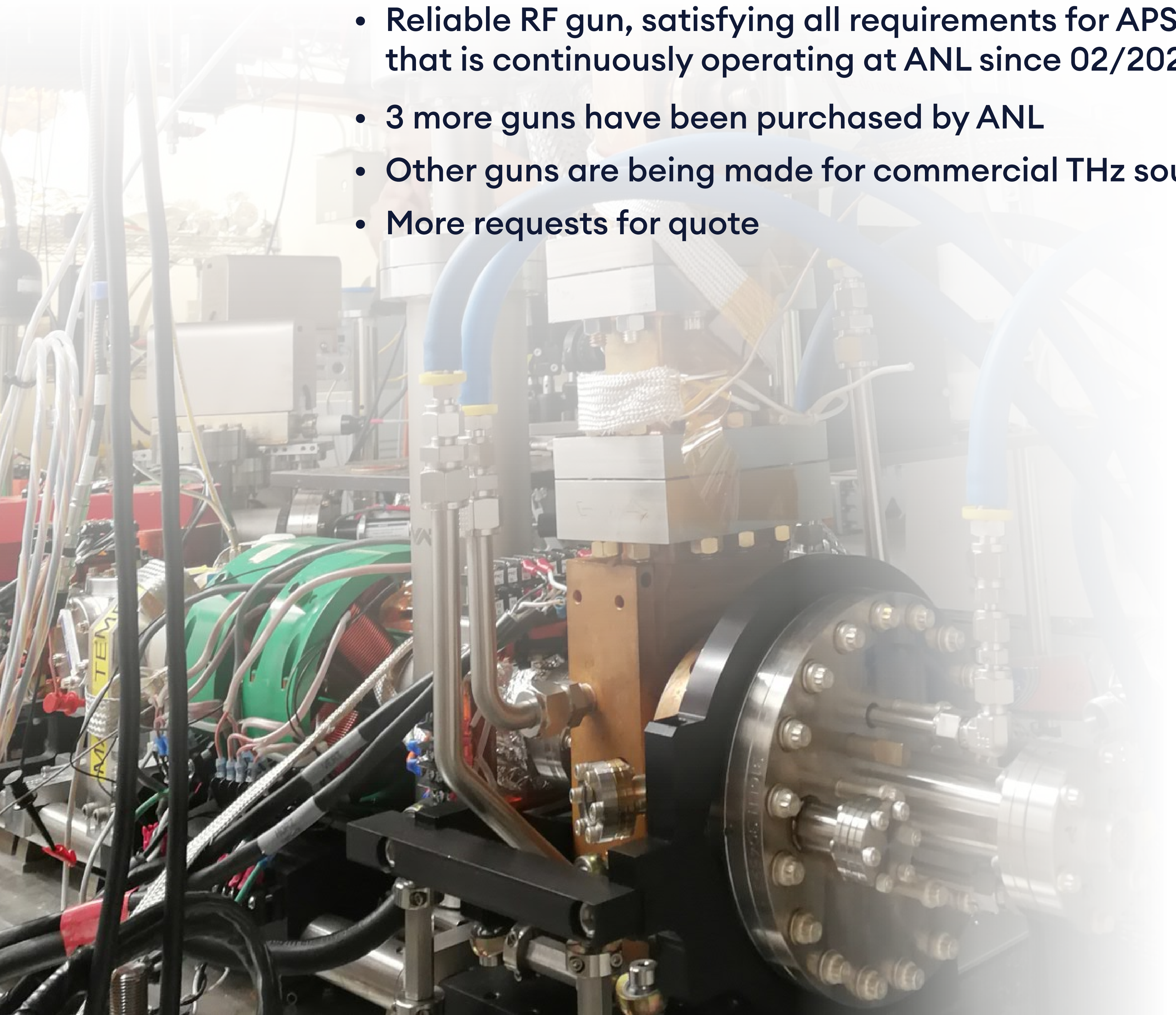
Example of a textbook SBIR project

- **ANL had problems with the existing thermionic RF guns and needed a replacement**
- **ANL put the topic in the SBIR solicitation**
- **DOE BES awarded 7 Phase I grants in this topic, including 2 awards to RadiaBeam**
- **During the project, ANL:**
  - Shared all the experience with the previous gun Clearly stated adequate parameters and requirements
  - Supplied old cathode for post-mortem inspection
  - Provided old gun design and suggested RF design improvement
  - Delegated a team of engineers to help RadiaBeam with the design and integration
  - Provided detailed feedback at every step of the project
  - Hosted high-power and beam tests
  - Installed at ANL injector and provided regular feedback on the performance
- **All of this was provided by APS/ANL in-kind**
- **DOE fully supported this project (Phase IIB and IIC awards)**

This resulted in...

Useful commercial product:

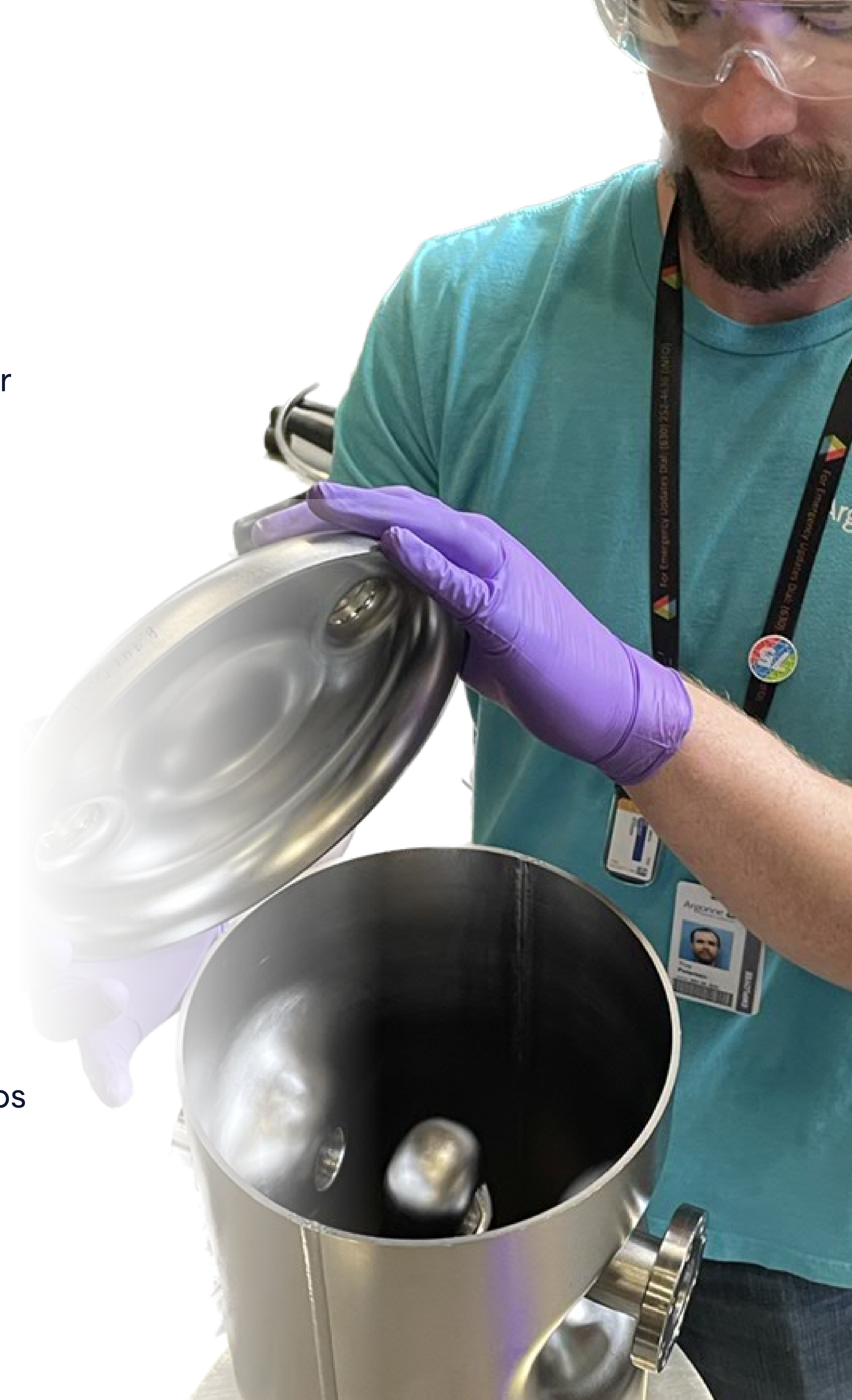
- Reliable RF gun, satisfying all requirements for APS-U that is continuously operating at ANL since 02/2021
- 3 more guns have been purchased by ANL
- Other guns are being made for commercial THz source
- More requests for quote



SBIR Company of the Year by DOE in 2022!

Example of a good R&D project (Lab-led)

- ANL (Physics Division) requires stand-alone SRF cryomodules for energy booster at ATLAS facility
- ANL approached RadiaBeam (and Fermilab) to apply for a NP award
- Being the world-leading organization in low-beta cavities fabrication, ANL has taken the leadership for the cavity development
  - Provided clear and straightforward tasks for the design and fabrication
  - Shared the materials and equipment (in kind)
  - Provided the guidance for Nb fabrication from their engineers and technologists
  - Provided detailed feedback at every step
  - Allowed task flexibility and focused on the tasks that they really needed
- **Result:** we have been able to machine all Nb and Nb-Ti parts, and the cavity was fabricated
- Commercially-wise, RadiaBeam can now provide Nb-machined parts to the labs



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Challenges

of building an accelerator company

Other (non-DOE) Grants:

Examples of indirect commercialization

Challenges with R&D projects outside DOE

- Many exciting opportunities in DOD, DHS, NIH, etc., but rarely centered on accelerator technology
- Programs are not consistent (priorities, topics and people change frequently)
- Sometimes the requirements are non-realistic
- Some agencies use extremely challenging contractual requirements
- Still often detached from the procurement program

ARCIS: adaptive rail cargo inspection system

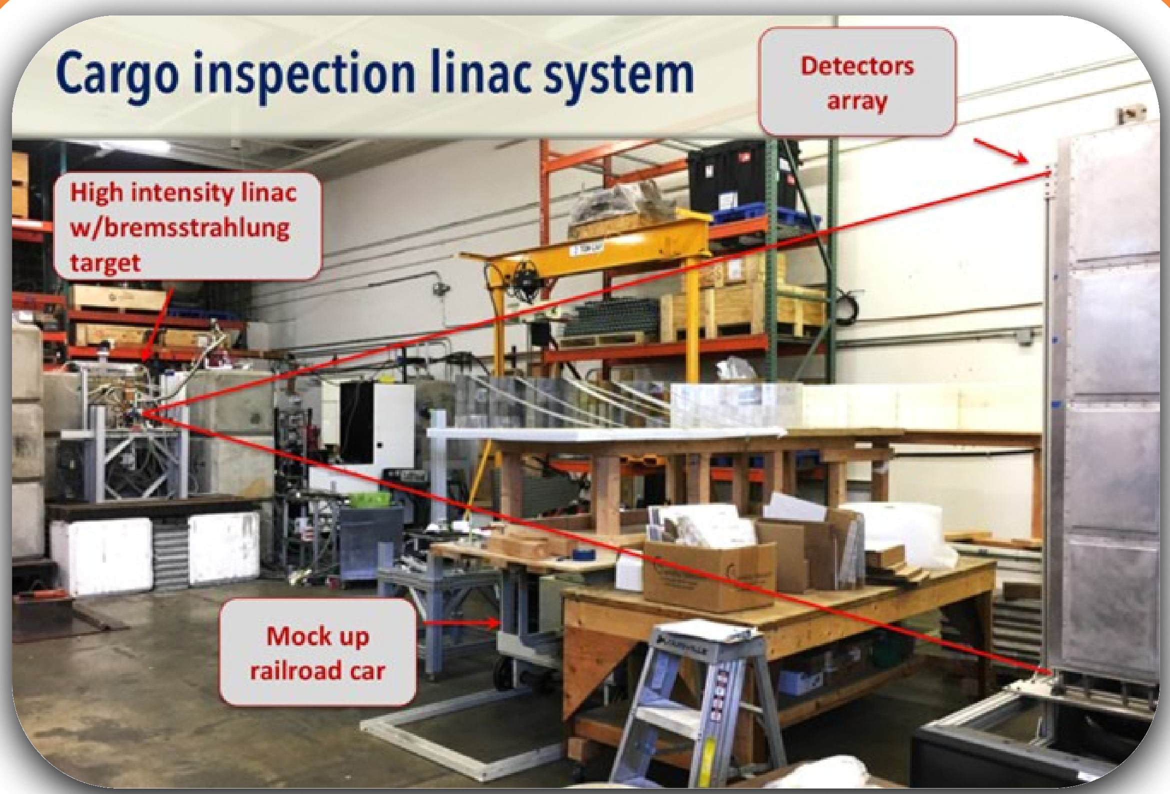
- **R&D project to develop fast, up to 45 km/h, rail train scan system (funded by DHS)**

  10 kW beam power, energy ramped pulses for real time material discrimination

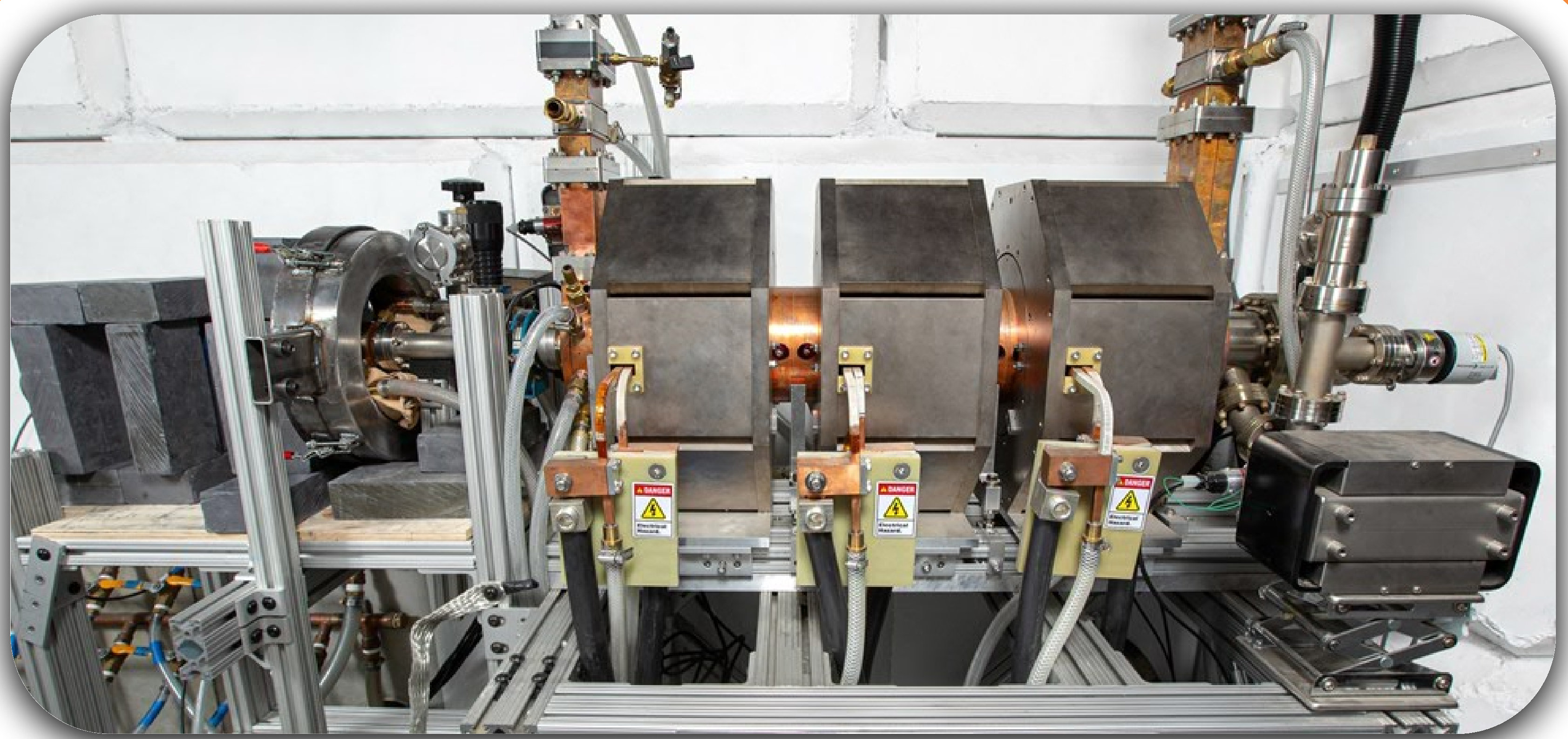
- **Developed ARCIS linac, including ramped pulse capabilities**

  Mock-up rail cargo target tests demonstrated fast materials discrimination

- **The ARCIS program had no follow through, but RadiaBeam redeployed the ARCIS linac for testing services, offering variable energy (2 – 9 MeV) high-power (10 kW) beam**
  - Electron beam services: materials testing for sterilization, radiation biology, FLASH, etc.
  - X-ray inspection services: Radiography and CT of high-value parts (e.g., aerospace)



ARCIS



“FLEX” X-Ray inspection system

Compact Inspection Linac

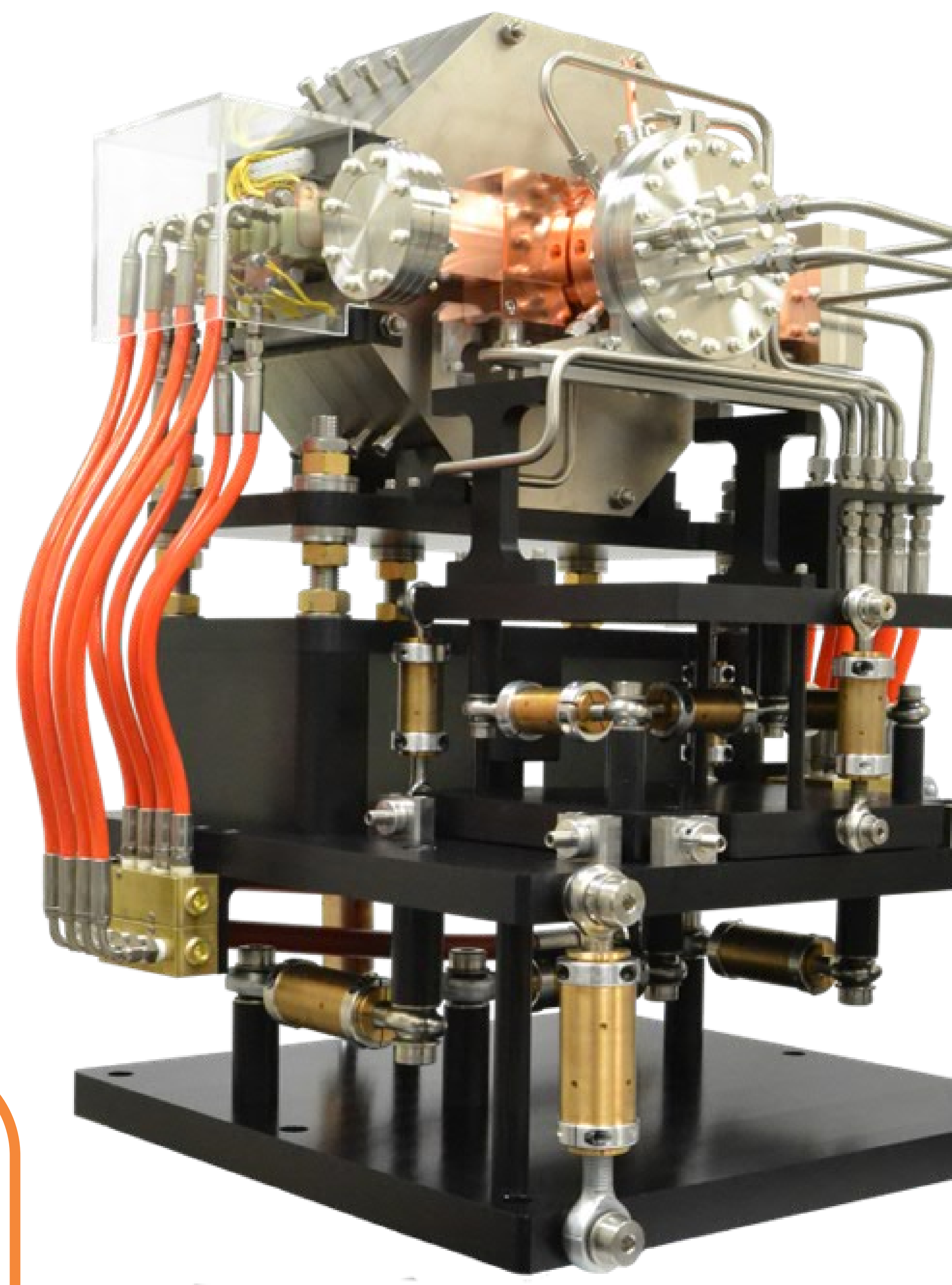
- In 2016, we designed a compact X-band dual-energy linac for mobile cargo inspection systems (DNDO granted)
  - Can operate in conventional 4/6 MeV interlaced energies regime
  - High repetition rate allows using fast Scintillation-Cherenkov detectors
- After years of trying, we were not able to find a cargo inspection customer: they are generally happy with existing, low-cost linacs and betatrons.
- The linac was reused in novel robotic 4π X-ray radiotherapy system

3 Challenges

of building an accelerator company

Sales: And what is the problem with them?

Sales to National Labs



First line of business for RadiaBeam: magnets, diagnostics, and custom RF structures

Challenges:

- Unpredictable market: $ millions of orders one year, and zero the next year.
- Lab procurement rules are difficult.
- Labs often do the design and engineering themselves, removing higher value work and resulting in overengineered products
- Whenever they can get away with it, the labs will make things for themselves and for other labs

project team

Sales to Industrial Customers

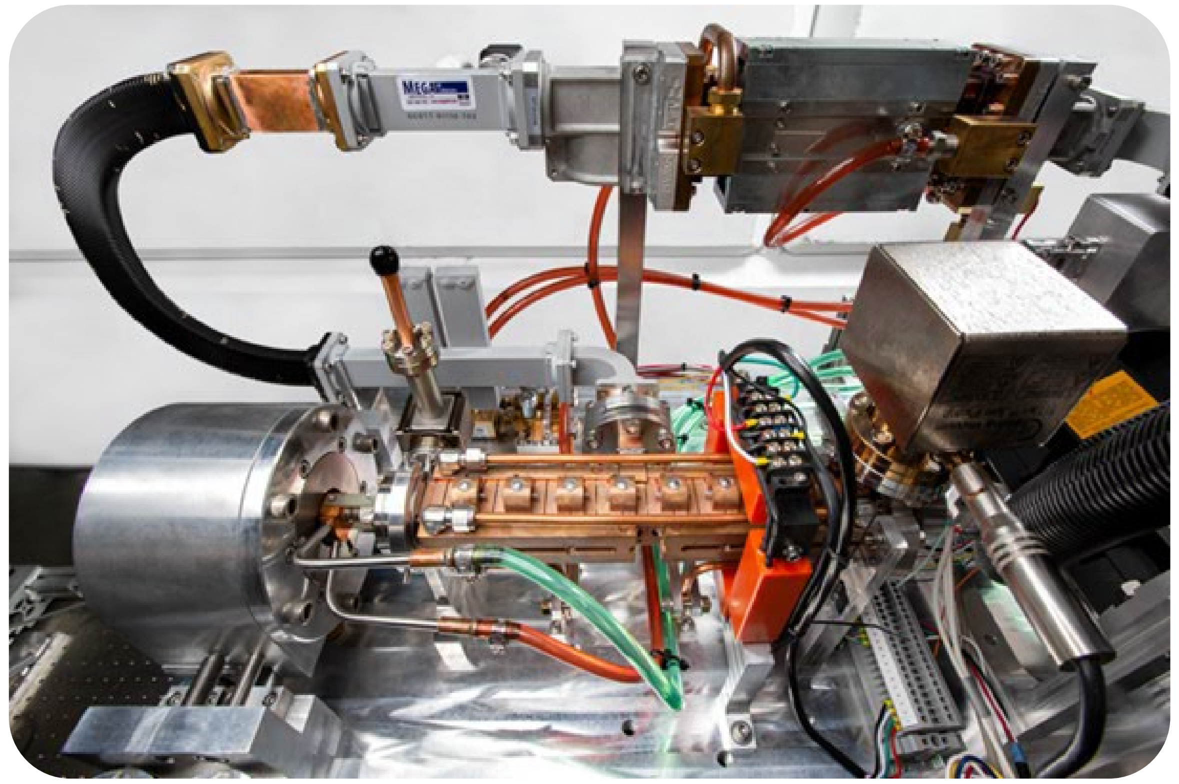
- The market for medical and industrial accelerators is significant, but it is in most cases served well by mature products
- Medical/industrial customers are very cost-sensitive and often want to make linacs themselves to control the supply chain and IP

  When they need help, it is usually just for prototype development or to solve some short-term emergency

- Beware of “technology push”: the market usually doesn’t need what you think is a great idea

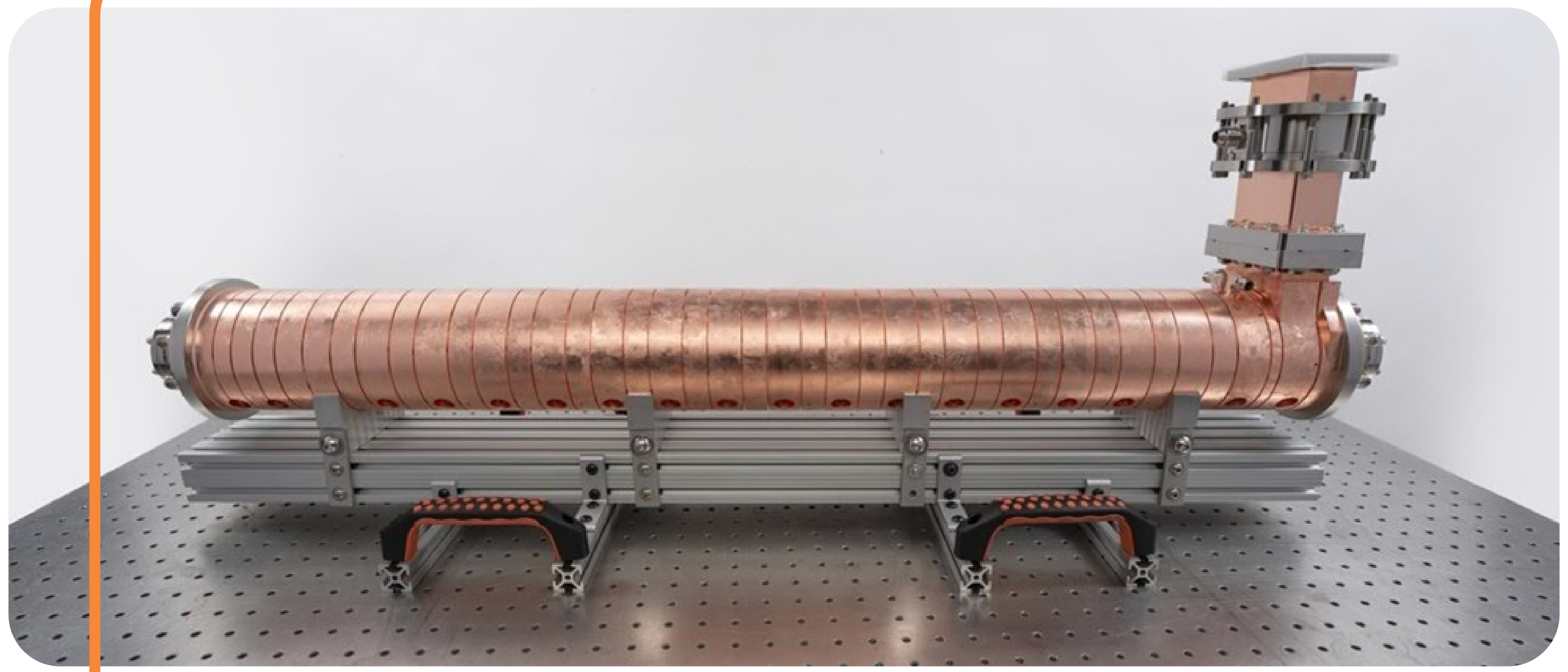
  Old but reliable devices can be preferrable to novel high-performance ones

- While we have had some success with OEM linac sales, further growth requires developing complete linac systems for market segments that are not currently well-served



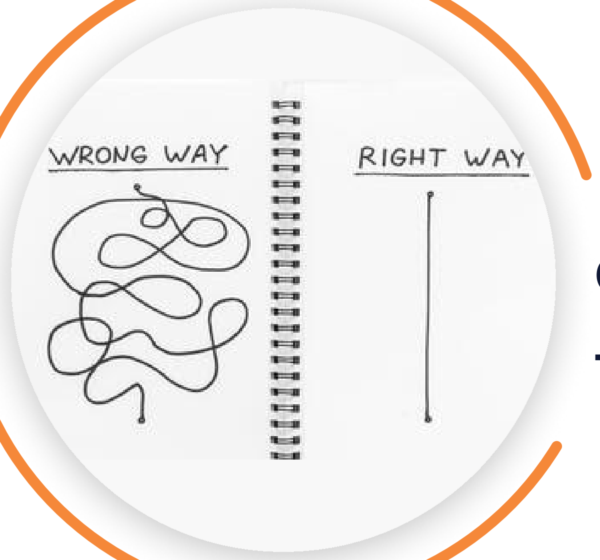
Example of Industrial Linac Sales

- One of our customers had attempted to manufacture their own linacs with the help of an underqualified staff physicist and national lab consultants
- After spending months RF conditioning with no progress, they contacted RadiaBeam
- We tried to fix their linacs, but realized they were beyond repair due to multiple design and manufacturing mistakes
- In < 1 year, we designed, engineered, built, tested and delivered replacement linacs
- As thanks for our efforts, the customer now is talking to a cheaper manufacturer to build linacs for them



RadiaBeam-built structure

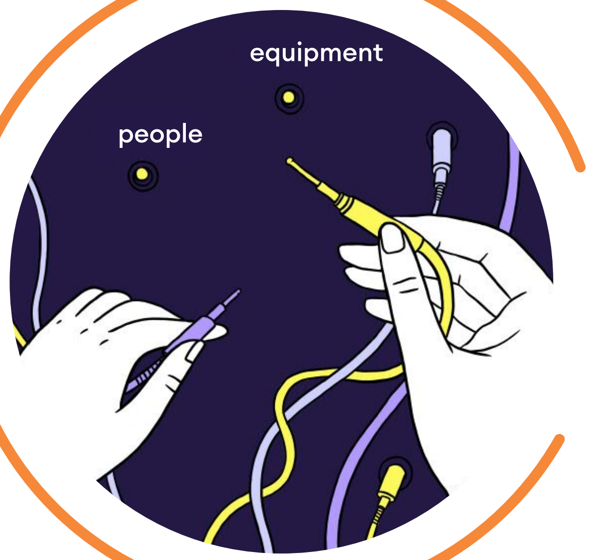
Summary of Challenges



Customer's first choice is often to make things themselves

Funding opportunities and customers' needs are **not sufficiently aligned in space and time**

US labs seem less interested/capable of working with industry than EU



Expensive industry (people + equipment + time) but highly segmented and inconsistent market, DOE SBIR is as close as it gets to an anchor customer

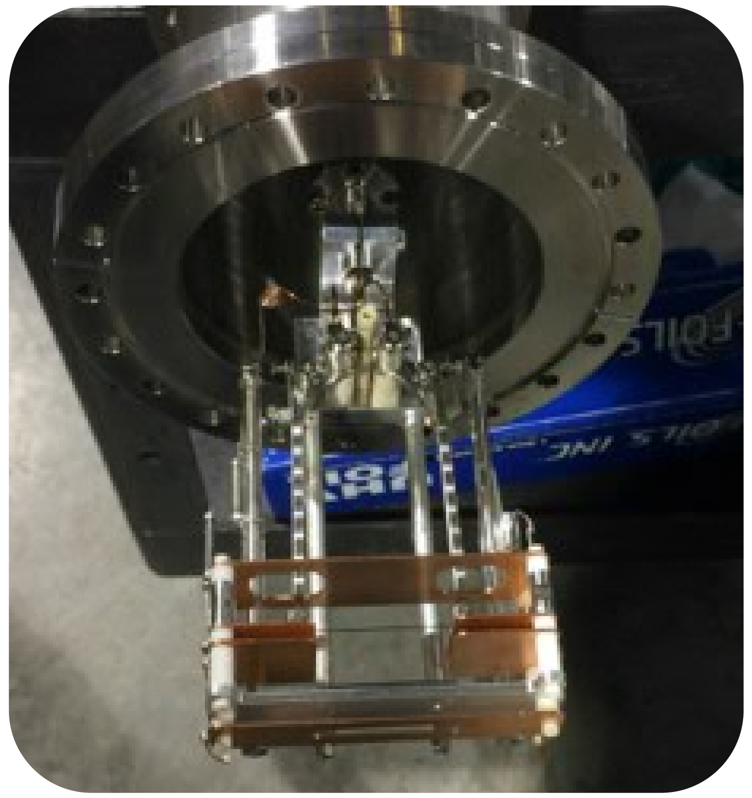
3 Raison d'être

and future vision of RadiaBeam

Serving accelerator community

Continue serving accelerator community (light sources and discovery science facilities) with the most advanced industrially produced solutions for their needs

- Continue supporting existing line of products
- SRF parts manufacturing
- SC insertion devices
- Advanced diagnostics


BSM focusing system installed at SNS


Photoinjector electron source for FEL facility

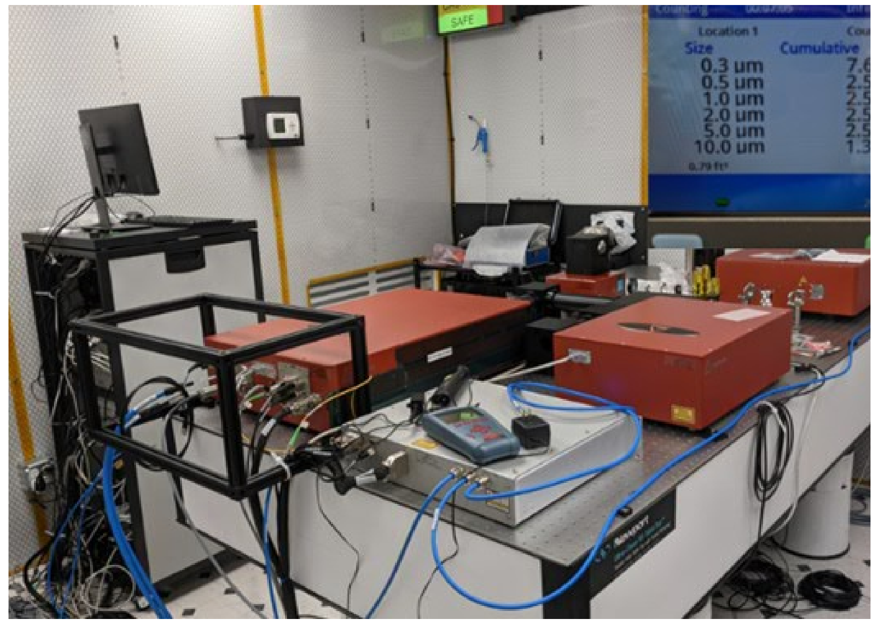

LCLS dechirper at SLAC


Integrable optics magnet for Fermilab

Advanced Accelerators and Light Sources

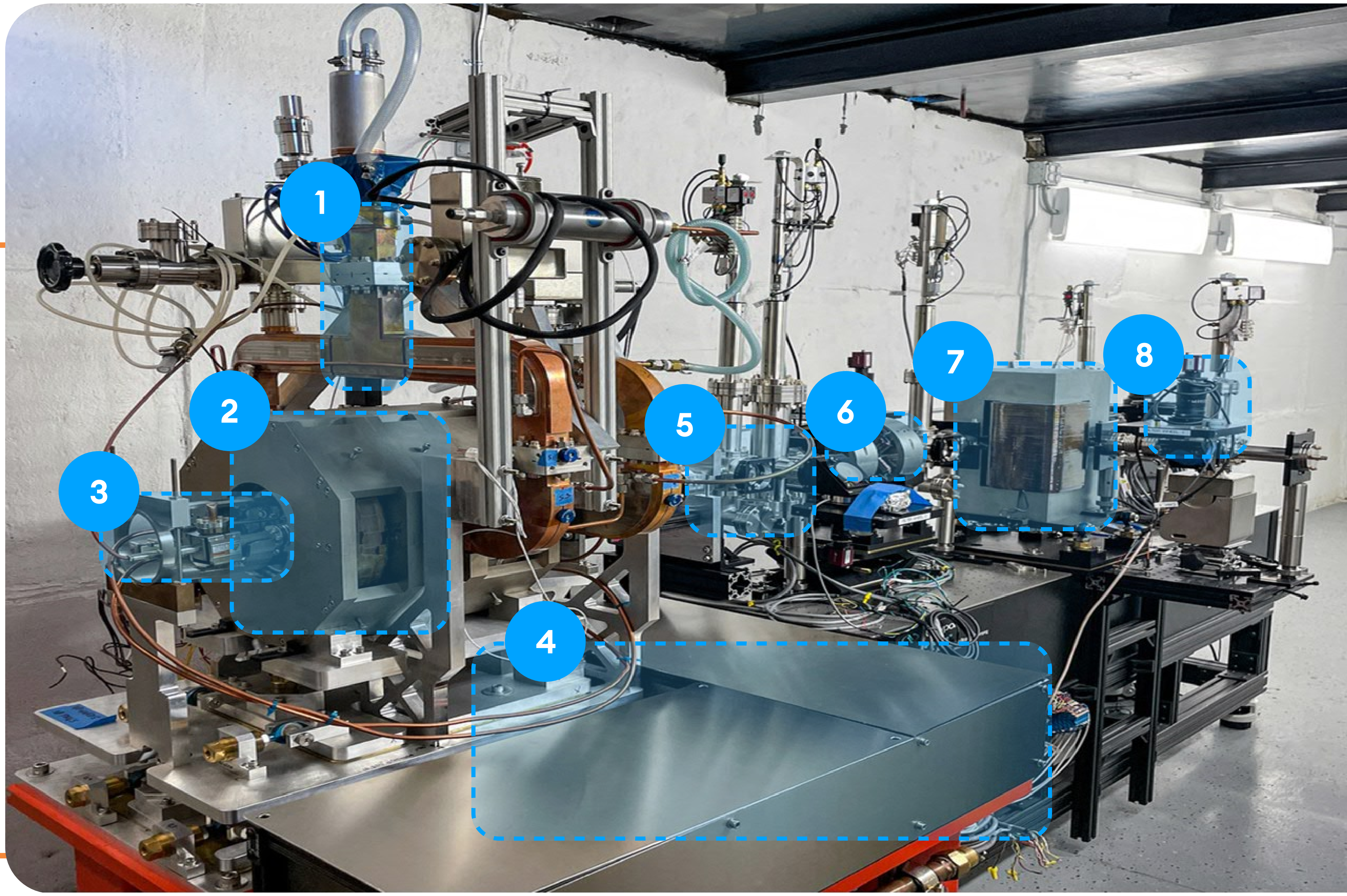
We are currently developing an Inverse Compton Scattering gamma ray source

50 MW ScandiNova klystron



Amlitude Magma UV lasersystem

1 RF power input
2 Emittance compensation solenoid
3 Cathode assembly
4 UV laser optics and diagnostics box
5 Beam imaging and emittance diagnostics & BLIS (bunch length) interferometer
6 Focusing quadrupoles
7 Spectrometer dipole
8 Spectrometer imaging optics
9* UV laser line



This research was developed with funding from the Defense Advanced Research Projects Agency (DARPA). The views, opinions and/or findings expressed are those of the author and should not be interpreted as representing the official views or policies of the Department of Defense or the U.S. Government

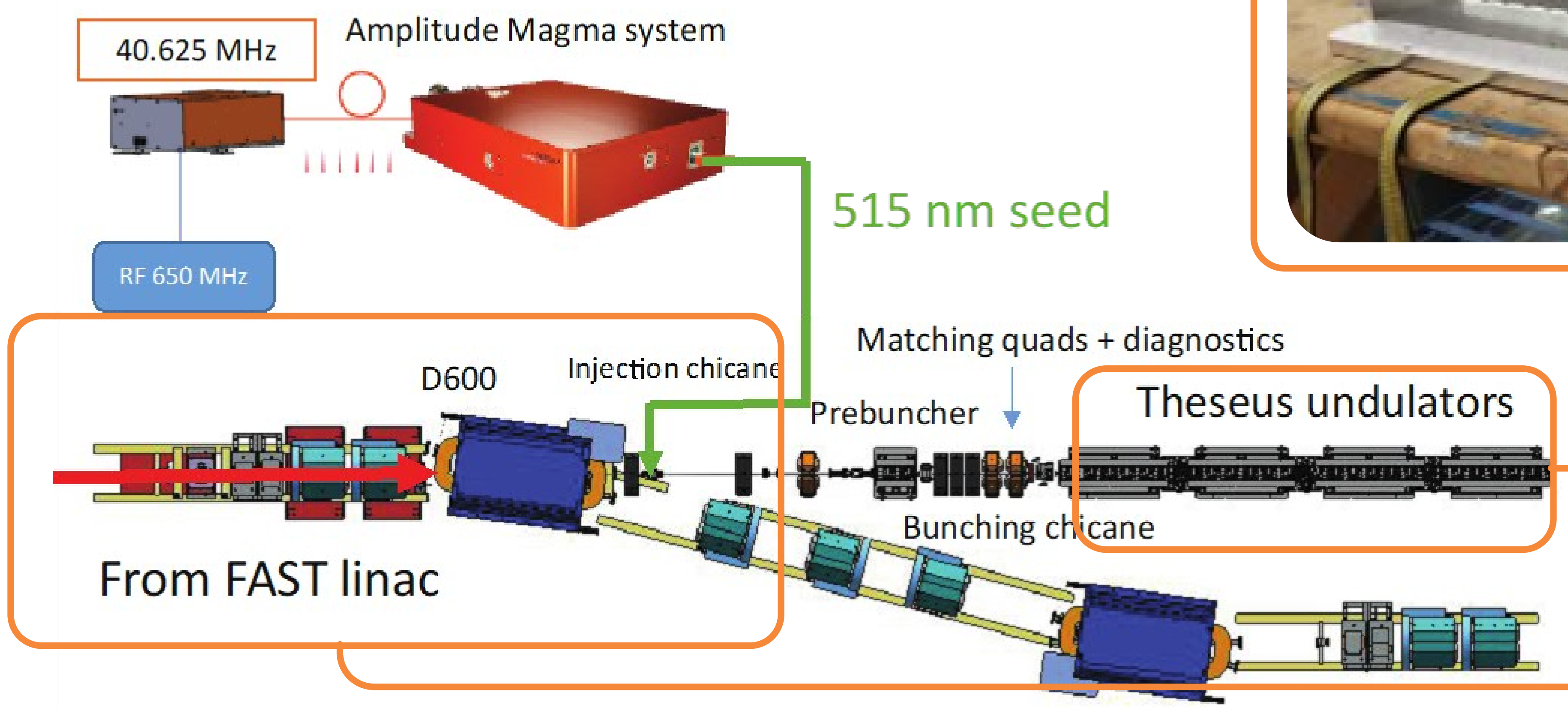
Advanced Accelerators and Light Sources

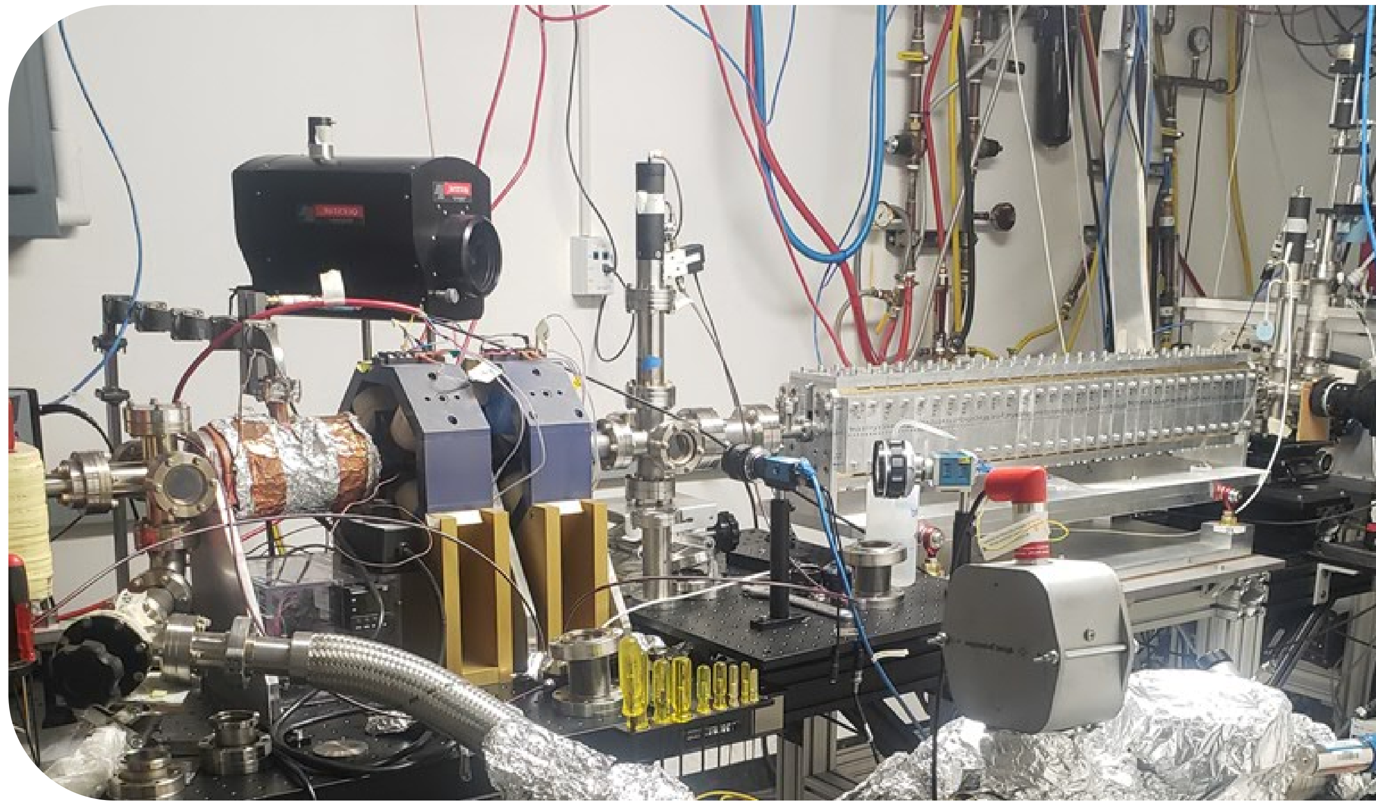
Working with UCLA on high efficiency FEL program (TESSA). Two concurrent efforts:

- A project at Fermilab to demonstrate ~ 10% beam to light conversion efficiency at optical wavelength in amplifier and oscillator configurations in 4 m long undulator, using e-beam from SC FAST linac
- THz TESSA program at UCLA and RadiaBeam

- Recently demonstrated 10 % efficiency in single pass THz FEL.
- Strongly tapered helical undulator + Waveguide tuned to "zero-slippage" FEL regime where group and phase velocity of the radiation are matched to the e-beam.
- Made it to Nature Cover

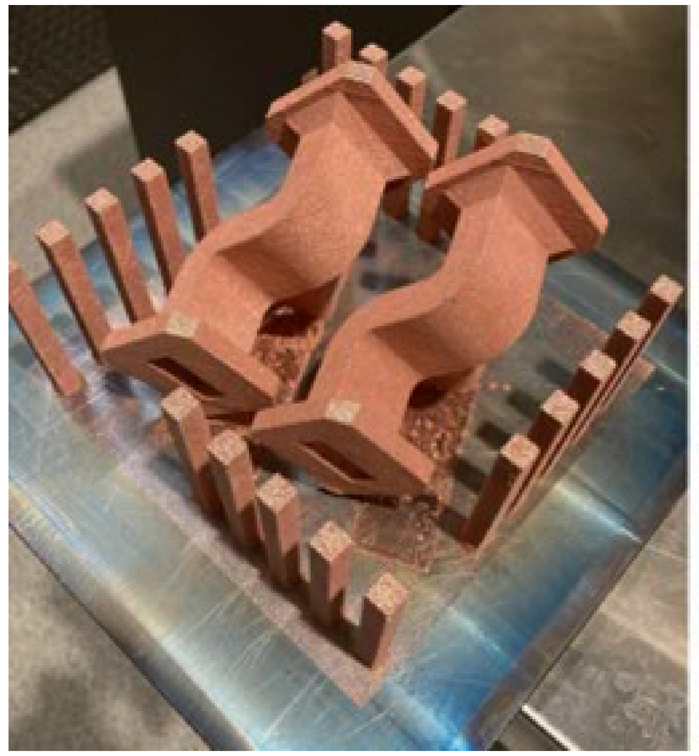
A. Fisher, Y. Park, M. Lenz, A. Ody, R. Agustsson, T. Hodgetts, A. Murokh and P. Musumeci. "Single Pass High Efficiency THz FEL", Nature Photonics 16, 441–447 (2022).

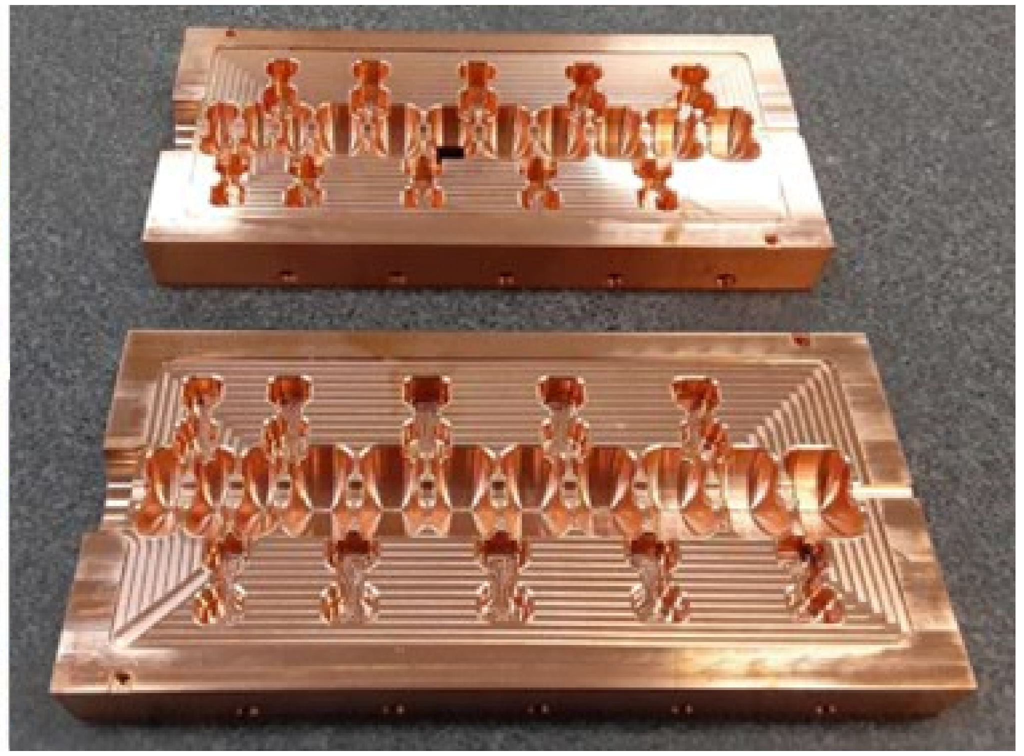


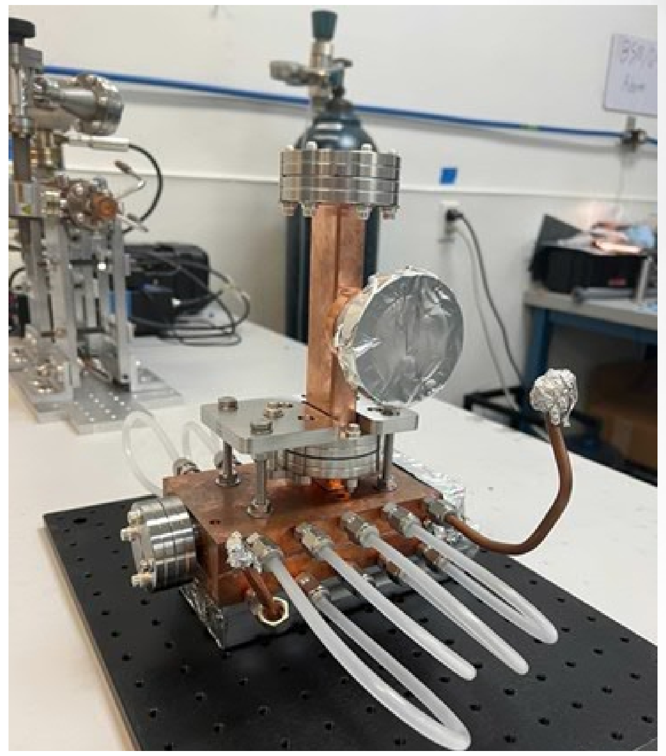


Accelerator systems and components

- **Serving industrial, medical, environmental and security community with accelerator sys (go to place to buy a linac or linac systems)**
  - Compact linac development
  - Linacs for novel medical modalities
  - High power linacs for radiation processing (sterilization and food)
- **Active R&D program with support from the US DOE to develop new accelerators for indu**
  - Self-contained irradiators (2 – 4 MeV)
  - Portable linacs for radiography (1 – 2.5 MeV)
  - Modular linacs for sterilization (5 – 10 MeV)
  - Innovations in manufacturing (i.e., split linac, and AM)
  - High frequency RF (X- or Ku-band) to reduce size







Conclusions

An accelerator company is expensive, time-consuming, risky, low margin and low growth

More like a medieval city guild than a silicon valley startup

Nevertheless, industry can offer value for accelerator R&D

- **We can** build professionally-engineered products
- **We can** carry out R&D in a more dynamic way
- **We can** be a bridge between the commercial applications and pure R&D

Despite all the problems, working at RadiaBeam allows fun and flexibility

- **We have** a beer station in our office
- **We have** company-sponsored ski trips
- **We don’t need** government approval to attend conferences
- **We have** company credit cards and can pay for drinks for our customers and friends

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RadiaBeam

Thank you for your attention!

QUESTIONS?

speaker **Sergey V. Kutsaev** — & co-authors **S. Boucher, A. Murokh**