

# PROTON THERAPY FOR CANCER: Addressing a Big Problem With a Small Machine\*’#

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**Granada High School**

**February 5, 2011**

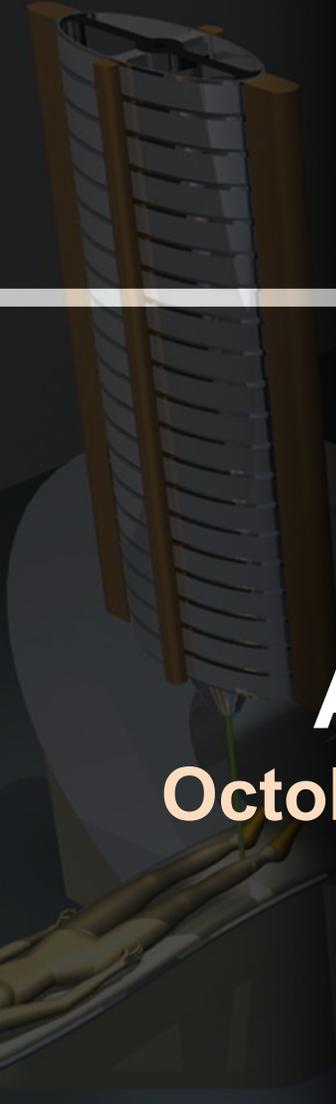
LLNL-PRES-468011

\*This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

#Patents Pending



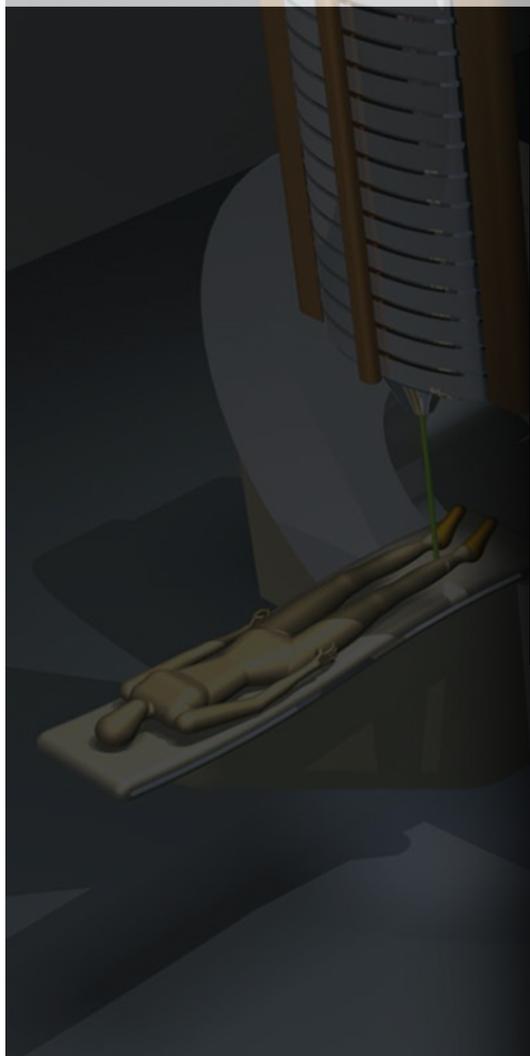
SCIENCE ON SATURDAY



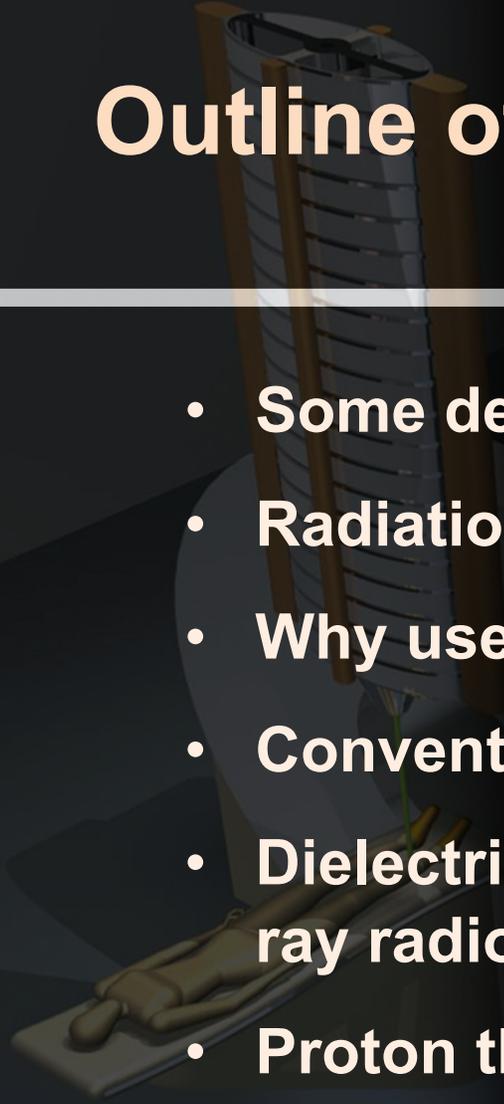
# DEDICATION

**Antoinette Ruggiero**  
**October 31, 1956 – January 1, 2011**

# CNN coverage of our work



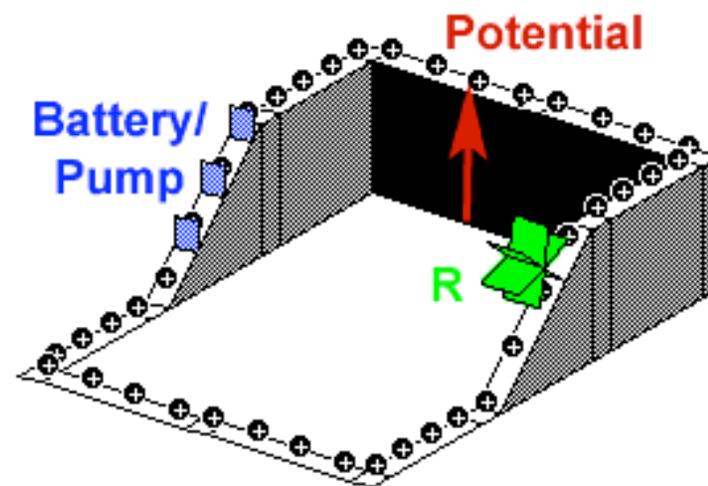
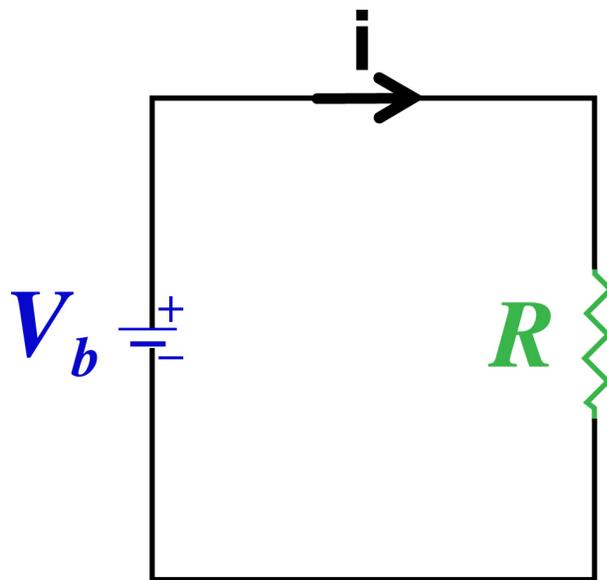
# Outline of today's talk



- **Some definitions**
- **Radiation and cancer: a double-edged sword**
- **Why use protons for cancer therapy?**
- **Conventional proton therapy systems**
- **Dielectric Wall Accelerator (DWA) for flash x-ray radiography**
- **Proton therapy concept**
- **Summary**

# Voltage is the analog of pressure in a fluid circuit

Current ( $i$ ) is the analog of mass flow rate in a fluid circuit



# Voltage differences drive current flow

- Voltage *difference* is the capacity to do work
- Unit is the Volt

9 Volts



110 Volts



350,000 Volts



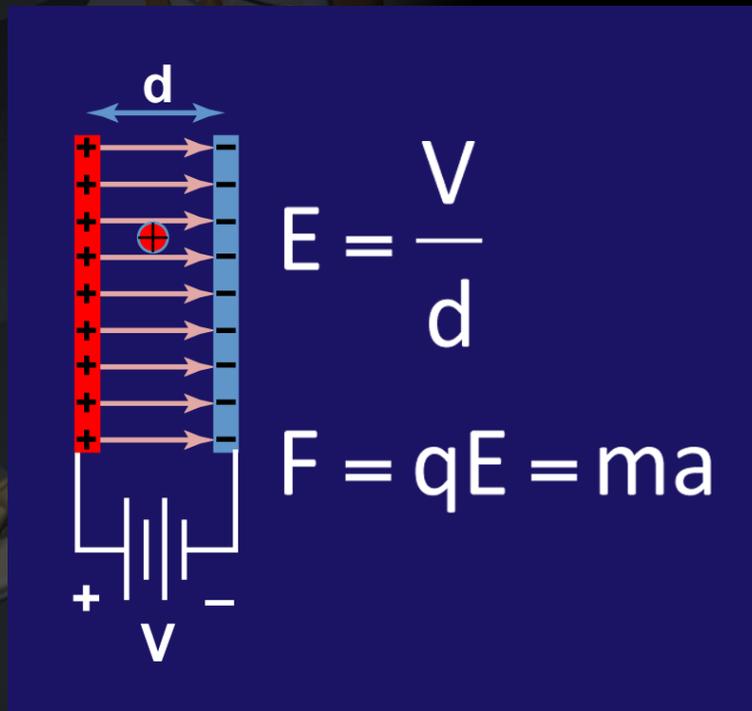
100,000,000 Volts



# Electric fields exert forces on charged particles

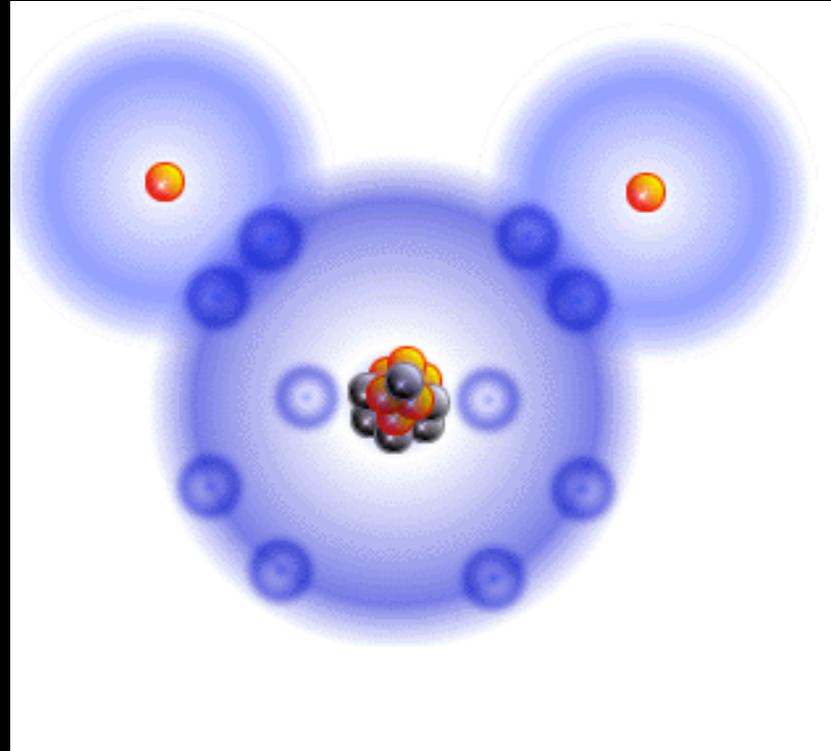
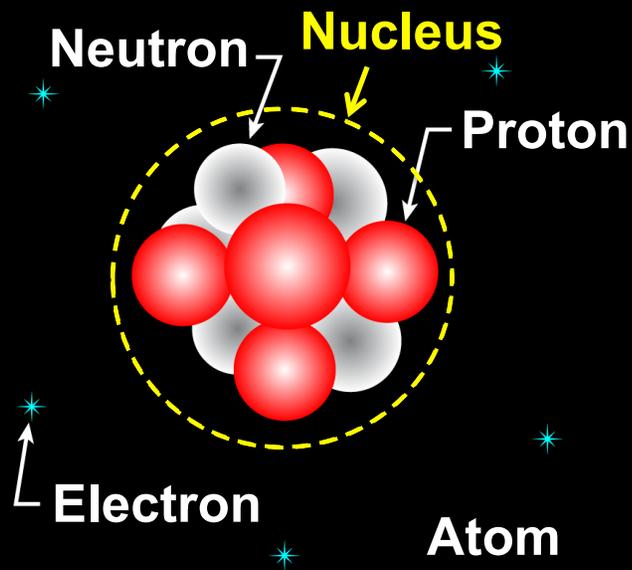
Electric field = Voltage *difference*/Distance

Unit is Volt/meter



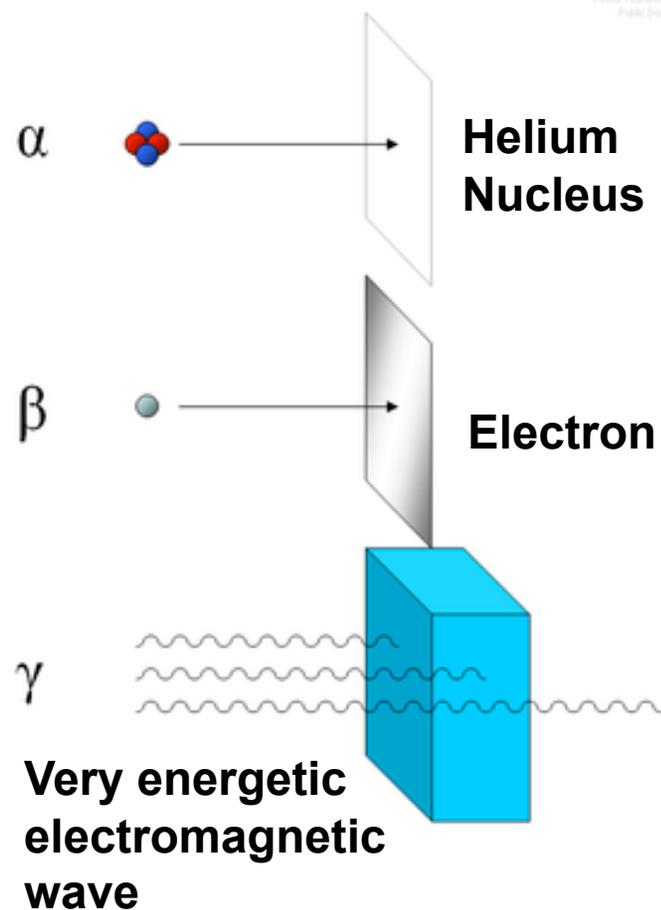
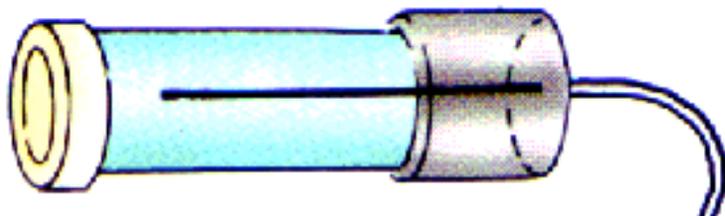
- Particle energy = charge x voltage difference through which it moves
- Unit is the *electron volt* =  $1.6 \times 10^{-19}$  J
- MeV = 1,000,000 electron volts

# Atoms and molecules are the basic building blocks of living matter

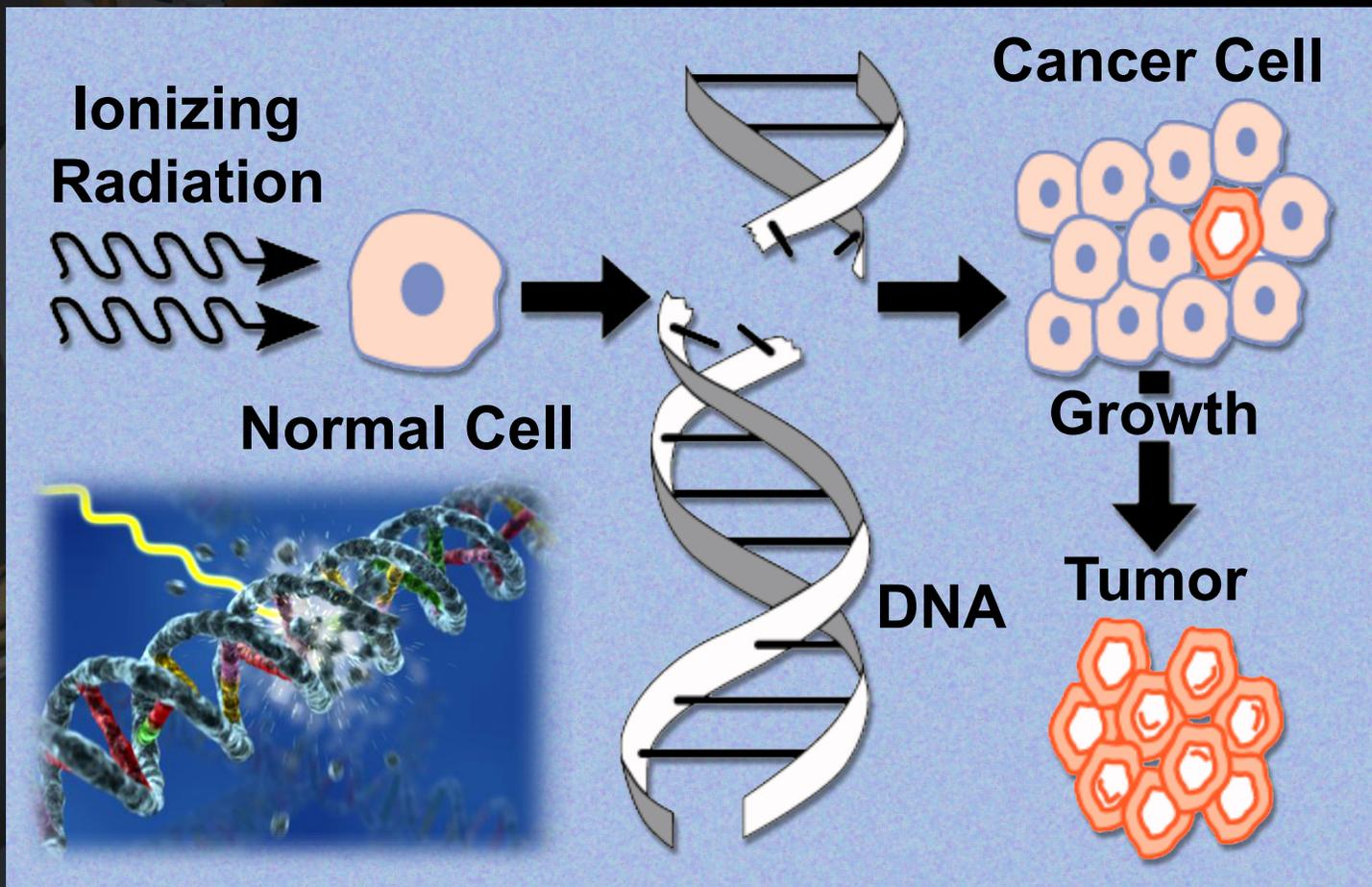


# What is *ionizing* radiation?

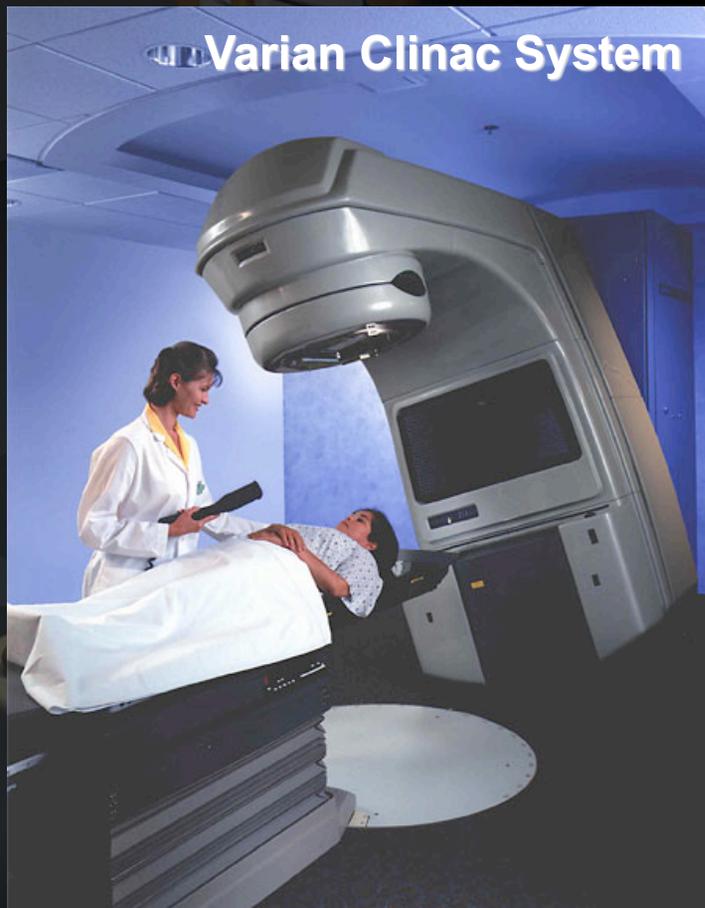
- Any particle or electromagnetic wave energetic enough to eject an electron from an atom or molecule



# Radiation can cause cancer

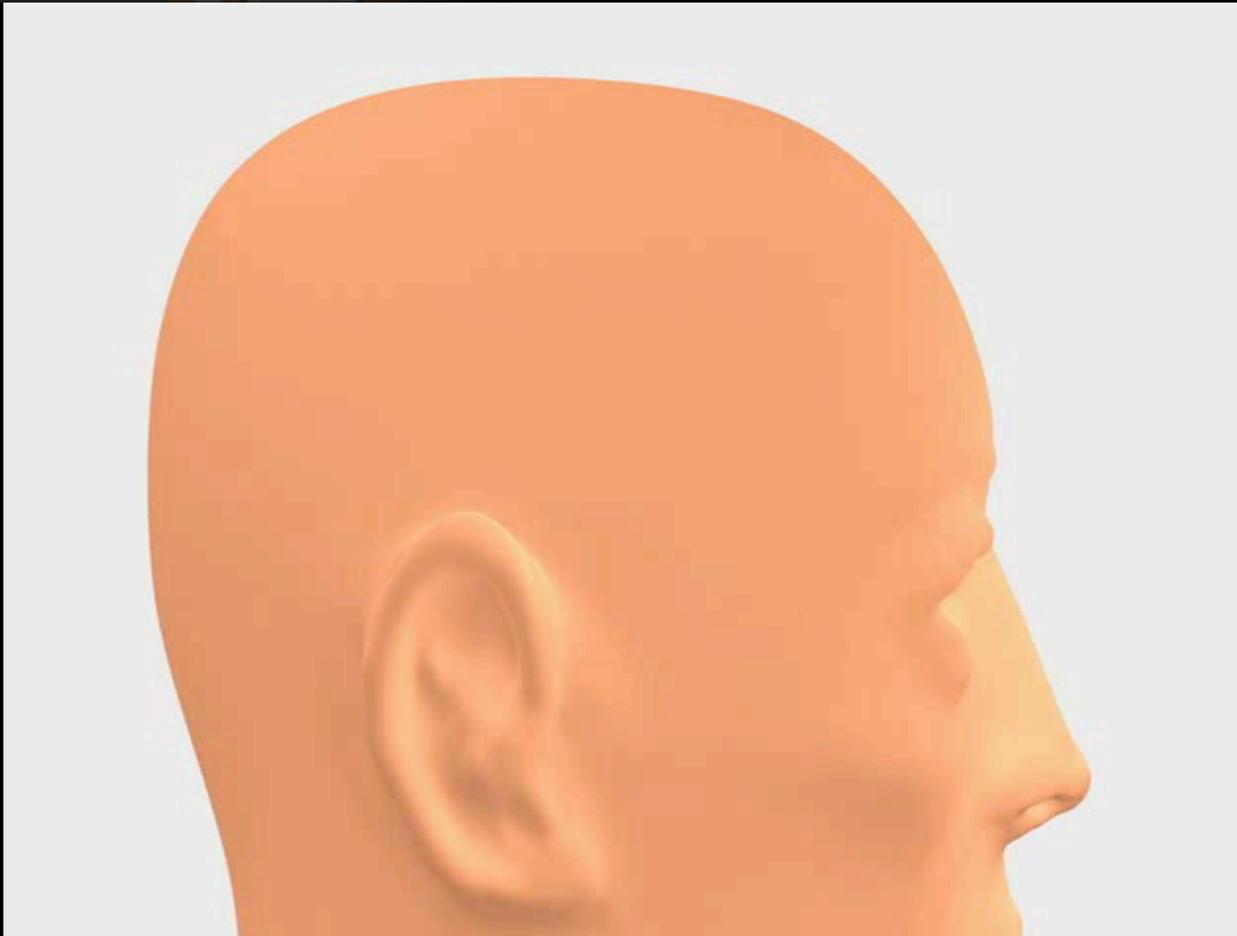


# Conventional radiotherapy is done with x-rays



- 1 in 3 people will develop cancer
- 50% of those will be treated with radiation
- More than 2,000 locations in the U.S. offer (x-ray) radiation therapy
  - These systems fit in a single room

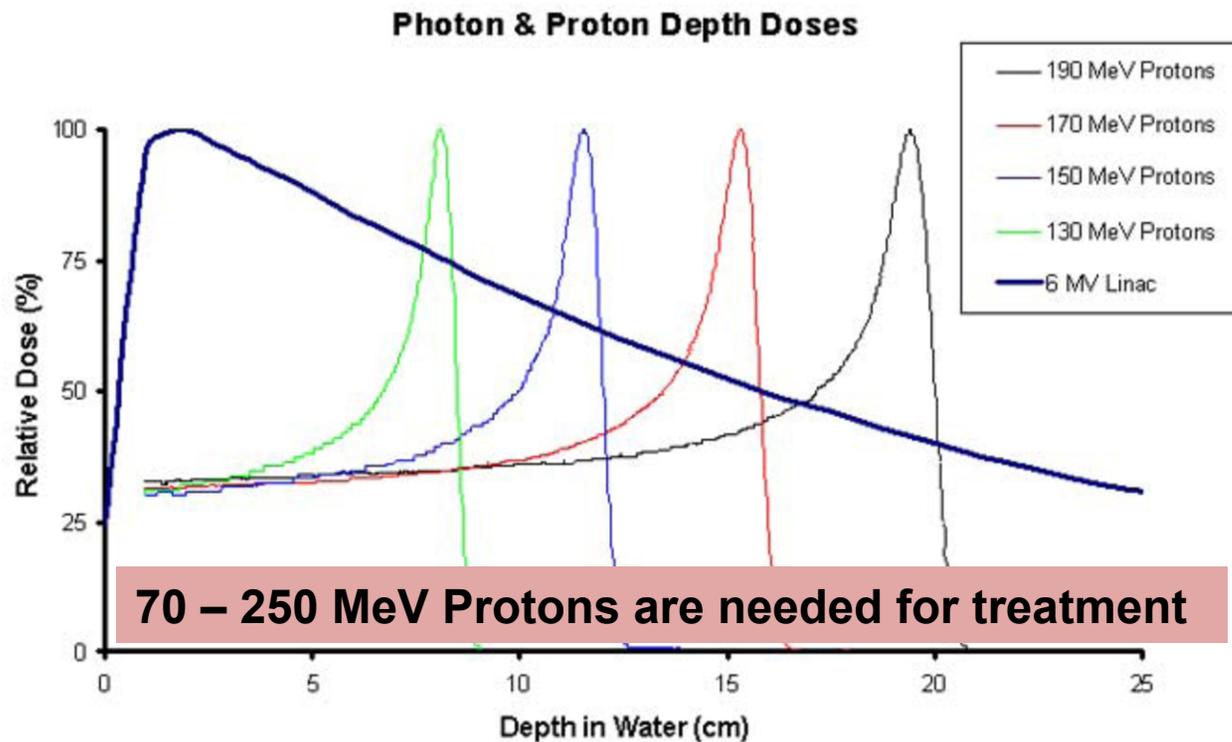
# Proton treatment offers numerous advantages over x-rays



- **No exit dose**
- **Less entrance dose**
- **Potential to deliver higher dose to tumor**
- **Can treat recurrences**
- **Can treat tumors close to critical organs and structures**

Courtesy ProCure

# Protons allow much more precise dose delivery than x-rays



Boyer, Goitein, Lomax and Pedroni, Physics Today, Sept. 2002

# Current proton therapy centers are massive facilities

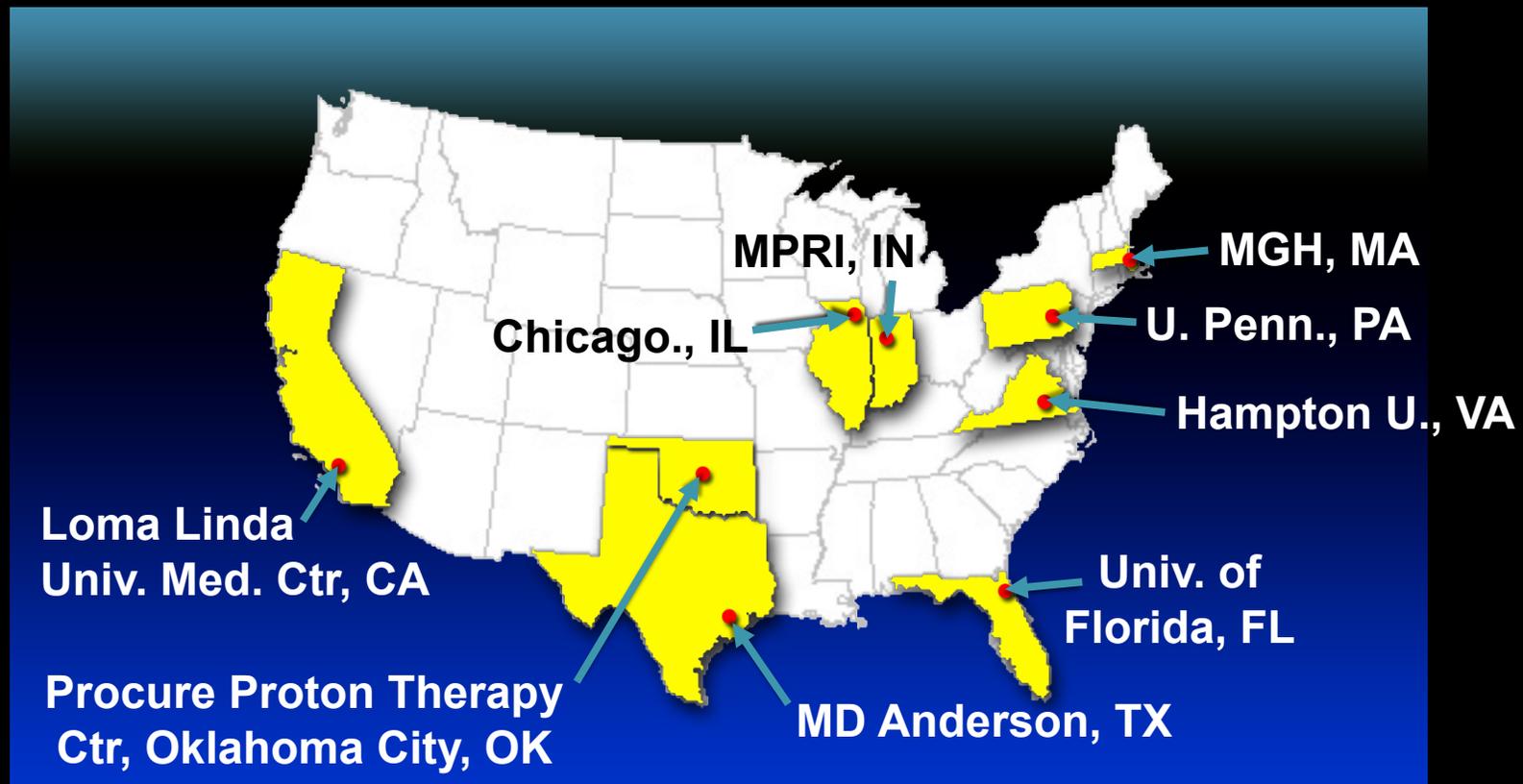


Courtesy IBA

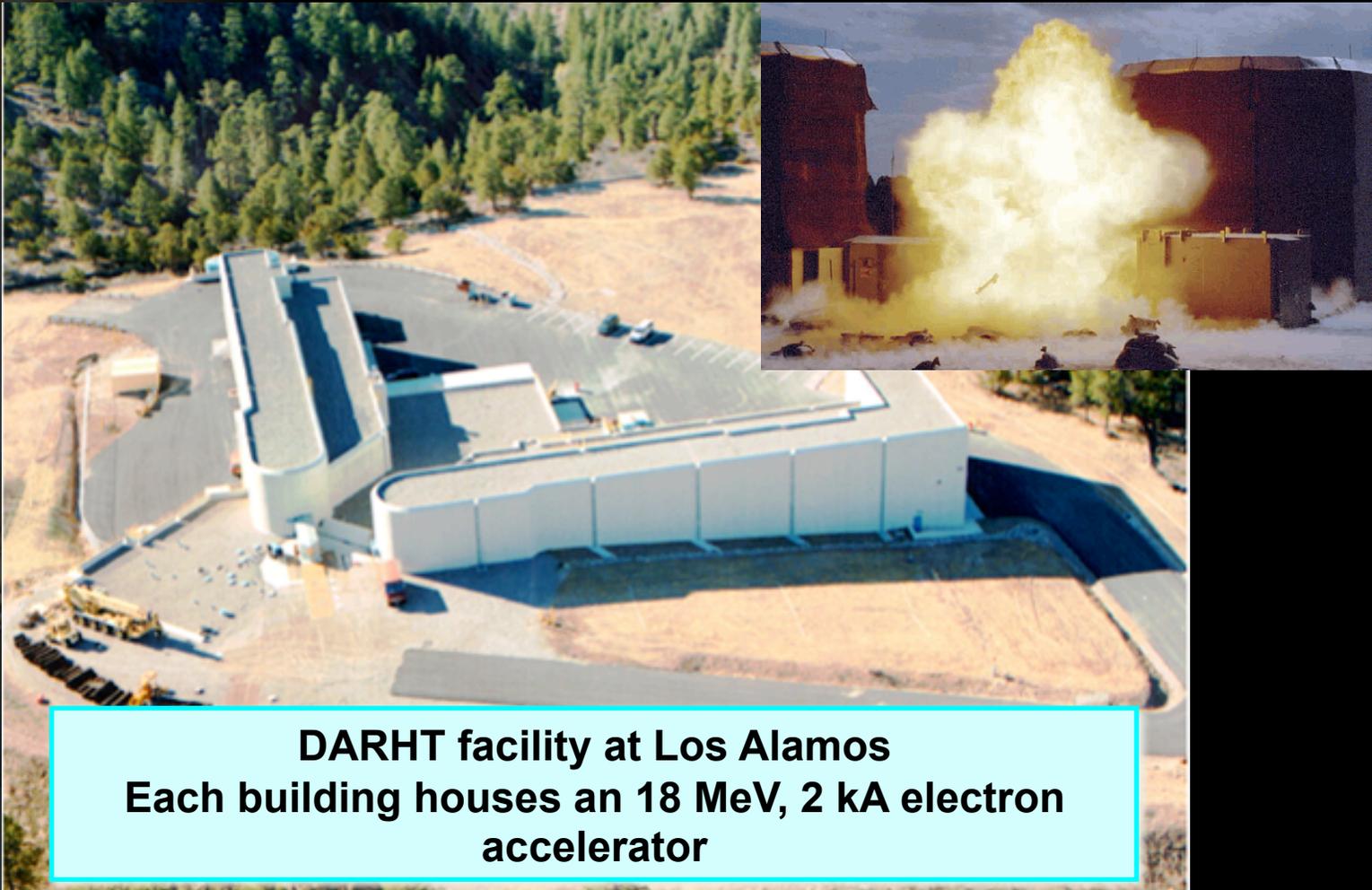
# Massive gantries provide proton irradiation from 360°



# There are 9 locations in the U.S. that offer proton therapy



# New accelerator technology originated with a desire for more compact flash x-ray sources

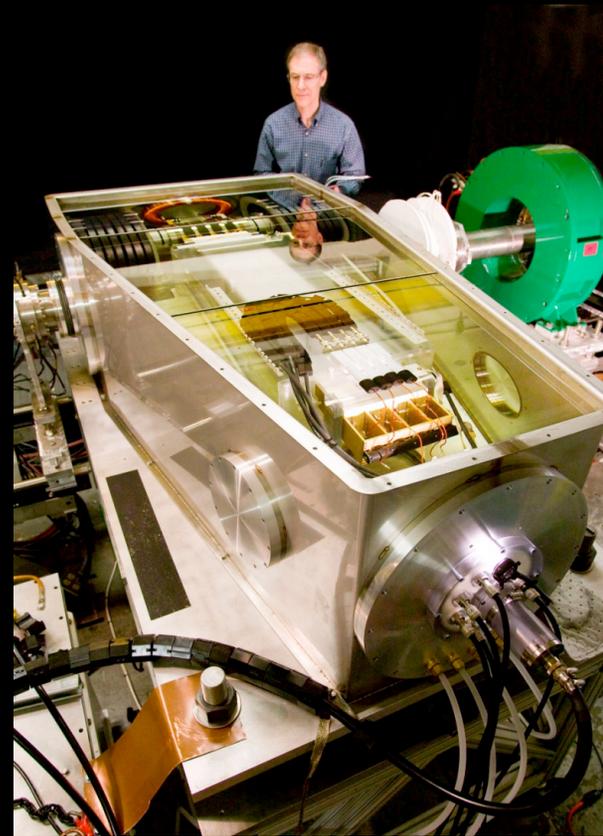


**DARHT facility at Los Alamos**  
Each building houses an 18 MeV, 2 kA electron  
accelerator

# Dielectric Wall Accelerator (DWA) concept was developed to make smaller radiography machines



**AIRIX Radiography Machine**



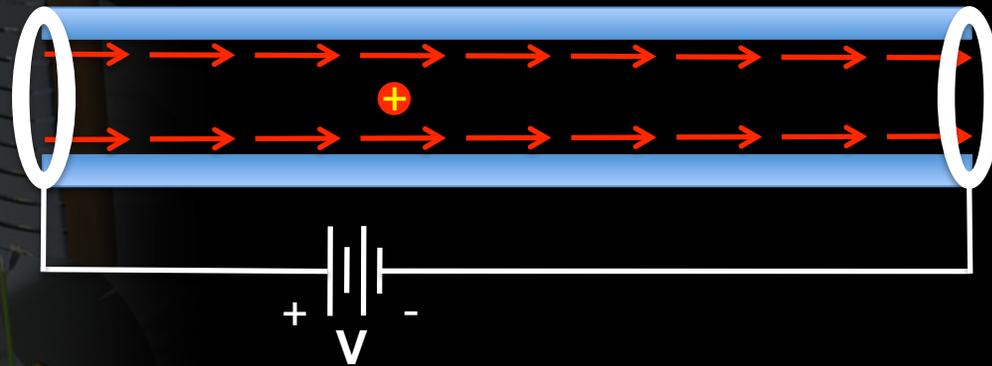
**Prototype DWA Module**

# Particle accelerators move particles with an electric field

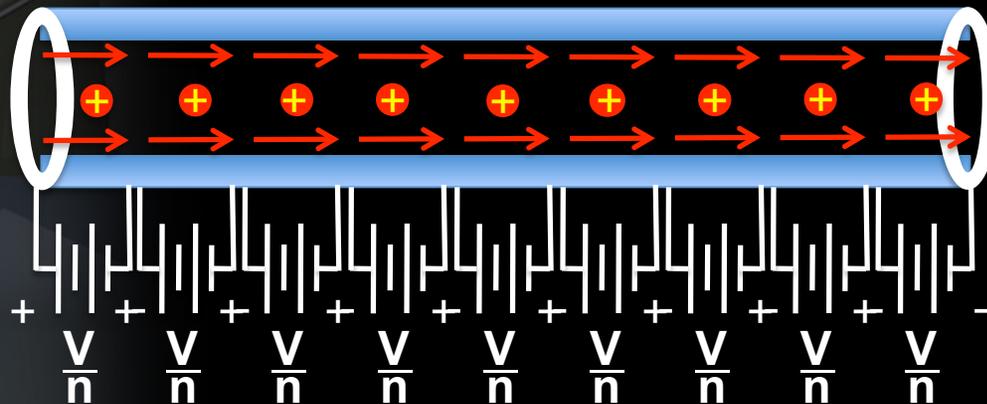


# Two approaches to a linear accelerator

Apply total voltage across beam tube - electrostatic



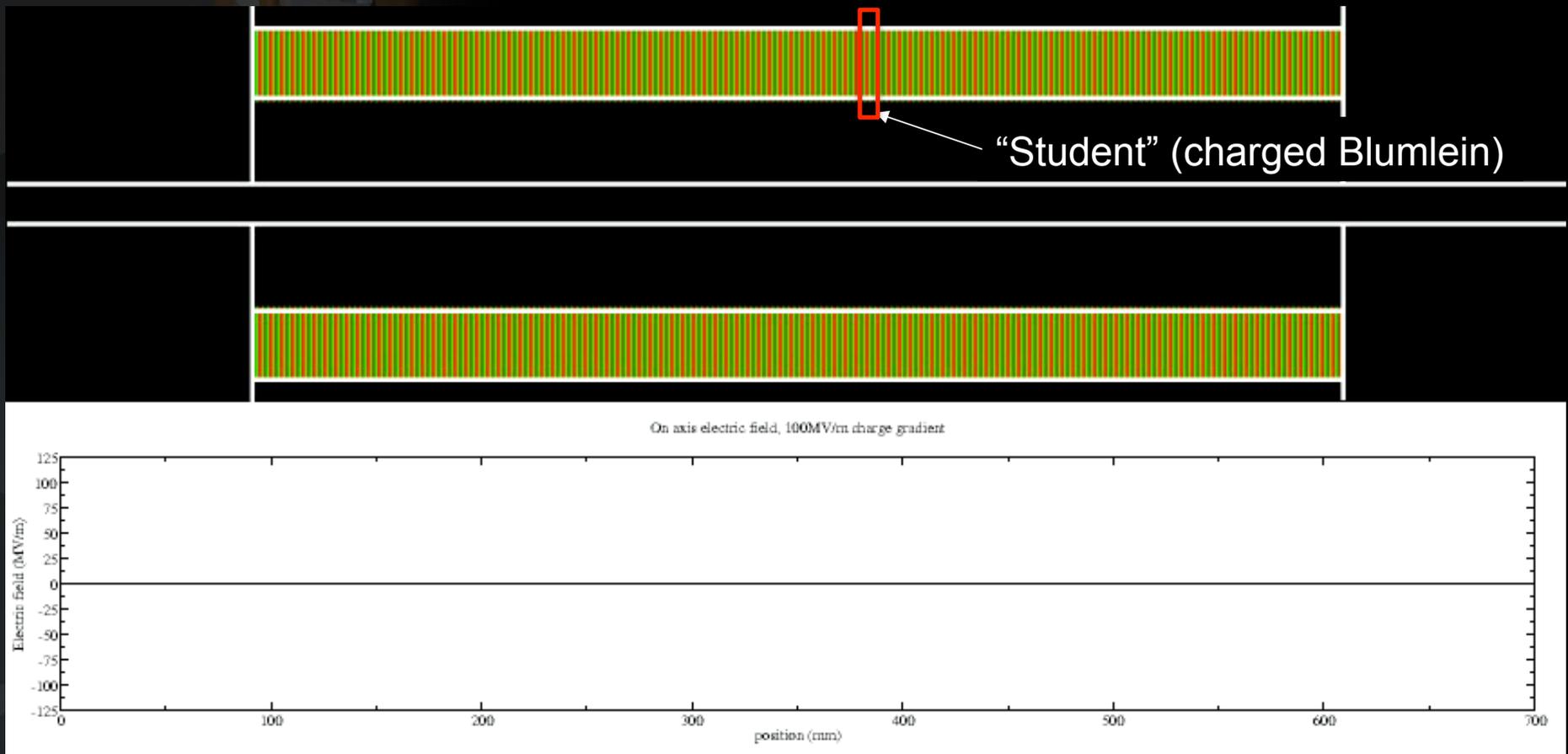
Provide *local electric field* and move it with the particle – traveling wave



# Accelerating wave demonstration

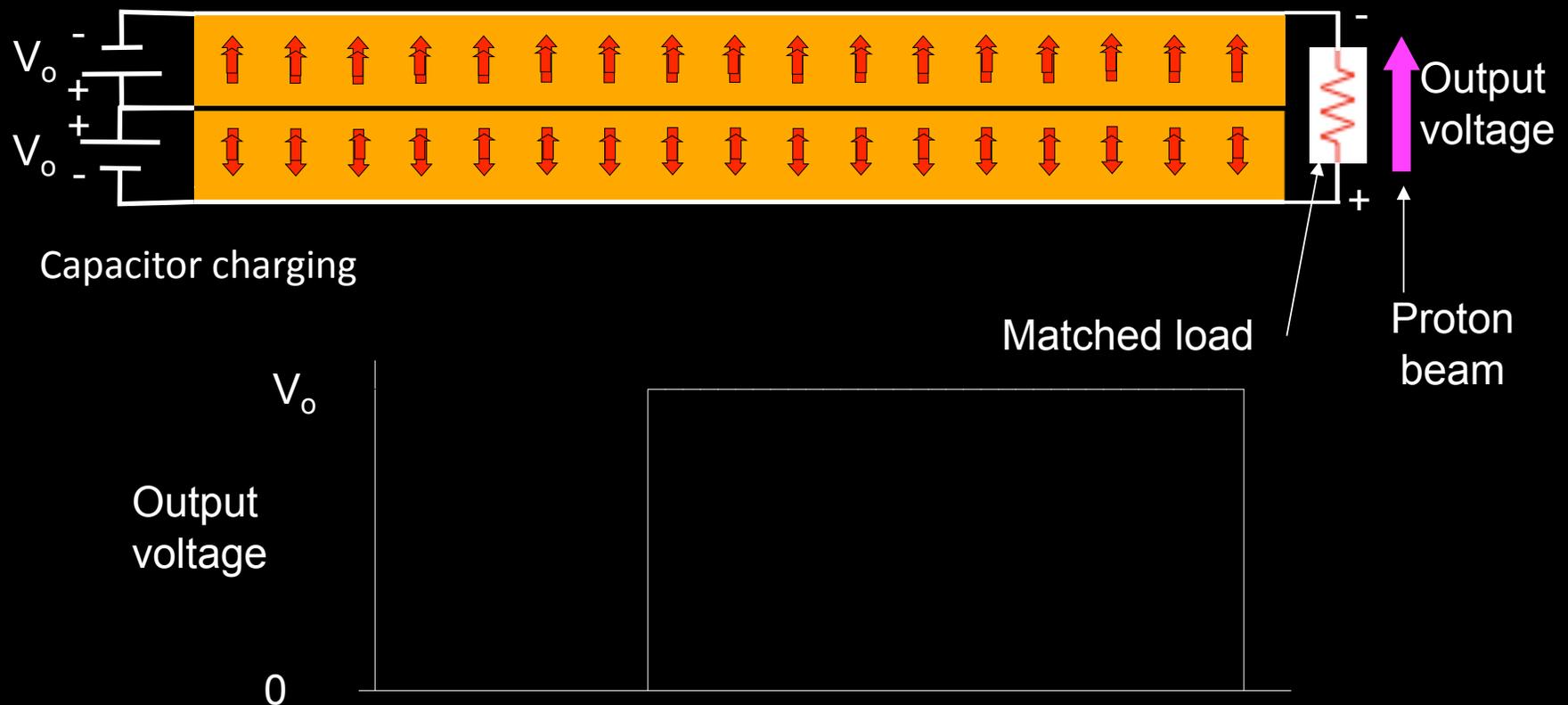


# DWA supports a virtual traveling wave by continuous wall excitation\*



\*US patent 7,576,499 B2

# Operation of a basic Blumlein\* pulse generator

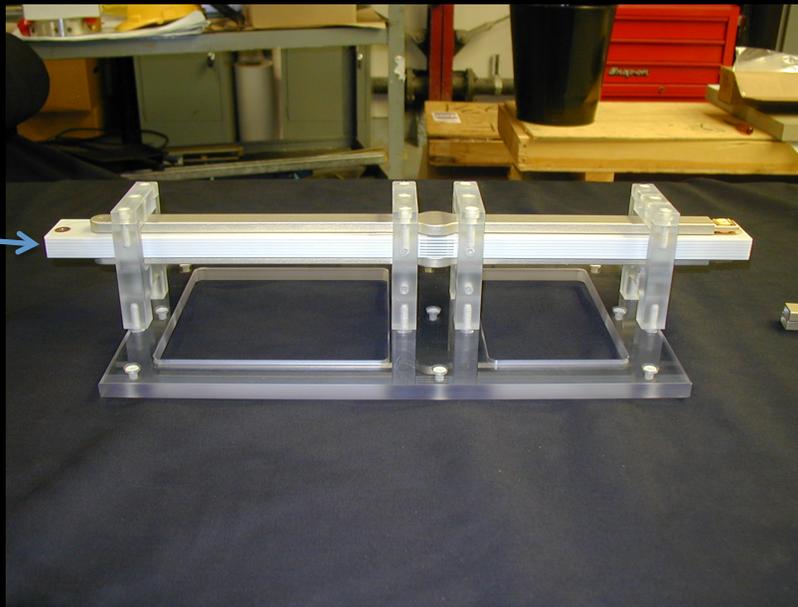


\* Alan Dower Blumlein (1903 – 1942)

# Blumlein example

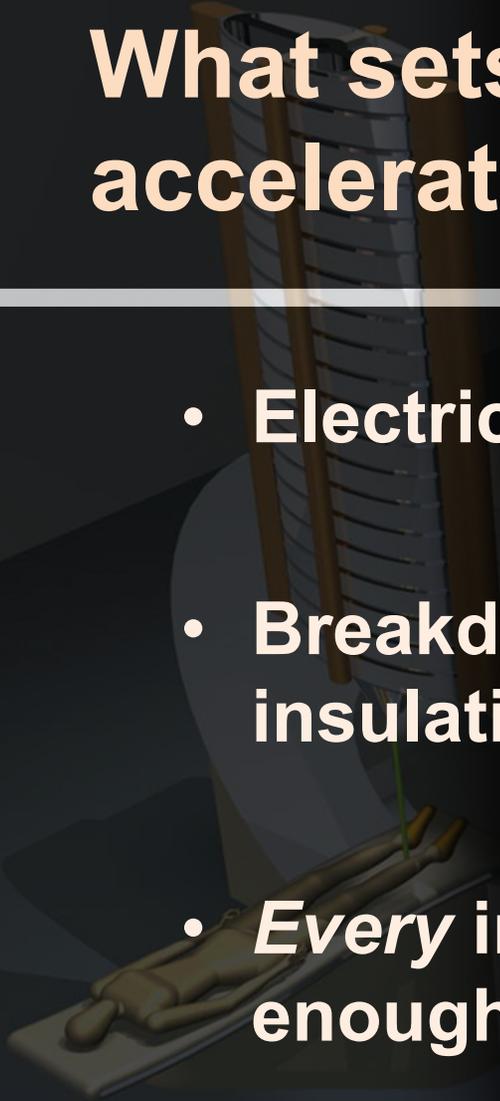
- These lines generate pulses 3 ns long

Stack of 7 Blumleins



# What sets the length of the accelerator?

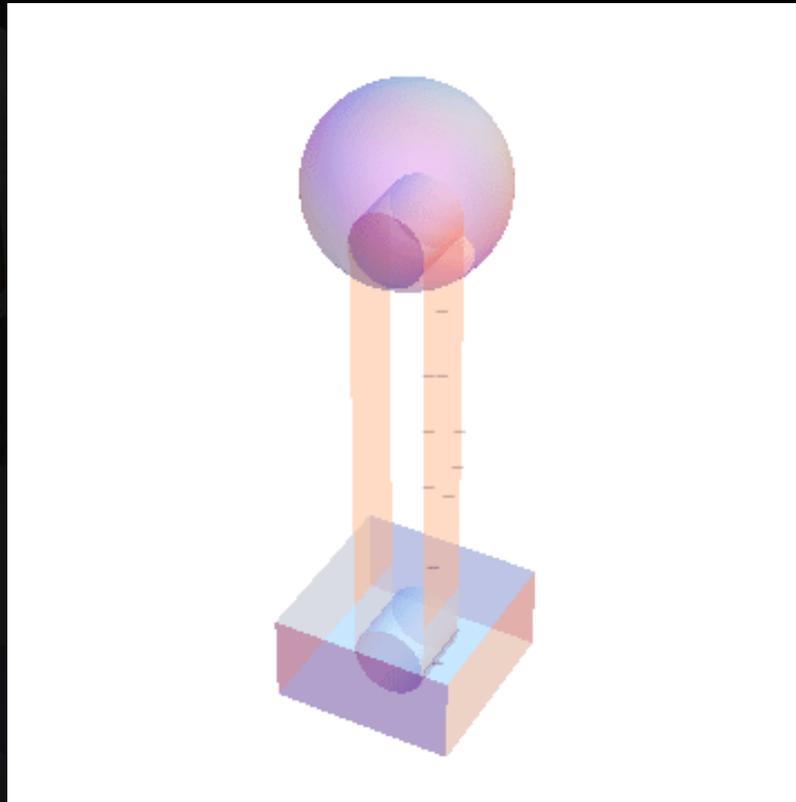
- **Electrical breakdown**
- **Breakdown is the failure of electrical insulation**
- ***Every* insulator will fail with a large enough electric field**



# Breakdown demonstration

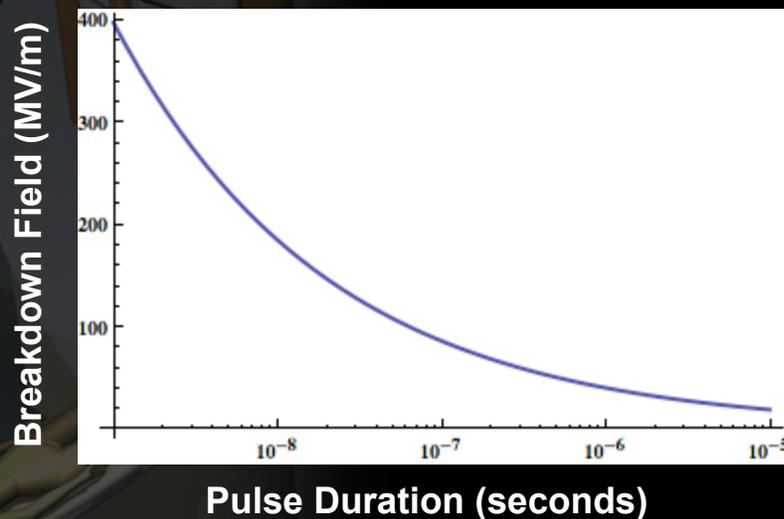


# Van de Graaff electrostatic generator



# Electrical breakdown can occur in gasses, liquids and solids

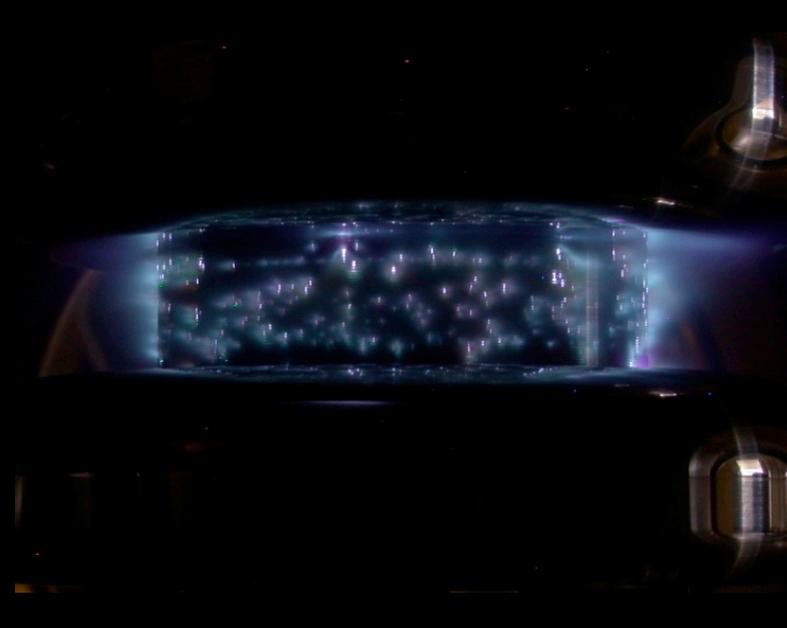
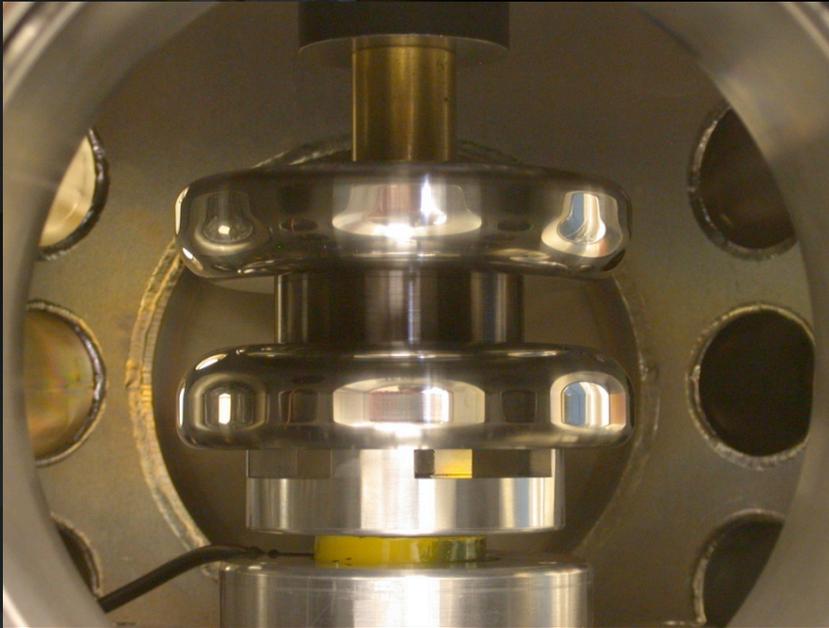
Breakdown strength of insulating oil as a function of pulse duration



In general, breakdown thresholds *increase* with *decreasing pulse durations*



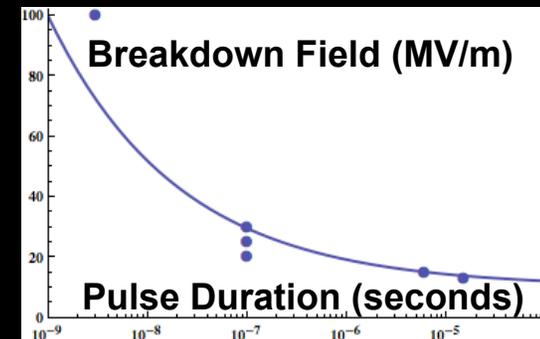
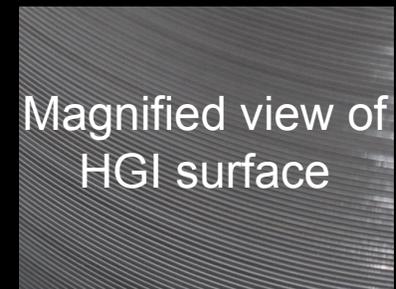
# Breakdowns also occur along boundaries between materials



**A particularly weak point is the interface between an insulator and vacuum, as along the inner wall of the accelerator**

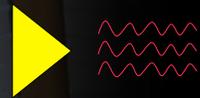
# We use three different techniques to inhibit breakdown

- Novel beam tube
  - High gradient insulator (HGI)
- Short pulses ( ~ 1 ns)
- Advanced materials



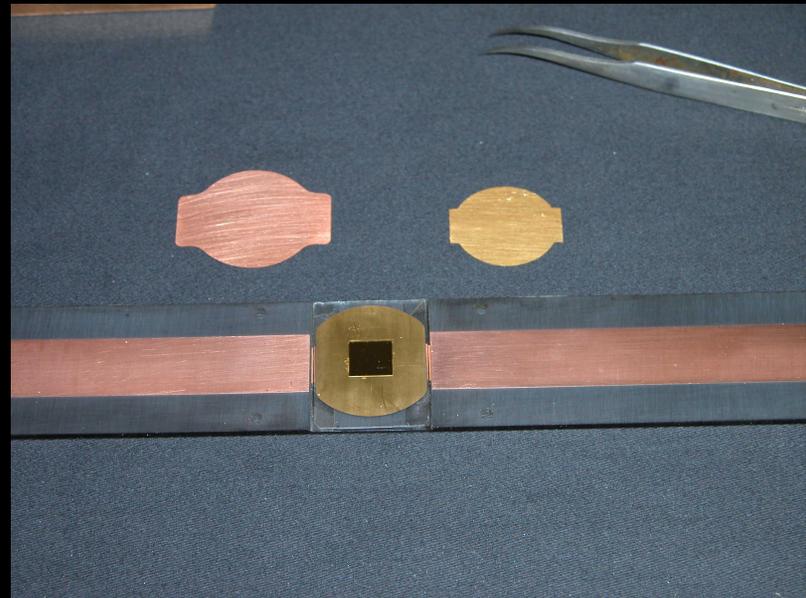
# Blumleins use new photoconductive switches for precise timing and high voltage operation

Laser pulse



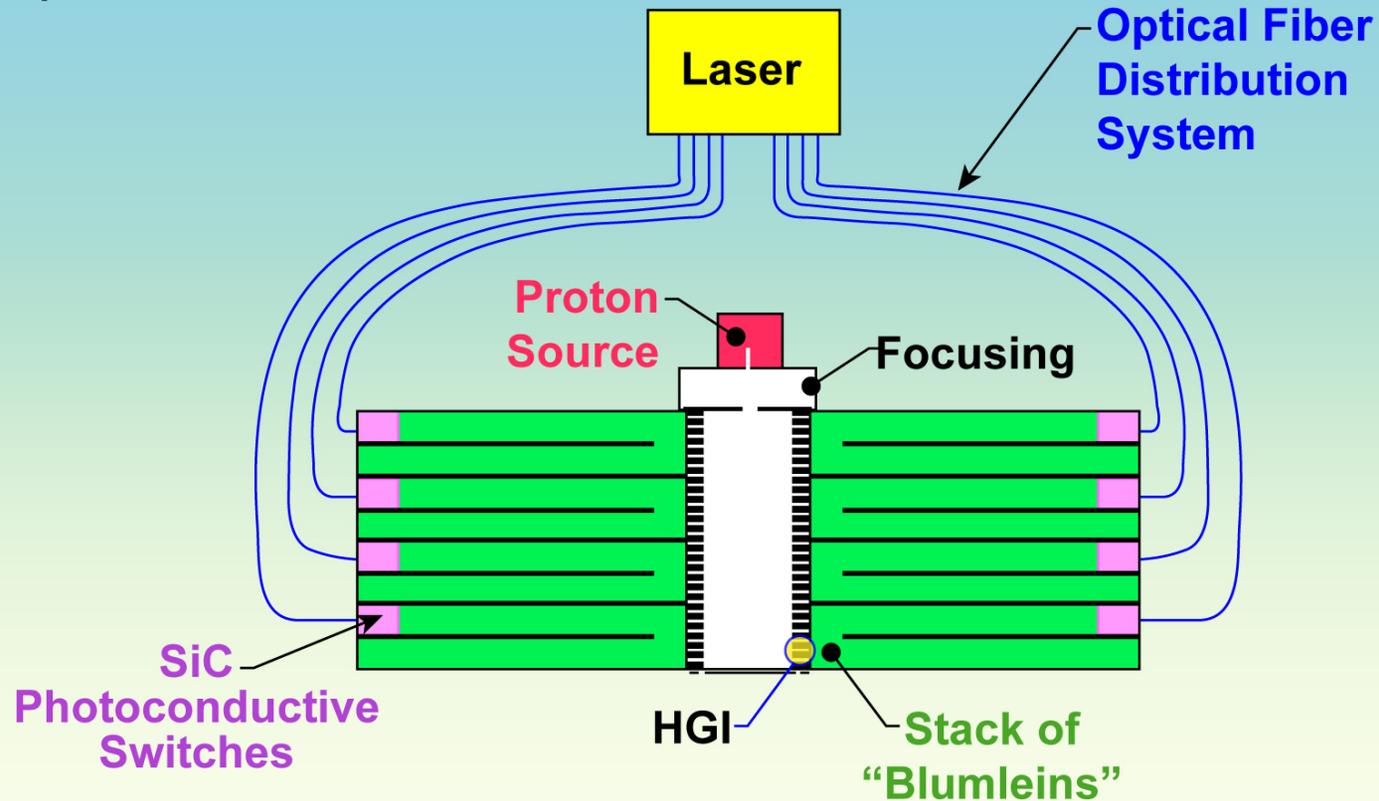
Electrical  
Contacts

SiC



# Stacks of Blumleins, with independent switch triggers, implement the virtual traveling wave accelerator\*

\*US patent 7,576,499 B2



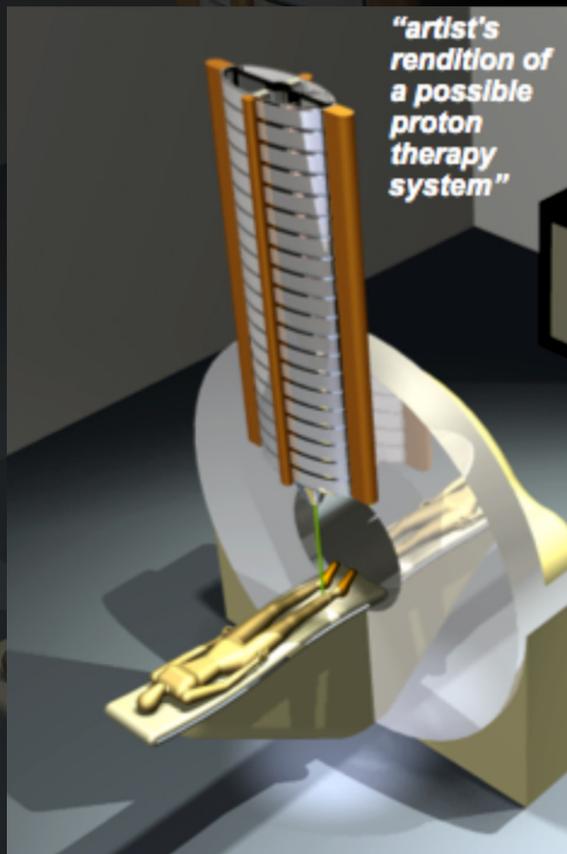
# We are working with Tomotherapy, Incorporated and CPAC to develop a compact proton DWA

*“Artist's rendition of a possible proton therapy system”*



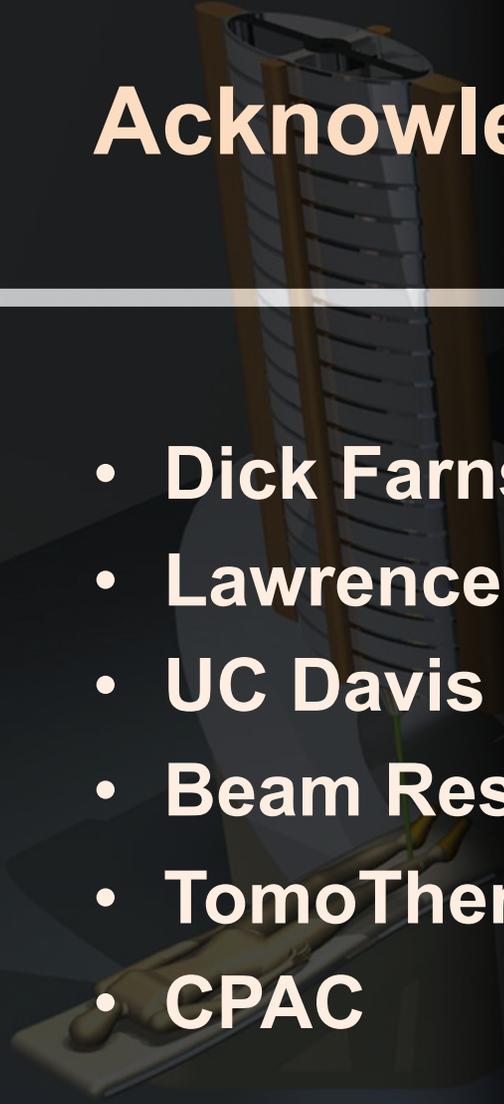
Tomotherapy has licensed the DWA technology from the Lawrence Livermore National Laboratory and the Compact Particle Acceleration Corporation (CPAC) has a Cooperative Research and Development Agreement (CRADA) with LLNL

# Summary



- **Proton therapy is a potentially superior form of radiation**
- **The Dielectric Wall Accelerator promises to dramatically reduce the size and cost of proton therapy machines, making them more widely available**
- **The ultimate objective is to provide proton machines that can fit in a local clinic**

# Acknowledgements



- **Dick Farnsworth and Marsha McInnis**
- **Lawrence Livermore National Laboratory**
- **UC Davis Cancer Center**
- **Beam Research Program at LLNL**
- **TomoTherapy, Inc.**
- **CPAC**



*Questions?*

# CPAC produces first beam

