CERN-ACC-SLIDES-2016-0005

EuCARD-2

Enhanced European Coordination for Accelerator Research & Development

Presentation

RadiaBeam Technologies - Company Overview

Rosenzweig, J. (UCLA) *et al*

17 November 2014

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This work is part of EuCARD-2 Work Package **5: Extreme Beams (XBEAM)**.

CERN-ACC-SLIDES-2016-0005

Company Overview

Alex Murokh

Vice President and Chief Technology Officer

RadiaBeam Technologies, LLC

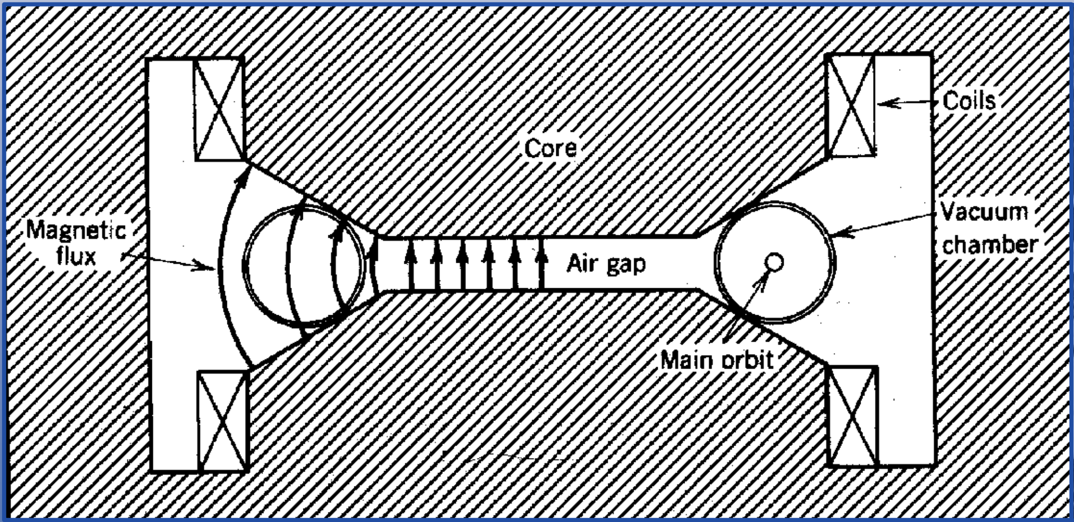
Company Background

- RadiaBeam Technologies was founded in **2004**, a spin-off from UCLA Particle Beam Physics Laboratory


- Initial business idea was to develop a ***Radiatron***, a high duty cycle FFAG betatron, for industrial applications.

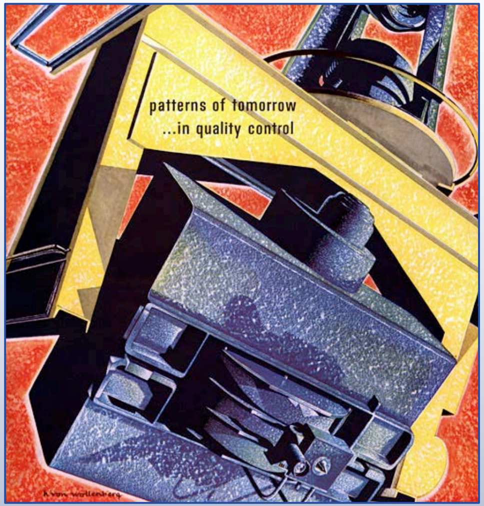
Classic Betatron

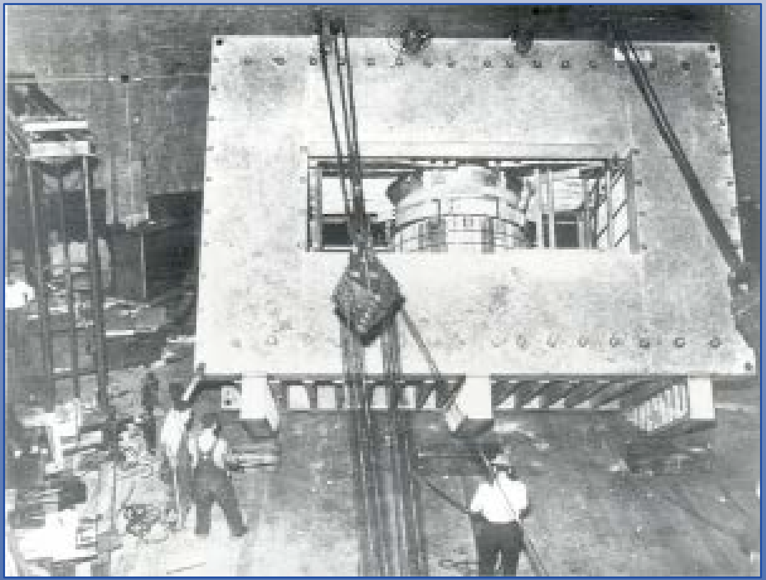
- Developed in 1940 by Donald Kerst (U of Illinois)
- Induction acceleration
- A the right injection phase e-beam orbit is contained by changing dipole field
- Shaped poles provide weak focusing (stable orbit)



Classic Betatron

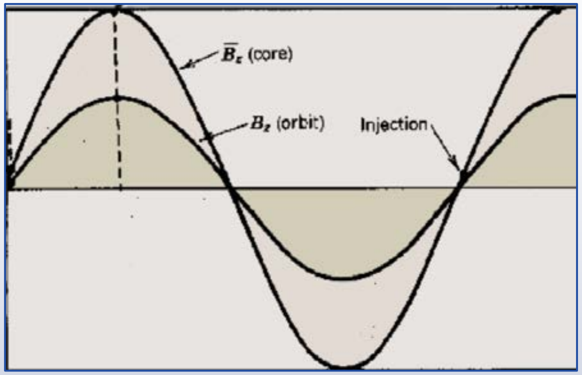
- Betatrons became dominant technology through 40s and 50s
- Major research effort at MURA
- Industrial radiography and radiotherapy (Allis-Chalmers)



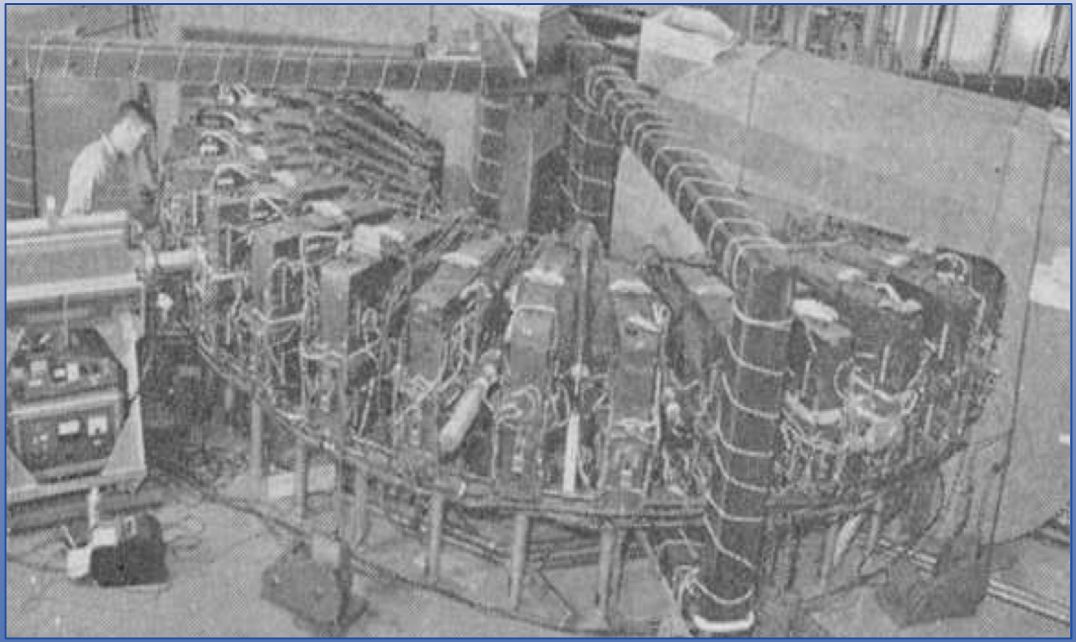


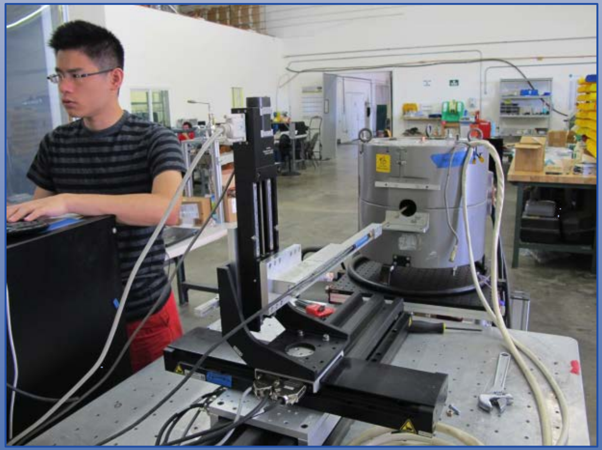
Classic Betatron

- Low duty cycle
- Low repetition rate
- *Replaced by linacs in 60s*
- Fixed-Field Alternating Gradient (FFAG)
- Small radiography market



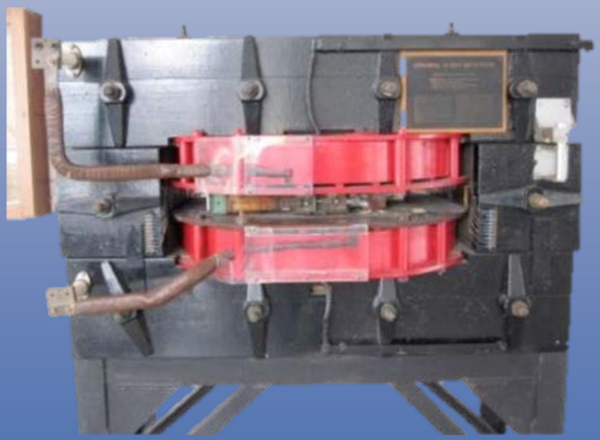
MURA 50 MeV FFAG betatron

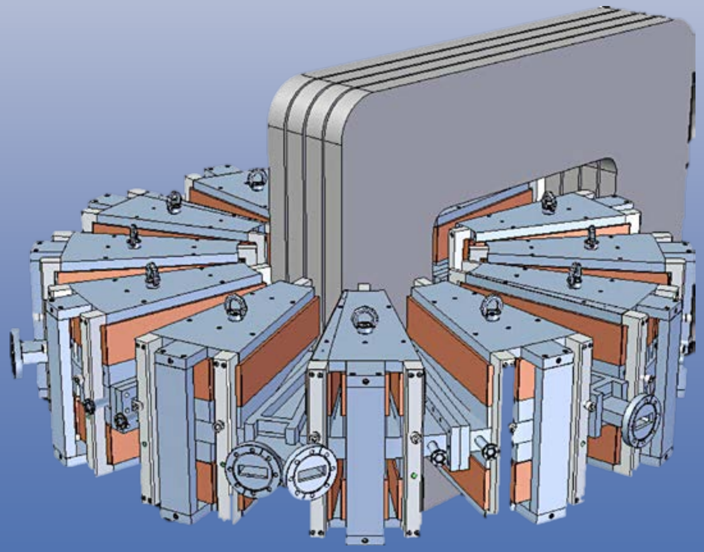




Radiatron

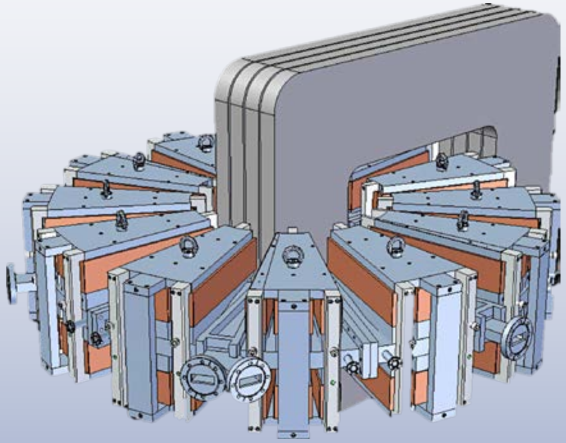
- Technological advances enabling rethink of a classical betatron:
  - Introduction of novel, low cycling loss magnetic materials (i.e. finemet), allowing r.r. over 10 kHz
  - Surge in computational capabilities to model FFAG lattice
  - Development of IGBT power switching electronics





Radiatron vs. Linac

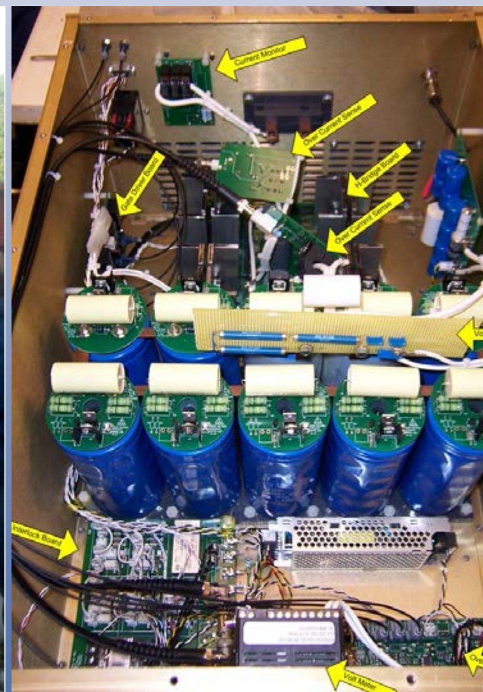
- 6 MeV classic betatron, linac and Radiatron:



r.r. ~ 100 Hz Duty cycle ~ 1% Peak current ~ 10 µA E-beam power ~ 1 W Dose ~ 3 cGy/min-m	r.r. ~ 100 Hz Duty cycle ~ 0.1÷0.3% Peak current ~ 0.03÷1.0 A E-beam power ~ 0.2÷20 kW Dose ~ 0.01÷1 kGy/min-m	r.r. ~ 10 kHz Duty cycle ~ 20% Peak current ~ 15 mA E-beam power ~ 20 kW Dose ~ 1 kGy/min-m
Still in use in a low dose security applications	Replaced betatrons for most applications (competition from Rhodotron above 100 kW)	no RF components less expensive > 10 kW High duty cycle

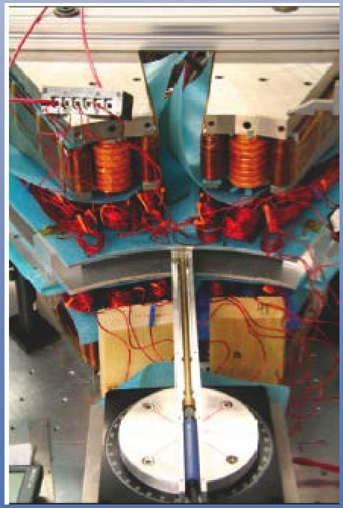
Radiatron Development

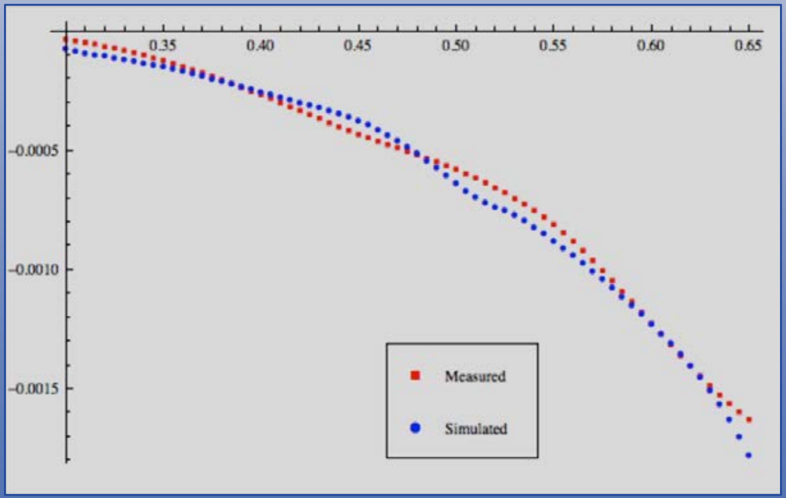
- DOE SBIR grant to develop a prototype system (6 MeV, 10-20 kW average power)
- 2004-2005: beam dynamics design/engineering
- 2006-2007: prototype construction

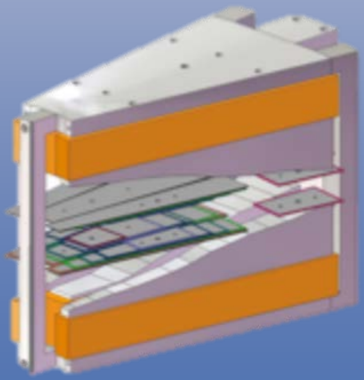


Radiatron Development

- 2007: ran out of $$
- the biggest unresolved technical challenge was FFAG magnets and extraction
- *IBA s.a*. became interested in Radiatron
  - Offered access to IBA codes to study extraction
  - Funded magnets redesign (no success)

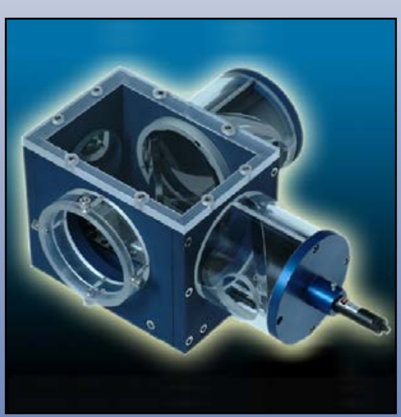






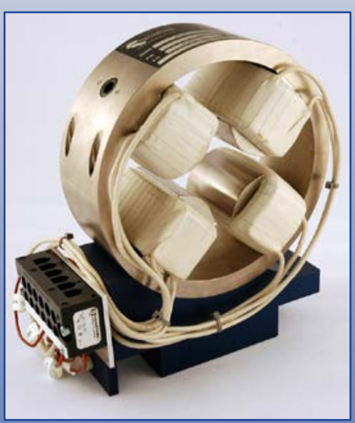
Products

- 2009: IBA funding ran out, Radiatron development had to stop
- Fortunately since foundation we tried to develop and sell other products (longitudinal and beam profile diagnostics, magnets, RF structures).



1st product sold (2004): THz interferometer for bunch length measurements (licensed from U. of Georgia); delivered to *INFN*

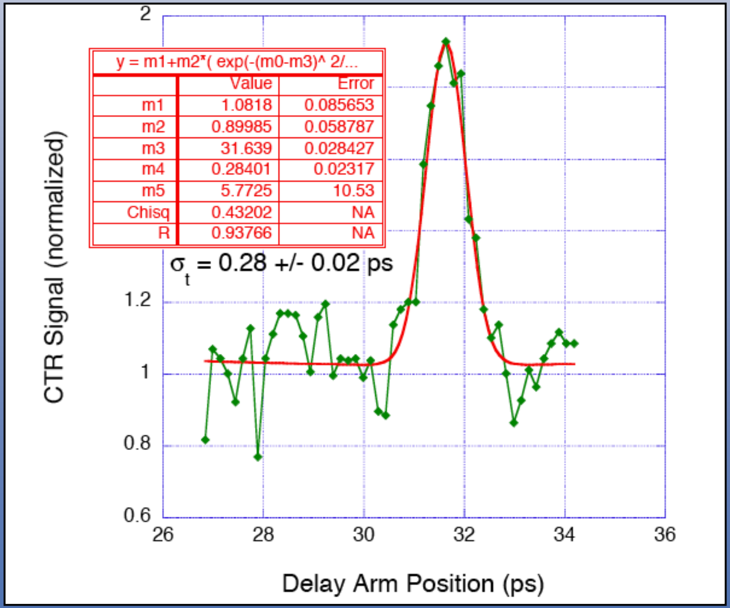
2nd product sold (2005): quadrupole triplet for low energy beamline; delivered to *Accuray*



- SBIR Program also offered multiple new opportunities (products/R&D – positive feedback)

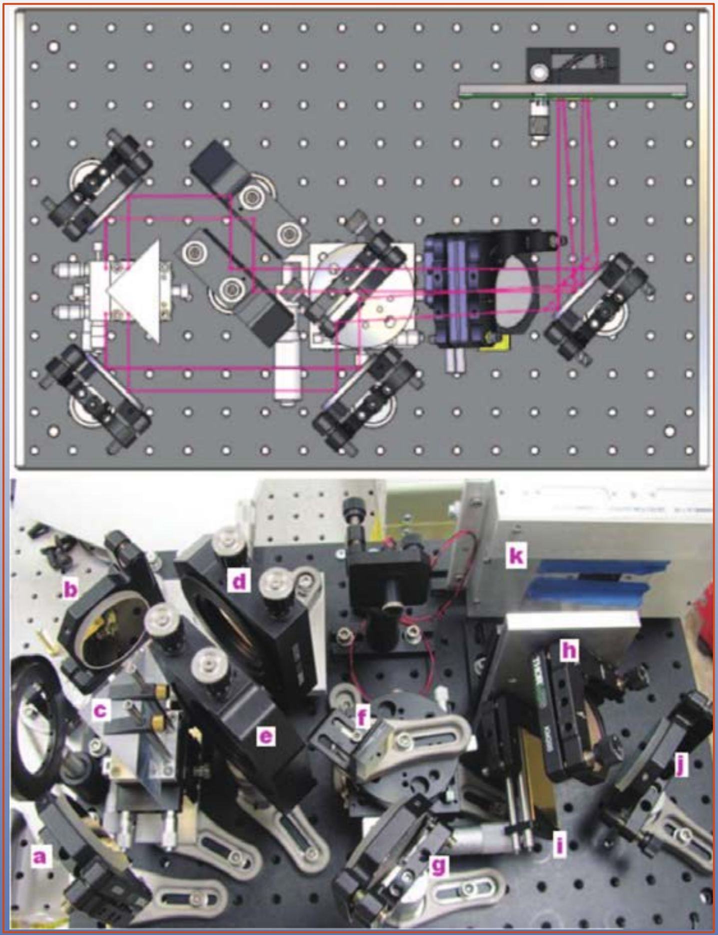
Longitudinal Diagnostics

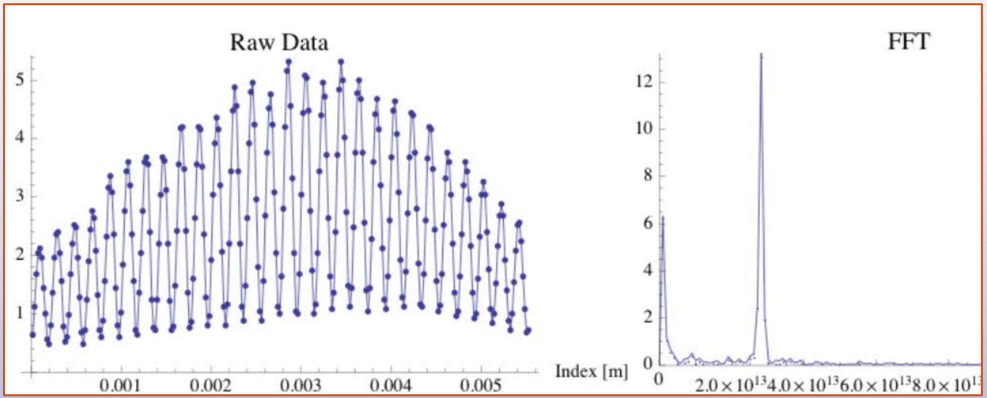
- Spectral measurements are often done with THz interferometer
- RadiaBeam licensed an interferometer design from Uwe Happek (U-Georgia)
- Sold > 10 units, including complete systems

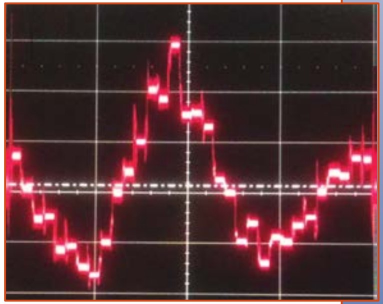


Real Time Interferometer

- Single shot interferometer (DOE SBIR, 2008-2011)



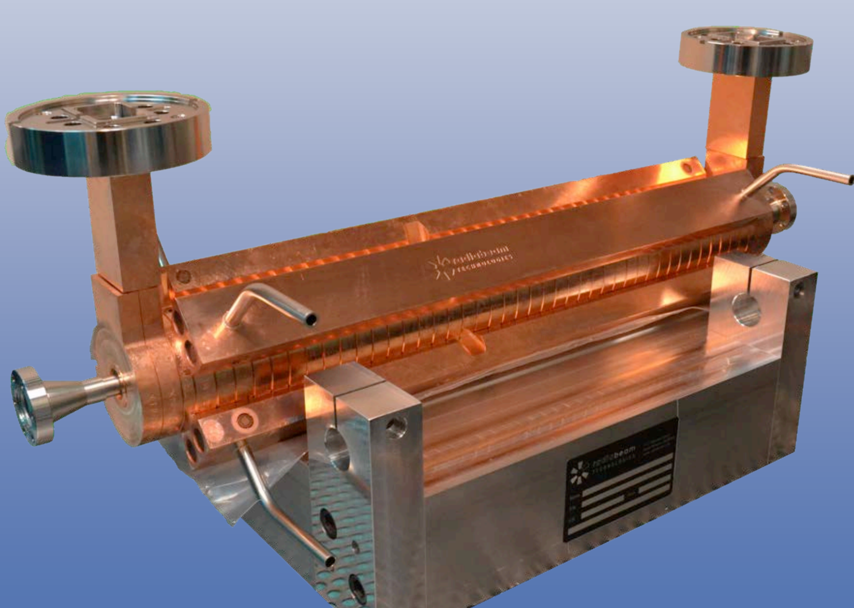


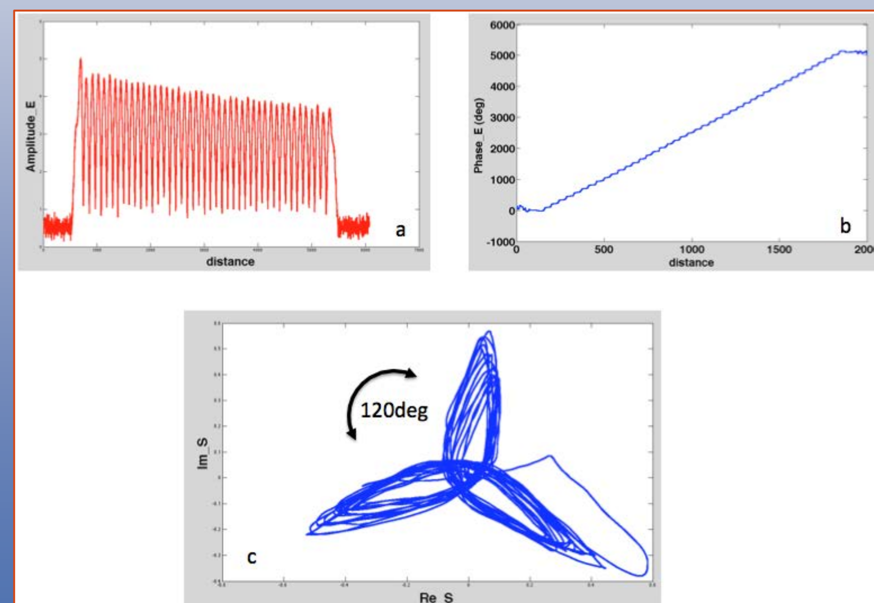


Thangaraj *et al*., *Rev. Sci. Instrum*. **83**, 043302 (2012)

X-band deflecting cavity

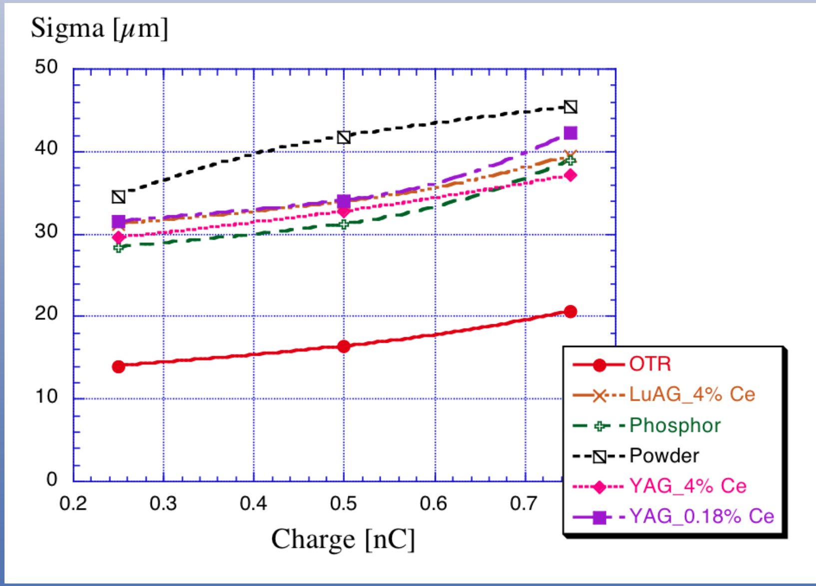
- X-band deflector (DOE SBIR grant 2007-2012)
  - Enables ~ 10 fs longitudinal resolution
  - Delivered completed structure to BNL ATF
- Provided a major boost to RF capabilities





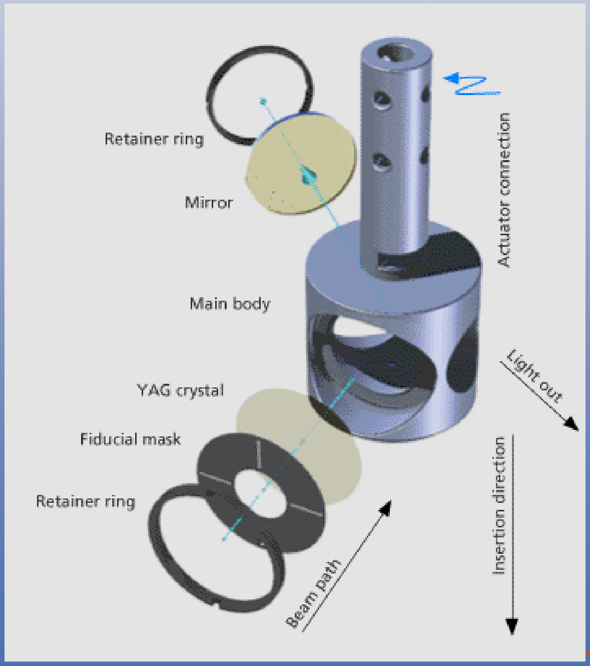
Beam Profile Diagnostics

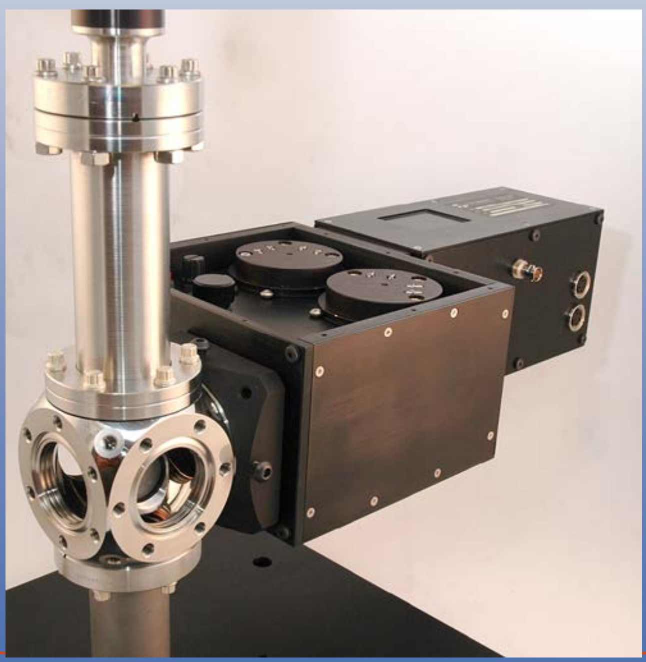
- Scintillating screen are the most useful diagnostics
- At higher beam densities OTR and wire scanner more accurate
- The best approach is to have multiple diagnostics available



IBIS-I

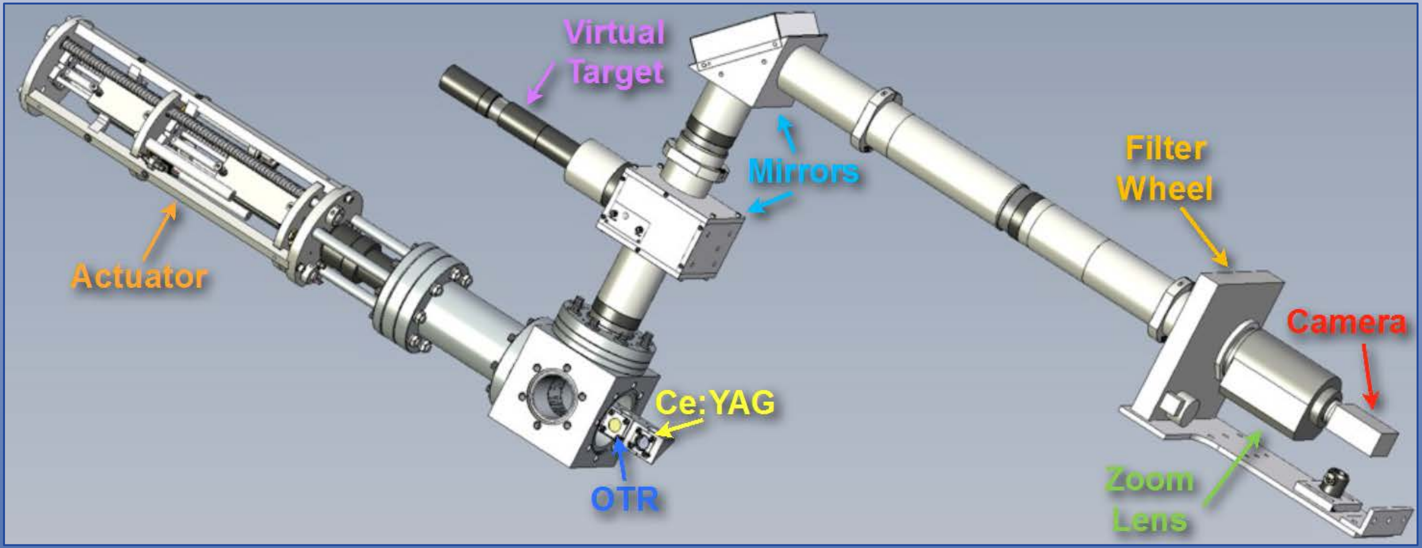
- Integrated beam imaging system (IBIS-I)
- Single position easily replaceable diagnostics, and optical module (attached by kinematic mount)
- Market failure (developed in 2005, sold 8 units, discontinued in 2009)

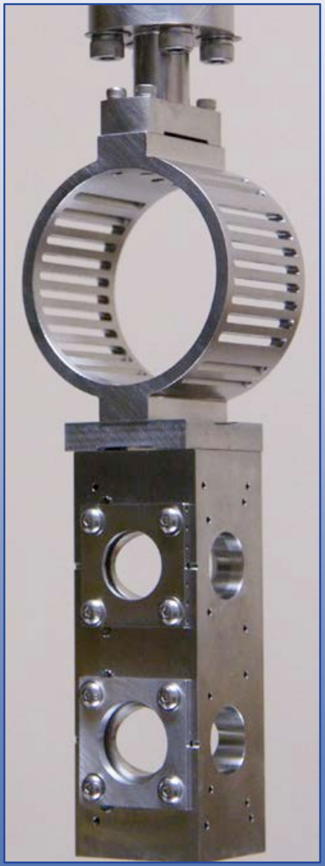


IBIS-2 (multi-position)

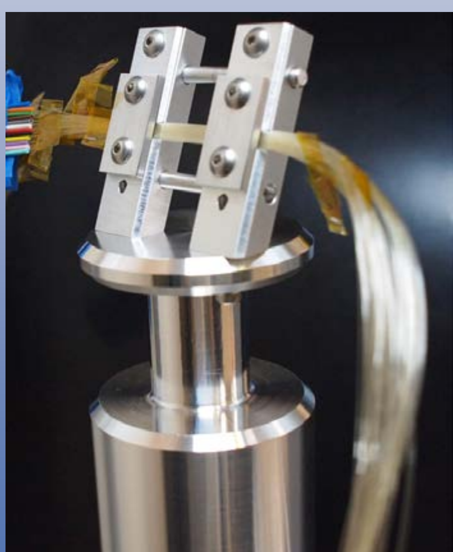
- Multi-position pneumatic actuator system
- Up to 4 diagnostics at the same port
- Modular system with multiple add-ons
- Lunched in 2010, sold ~ 70 systems (large orders, i.e. 20 identical units)

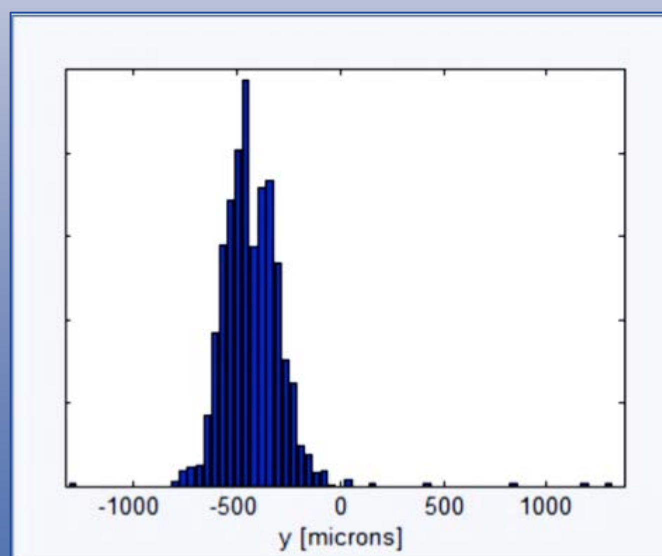


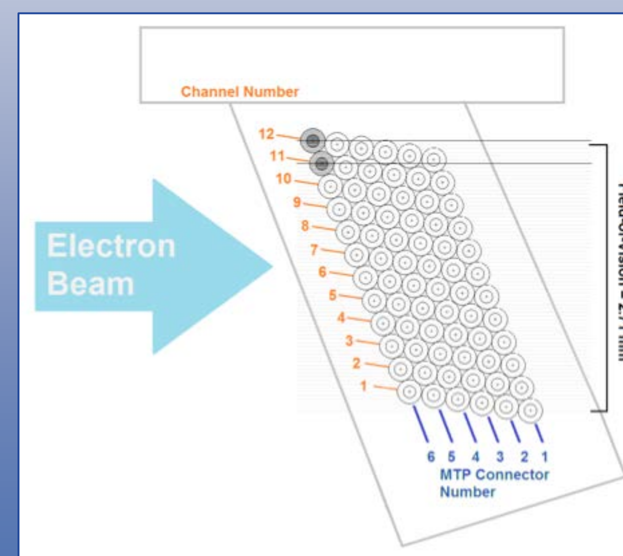


New Developments

- COTR discovery introduced a new range of problems for transverse diagnostics at X-FELs
- Wire-scanners work well, but multi-shot
- Developed Cherenkov single-shot “wire scanner” based on fiber mesh (DOE SBIR 2010)

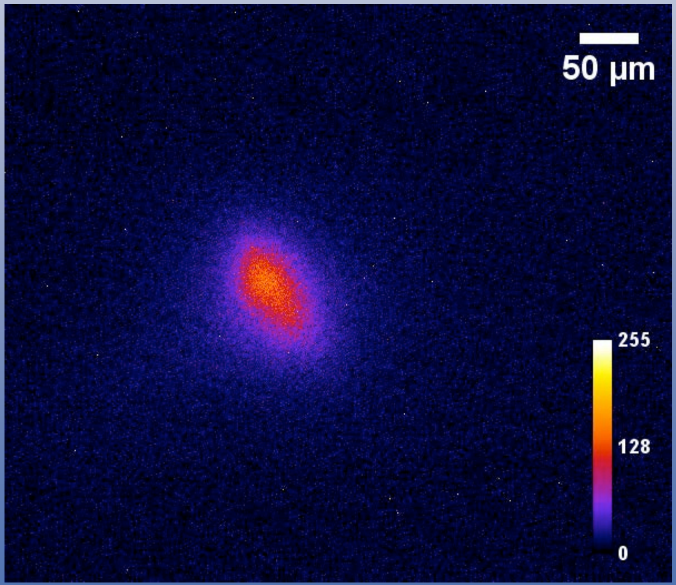


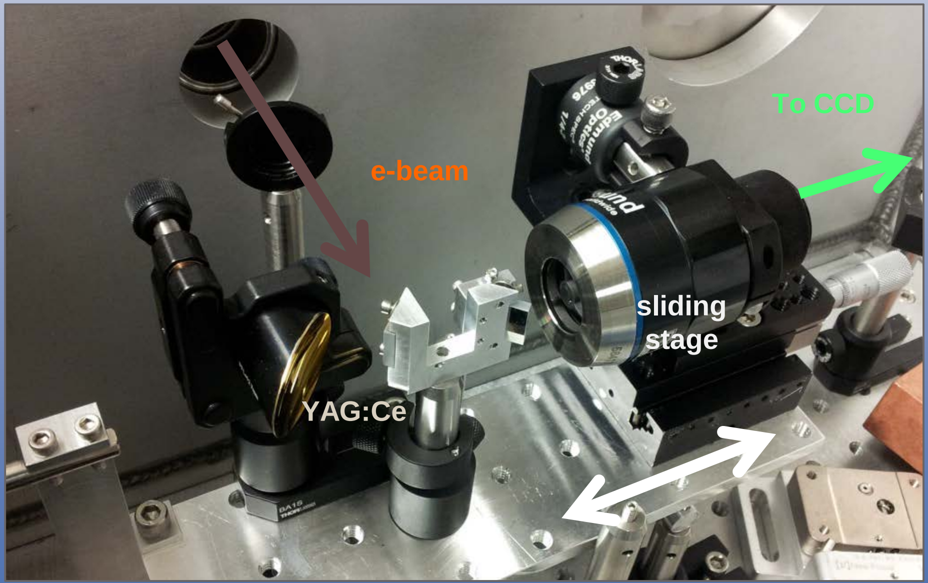




New Developments

- Dielectric Laser Accelerators, although in infancy, require sub-micron diagnostic resolution
- Developed reflective DUV OTR diagnostics
- Initial tests indicated 0.5 µm resolution





Present Status

- In 2012 recorded ~ $7 million in revenue, of which about 30% are product sales
- Currently over 40 employees, including 8 PhD scientists

Facilities

radiabeam TECHNOLOGIES

- Machine shop (clean and regular)
- Assembly area
- Magnetic measurements

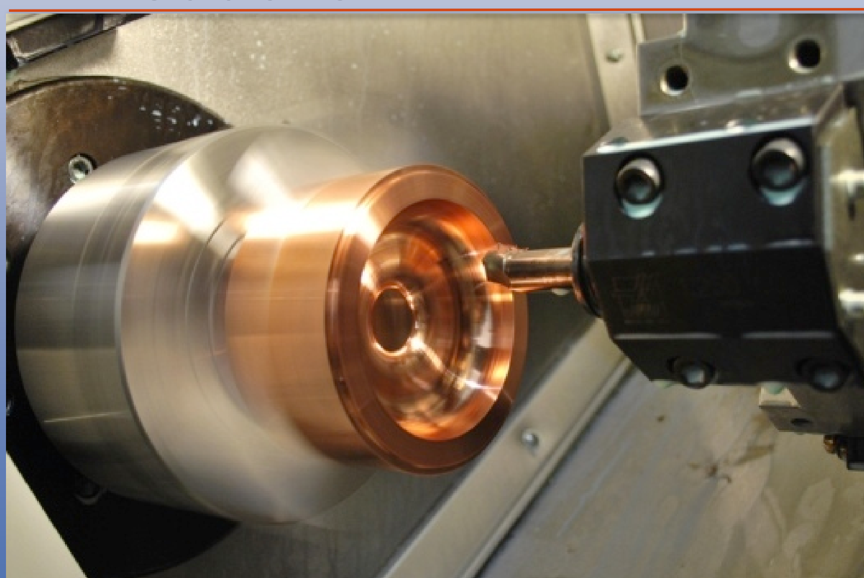
Facilities

- Hot cell
- Clean room
- Chemical processing
- RF test area
- Laser lab

Capabilities

radiabeam TECHNOLOGIES

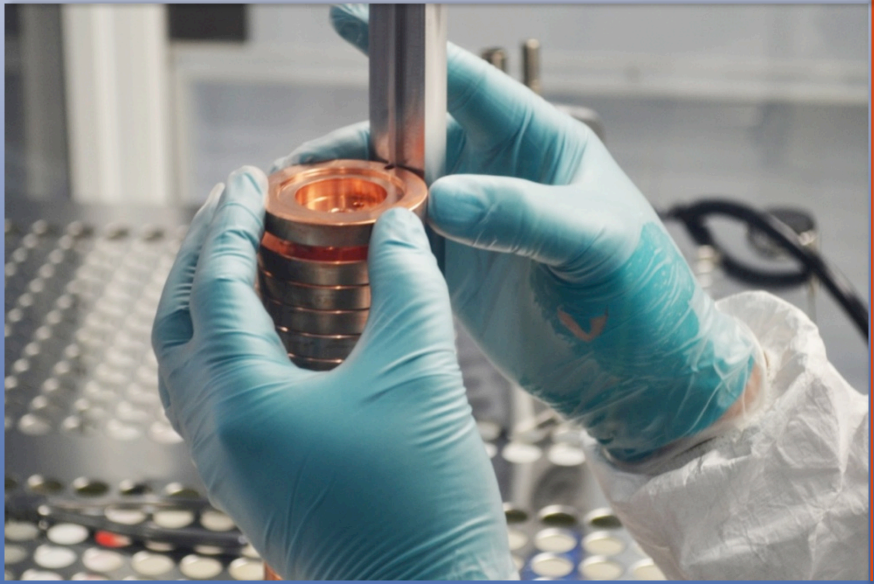
- Mechanical engineering
- CAD
- Programming
- Prototyping
- Production

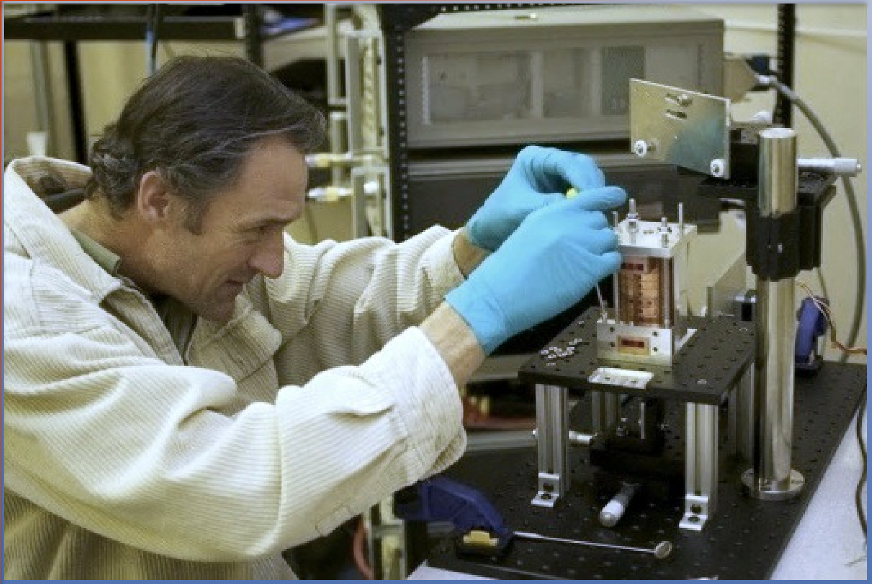


Capabilities (RF)

radiabeam TECHNOLOGIES

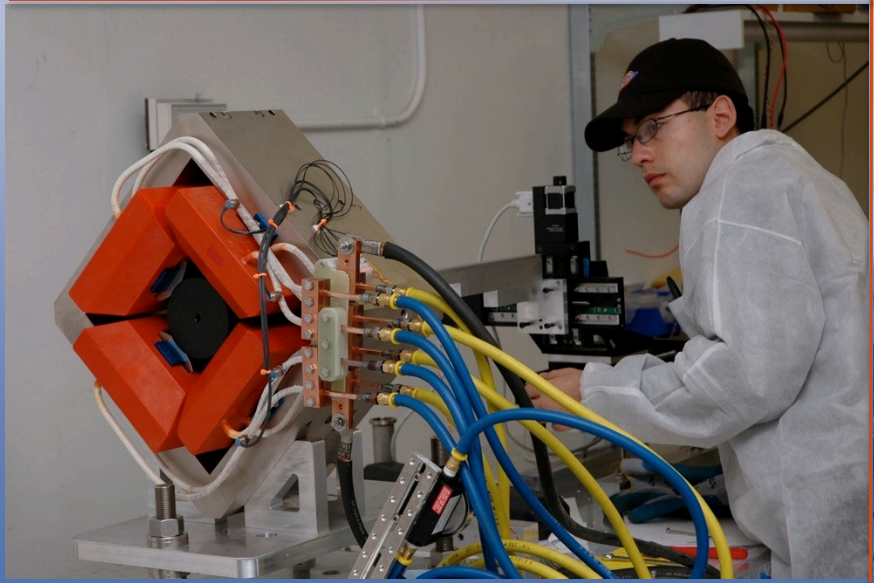
- RF design and engineering
- Production and RF surface processing
- Cell sorting, brazing, tuning, etc.





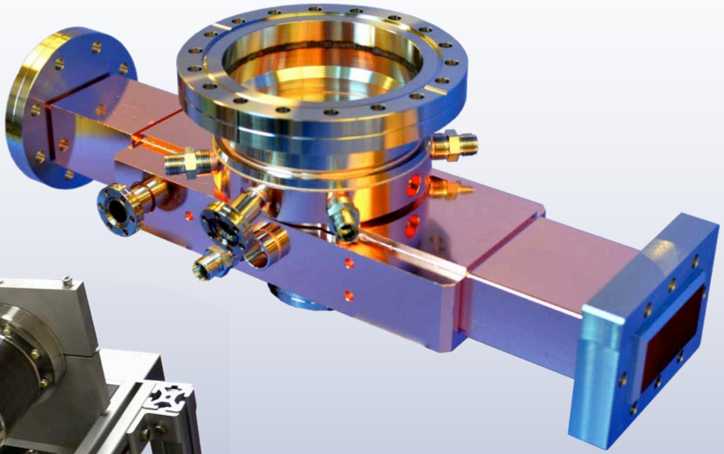
Capabilities (Magnets)

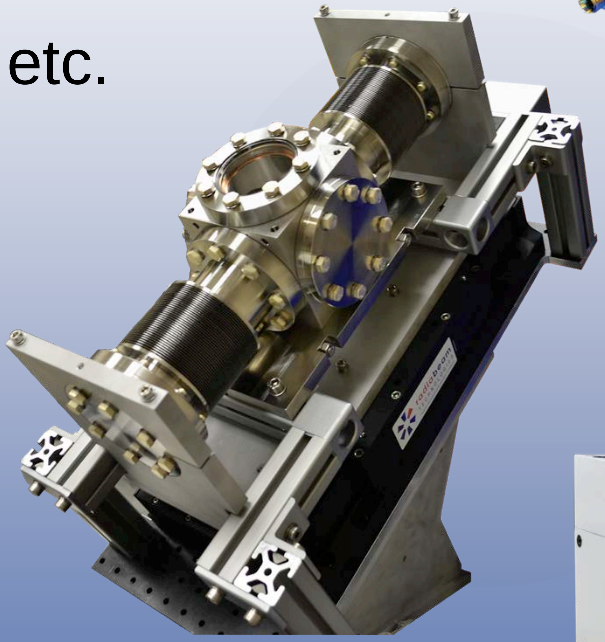
- Magnetic design and engineering
- Coil winding/ QA
- Magnetic testing
- EMs and PMs



Research Products

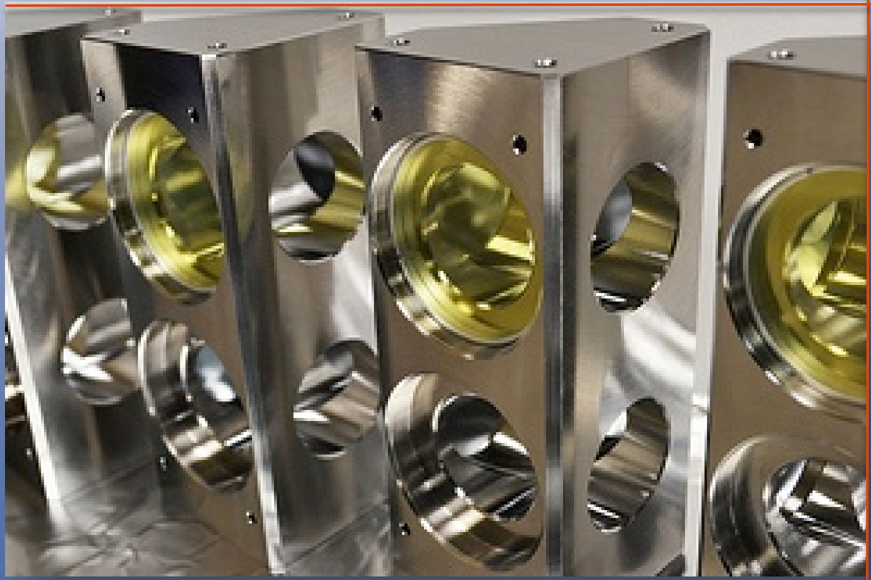
- Diagnostics
  - Transverse
  - Longitudinal
  - Charge, emittance, etc.
- RF structures
  - RF photoinjectors
  - Linacs, deflectors
- Magnetic systems
  - Electromagnets
  - Permanent magnets
  - Systems (chicanes, final focus, etc.)





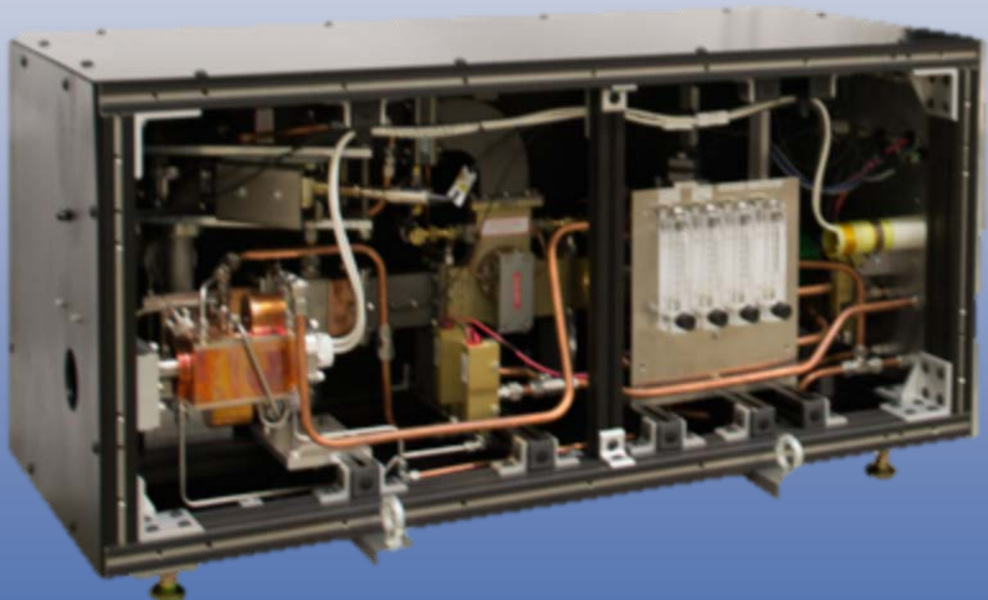
Production Capabilities

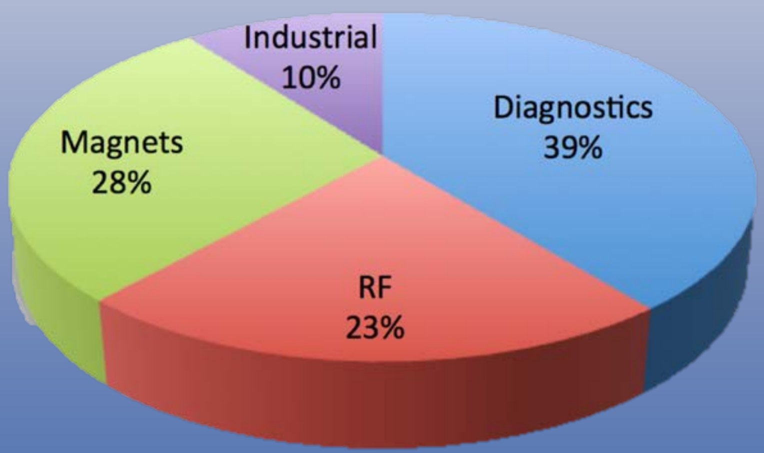
- Prototyping and small scale production
- Testing, shipping, installation, support
- Turn key systems



Industrial systems

- Entered into industrial accelerators market in 2012
- Sold two turn-key linac systems
- Potential area of growth, but very competitive
- Very cost-sensitive non-expert customers





Customers

radiabeam TECHNOLOGIES

Argonne National Laboratory
Brookhaven National Laboratory
ENEA – Ente per le Nuove Tecnologie, l'Energia e l'Ambiente
FERMI @elettra
SLAC National Accelerator Laboratory
MAX-lab

PAL 포항가속기연구소 Pohang Accelerator Laboratory
TRIUMF
Lawrence Livermore National Laboratory
NIOWAVE
University of Colorado Boulder
Indiana University Bloomington

Information Systems Laboratories
eXcillum
Yale
CANDLE
Sandia National Laboratories
UCLA

Sterigenics
SPARKLE s.r.l.
Paul Scherrer Institut PSI
Schlumberger
SIEMENS
Fermilab

Wright State University
Oak Ridge National Laboratory
Idaho Accelerator Center
The University of Wisconsin Madison
Los Alamos National Laboratory
TRAD Tests & radiations

The College of Judea & Samaria
Berkeley Lab
TeamBest – healthcare for everyone – Your True Partner
iba
ACCURAY
Michigan
KAERI
LNLS

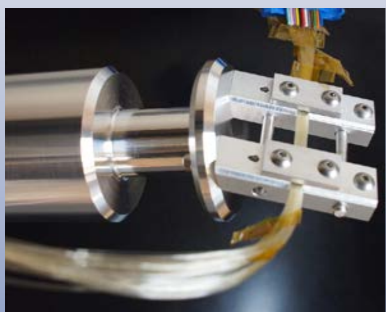
MU
Canadian Light Source – Centre canadien de rayonnement synchrotron
東京大学 The University of Tokyo
NSRRC
Vanderbilt University
University of Hawaii
CINEL
INFN
KTH Vetenskap och Konst

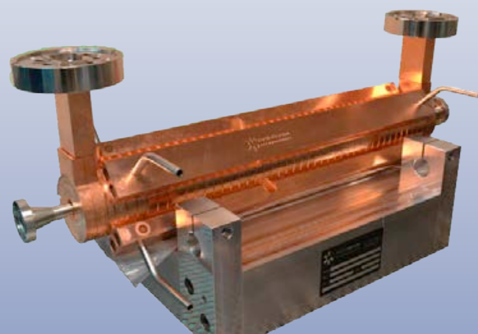
Business Development

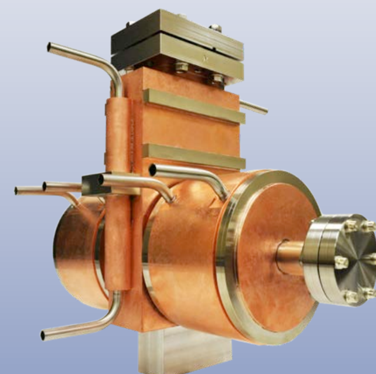
- RadiaBeam Technologies (founded in **2004**)
- RadiaBeam Systems (**2010** – industrial accelerators)
- RadiaBeam Europe (**2013** –EU subsidiary)
- RadiaSoft (**2013** – software development)

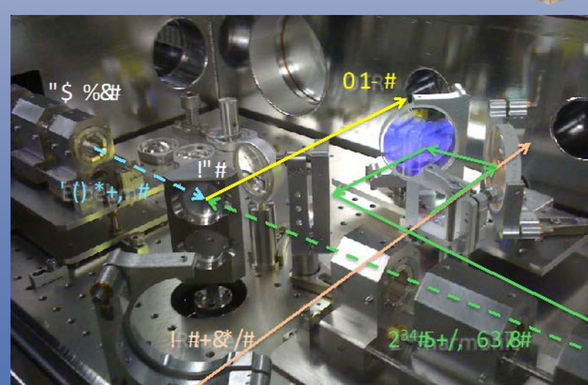
Funding agencies

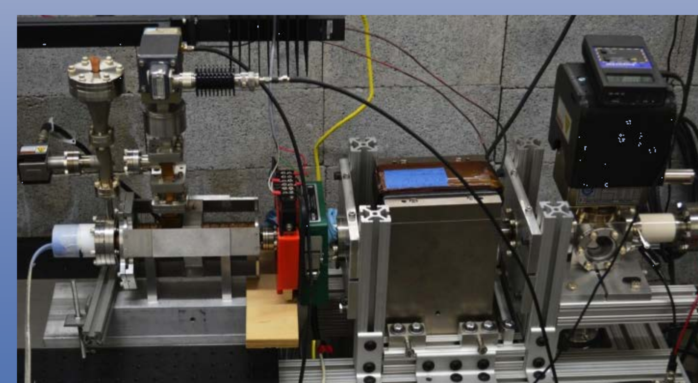
- #1 customer is US funding agencies
- about $3M/year in SBIR funding
- R&D to develop new products and technical solutions





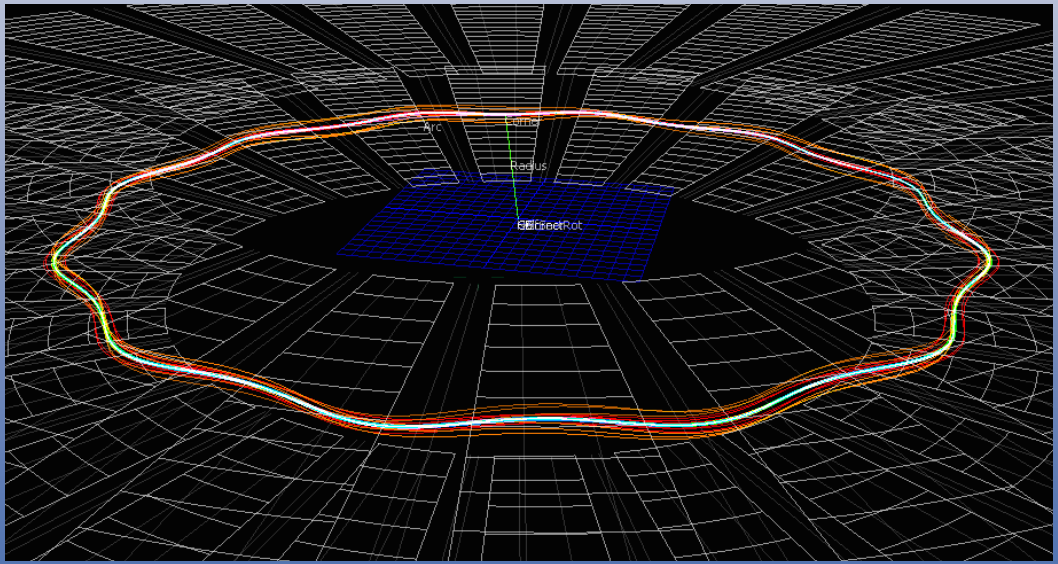


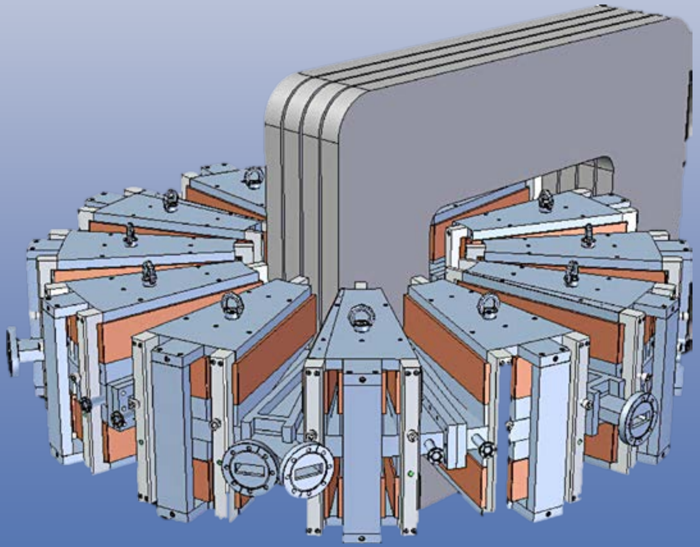




Epilogue

- 2014: received a DOE grant to adapt Radiatron for nuclear resonance fluorescence (NRF) application
- For NRF high duty cycle is the key advantage
- Redesign in progress
- Hopefully we'll get it to work this time

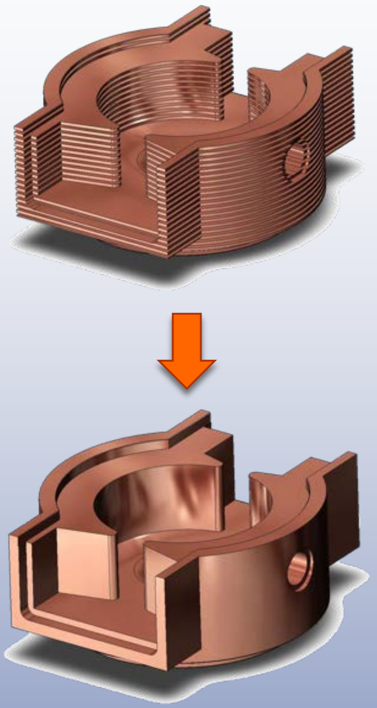




Back up slides

RF Structures

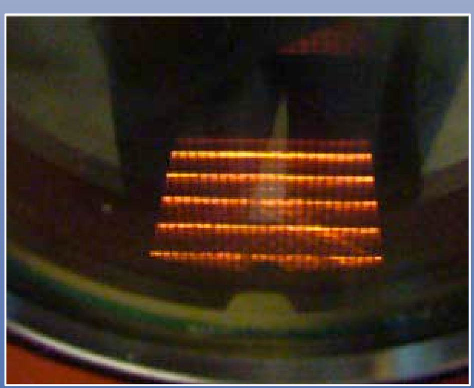
- Layer-by-layer Manufacturing (copper)
  - Solid free form fabrication enables internal features (i.e. cooling) without additional brazing steps
  - Developed process for copper to achieve full density
  - SFF cathode has been tested at 70 MV/m at UCLA

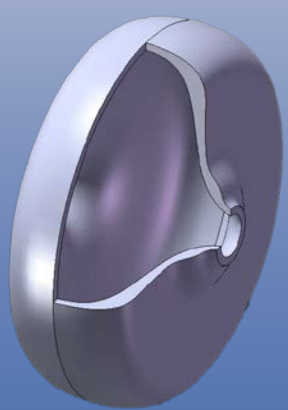


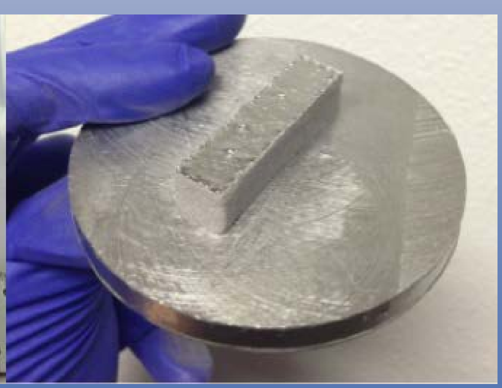
RF Structures

- Layer-by-layer Manufacturing (niobium)
  - There are multiple applications towards superconducting RF cavities, couplers, HOM dampers, etc.
  - Started developing SFF process for niobium

Parameter \ Material	EBM Niobium	Wrought Reactor Grade Niobium
Density (g/cm^3)	8.40 – 8.51	8.57
RRR	19 – 24.7	~ 40
Vickers Hardness (GPa)	0.82 – 0.86	0.76 - 0.85

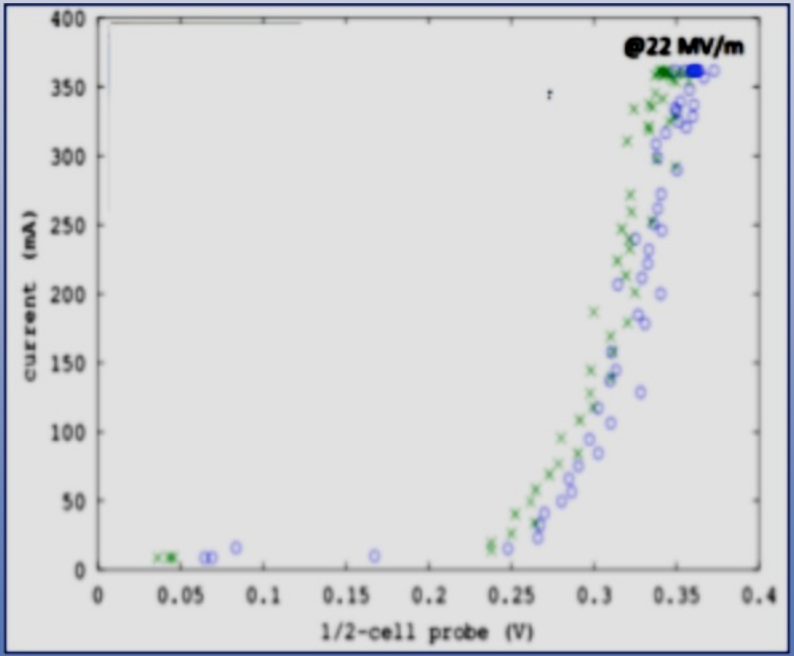


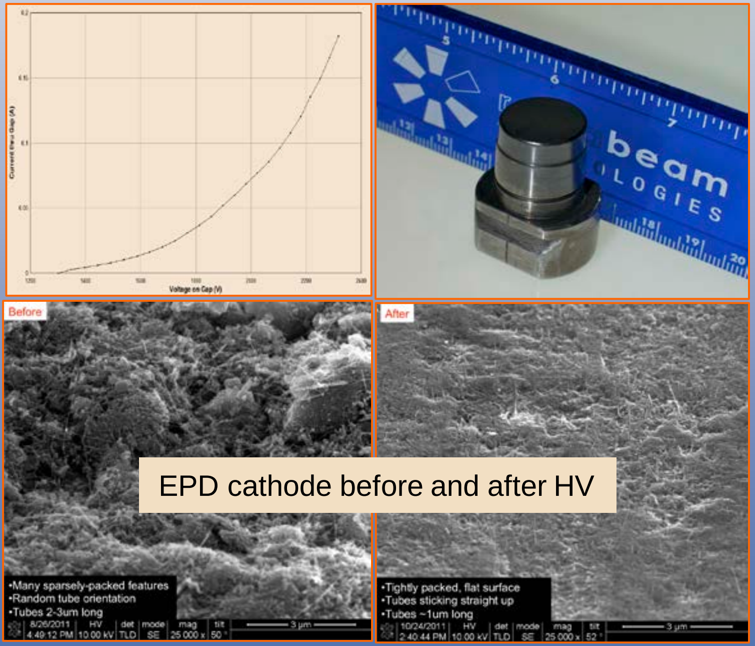




CNT

- Carbon Nanotube Cathodes capable of producing good current density with low thermal emittance
- Measured 300 mA field emission current (limited by beam loading)

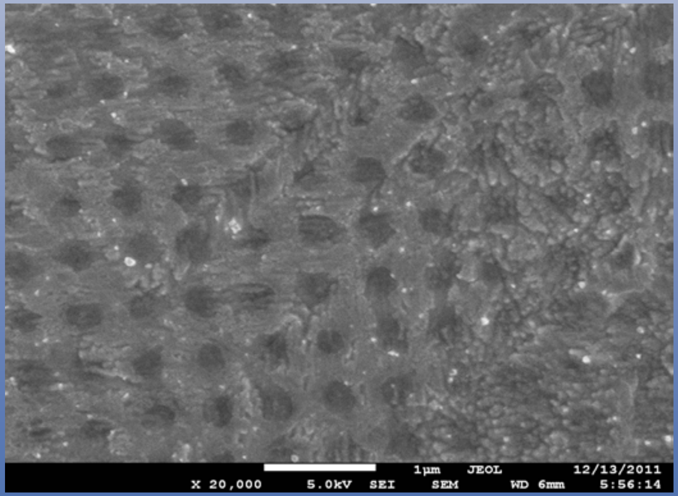


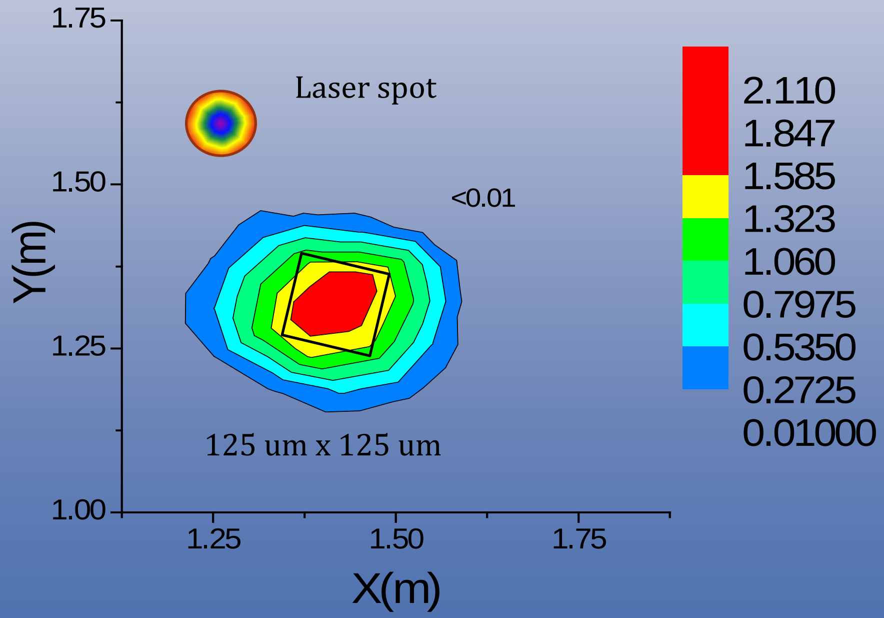


Nano-patterned cathode

- DOE STTR with UCLA (P. Musumeci)
- Periodic nano-scaled surface patterns (metallic cathodes with enhanced surface plasmon resonance, improve multiphoton emission)
- 3000 times QE enhancement

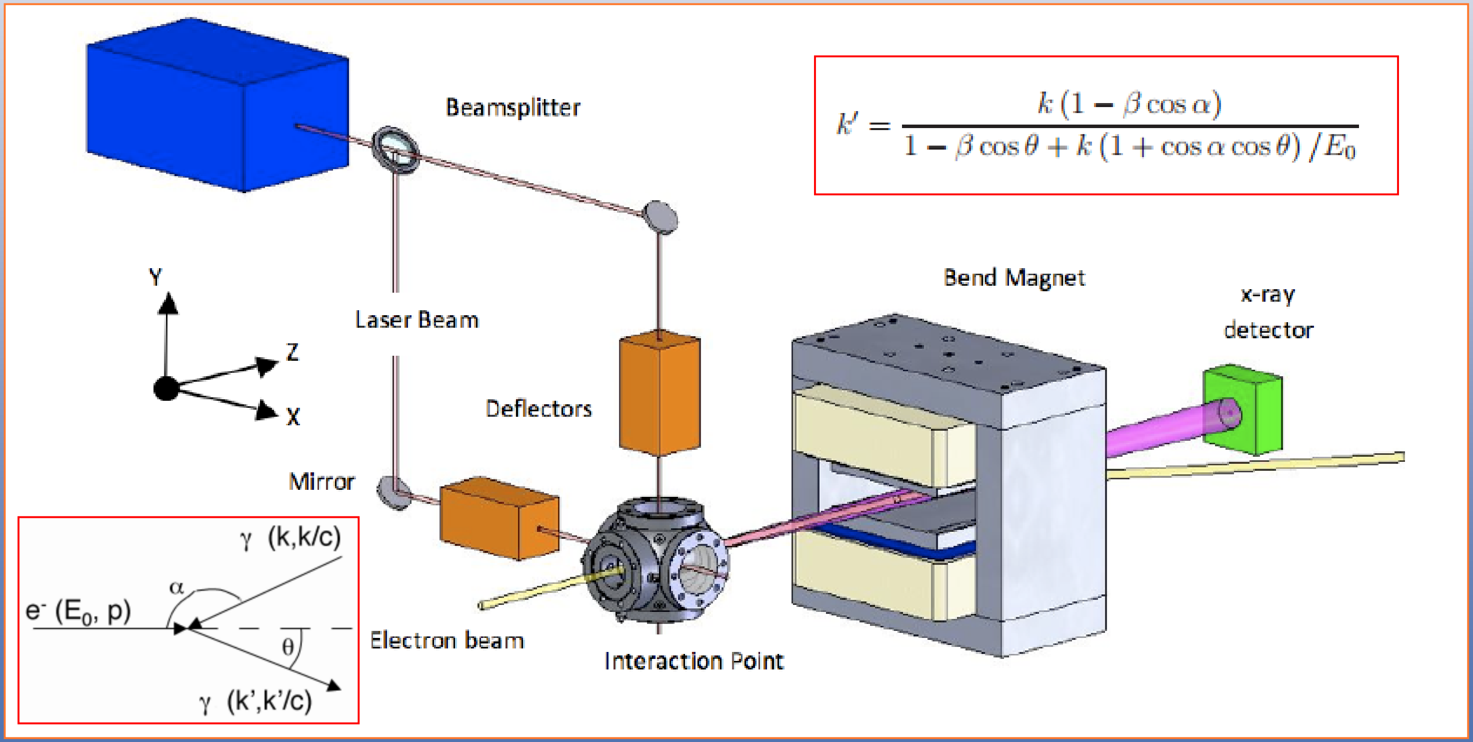
R. Li et al., *PRL* **110**, 074801 (2013)





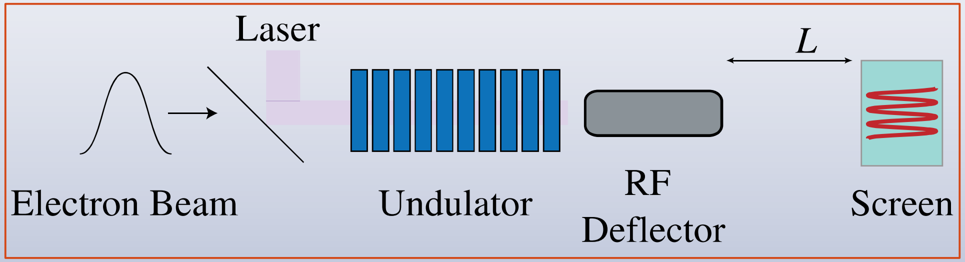
Laser Wire Scanner

- Ongoing experiment at Cornell ERL
- Components (laser source, optical transport and transducer, *interaction chamber* and *X-ray detection system*)

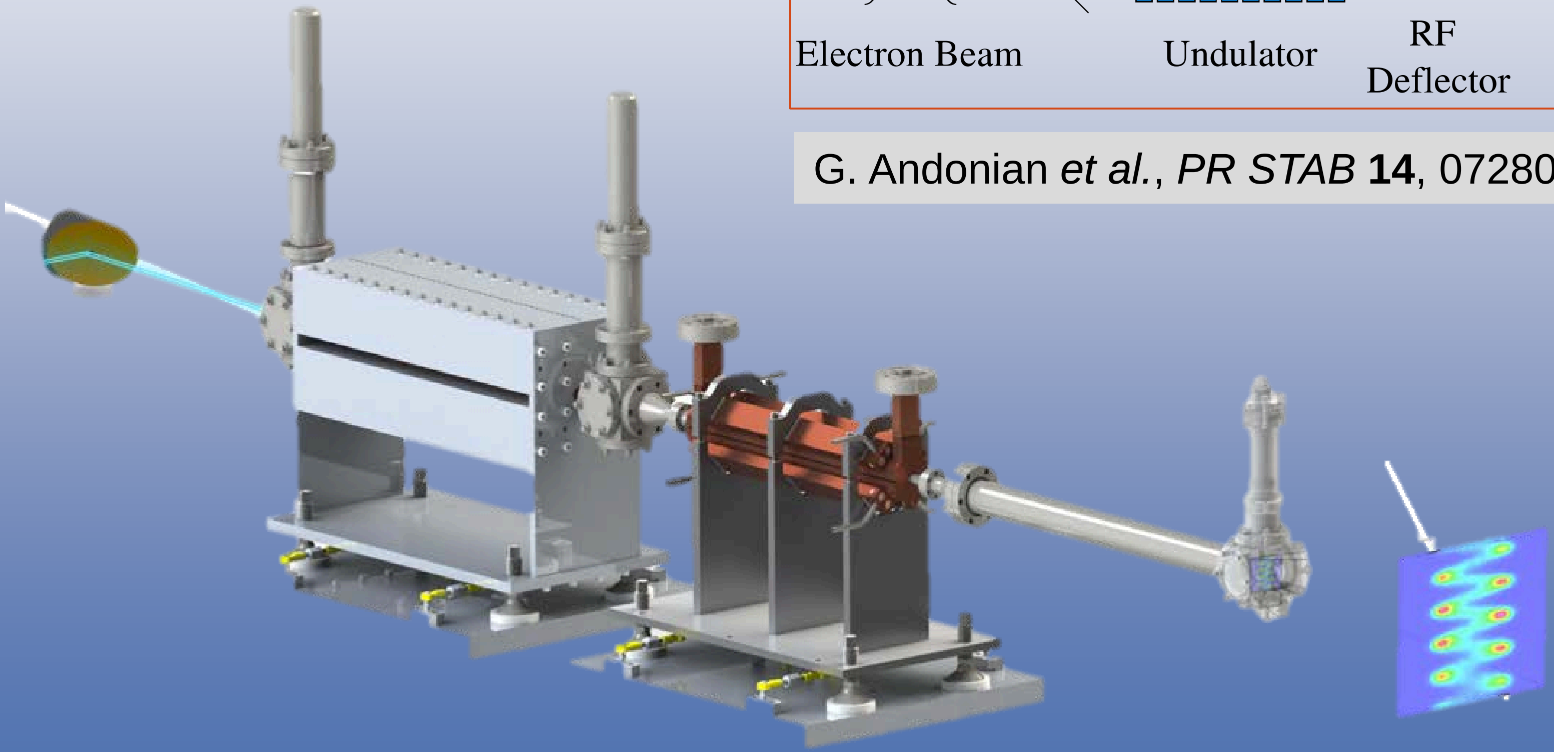


Attoscope

- Enhancement to RF deflector
- Laser/e-beam interaction
- Sub-fs resolution

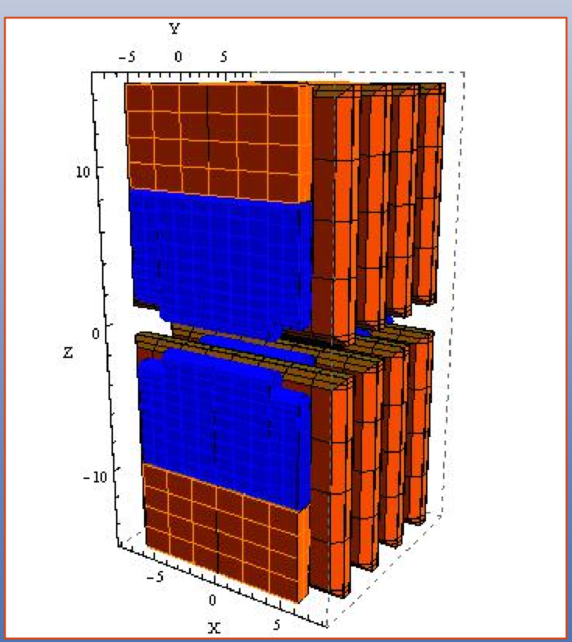


G. Andonian *et al.*, *PR STAB* **14**, 072802 (2011)



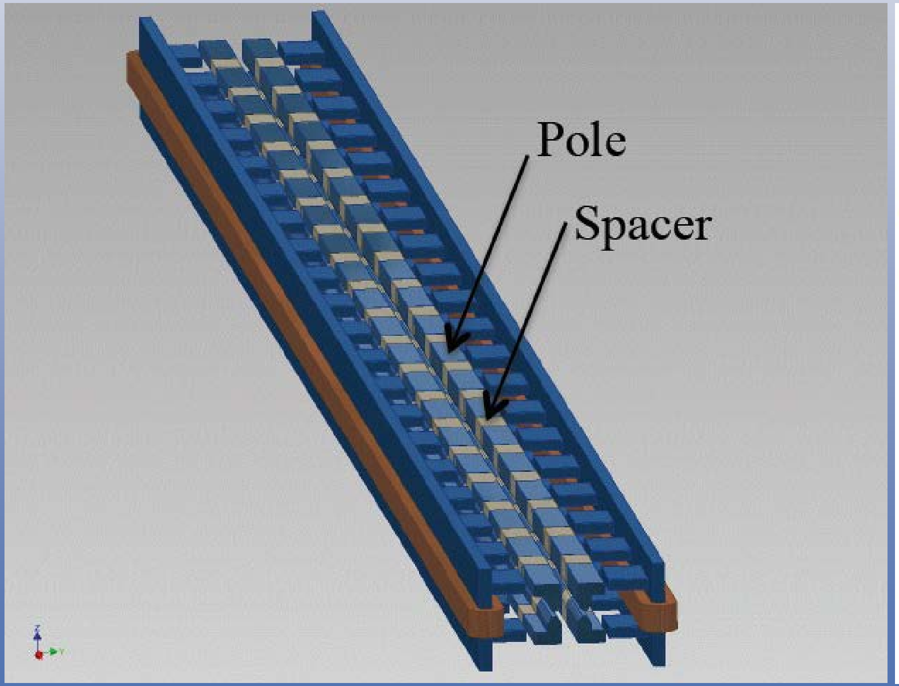
Short period undulator

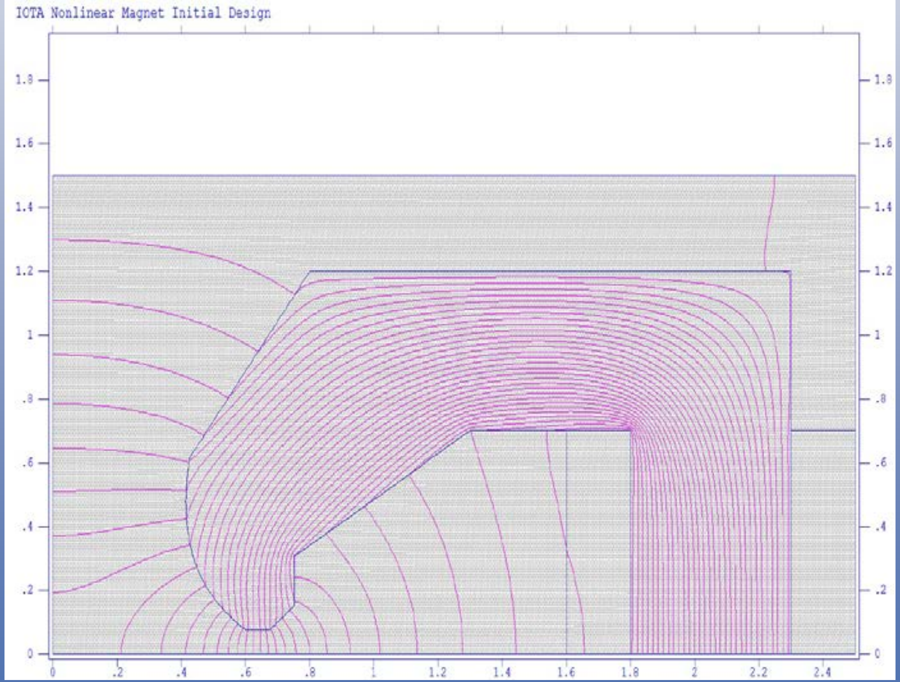
- Textured Dy has saturation inductance > 3 T (below 90°K)
- Combination of PrFeB magnets and Tx Dy pole may lead to an ultra short period undulator (~ 7-9 mm), while maintaining normalized field strength, K~1



IOTA

- Collaboration with Fermilab to develop novel magnetic lattice for storage rings
- 2 m device is split into 20 magnets (prototype in fabrication)

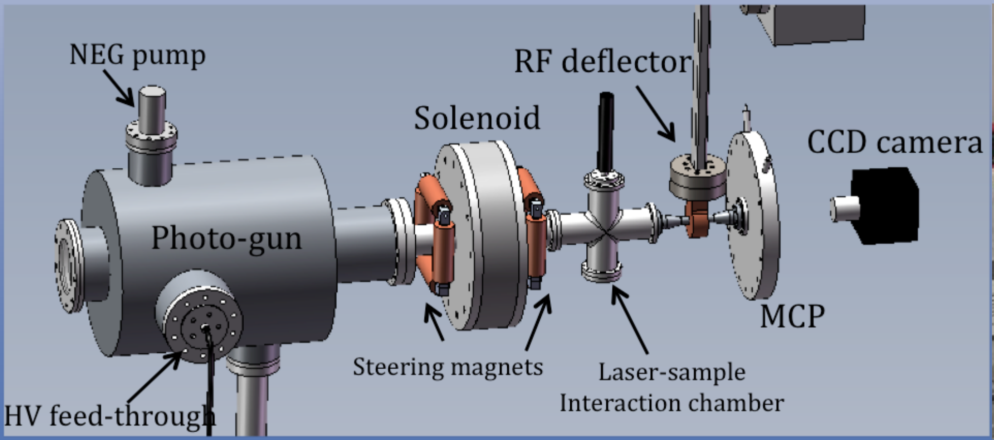




UED

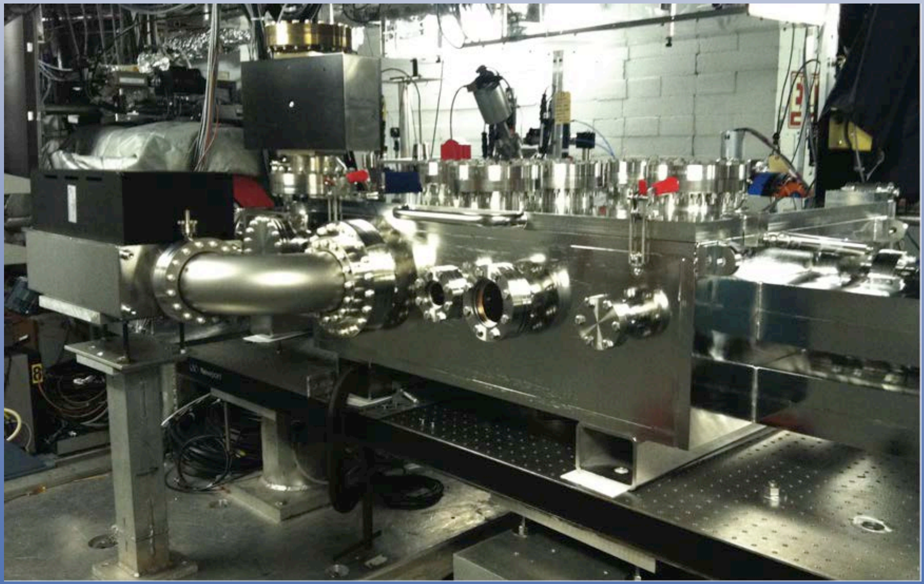
radiabeam TECHNOLOGIES

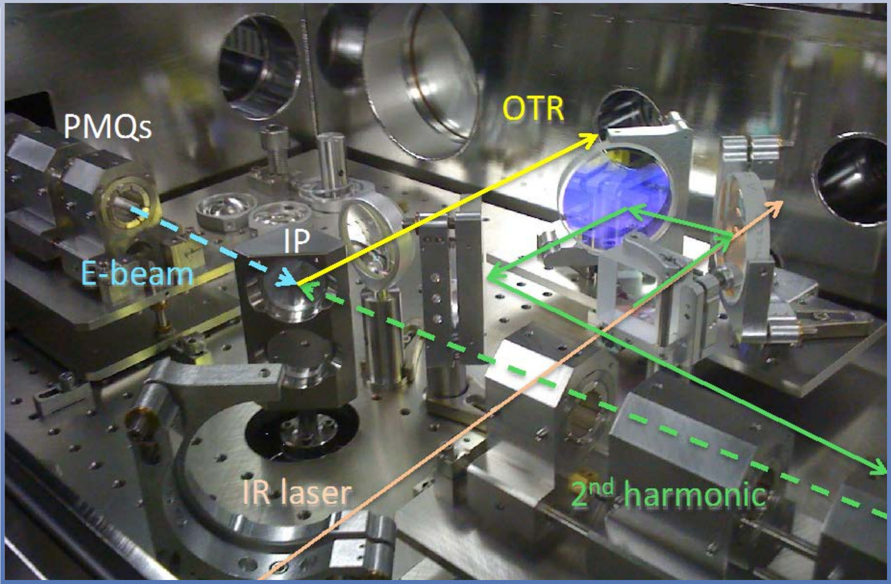
- Ultra Fast Electron Diffraction: Compromise between Conventional and Relativistic UED systems
- Possibility of performing the same type physics of current UED systems but cheaper and more compact (no fs-laser required)



ICS

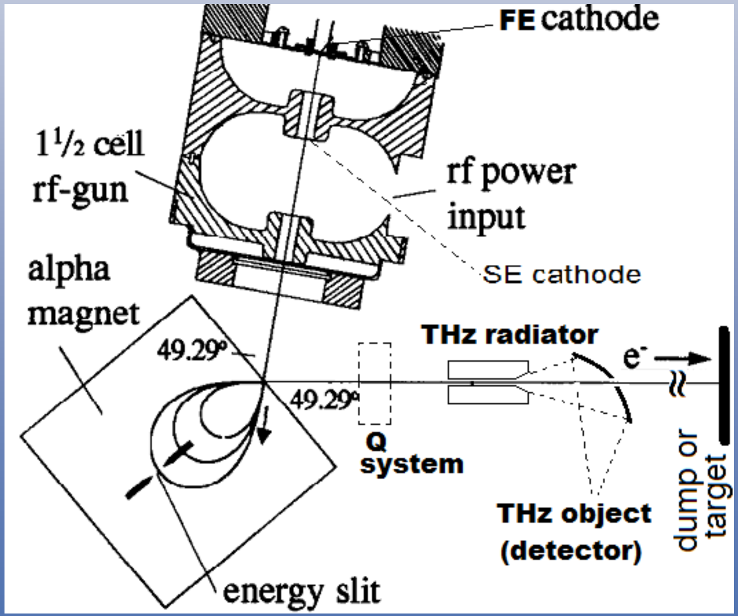
- Inverse Compton Scattering (ICS) gamma ray source
- High spectral brightness, directionality, tunability
- With the laser re-circulation, 10^{13} photons/s is feasible
- Conducted a pilot experiment at ATF-BNL

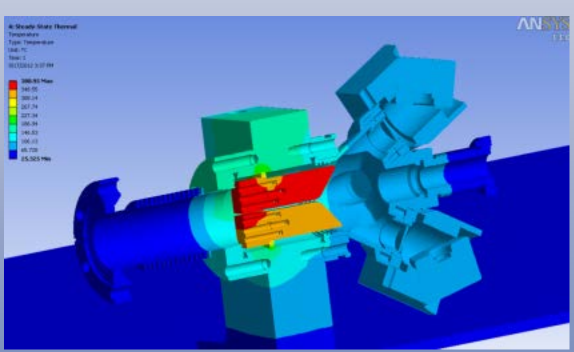


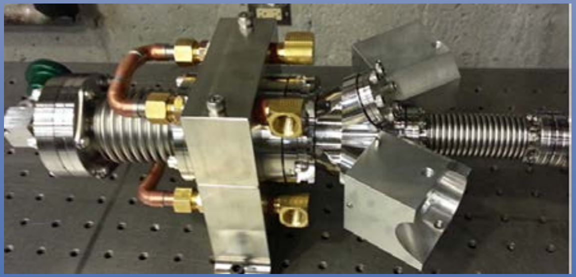


THz Source

- Design and build a prototype of a dedicated THz source delivering over 10 W out-coupled power form periodic corrugated radiator
- E-beam spectral structure is formed by alpha magnet rather than photocathode (high average power)

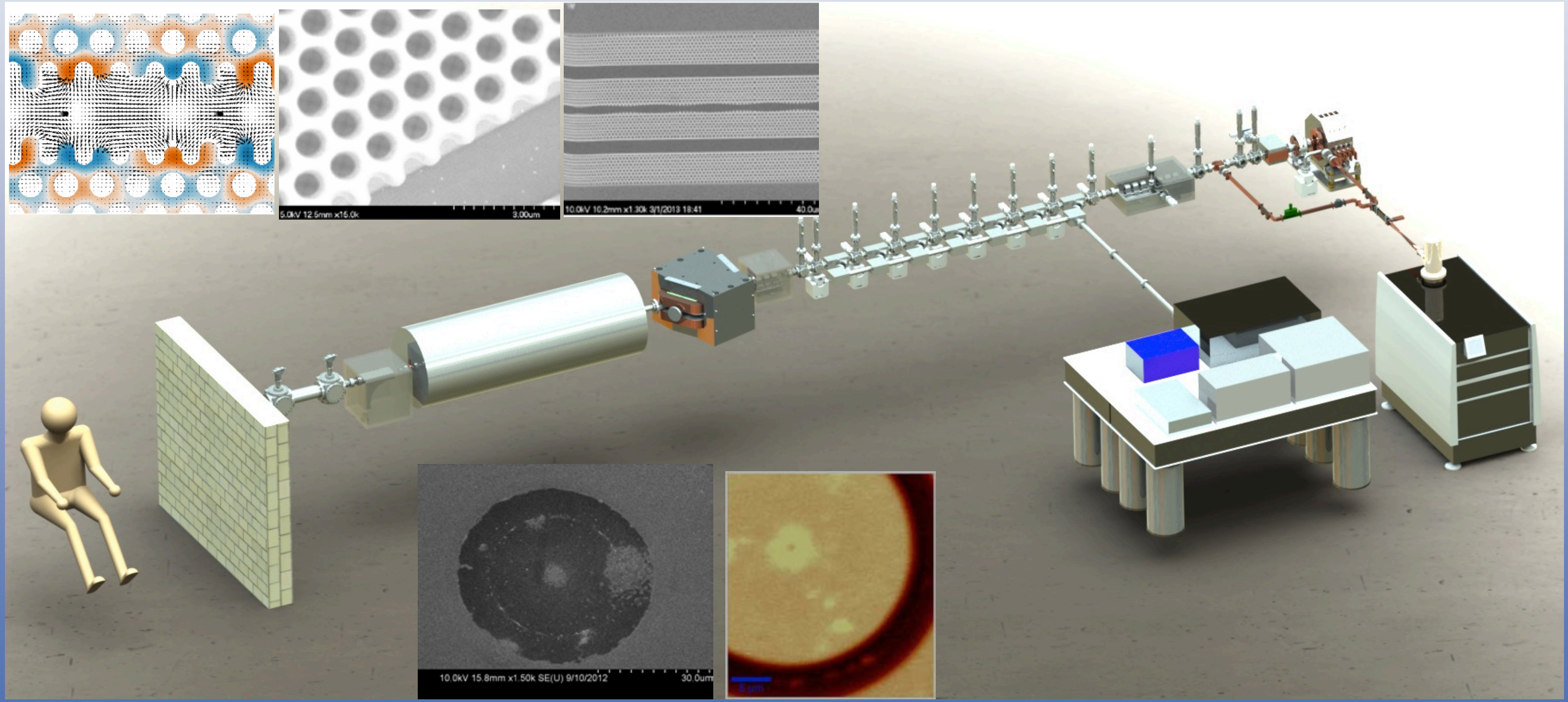






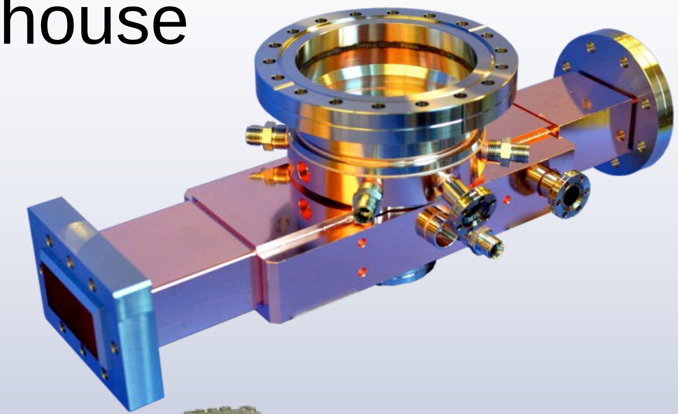
DLA

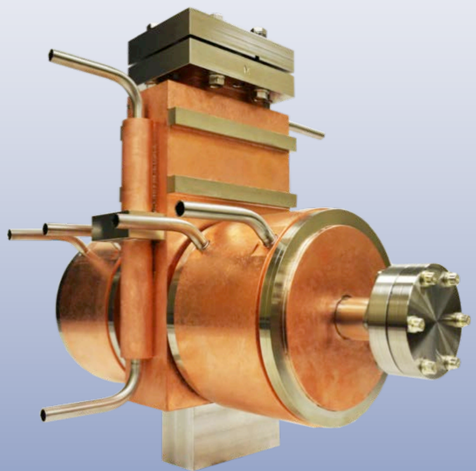
- DARPA funded project (RBT-UCLA-Stanford-PSU-BNL)
- Room size hard X-ray Free Electron Laser

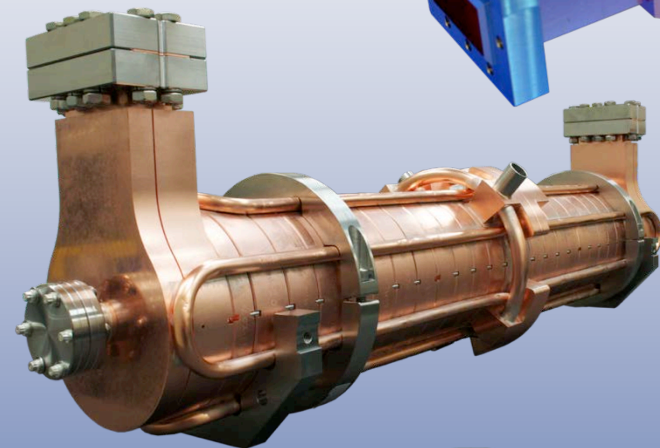


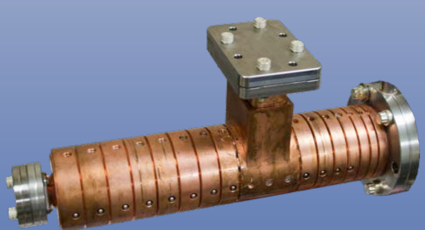
RF structures

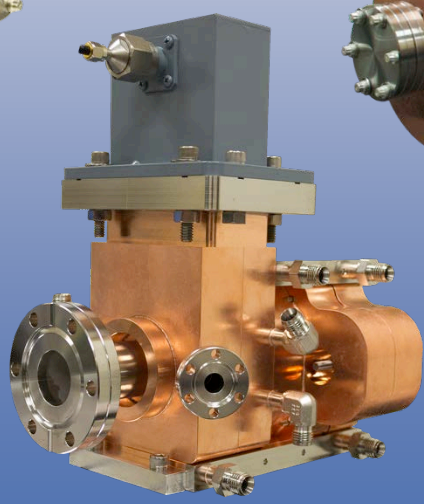
- Designed, fabricated, and tested in-house
- L, S, C and X-band / multiple types

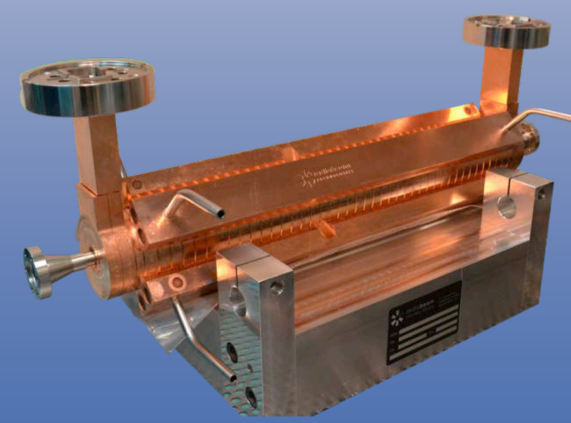






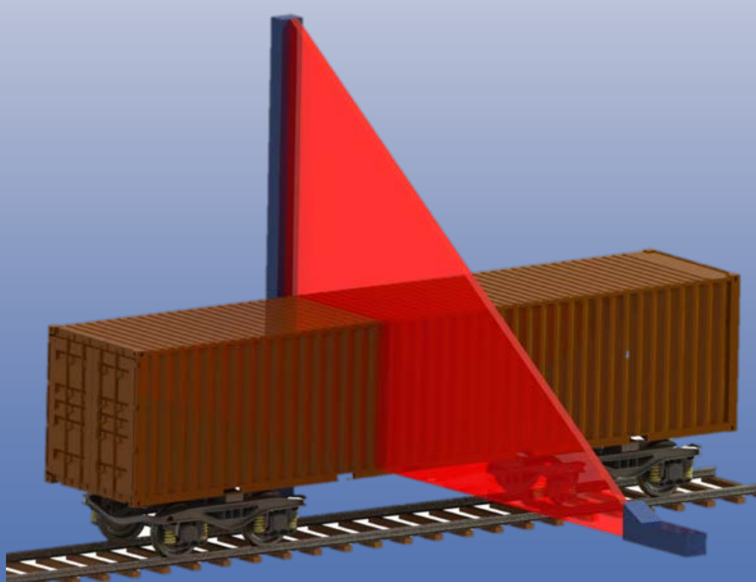


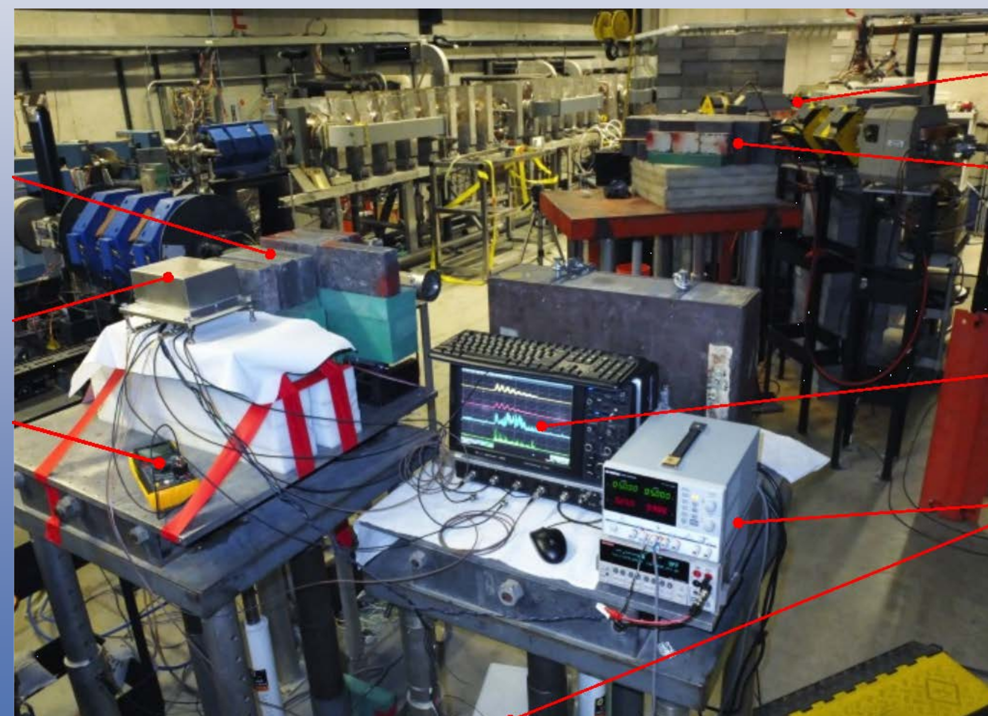




Cargo Screening

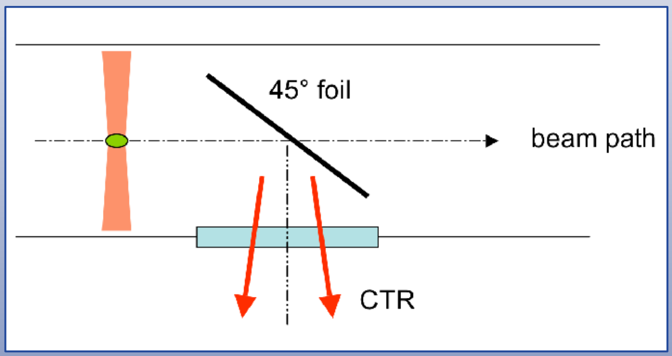
- ARCIS (Adaptive Rail Cargo Inspection System)
- Novel proprietary detection scheme to enable 100% detection at 45 km/h train speed, and at lower dose.

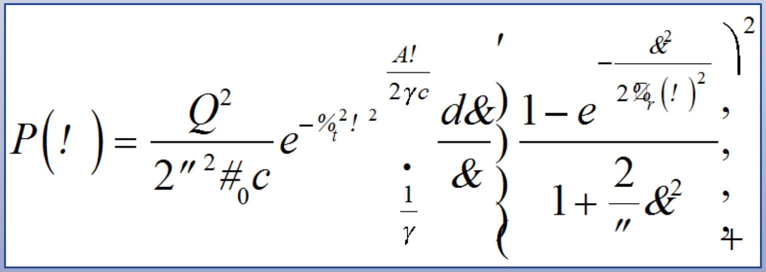


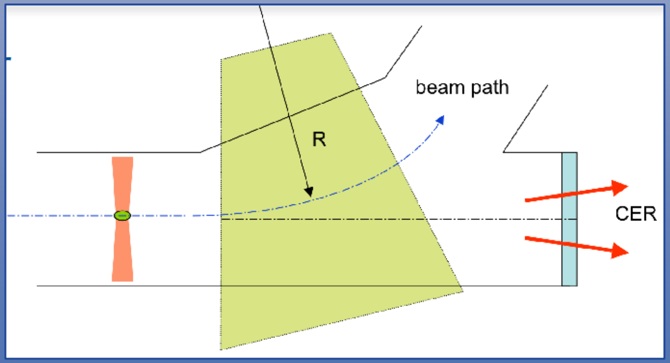


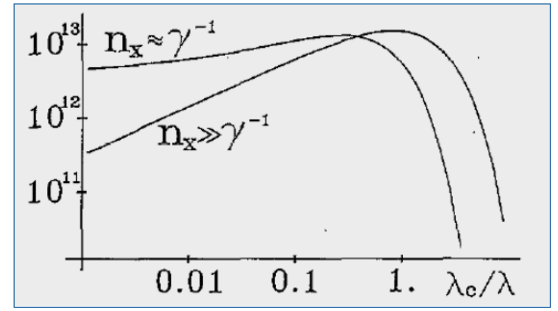
Longitudinal Diagnostics

- Spectral analysis of coherent radiative processes allows to monitor longitudinal beam profile on a sub-picosecond time scale









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