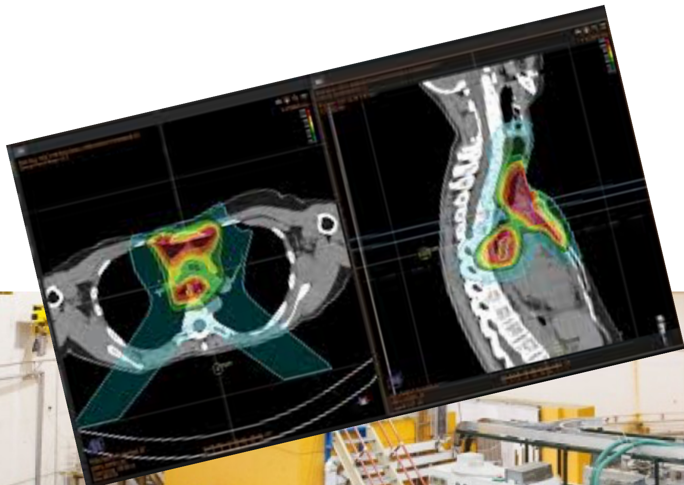
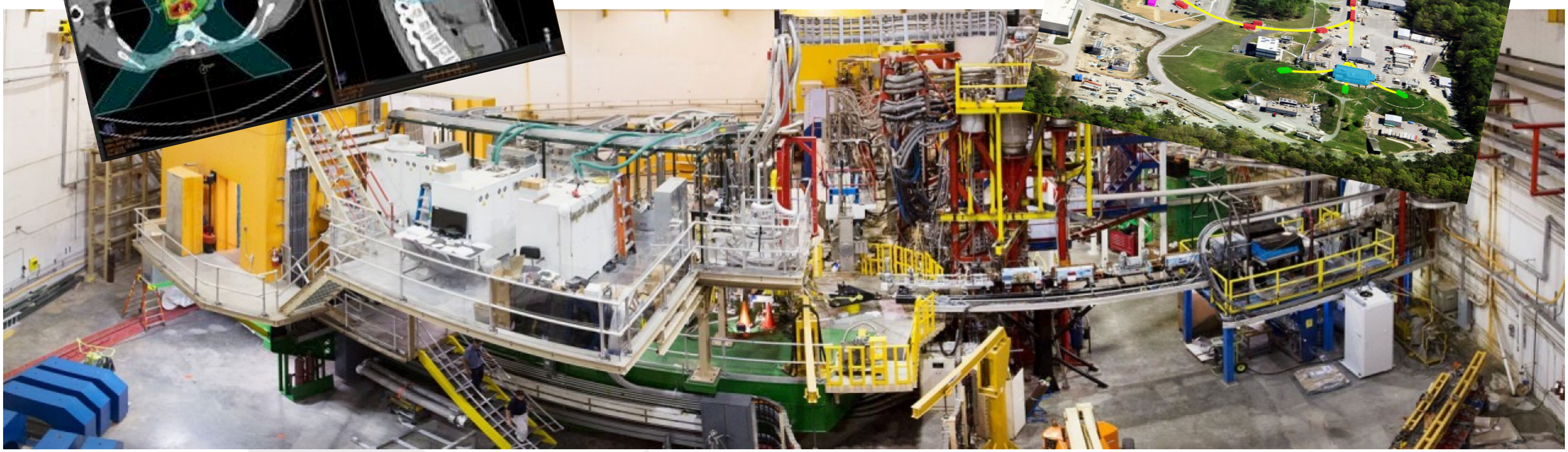
Career Opportunities from Fundamental Nuclear Physics to Patient Treatment

Cynthia Keppel
Thomas Jefferson National Accelerator Facility



EINN Frontiers and Careers 2023



Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

Pleased to meet you….

A challenging talk, to include:

- Some of your personal story
- Some details of your research
- Medical physics opportunities
- National laboratory career opportunities and advice
- General career mentoring

My personal story? Counting down from  ....

5. *Current* Job Titles

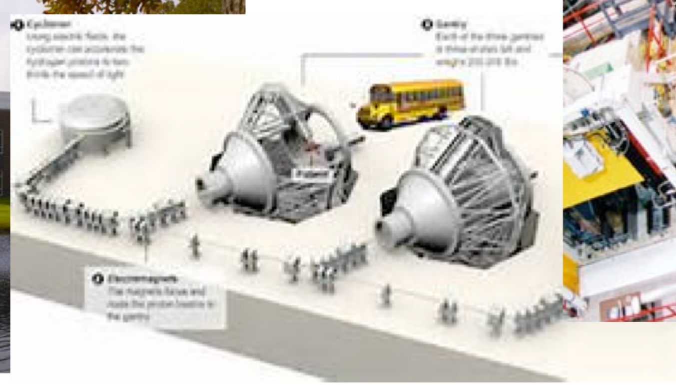
   i. Associate Laboratory Director for Physics, Thomas Jefferson National Accelerator Facility

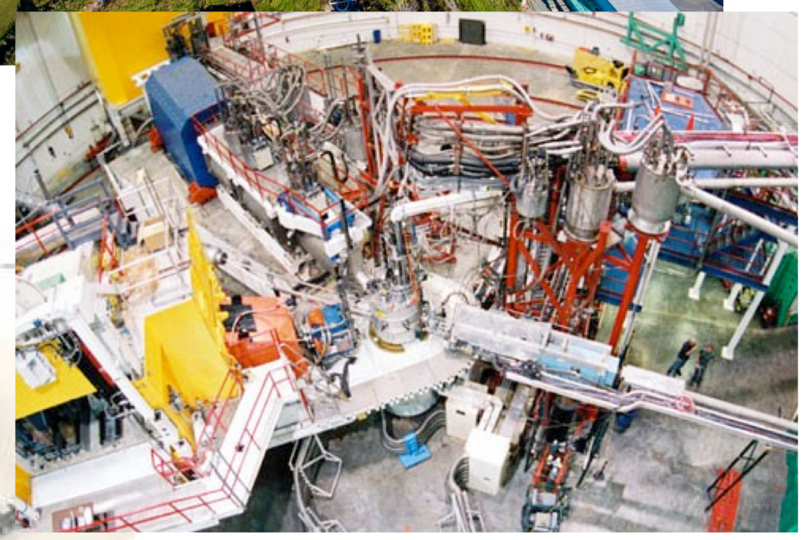
   ii. Senior Executive Director, Hampton University Proton Therapy Institute

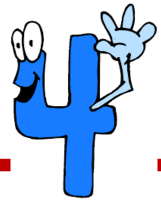
   iii. Owner, 3q Scientific Consulting, LLC (private sector clients)

   iv. Chief Technology Officer, Hyperhtermia Cancer Institute

   v. Community Faculty, Eastern Virginia Medical School







4. Cars

Who am I?

321…

3. Kids

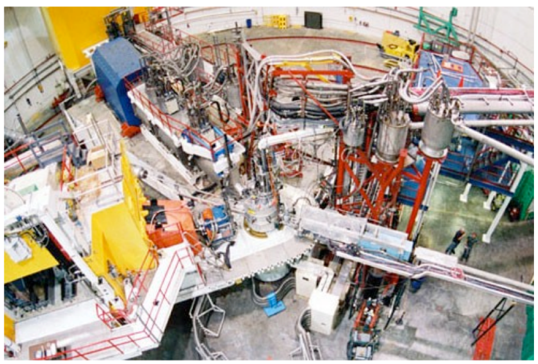
2. Grandkids

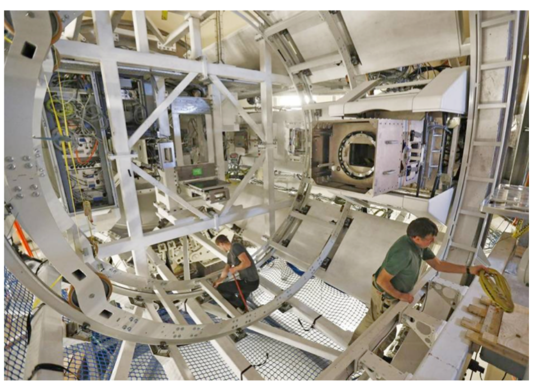
1. Foxhound

Some details of my research…

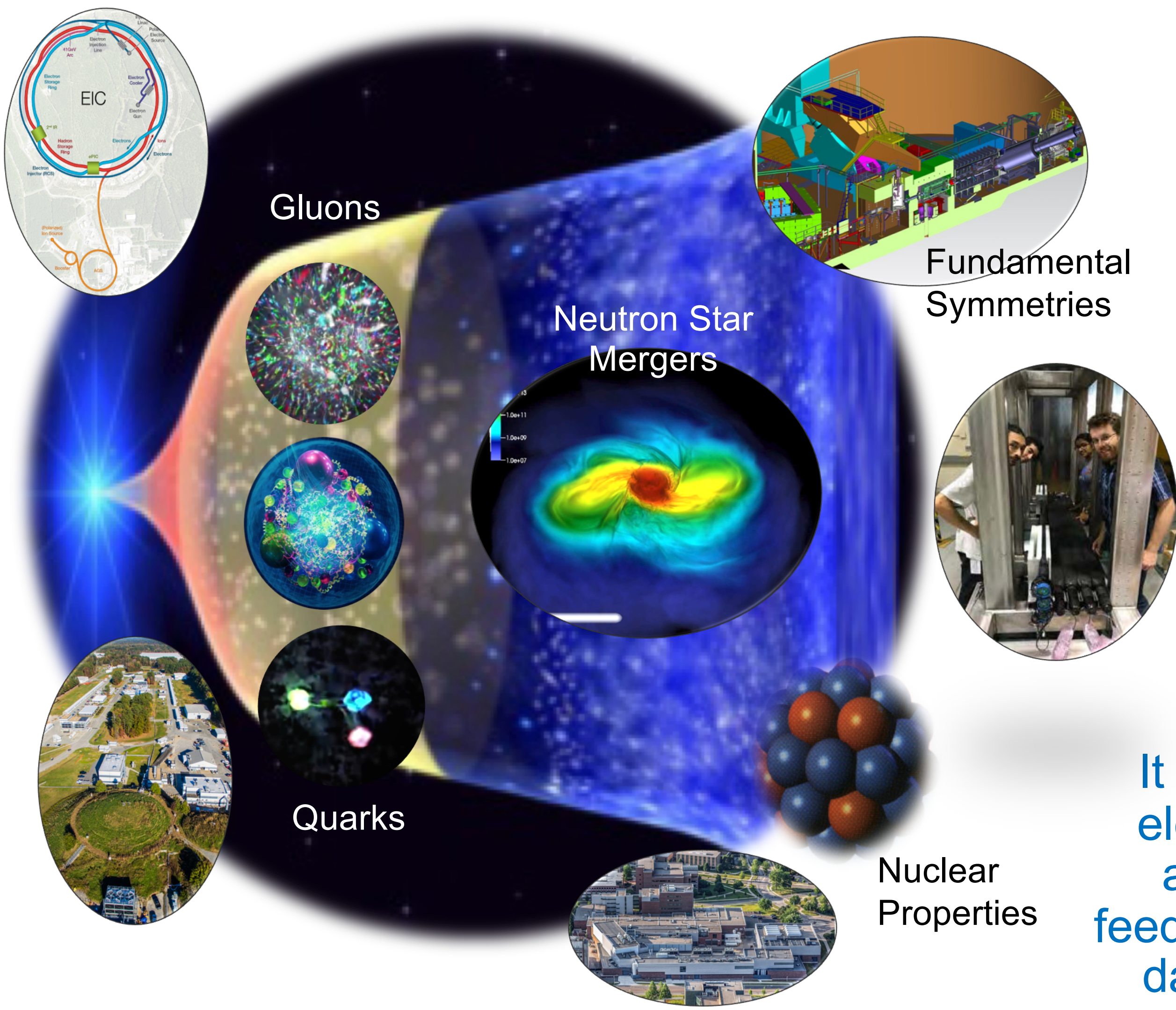
in·ter·face
ˈin(t)ərˌfās/ *noun*
1. a point where two systems, subjects, etc., meet and interact.

Nuclear Physicist,
Cancer Researcher,
Entrepreneur





Nuclear Physics: From Small-x to Heavy Nuclei



2023 Nuclear Science Questions

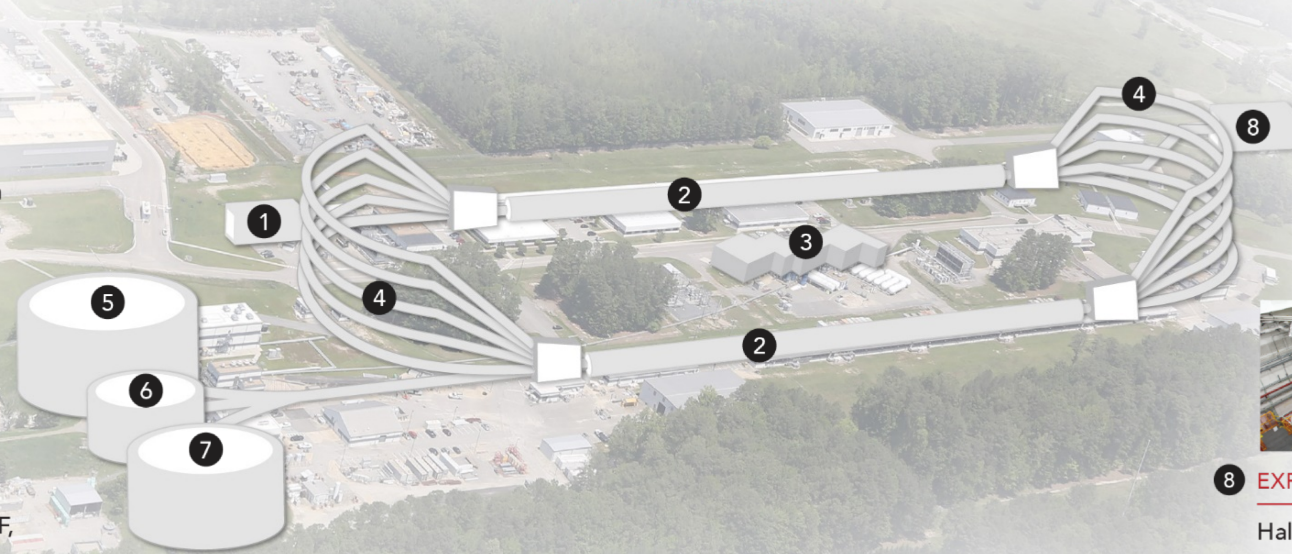
1. How do quarks and gluons make up protons, neutrons, and, ultimately, atomic nuclei?
2. How do the rich patterns observed in the structure and reactions of nuclei emerge from the interactions between neutrons and protons?
3. What are the nuclear processes that drive the birth, life, and death of stars?
4. How do we use atomic nuclei to uncover physics beyond the Standard Model?

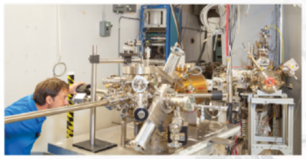
It takes advanced detectors, electronics, data acquisition, accelerators, engineering, feedback and controls, software, data science, ***and talented, skilled people*** to tackle these challenging questions

Also team work, organization, resource management, communication,….

CEBAF AT JEFFERSON LAB

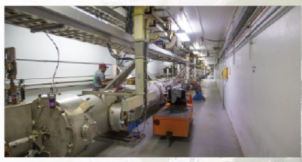
Jefferson Lab's Continuous Electron Beam Accelerator Facility (CEBAF) enables world-class fundamental research of the atom's nucleus. Like a giant microscope, it allows scientists to "see" things a million times smaller than an atom.





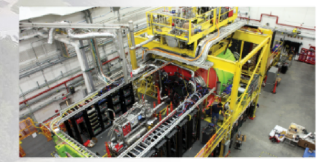
1 INJECTOR

The injector produces electron beams for experiments.



2 LINEAR ACCELERATOR

The straight portions of CEBAF, the linacs, each have 25 sections of accelerator called cryomodules. Electrons travel up to 5.5 passes through the linacs to reach 12 GeV.



8 EXPERIMENTAL HALL D

Hall D is configured with a superconducting solenoid magnet and associated detector systems that are used to study the strong force that binds quarks together.

3 CENTRAL HELIUM LIQUEFIER

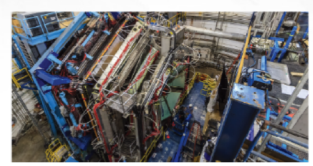
The Central Helium Liquefier keeps the accelerator cavities at -456 degrees Fahrenheit.

4 RECIRCULATION MAGNETS

Quadrupole and dipole magnets in the tunnel focus and steer the beam as it passes through each arc.

5 EXPERIMENTAL HALL A

Hall A is configured with two High Resolution Spectrometers for precise measurements of the inner structure of nuclei. The hall is also used for one-of-a-kind, large-installation experiments.



6 EXPERIMENTAL HALL B

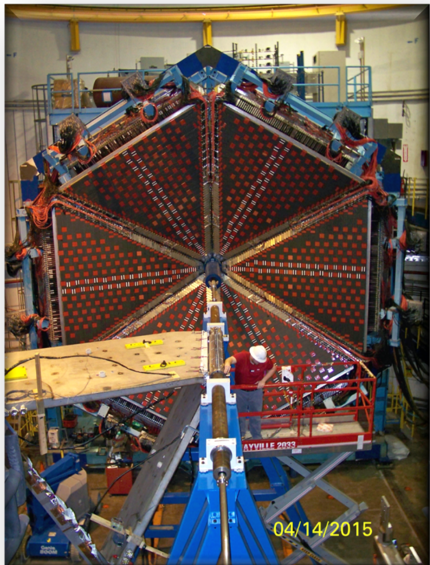
The CEBAF Large Acceptance Spectrometer surrounds the target, permitting researchers to measure simultaneously many different reactions over a broad range of angles.

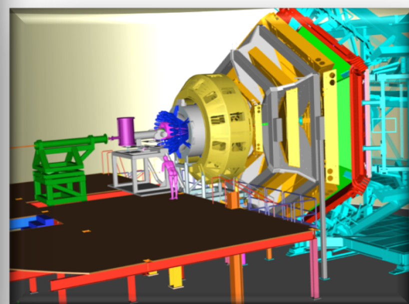
7 EXPERIMENTAL HALL C

The Super High Momentum Spectrometer and the High Momentum Spectrometer make precise measurements of the inner structure of protons and nuclei at high beam energy and current.

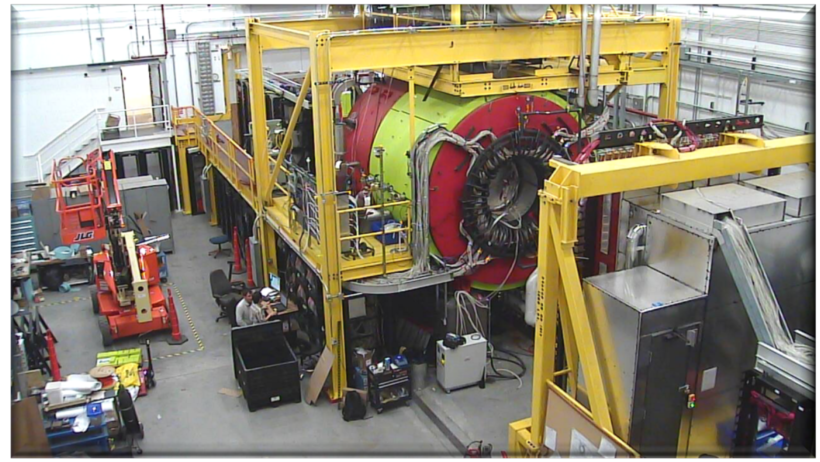
Detectors in 4 Halls = Numerous Scientific Capabilities!

Hall B **– understanding nucleon structure via 3D imaging**

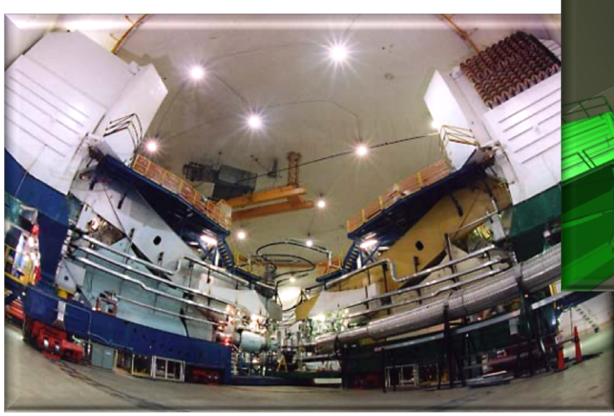


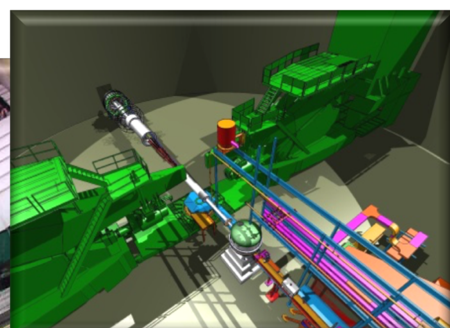


Hall D **– exploring origin of confinement by studying exotic mesons**



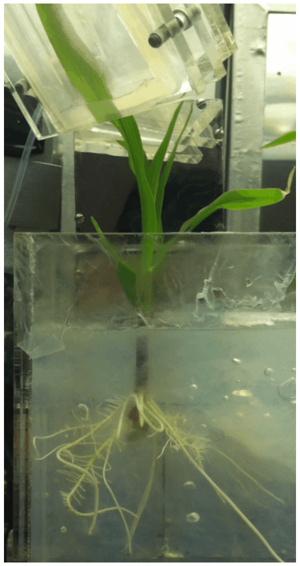
Hall A **– charge distributions, future new experiments**





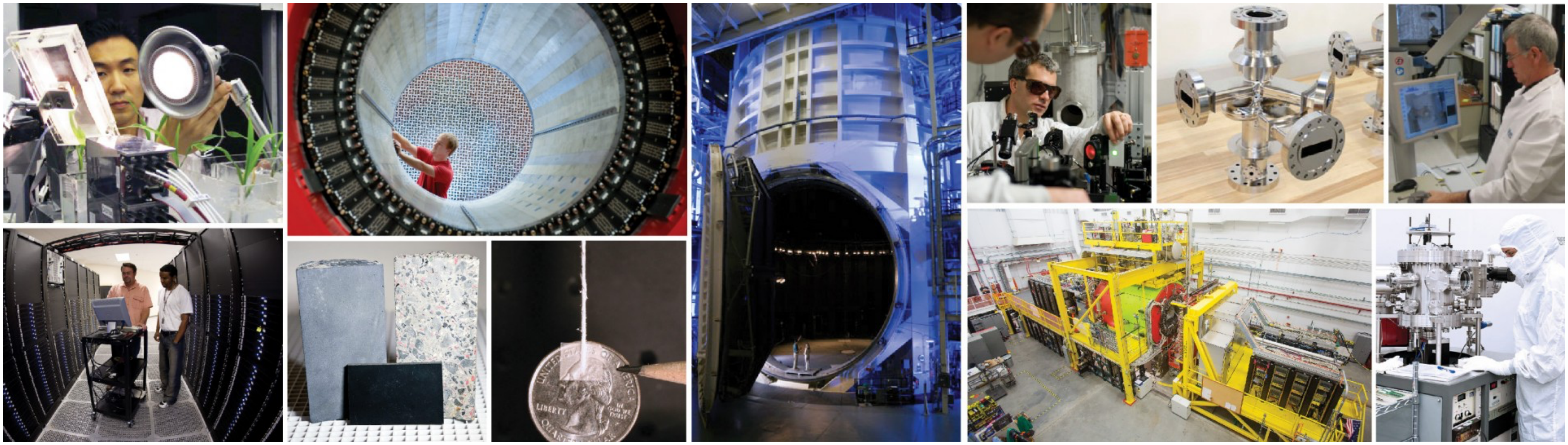
Hall C **– precision determination of quark properties in nucleons/nuclei**

JLab Medical Technology Development



Synergistic Development with Nuclear Science

- Instrumentation and Detection Systems
- Computing, Software and Data Management
- Particle Accelerator Technology

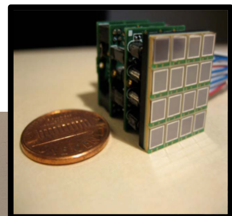
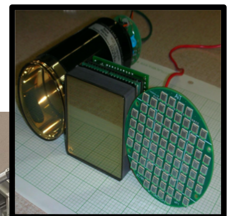


Medical Applications of Nuclear Physics

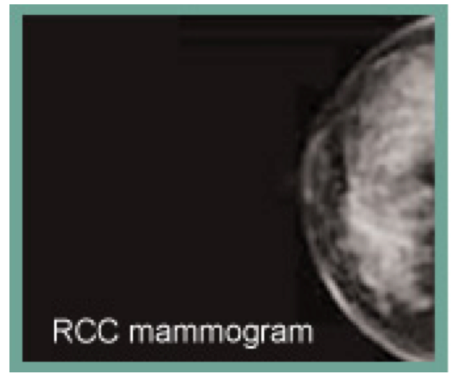
Particle Detector Spin-Off Advances Patient Care

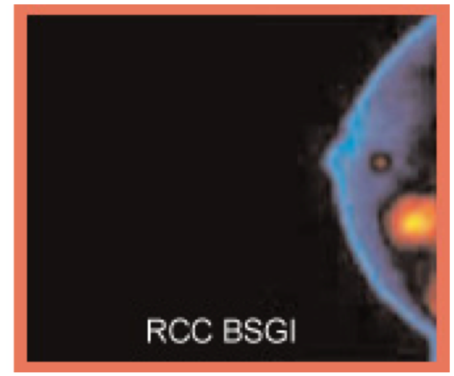
Nuclear physics detector technology developed to explore the structure of matter at Jefferson Lab leads to new and advanced tools for better patient care.

Basic tools for nuclear physics research
photomultiplier tubes, silicon photo multipliers, scintillator and detector electronics.


SBS Hadron Calorimeter





*Compact gamma camera for breast cancer **detection***

- Led to several Jefferson Lab **patents and a start-up company – now sold to SmartBreast**

Jefferson Lab

Particle Detector Spin-Off Advances Patient Care

Nuclear physics detector technology developed to explore the structure of matter at Jefferson Lab leads to new and advanced tools for better patient care.

Hand held gamma camera to guide surgeons

Jefferson Lab handheld silicon photomultiplier based gamma camera to assist with cancer surgery undergoing clinical studies at the University of Virginia.

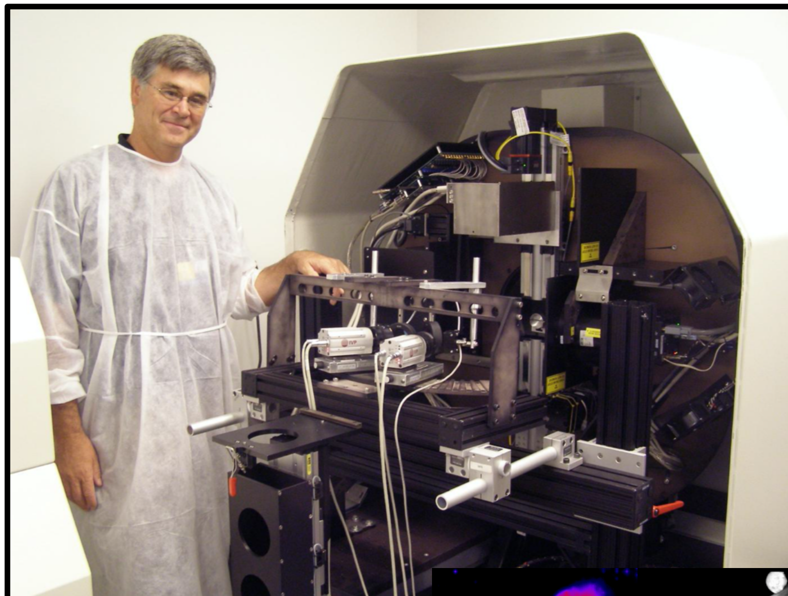
- **Silicon photo multipliers** provide precise imaging at low voltages
- Now also **wireless**, to give flexible motion without tethering
- Working on on-board display

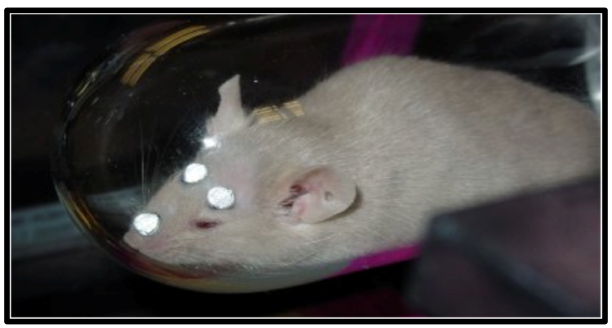
Advancing Brain Imaging Technologies

Methods based upon anesthesia inhibit/complicate brain based studies. Scientists work towards imaging methodology in awake humans to study neurological based diseases.

AwakeSPECT System is **based on technology developed by Jefferson Lab**, with contributions from ORNL, Johns Hopkins University and University of Maryland.

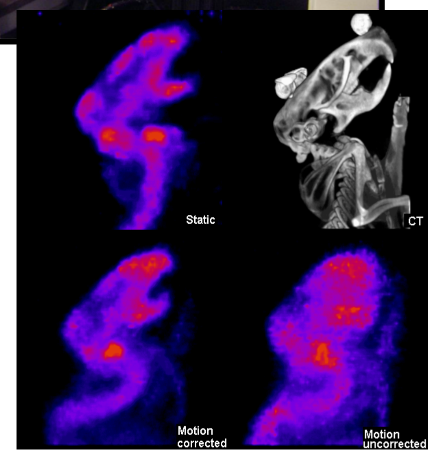
- Utilizes custom-built gamma cameras, image processing system, infrared camera motion tracking system and commercial x-ray CT system.
- Acquires functional brain images of conscious, unrestrained, and un-anesthetized mice.
- Can aid research into Alzheimer's, dementia, Parkinson's, brain cancers, traumatic brain injury and drug addiction.





Three IR markers attached to the head of a mouse enable the AwakeSPECT system to obtain detailed, functional images of the brain of a conscious mouse as it moves around inside a clear burrow.

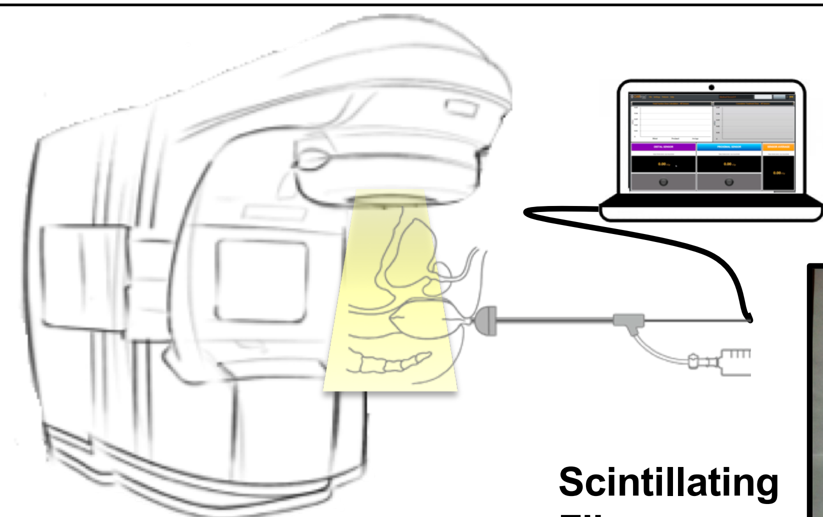
Gamma cameras based on nuclear physics detector technology.

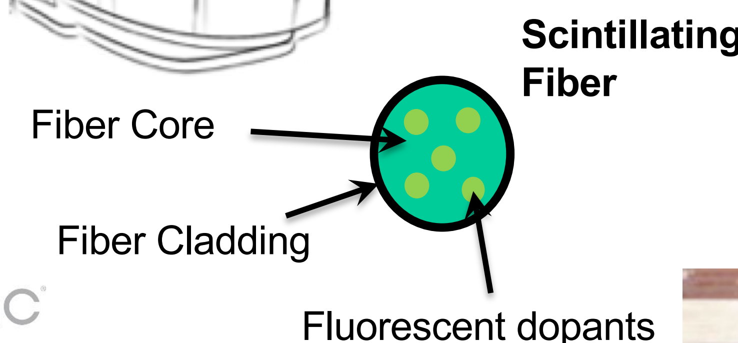


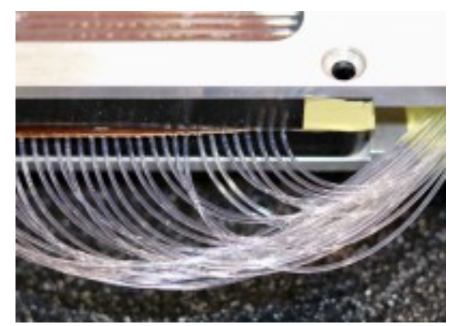
Enabling Real Time Radiation Treatment Dosimetry

Nuclear physics detector technology incorporates real time dosimetry monitoring into radiotherapy cancer treatment procedures.

- Radiation treatment dose uncertainties can affect tumor control and may increase complications to surrounding normal tissues.
- The current standard of practice does not provide information on actual delivered dose to the tumor.
- **Nuclear scientists at Jefferson Lab and Hampton University developed real-time, in vivo, dosimetry technology (3 patents)**
- Licensed to Radiadyne, created OARtrac
- Plastic scintillating detector (PSD) fiber technology with balloon-type patient organ immobilizers to measure real time dose delivery.







2018 Awards

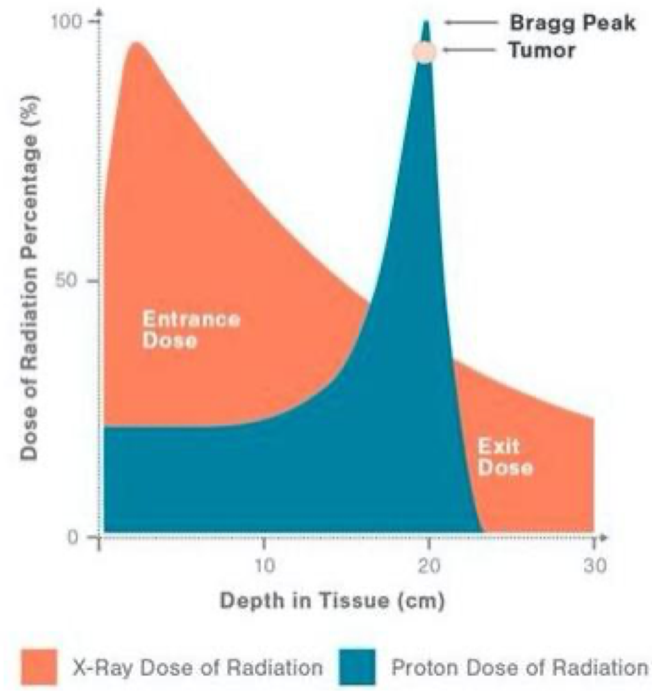
MEDTECH BREAKTHROUGH AWARDS

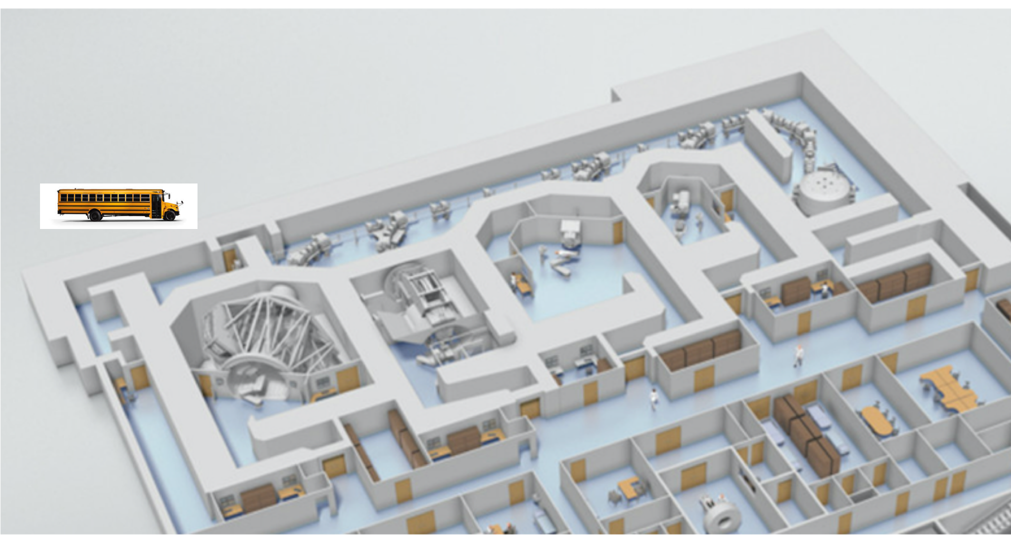
Proton Therapy for Cancer Treatment

Radiotherapy with a **proton accelerator** allows oncologists to design fine-tuned three-dimensional cancer treatment plans.

Fundamental nuclear physics: Bragg peak determines
proton energy loss = dose to patient

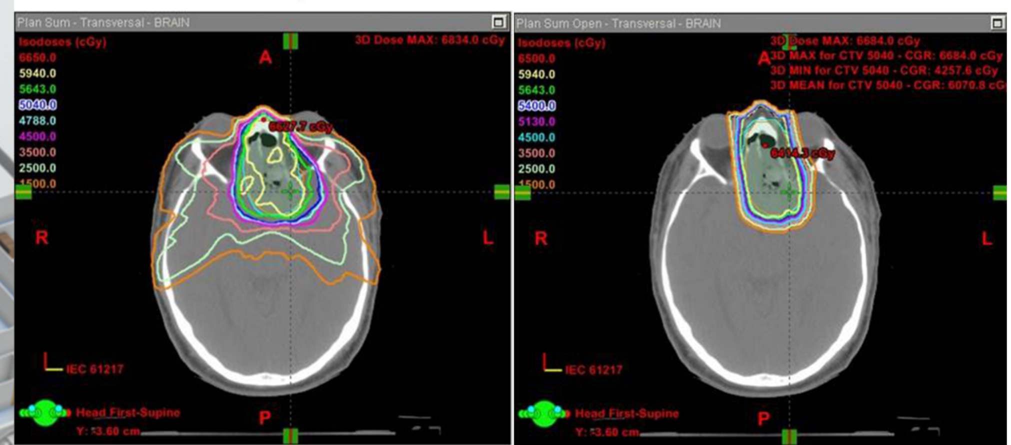
- Enables higher precision localized treatment
- Has fewer side effects due to reduced stray radiation outside the tumor region
- Nuclear physics technology to enable this includes **simulation, beam transport, acceleration, dose monitoring**, *and more*
- Jefferson Lab scientists have been instrumental in the design, construction and treatment plans at nearby Hampton University Proton Therapy Center, and other facilities.





X-Rays

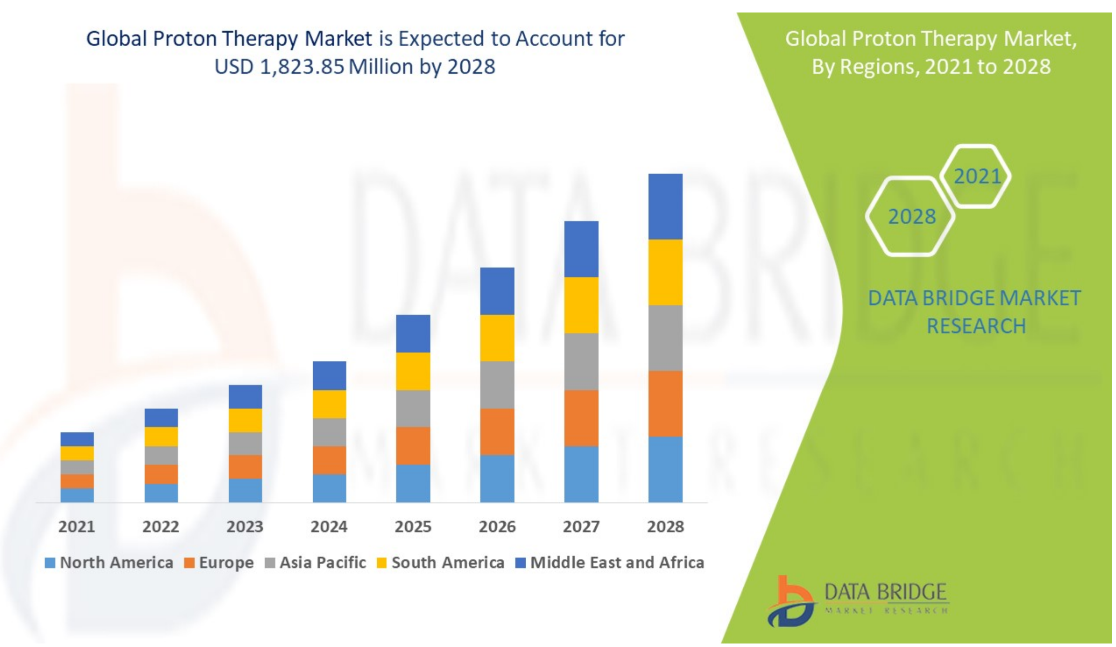
Protons



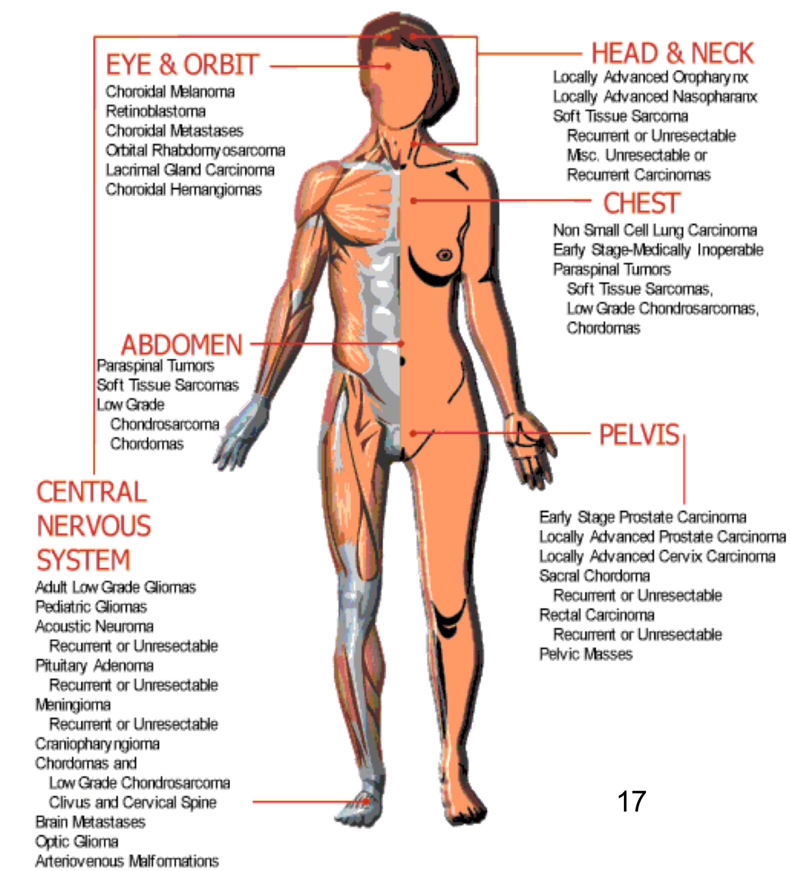
Proton Therapy for Cancer Treatment

- >250,000 patients have been treated with particle therapy worldwide
- Current average ~20,000 patients treated annually.
- >800 clinical studies

Market growth

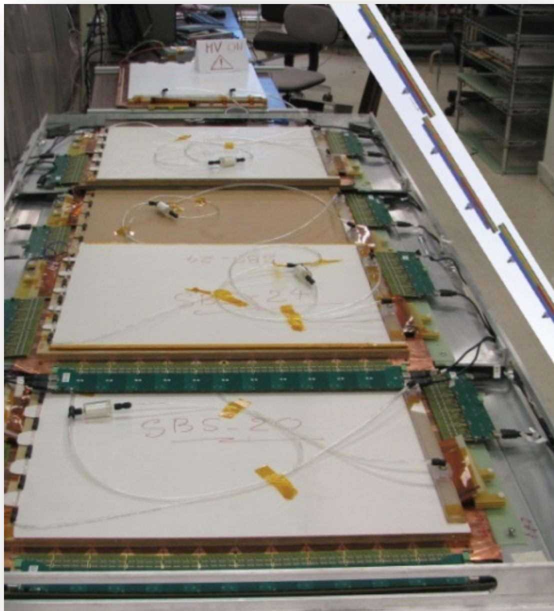


Tumor sites treated



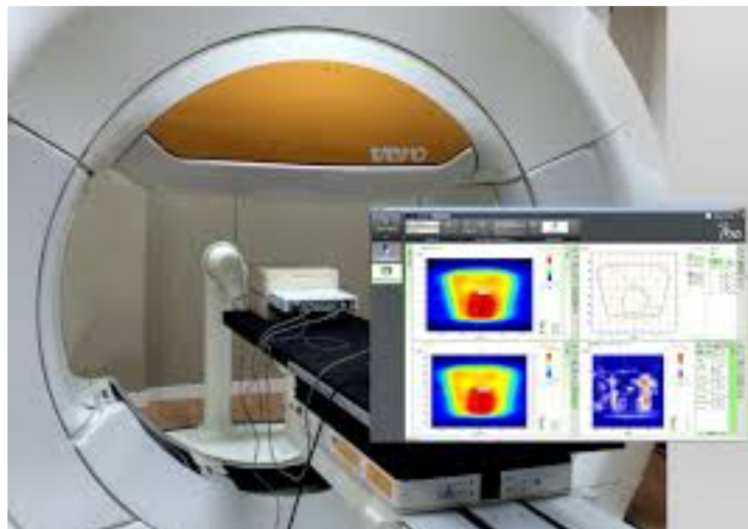
Proton Beam Characterization and Dosimetry

Gas Electron Multiplier Detectors for Jefferson Lab Hall A Super Bigbite Spectrometer

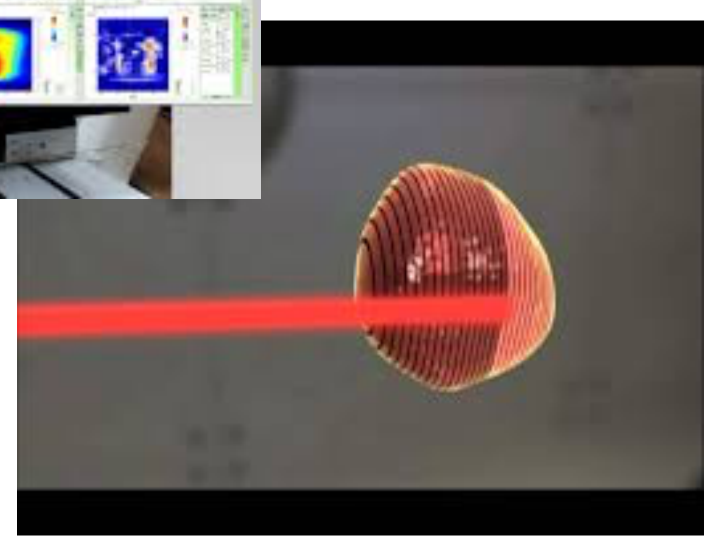


70 **micron** resolution

7 **mm** resolution

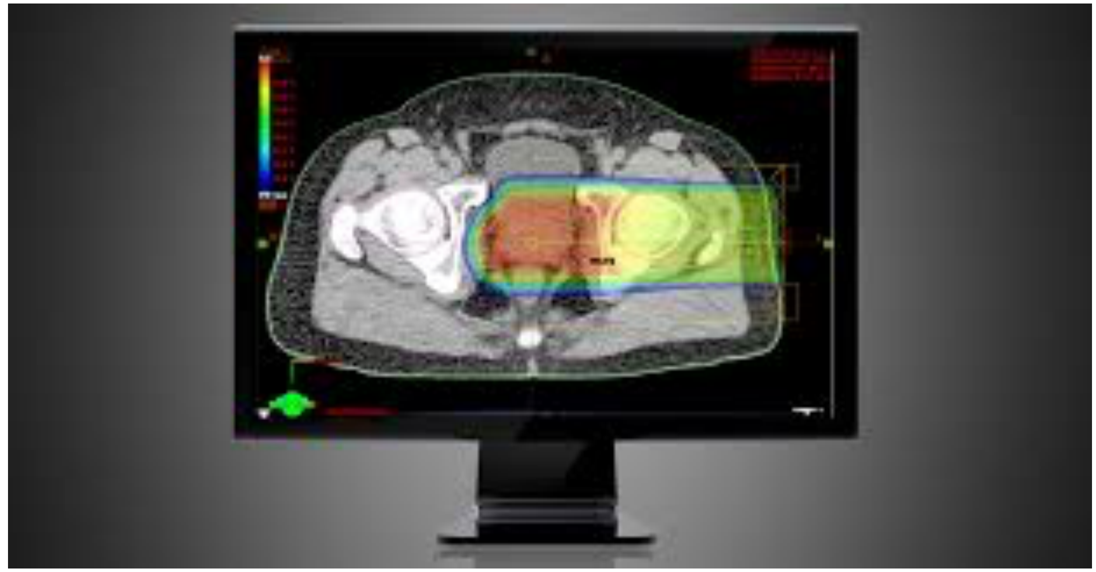


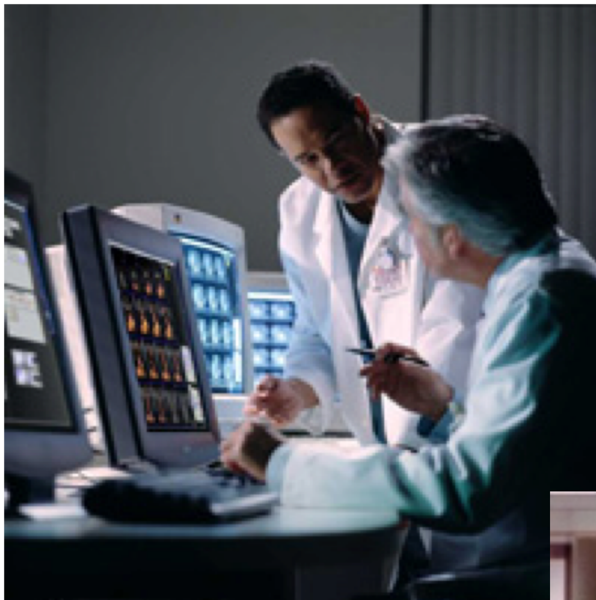
Potentially excellent tool for (new) pencil beam scanning delivery



Proton Beam Simulation

Varian Medical Systems "Eclipse" software product

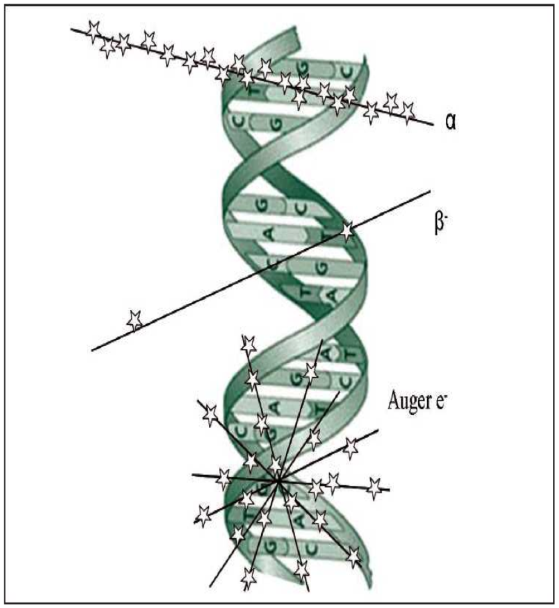


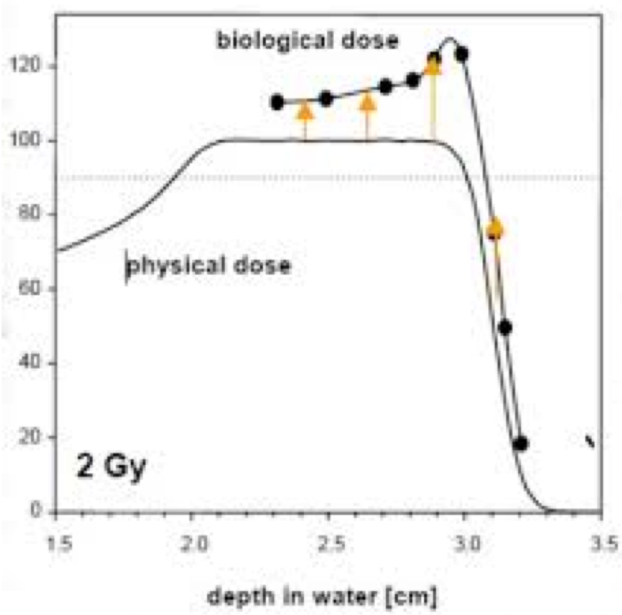


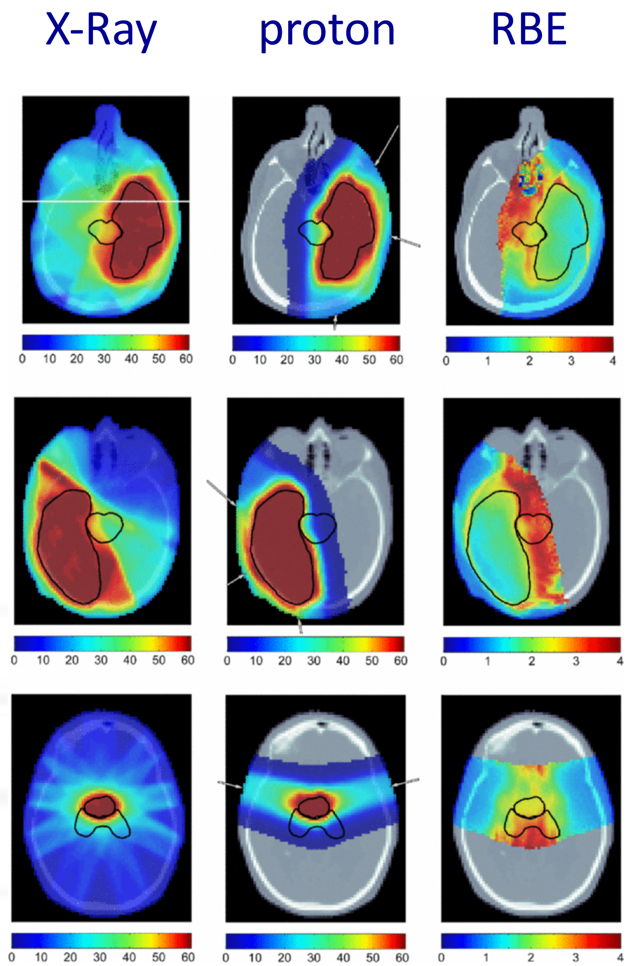
Doctors prescribe dose based on (CT) images of tumor volume and location

Physics team *simulates radiation transport through patient using* beam angles, energies, devices, etc. in patient to achieve desired dose

Proton Beam Simulation – "BioEclipse" Development







Effect of RBE-weighted treatment planning on brain tumor dose distributions

JLab, Eastern Virginia Medical School, HUPTI

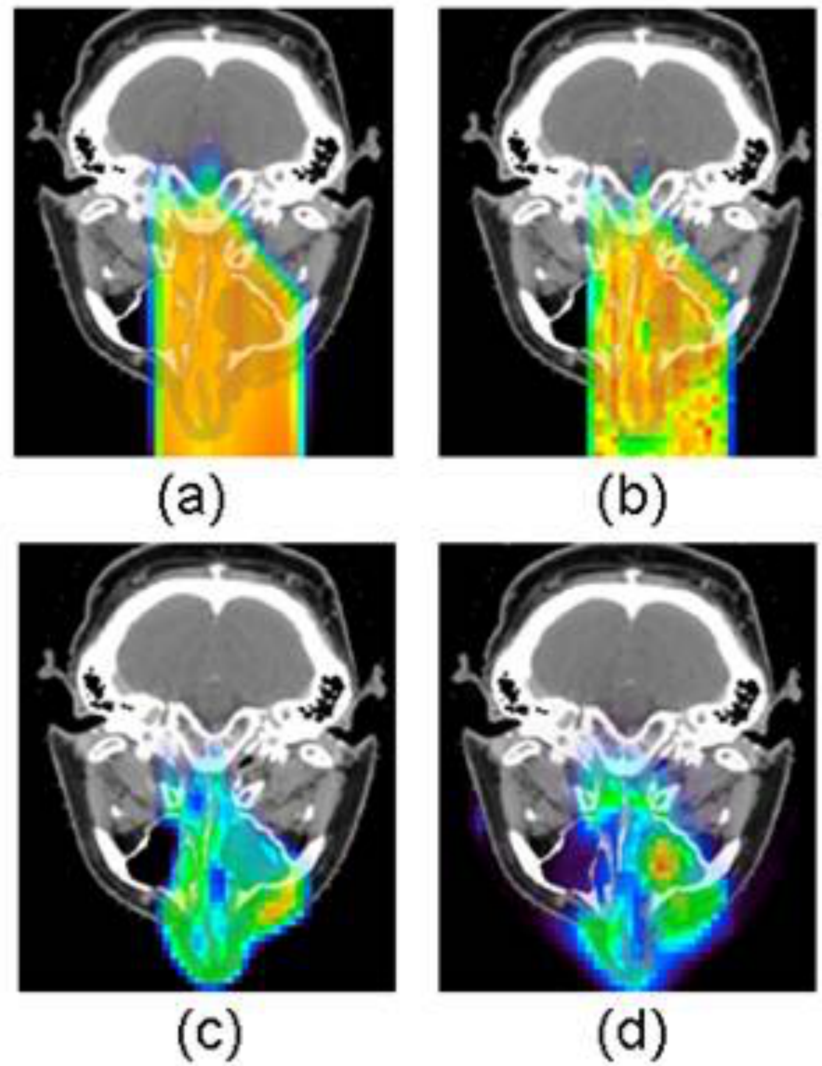
- *"Relative Biological Effectiveness"* (RBE) factor allows comparison between the killing power of radiation of type *R* to that of X-rays.
- A *single (RBE) value* is currently applied to all proton patient treatment plans, RBE=1.1
- We were able to show that RBE's at the *far side* of the treatment volume can be significantly higher

Jefferson Lab

PET Imaging of Proton Beam Delivery

nasal cavity melanoma

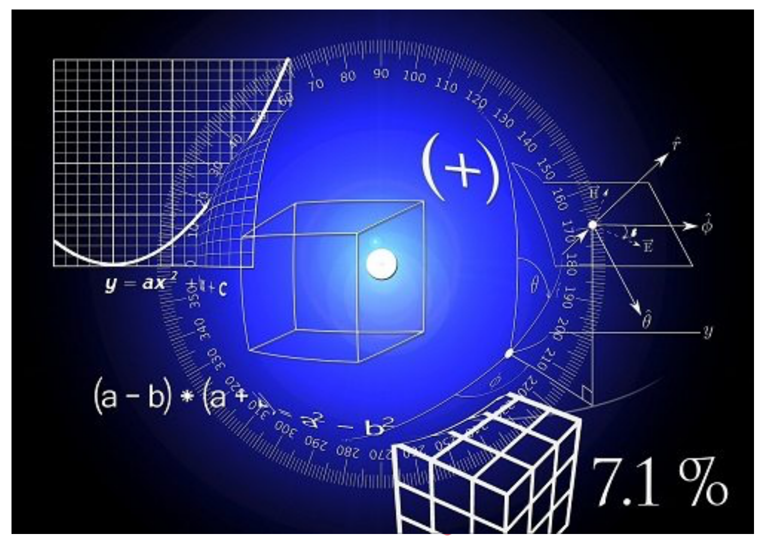
Radionuclide	Half life (min)	Nuclear reaction channels Threshold energies (MeV)
^{15}O	2.037	^{16}O(p,pn)^{15}O/16.79
^{11}C	20.385	^{12}C(p,pn)^{11}C/20.61,
		^{14}N(p,2p2n)^{11}C/3.22,
		^{16}O(p,3p3n)^{11}C/59.64
^{13}N	9.965	^{16}O(p,2p2n)^{13}N/5.66,



- Promising for range verification
- Develop into dose verification?
- Or, try using ^{11}C beam for treatment and imaging?

Careers

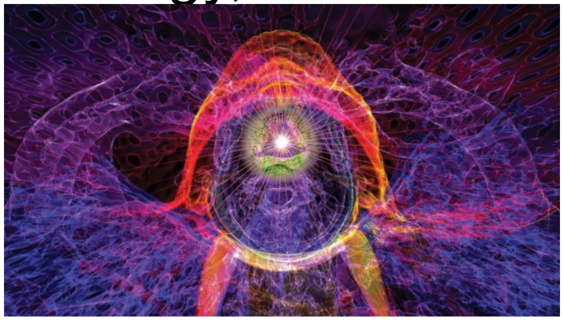
1. Physics provides you with many tools! To name a few we've touched on…
   - Detectors and instrumentation
   - Complex problem solving
   - Computing
   - Data analytics
   - Data acquisition and electronics
   - Simulation
2. ALL are used for BOTH fundamental research AND medical technology development
   - Clinical medical physicists, dosimetrists
   - Academia (fundamental or applied research and/or teaching)
   - Health and radiation safety
   - Device development companies
3. *And other industries!...*



Careers in Medical Physics

- In US, clinics typically require Certification – a long path, involving:
  - CAMPEP (accrediting body) approved training
  - Mentored working hours in role (student and paid)
  - Multiple national examinations
- There are CAMPEP-approved graduate programs in medical physics, as well as residencies (post graduate training)
  - Residencies are a good way in to clinical medical physics for nuclear/particle physicists (relatively common)
  - Residencies are competitive, good to get (graduate) courses in radiation biology, anatomy and physiology AND show interest in the topic through research while working towards nuclear – or other – PhD
  - Clinical positions are ~>85% radiation oncology, ~<15% radiology
- Companies do not require Certification
  - Varian, Phillips, Siemens, GE, Elekta, BrainLab, Best Medical…hundreds!

  - Neither does Radiation Safety



Careers in "Physics"

You should not limit yourself to just searching for jobs with the specific title "physicist" – this might land you mostly on webpages about research positions in academia or national labs.

4% of physics bachelor's recipients and 17% of physics doctorate recipients are working in a field of employment ***titled*** physics or astronomy.

A diverse range of sectors seek out physicists, including investing, computer science, mechanical engineering, electrical engineering, and public policy.

Some companies will be less familiar with a physics degree than with engineering, so you need to explain the marketable skills that your physics degree gave you.

Other companies, particularly engineering companies that are anchored in physics, often reach out specifically to physicists!

General Advice

- To prepare yourself for a role of interest, from training to interview to advancement

  Put yourself in your employer's shoes!

  – What is their need, void, area of expansion that has motivated them to request this hire (or create a future hire)?
  – What skill sets, experience match this need best?
  – Focus on the overlap between their needs and your experience

- Don't undervalue networking!
  – Experimentalists, for example - don't just sit shift, be strategic and become known
  – Ask people at meetings about their research, search and prepare questions… let them know if you have some overlapping interests
  – Follow up

- Don't over-worry about not being on "primary" path
  – Look for creative opportunities

Careers

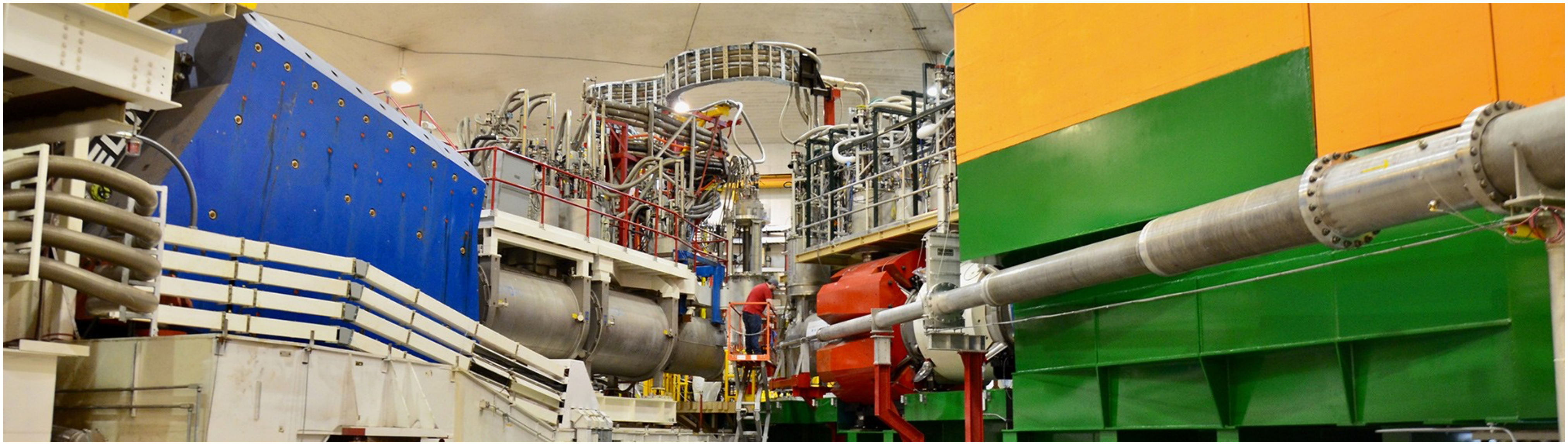
With great tools come great opportunities…

Overall employment of physicists is projected to grow 5 percent from 2022 to 2032, faster than the average for all occupations. [US Bureau of Labor Statistics]

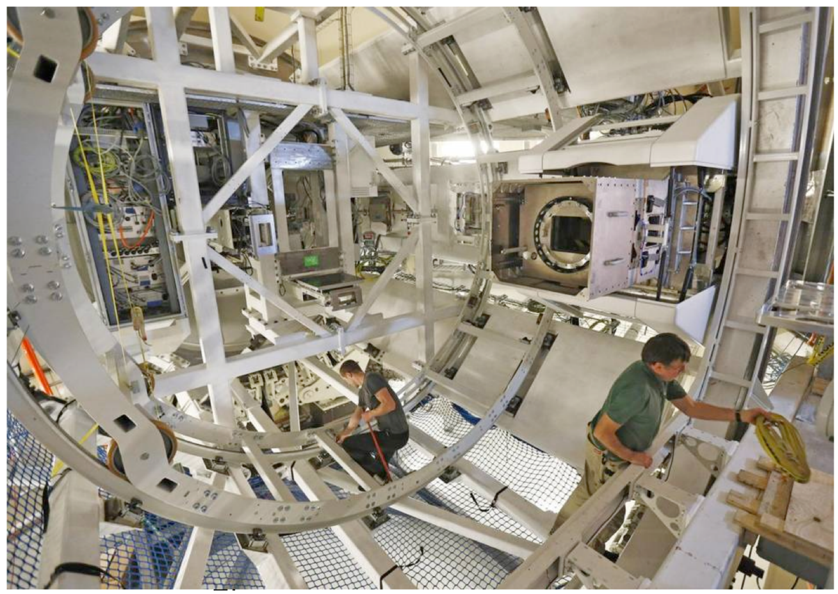
When General Electric acquired the machine learning startup Wise.io, CEO Jeff Immelt boasted that he ”had just grabbed a company packed with physicists.”

“I think physics gives you a mental framework for problem solving. It also teaches you to be willing to admit you're wrong.” – Elon Musk (Founder of SpaceX, Tesla, PayPal,.. and physics graduate!]

Jefferson Lab Hall C



Thank You!



Proton Therapy Gantry Under Construction

Jefferson Lab