Accelerator Design for Novel Cancer Therapy Efforts

Phia Morton[1,2], Emma Snively[1], Vivek Maradia[2,3], Claire Cho[4]

[1] SLAC National Accelerator Laboratory
[2] Stanford University
[3] Stanford University School of Medicine
[4] Cornell University

Accelerator Stewardship Program

Project collaborators: SLAC: Valery Borzenets, Manuel Cardoso, Matt Boyce, Emilio Nanni, Zenghai Li, Gordon Bowden, Valery Dolgashev, Xueying Lu, Julian Merrick, Ann Sy, Dennis Palmer, Greg Le Sage, Anatoly Krasnykh, Doug McCormick, Kaitlin Deering, Shirin Kuppusamy, George Wehner, Mira Bhatt, Chao Liu, **Arizona State University:** Sami Tantawi, **Stanford University:** Billy W. Loo Jr., **Loma Linda University:** Reinhard Schulte **UCSF:** Bruce Faddegon, Jose Mendez **Mevion Medical Systems:** Yan Zhang, Alexey Blazhevich, Townsend Zwart

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Outline

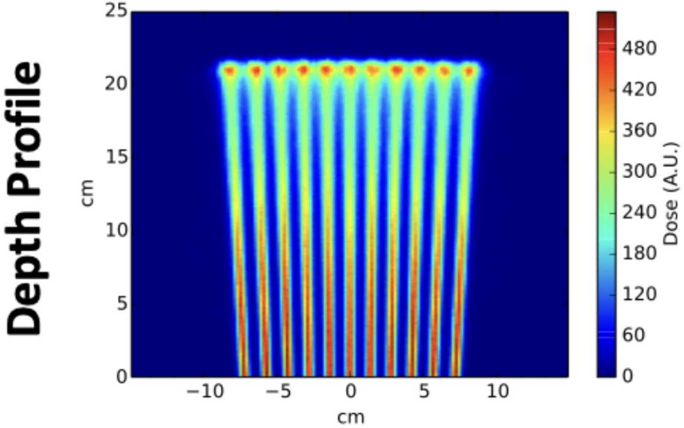
- What is proton therapy?
  - FLASH therapy
- Proton beam energy modulation with RF cavities
- Other medical accelerator projects at SLAC

Benefits of Protons

Excellent depth control, more localized doses

No exit dose

Pencil Scanning Technique



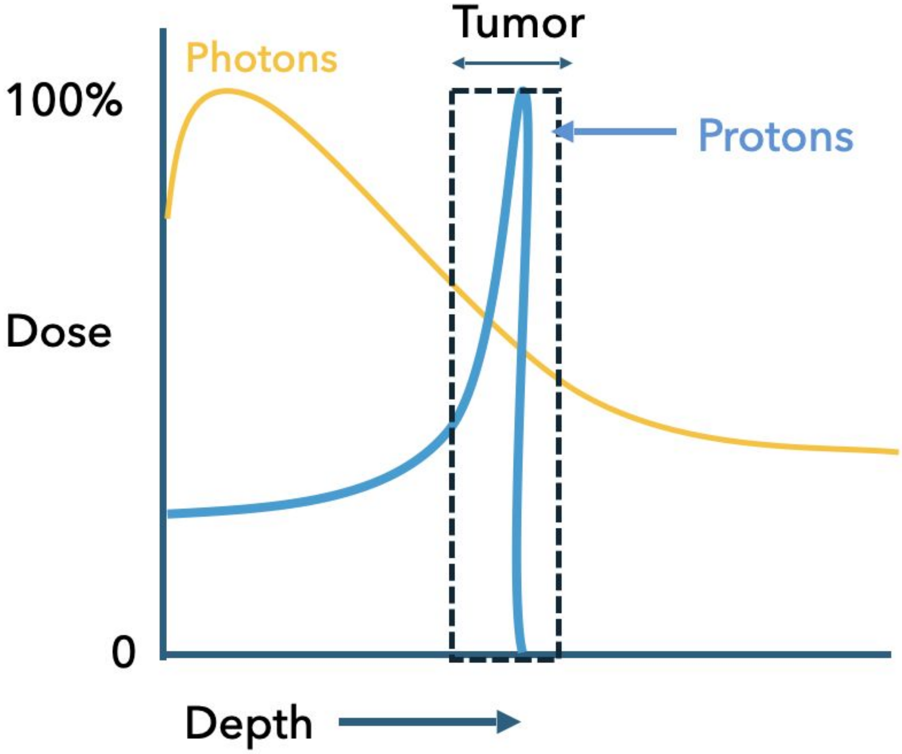


Image Credit: Claire Cho

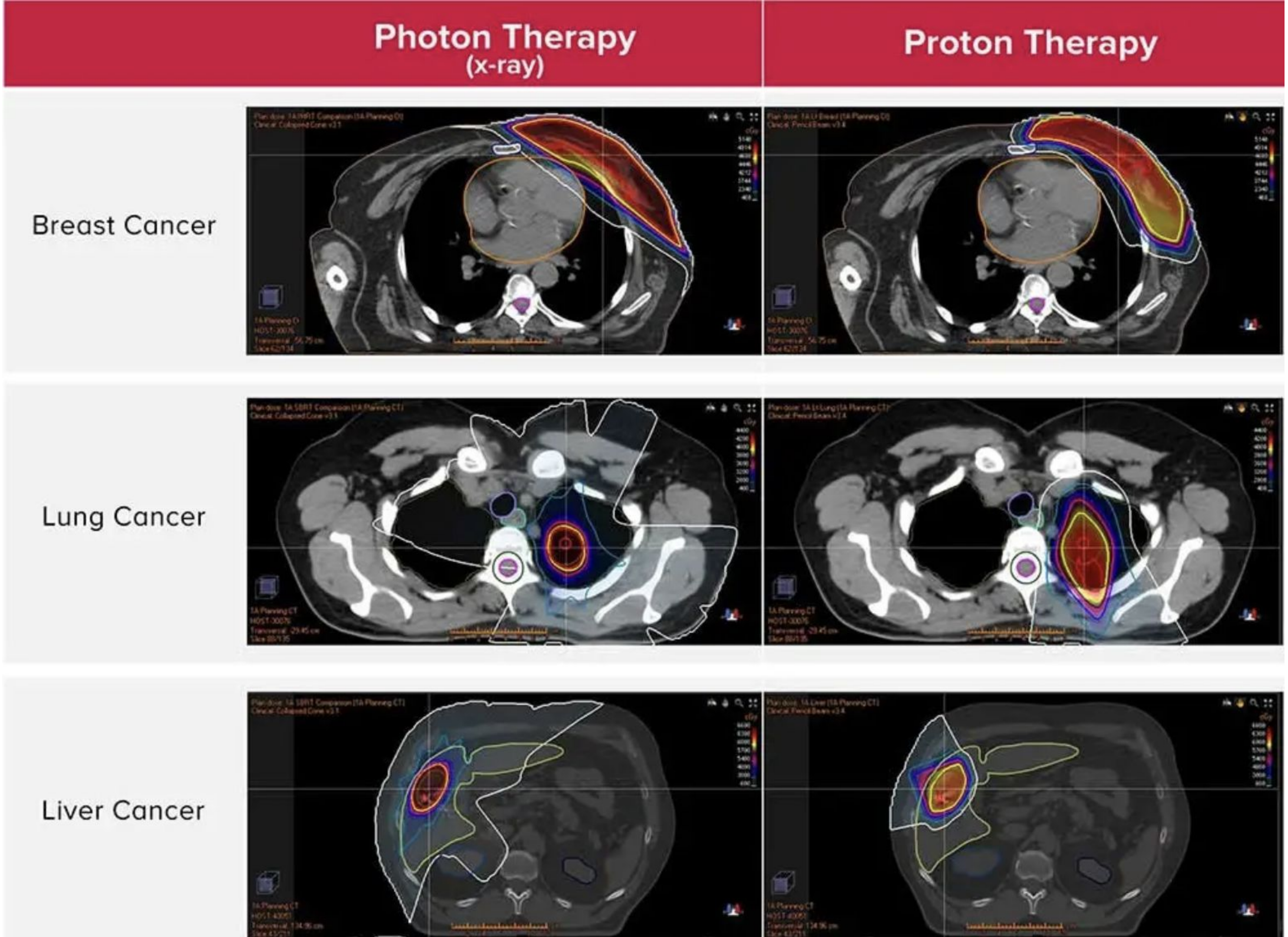


Image credit: Mevion Medical Systems

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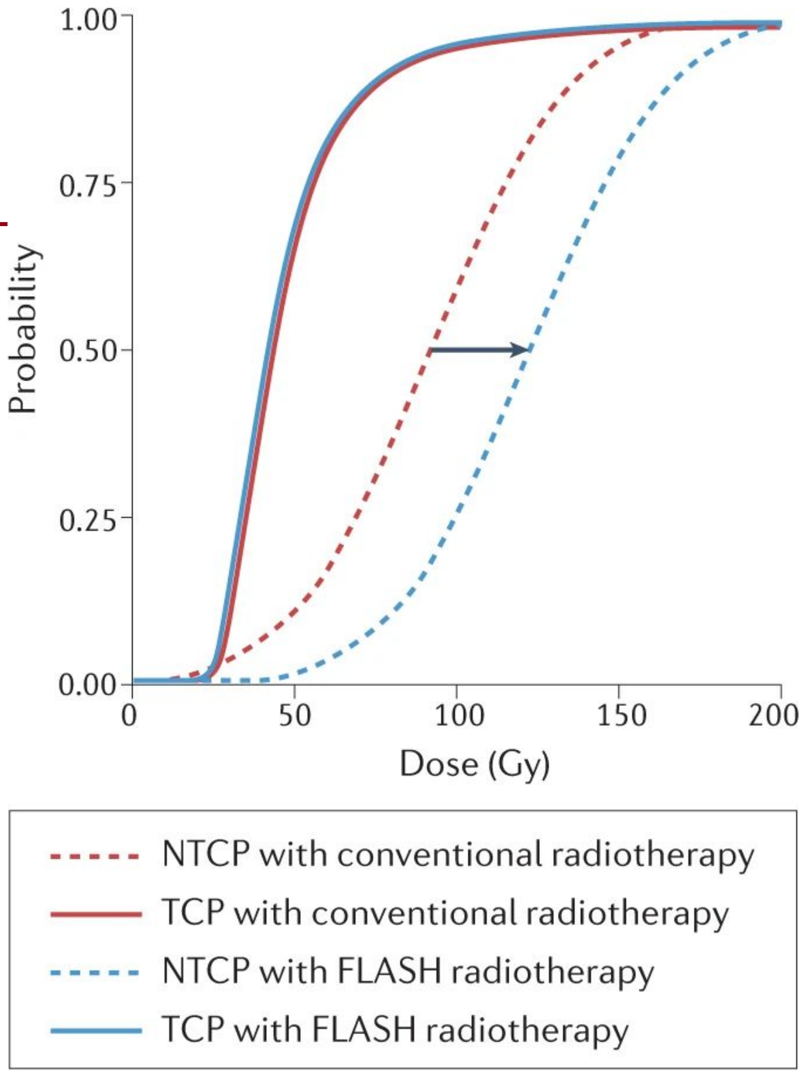
The Future: FLASH Therapy

Ultra-high dose rates ~40 Gy/s

Good tumor control probability (TCP)

Lower normal tissue complication probability (NTCP)



Vozenin, MC., Bourhis, J. & Durante, M. Towards clinical translation of FLASH radiotherapy. *Nat Rev Clin Oncol* 19, 791–803 (2022). https://doi.org/10.1038/s41571-022-00697-z

Challenges to Practical Implementation

- Mechanical energy degradation is **slow**
  - ~20-50 energy changes needed
  - Each ~0.5 seconds
- Worsens beam quality (multiple scattering)

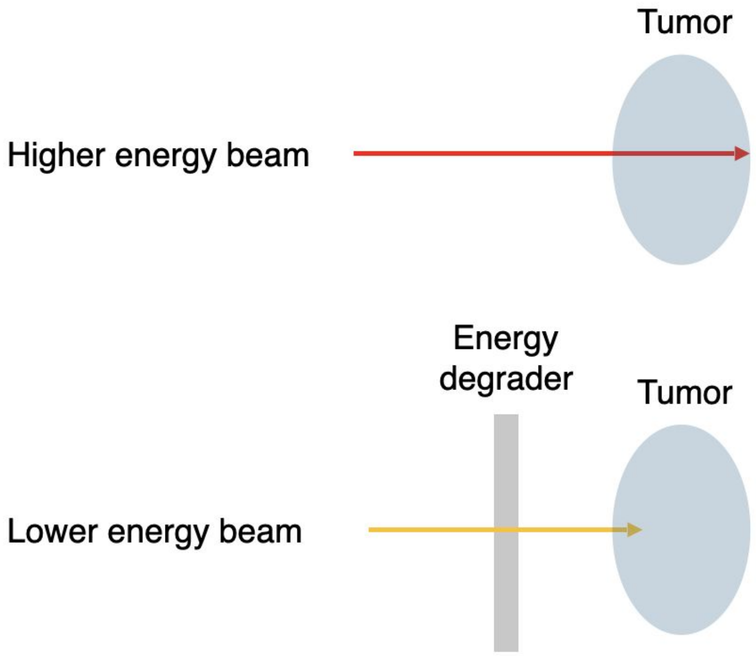


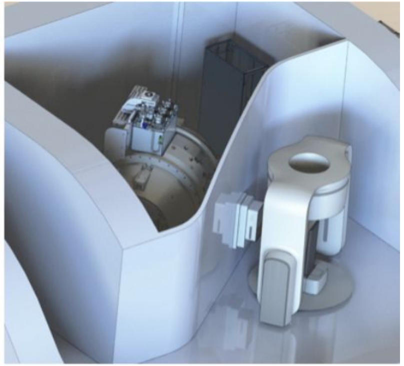
Image Credit: Claire Cho

Goals

- Simulate and test a novel approach for proton therapy energy modulation: using **radiofrequency (RF) cavities to change beam energy**.
- Design component technology to cover 4 L volume with >20 Gy/L/s
  - Energy modulator providing +/- 30 MeV
  - Deflector providing +/- 100 mrad
  - **System length ≤ 2 m**

Patient positioning system

Mevion S-250 Fit single room treatment system



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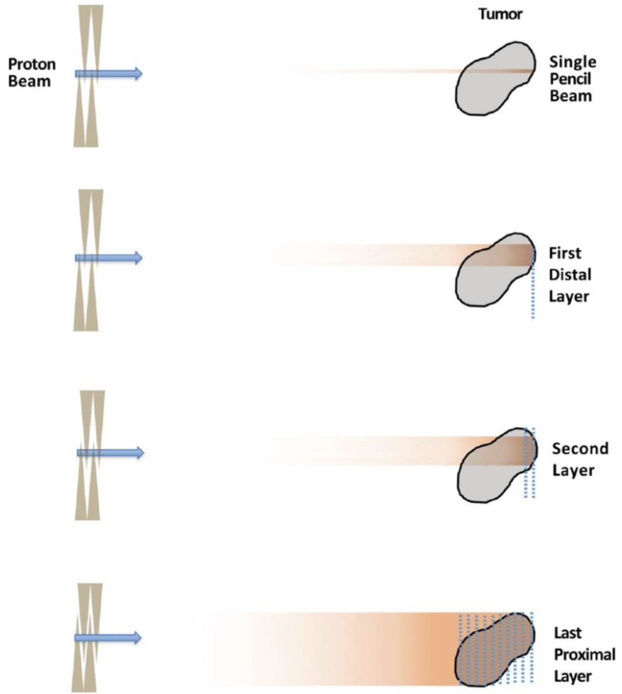
Energy Modulation with RF Cavities



INSTEAD

Variable electric field to accelerate/decelerate the beam

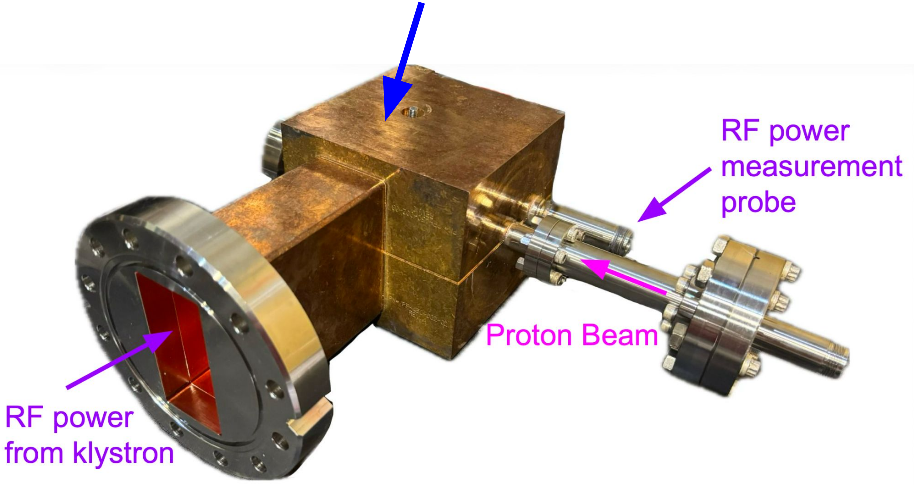
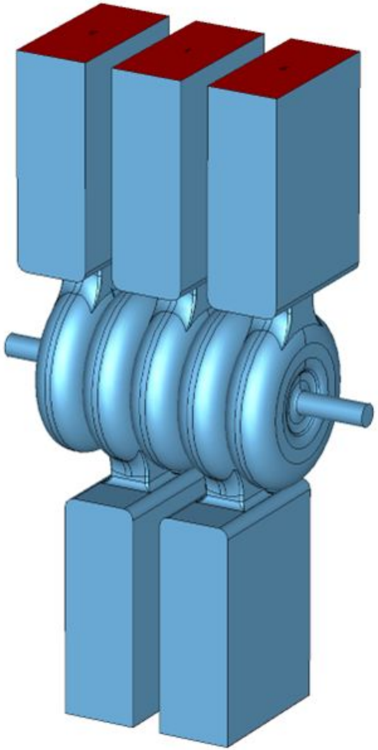
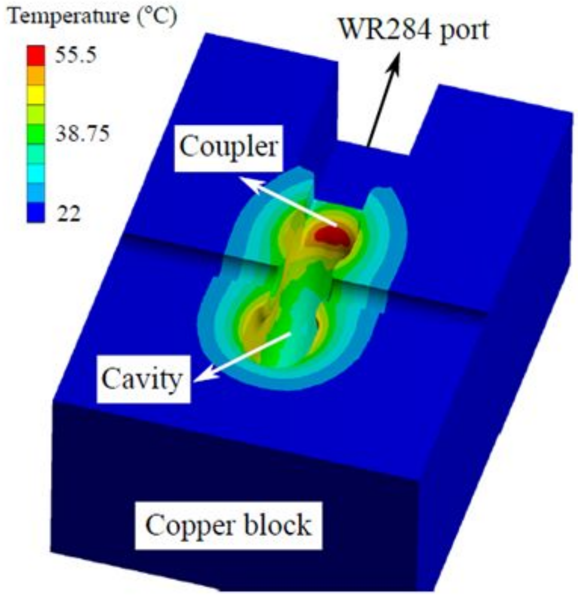


Image Credit: Claire Cho

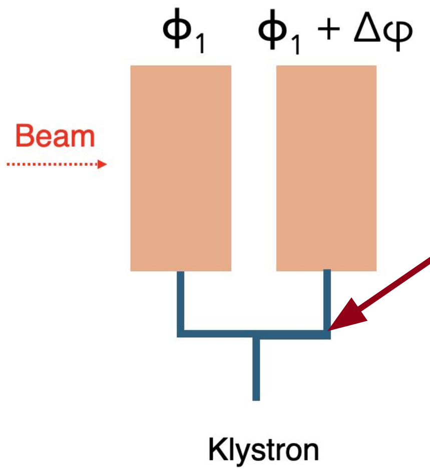
RF Cavity Design

Parameter	Value
Frequency	2.856 GHz
Beam aperture (diameter)	1.05 cm
Phase advance per cell	160°
Quality factor Q_0	11936
External quality factor Q_{ext}	11911
Shunt impedance r_s	54.8 MΩ/m
r_s/Q	4.6 kΩ/m
Average gradient E_a	$15\ \mathrm{MV/m} \cdot \sqrt{P/(100\ \mathrm{kW})}$
E_{peak}/E_a	2.26
$H_{\mathrm{peark}} Z_0/E_a$	1.25
Pulsed heating temp.	$0.53°\mathrm{C} \cdot [P/(100\ \mathrm{kW}]\sqrt{t_p(\mu s)}$





2 Cavities + Phase Shifter



Alters path length between cavities

Image Credit: Claire Cho

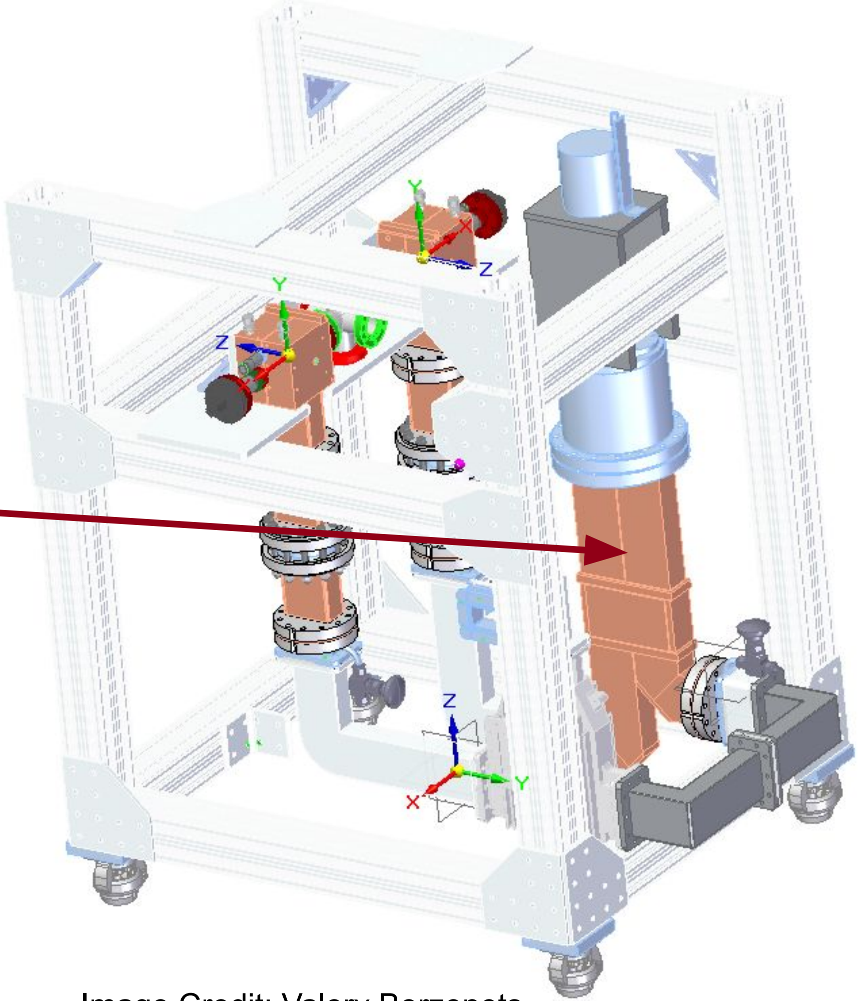


Image Credit: Valery Borzenets

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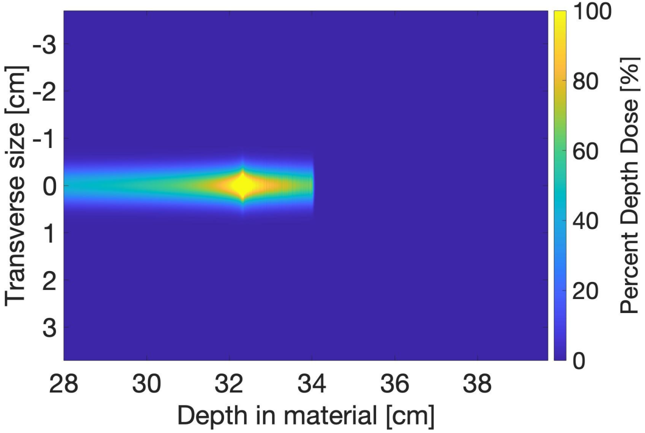
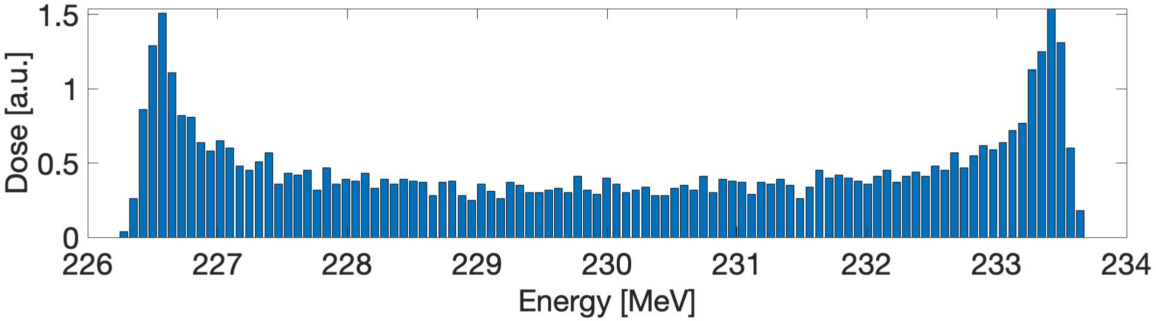
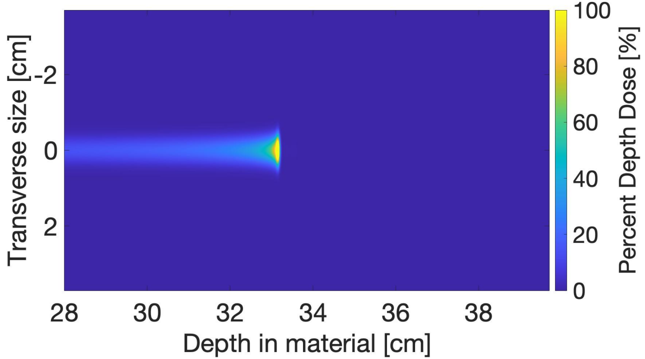
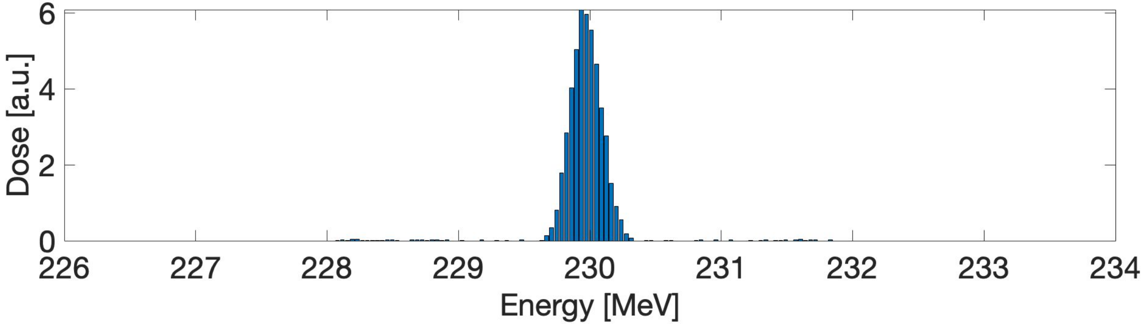
Adjustable Phase







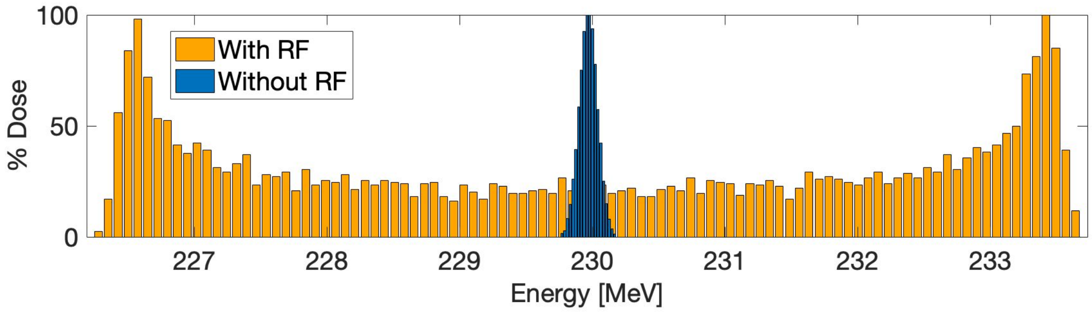


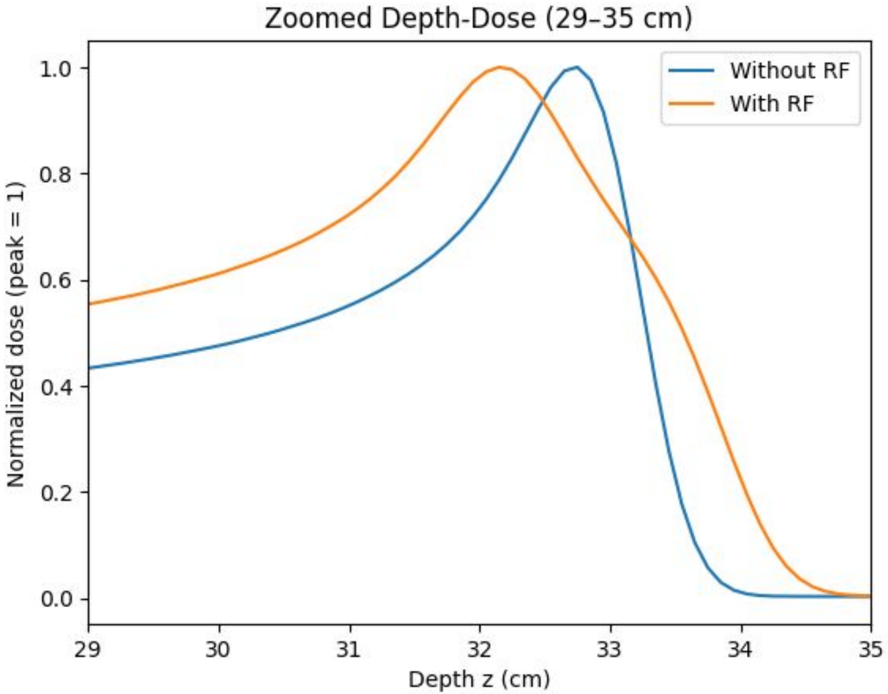
Simulation: 2 Cavities

Beam simulations performed using General Particle Tracer (GPT)

Translated to dose in TOPAS (Vivek Miranda, Stanford Med)

Increased energy spread = spread out Bragg Peak, cover larger tumor volume in a single shot





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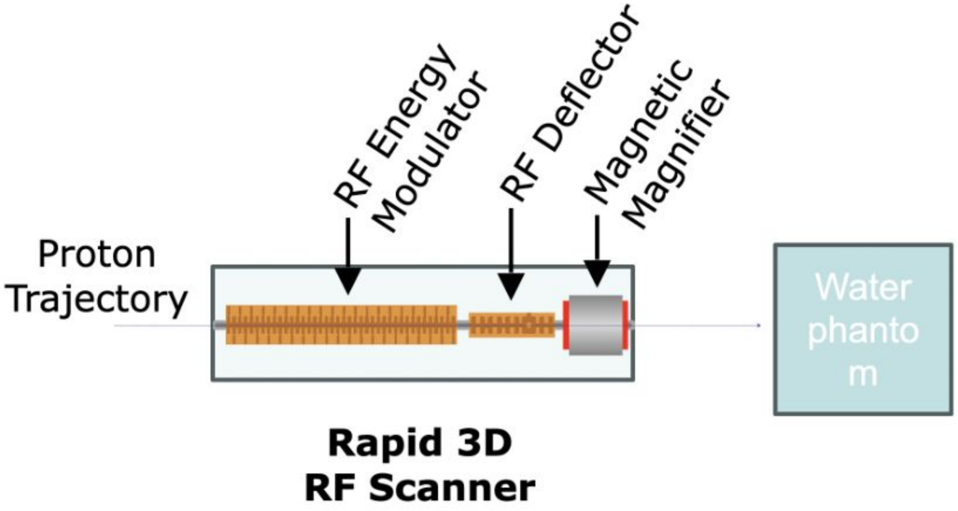
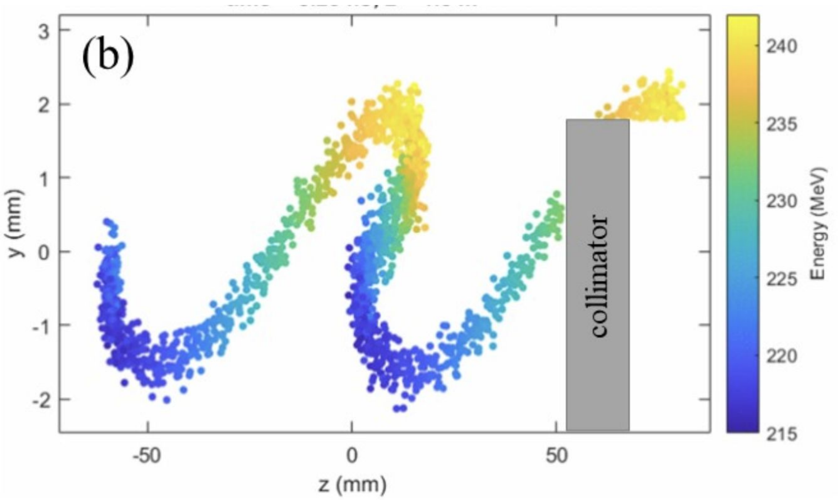
Energy Selection with a Chopper



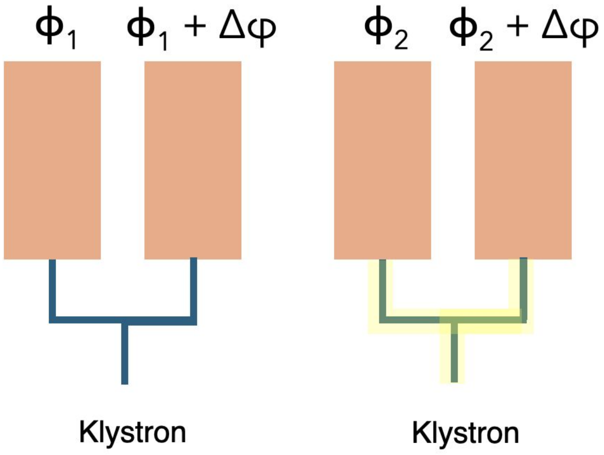


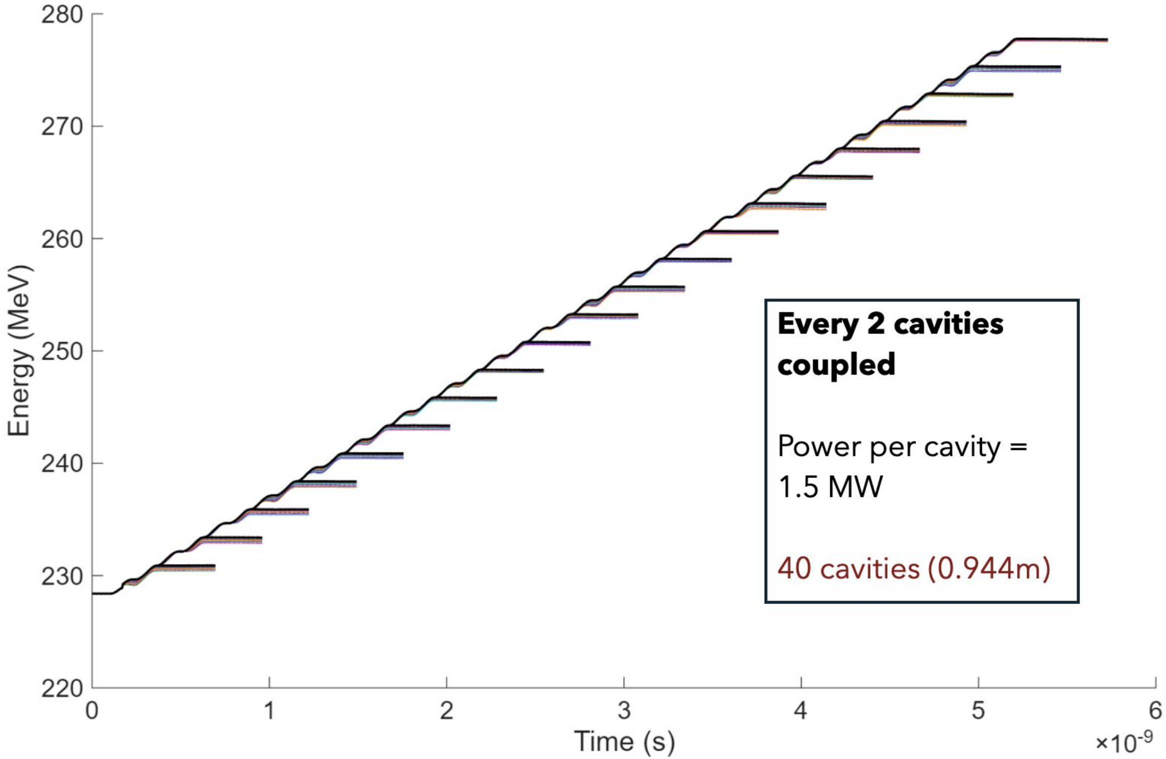
+more potential beam shaping and energy change with additional cavities or rapid RF amplitude control

Images: E. Snively

Simulation: Multicavity Phase Optimization

Energy modulation up to ~50 MeV in < 1 m





Work by SULI Intern Claire Cho

Experimental Setup

2 cavities

Phase shifter

Hybrid T splitter

Temperature control with a chiller

Faraday cups and power meter diagnostics

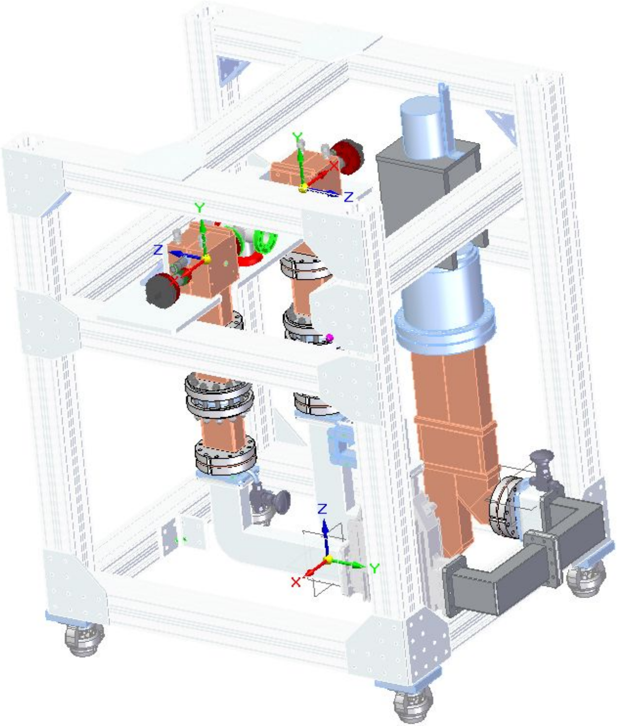


Image Credit: Valery Borzenets

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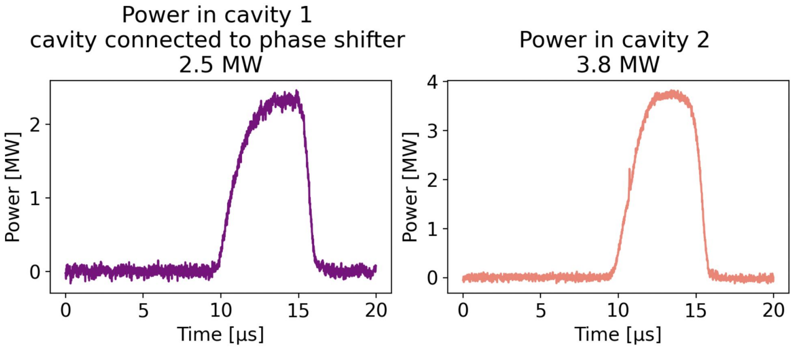
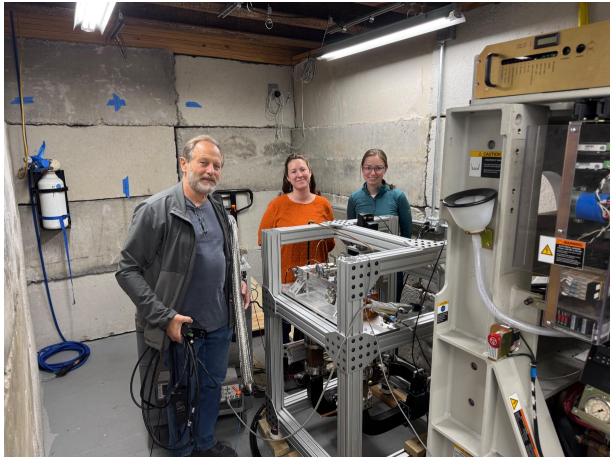
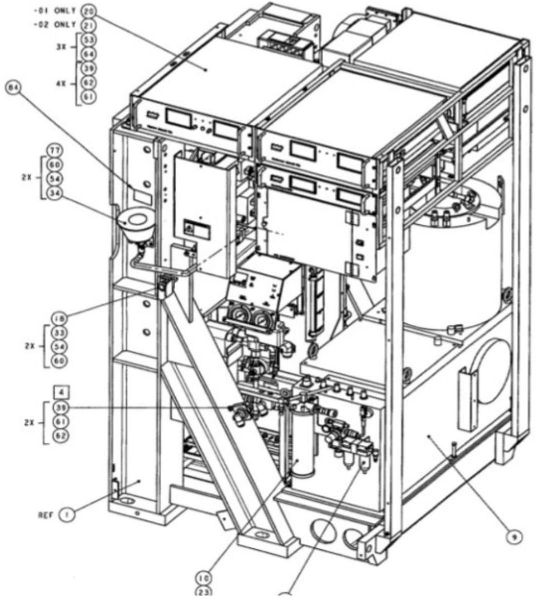
Klystron Testing at ROS







VKS-8252 Klystron	
Frequency	2.856 GHz
Fixed PRF	180/360 Hz
Pulse width	4.5 μs
Peak power	5-6 MW
Average power	5.5 kW

Design Review for the 3D High Speed RF Beam Scanner for Hadron Therapy of Cancer, E. Snively et al, 2024

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Testing at Mevion

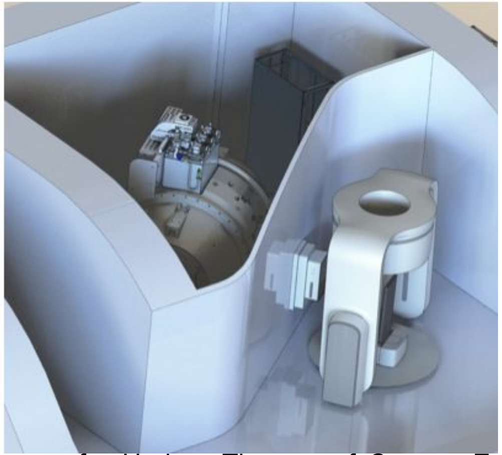
Test the 2 cavity setup with the Mevion test vault proton beam

Measure energy modulation and verify simulations with an ion chamber

RF source now installed in Mevion test vault

Patient positioning system

Mevion S-250 Fit single room treatment system



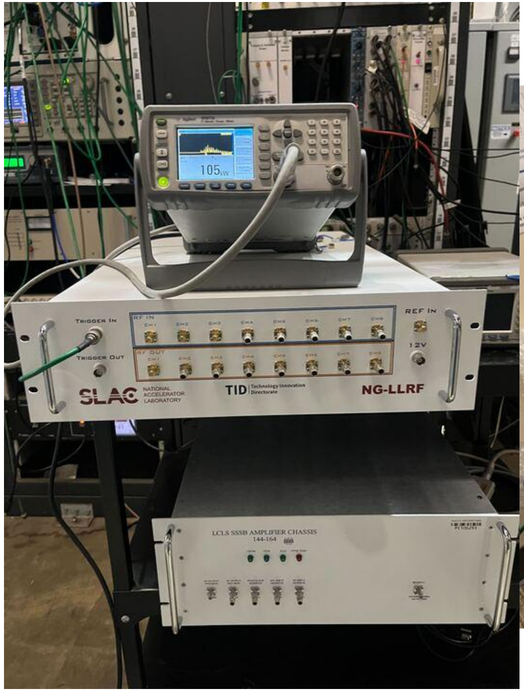
Design Review for the 3D High Speed RF Beam Scanner for Hadron Therapy of Cancer, E. Snively et al, 2024

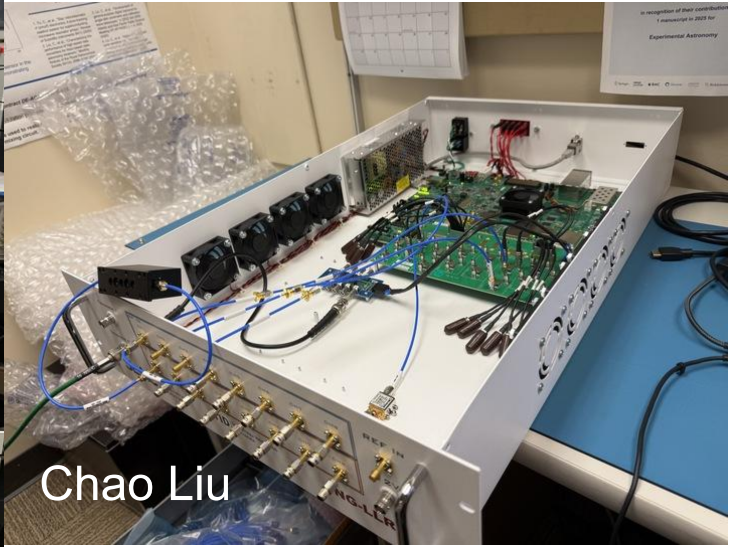
Synchronizing RF accelerator with synchrocyclotron

Problem Solving a Messy Trigger -

Intermediate processing of the external trigger from the ionization source signal with RFSoC

Data acquisition too!





Project to develop Low Level RF control with the RF System on a Chip (RFSoC) board

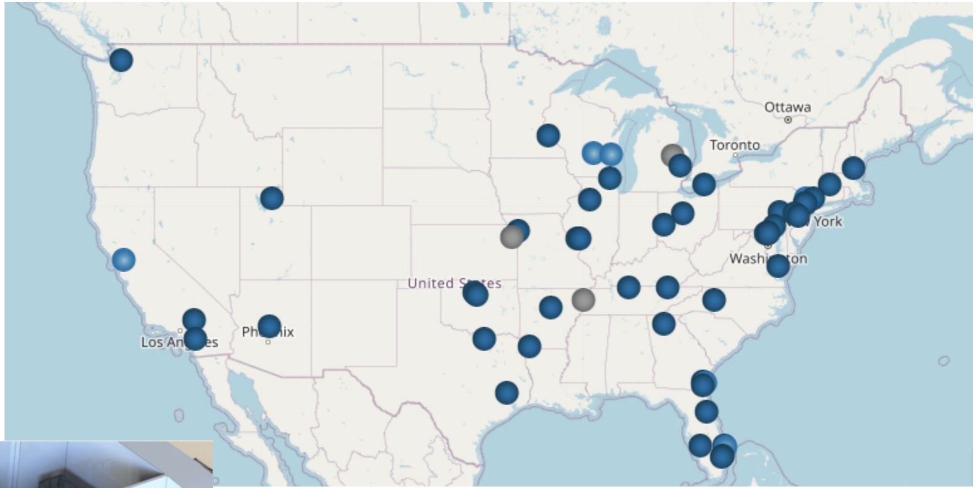
Importance of Compact Accelerator Design

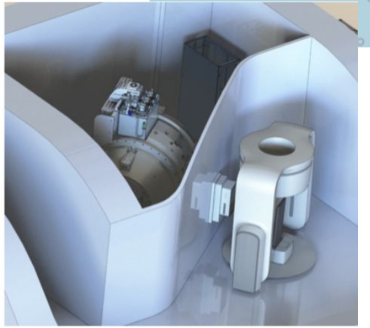
Important for practical implementation in hospitals

RF scanner is small enough to fit on a rotating gantry or at the end of a fixed beamline

Require large vaults

Smaller design = more access





Proton therapy centers in the US
https://proton-therapy.org/findacenter/

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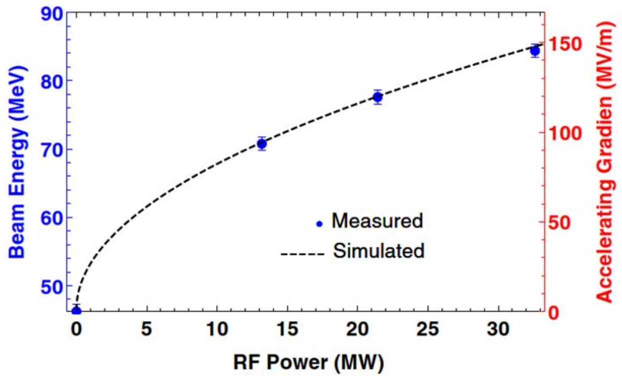
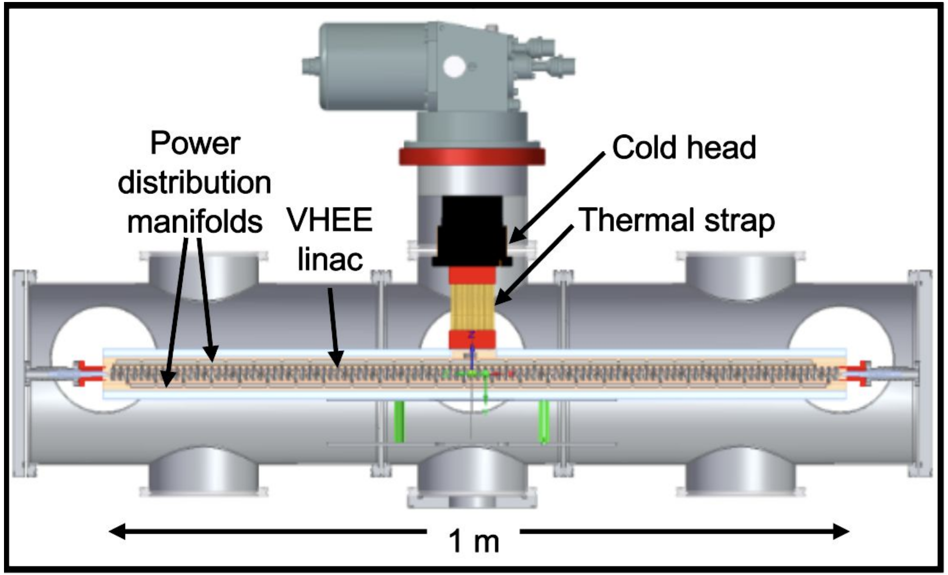
Cold Copper for Medical Accelerators at SLAC

- Compact accelerator R&D for high gradient linacs is key for very high energy electron (VHEE) therapy
  - Cold copper technology

See Sami Tantawi's talk on Tuesday

Accelerator Stewardship Program





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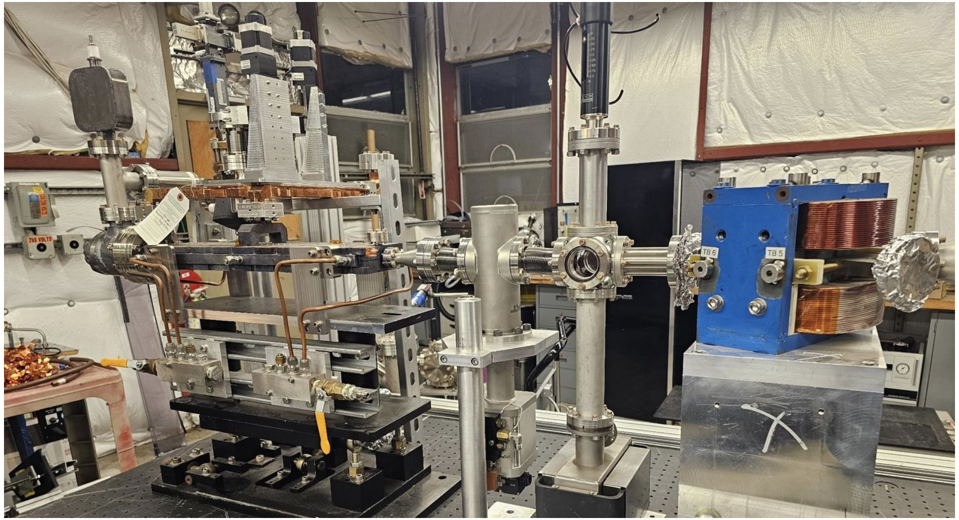
PRAB 24, 093201 (2021)

Emma Snively, 'Cold Copper for VHEE' (2025)

Broader Compact Accelerator R&D with Medical Applications



Compact X-band linac projects benchmarking portable accelerator infrastructure

Cavity with high temperature superconductor for RF pulse compression

A. Dhar

Conclusions

Compact RF accelerator technology

↓

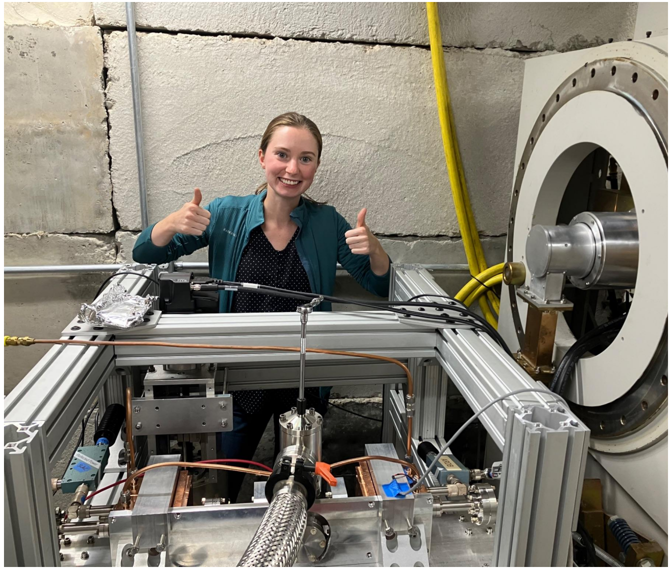
Rapid proton beam energy modulation

↓

FLASH therapy

+

Increased access to proton therapy



Reach out with questions to
phia@stanford.edu

Backup Slides

Troubleshooting

Temperature detuning

Reflected power through T splitter