Heavy ion accelerator research at CU School of Medicine

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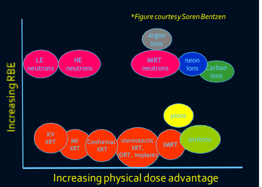
Radiation oncology at CU

- Part of NCI comprehensive cancer center located on Anschutz Medical Campus
- Medium size department
  - 12 rad oncs
  - 10 physicists
  - 6 dosimetrists
  - 40 therapists, nurses, support staff
- Treating 120 patients/day
- Wide variety of clinical services
  - External beam
  - HDR, LDR brachytherapy
  - SRS, SBRT, TBI, TSE
- Growing research programs

Motivation for particle therapy research at CU

- X-ray therapy approaching dose conformity limits set by physics of photon interactions
- Protons and heavy ions offer potential benefits compared to x-rays
  - Sharper dose gradients
  - Increased biological effect
- Uncertainties remain with particle therapy
- Facilities at CU and CSU well suited for particle therapy research
  - Strong basic science and radiation biology programs
  - Flint animal cancer center provides opportunity for translational research with large animal models

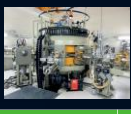


Why we should build our own particle accelerator

- Capital costs for proton and ion therapy systems still 1-2 orders of magnitude greater than x-ray systems
- Proton therapy experience shows clinical demand drives utilization
- Need a low cost accelerator capable of accelerating multiple ion species to energies suitable for cell and animal irradiation
- Limited options for purchasing an ion accelerator with desired specifications

Particle accelerators for heavy ion research

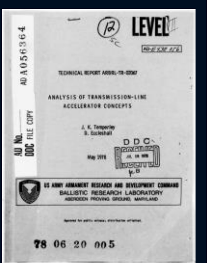
- Size and cost of heavy ion accelerators are barriers to ion therapy research
- Optimal design would be compact, low cost, and allows for acceleration of different particle species

Particle accelerator	Cost	Size	Multiple particles
RF Linac	$$	Small	Difficult
Cyclotron	$$$	Moderate	No
Synchrotron	$$$$	Large	Yes
Induction Linac	$$$$	Large	Yes

Transmission line accelerators

- Class of accelerators that uses transmission lines to propagate a traveling electric field excitation
- TLAs repeatedly apply modest line voltage to produce a high energy particle beam
- Gained US attention in 1970's after 5 MV/m linac built by Pavlovski et al. in USSR
- Linear geometry
- Low cost, high gradient alternative to traditional accelerator designs
- Technical limitations on materials and manufacturing have limited development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Transmission line basics

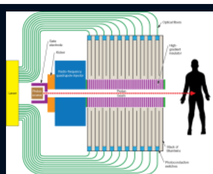
- Transmission lines transmit power over long distances with low loss
- Transmission lines are relevant when signal propagation time cannot be ignored
  - Usually account for TL effects when circuit size > λ/10
- Transmission lines support Transverse Electric Magnetic (TEM) waves
  - E and M fields are transverse to direction of signal propagation
  - Requires at least 2 conductors
  - No cutoff frequency
  - Hollow waveguides don't support TEM mode!
- Transmission line theory bridges gap between field theory and circuit analysis

Power distribution – 60 Hz, λ/10 = 500 km

Cell phone transmitter – 1.9 GHz, λ/10 = 16 mm

The Dielectric Wall Accelerator (DWA)

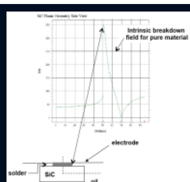
- Developed at LLNL for flash radiography
- Uses stacked transmission lines (Blumleins) fired in sequence to create a virtual travelling wave
- Produces high energy beam from many transmission lines that only support a fraction of the total voltage
- Uses optical switching
- Gradients on the order of 20 MV/m have been demonstrated
- Offers scalable, compact accelerator solution
- Suitable for accelerating any charged particle



Caporaso et al. 2007

Challenges with the LLNL design

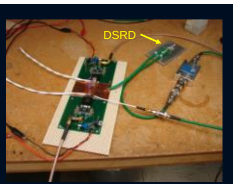
- High field stress placed on SiC closing switches for large fractions of the duty cycle which results in lower breakdown voltages
- Optical switches require expensive laser to fire
- Switching performance requirements are high
  - Nanosecond pulses require low jitter
  - Fiberoptics neccesary to control pulse timing
- Large number of switches are required for high gradient operation



Caporaso et al. 2007

Alternative approach is to use SLIM

- Stanford Linear Induction Method (SLIM) described by scientists at SLAC in 2008
- Based on pulse injection model
- Uses drift step recovery diodes (DSRDs) as opening switches to break current in series inductor
- Because DSRD used as opening switch, high field stress only present for time of pulse (typically nanoseconds)
- Thin transmission lines have low impedance (< 1 ohm)
- Difficult to drive such a small load with reasonable efficiency (all power used up in generator)



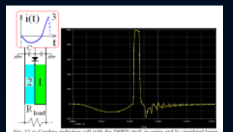
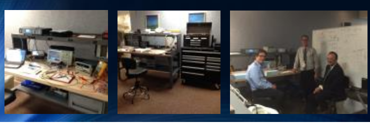
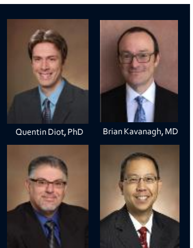


Fig. 12 a) Coreless induction cell with the DSRD stack in series and b) simulated beam loaded accelerating voltage

Getting started – our experience

- Would not be possible without the right group of people!
- Project grew out of discussions about whether you really had to spend > 50 million USD to do radiobiology research with heavy particles
- With a focus on low cost solutions, we began looking at modular designs that could scale
- Investment by department allowed us to set up electronics lab in empty vault and start learning by doing
- Also purchased CST Microwave Studio for design simulations

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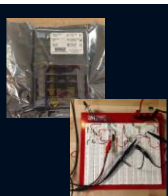
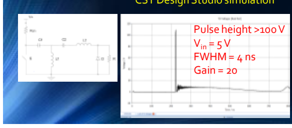
First attempts – diode pulser design

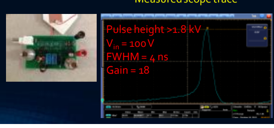
- After lots of study, focused on SLIM concept
- Limited success with DSRDs purchased from VMI - $250/diode
- Pulsed power group at USC describes alternative pulser architectures
- Successfully implemented USC pulser design
- Measured output impedance large compared to transmission lines



CST Design Studio simulation

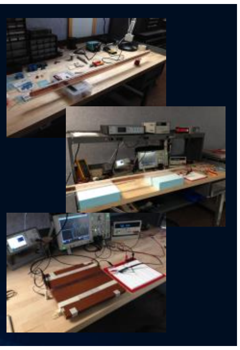


Measured scope trace



Initial Blumlein implementations

- Re-visit Blumlein architectures used in LLNL DWA
- Initial builds used:
  - Copper tape (0.05 mm)
  - Solid water (1 cm thick, 30 cm long)
  - PMMA (5 mm thick, 1.3 m long)
- Low voltage MOSFETS used for switching
- Pulse shapes consistent with expected results, though sub-optimal switching circuit was used



Interesting observation

- Caporaso has described asymmetric Blumlein accelerator
- Asymmetry comes from different dielectrics in lines, resulting in different wave speeds
- Fast wave turns pulse on, slow wave turns pulse off
- We noticed that fields also present on sides of the transmission lines
- Hypothesize that field can be reused by helically wrapping the lines on top of each other

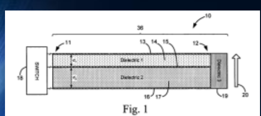
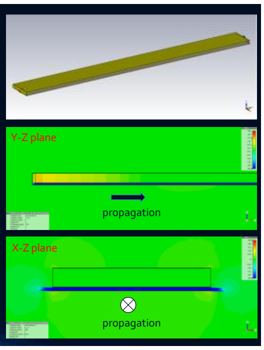
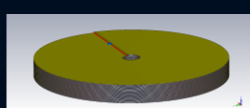


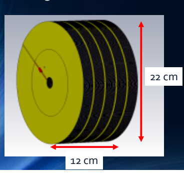
Fig. 1

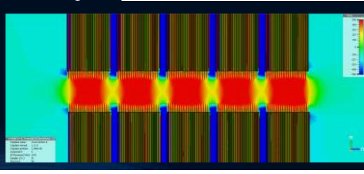


A helical transmission line DWA

- Helical structure with 20 turns/module, pitch = 1 mm
- Fields from fast line superimpose inside bore
- Slow line acts as dielectric screen
- Lines terminated in matched load
- Peak gradient 6 MV/m for 10 kV line voltage







Take home

- Experimental research alive and well in academic medical physics centers
- Someone has to believe in you
- Having a good team helps
- Be realistic and aim for projects that are scalable
- Leverage resources inside and outside department
- Department support is required
- Learning curve can be steep
- Passion is as important as research topic