Electron Beam Characterization: Optimizing Dose per Pulse for Use in FLASH and Pencil Beam Scanning

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Outline

1. Important Concepts:
   a. FLASH RT
   b. Pencil Beam Scanning
2. Methods
   a. Modified Linac
   b. Measuring Depth Dose
   c. Optimizing the Electron Beam
   d. Pencil Beam Scanning
   e. Simulations
3. Future Plans

Background

Radiation Oncology

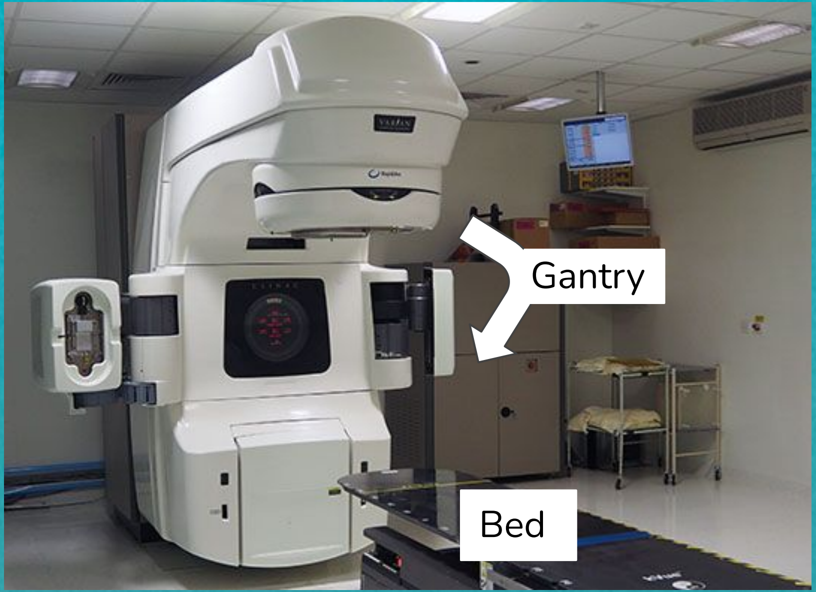
- Radiation is a common treatment for cancerous tumors
  - External Irradiation:
    - Proton therapy, X-Rays, Electrons
  - Brachytherapy
- Dose - the measure of ionizing radiation per unit mass
  - 1 Gy = 1 J/kg
  - Coined at the CRR!
- Conventional dose radiotherapy
  - 2-3 Gy/min
  - Typical treatment plan:
    - A few minutes/day, 5 days/week, up to 20 weeks
  - Short term and long term side effects

FLASH Therapy

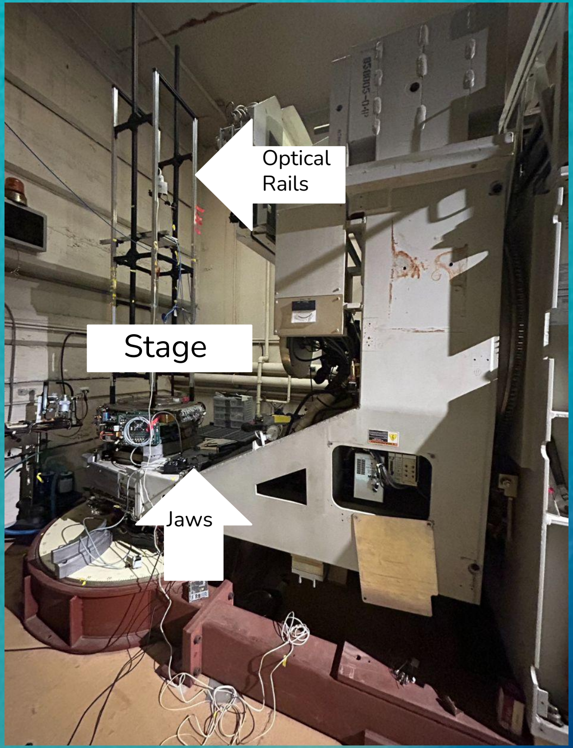
- FLASH- Ultra-High Dose Radiation
  - >40 Gy/s
  - Shows equivalent tumor killing effects while sparing the surrounding normal tissue
    - Biology is unknown
  - Instantaneous

Modified Varian Clinac 2100C

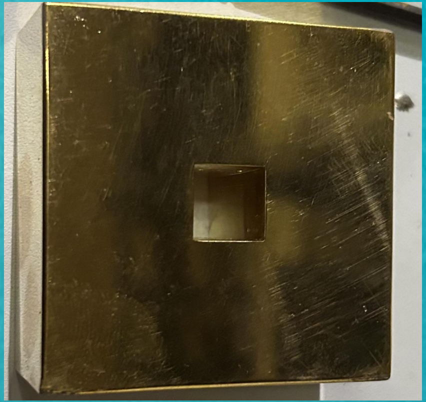
Modifications allow for operation in FLASH and superFLASH mode (9 MeV and 6 MeV)



(Radiology Oncology Systems)

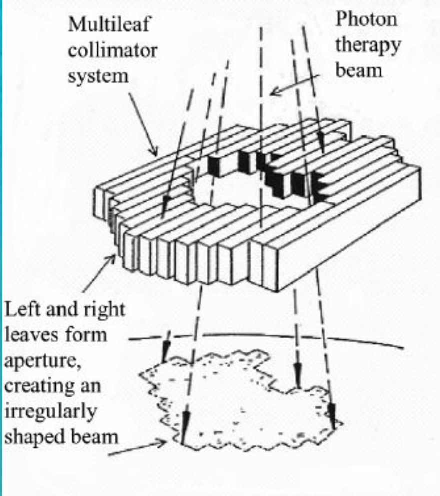


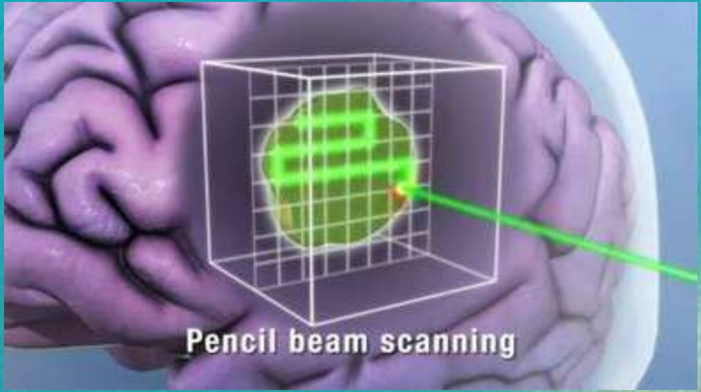
Beam Shaping



- Collimator
- Multileaf Collimators
- Pencil Beam Scanning
  - Very narrow particle beam scans over tumor
  - Established use in proton beam therapy

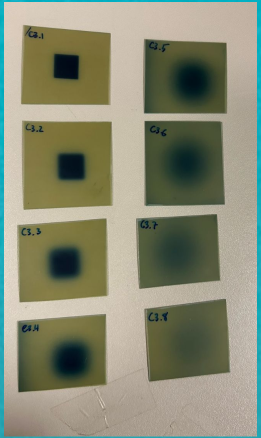
In case the videos didn't work:

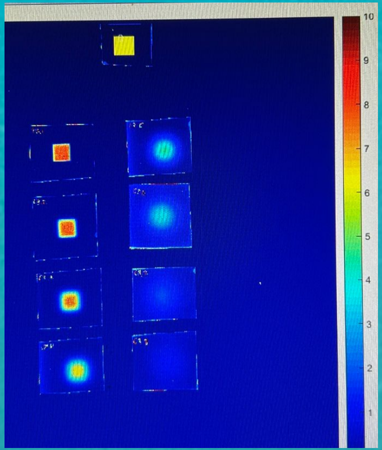




Methods

GAFChromic EBT3 Films Measure Dose





Irradiated films change in opacity. When scanned and processed by film reading software, Optical density is converted into dose measurements by the following:

Optical Density = $-\log_{10}$(Pixel Value Irradiated/Pixel Value Control)

Dose = (0.7404*Optical Density)/(0.818-Optical Density)

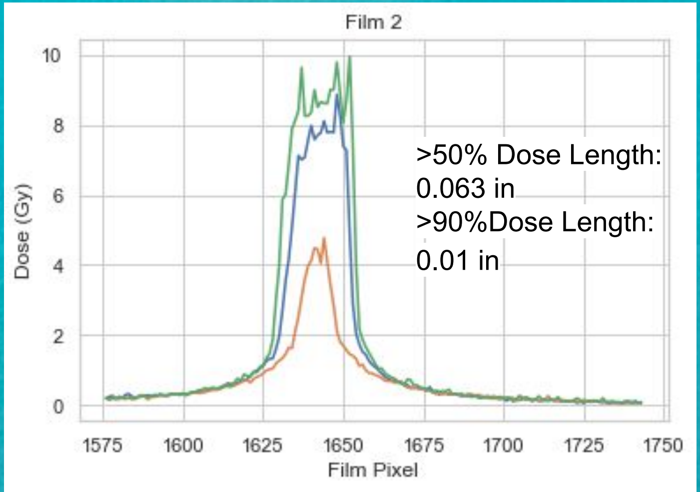
GAFChromic EBT3 Films Measure Dose

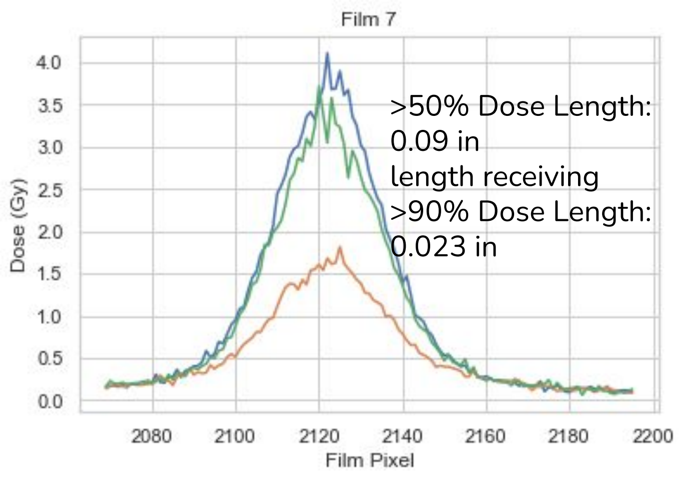
Camera film can help to provide insight into how film dosimetry works.

Light is a form of radiation!

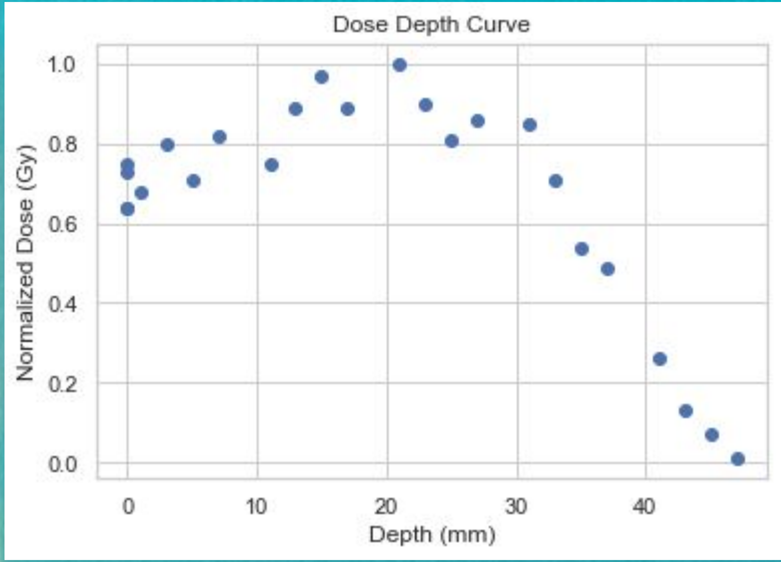
Reading Films

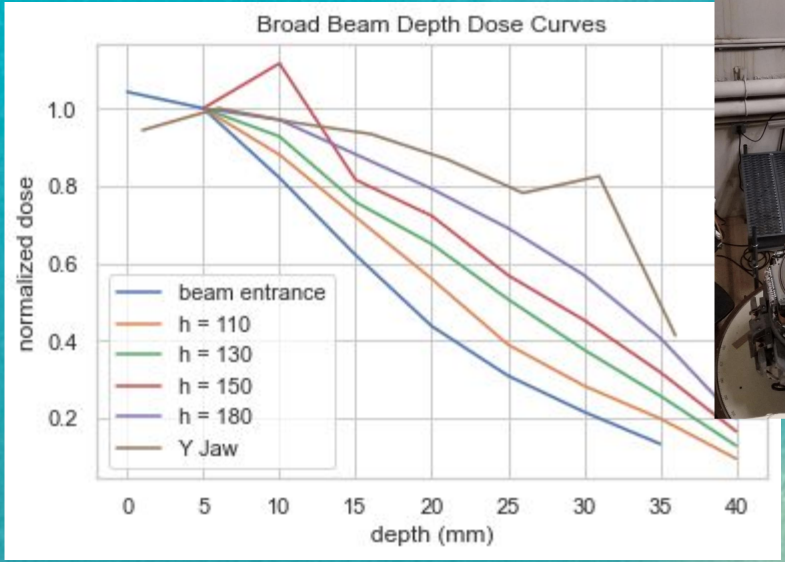
- Interested in the Distribution of Dose in PBS
  - Analyze film in cross-sections by going line by line in .dat file
  - Determine area where dose received > 90%*Max Dose
  - Surrounding dose vs Max dose

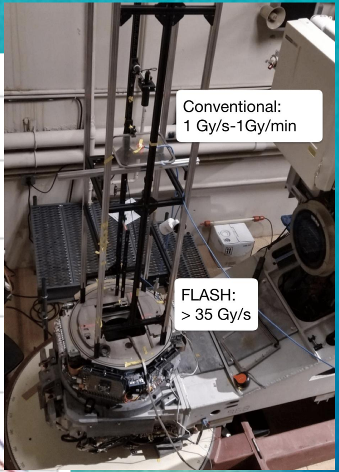




Experimental Depth Dose

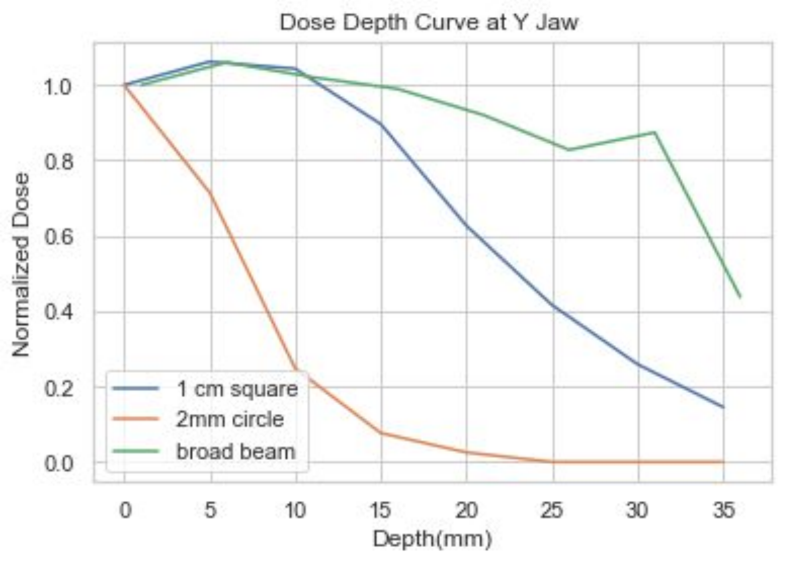


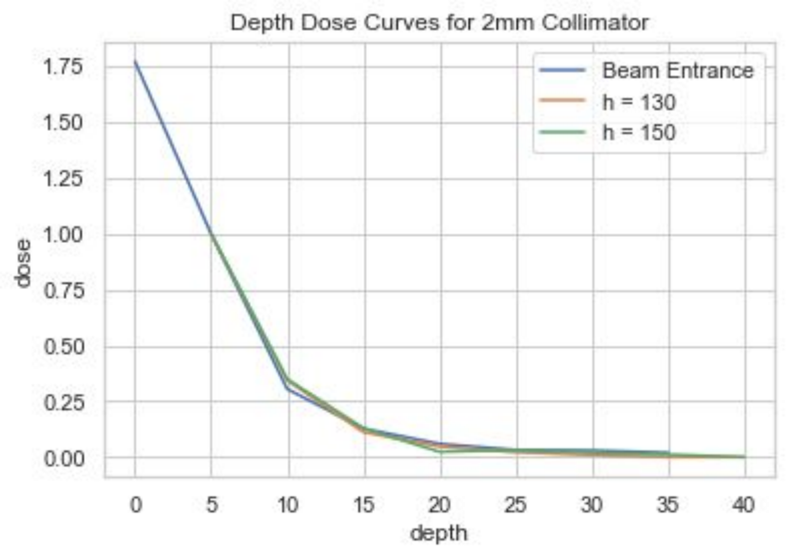




- h = height on optical rails
- SSD = Source to Surface Distance

Beam Scattering in PBS Collimators

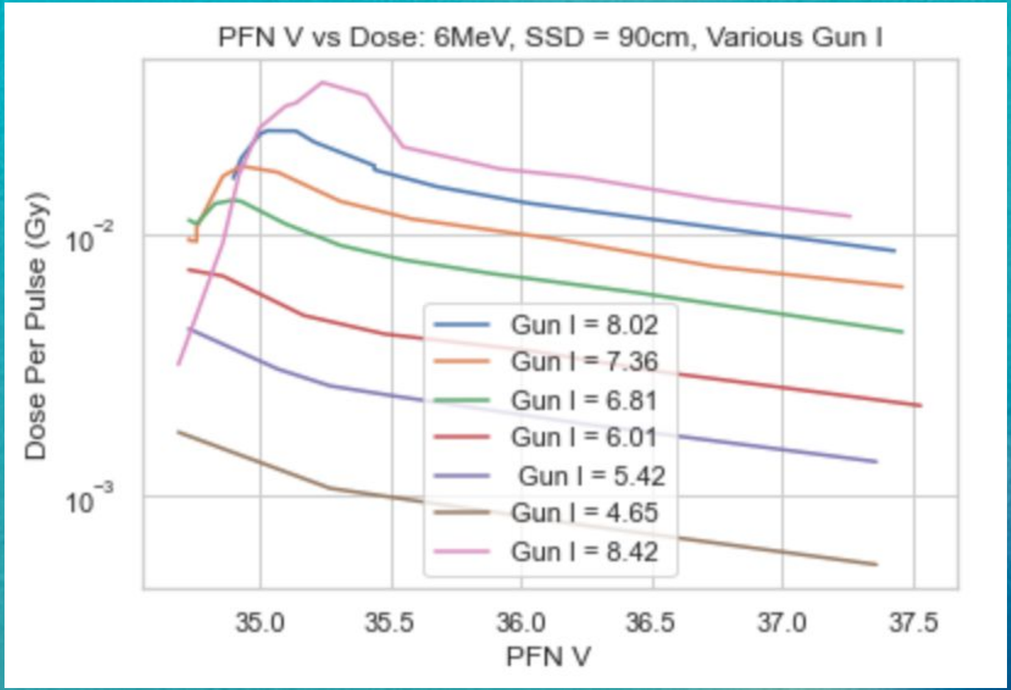




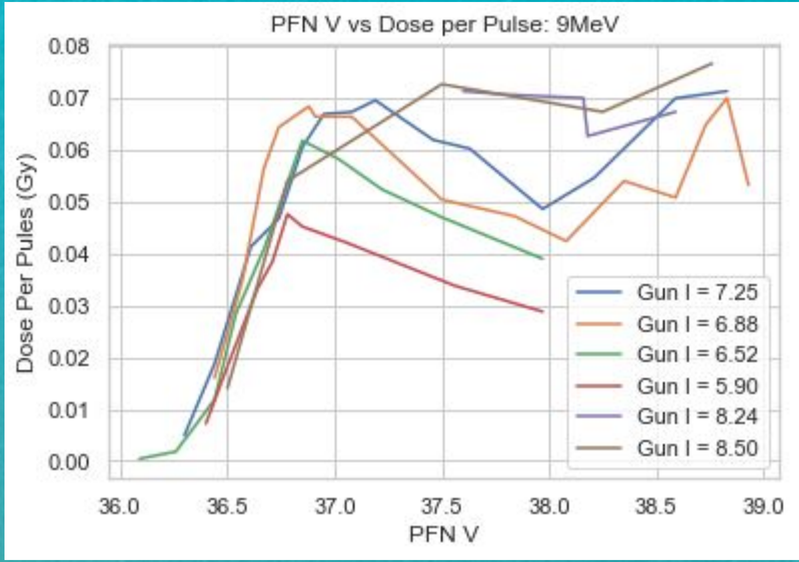
- Want: A small beam for PBS
- Loss of Beam intensity due to beam scattering

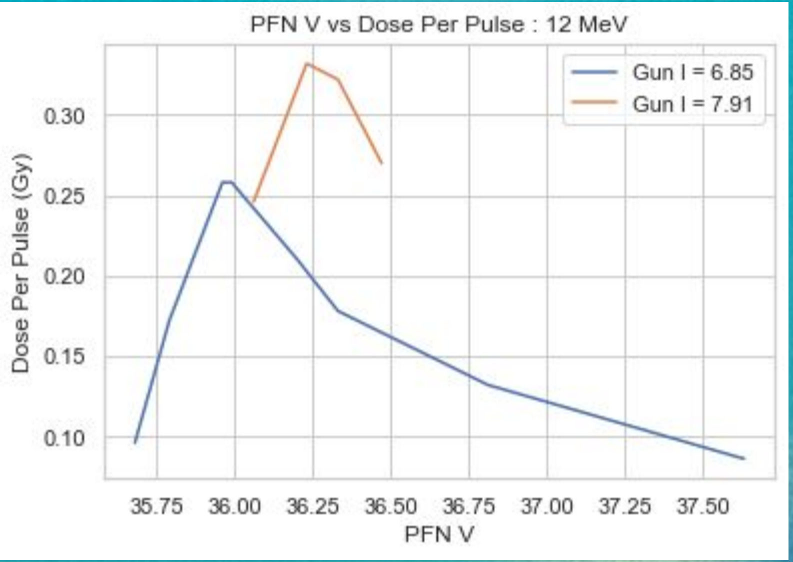
Optimizing PFN V for Each Gun I

- Pulse Forming Network Voltage (PFN V) determines the power provided to electron beam
- Gun Current describes the density of electrons exiting the electron gun to be accelerated
- To optimize the dose, there must the right amount of power to accelerate the electrons
- PFN V and Gun I work together to ensure maximum beam intensity



Limits to Optimization



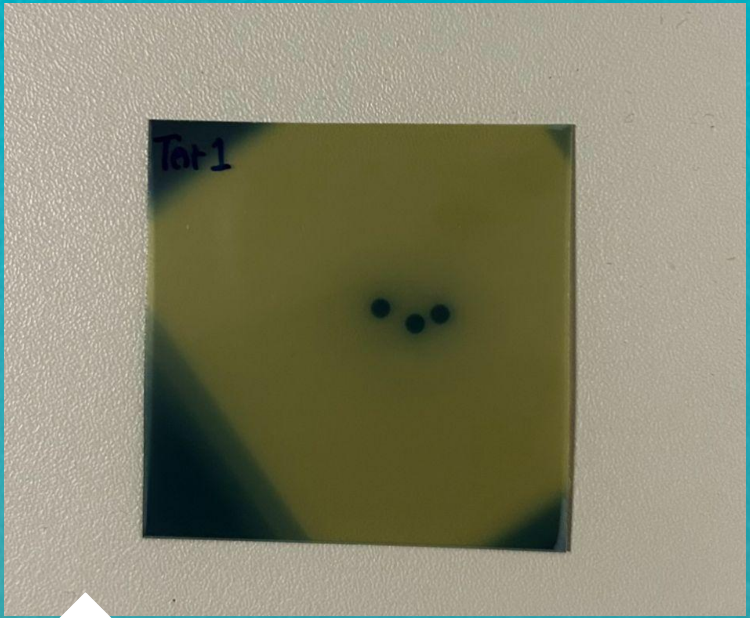


- Limits to achievable PFN
- Incomplete curves at higher energies

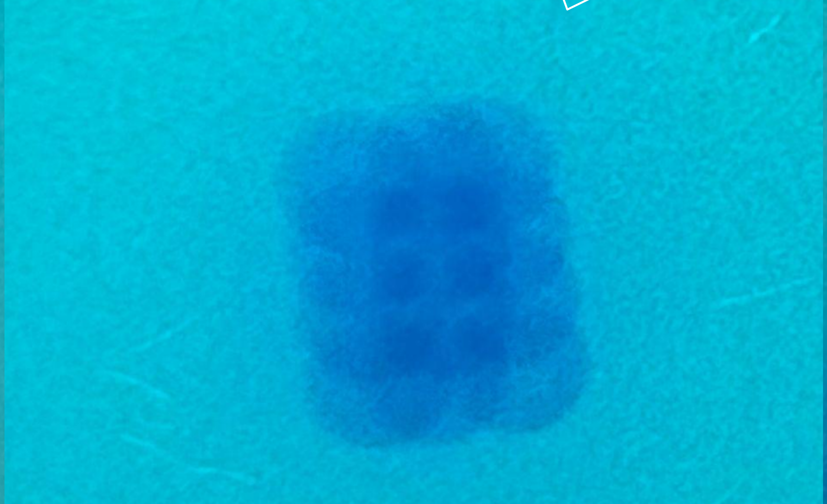
Results

Pencil Beam Scanning

These colors are so similar because the background is a partially irradiated film!

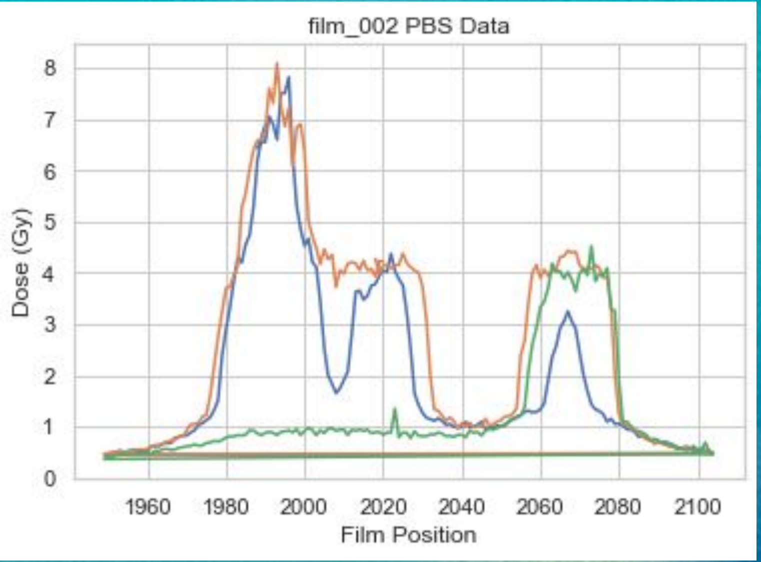


First Successful PBS!



- 3x4 Scanned Pattern
- Scanned the beam in a desired shape

FLASH effect in PBS

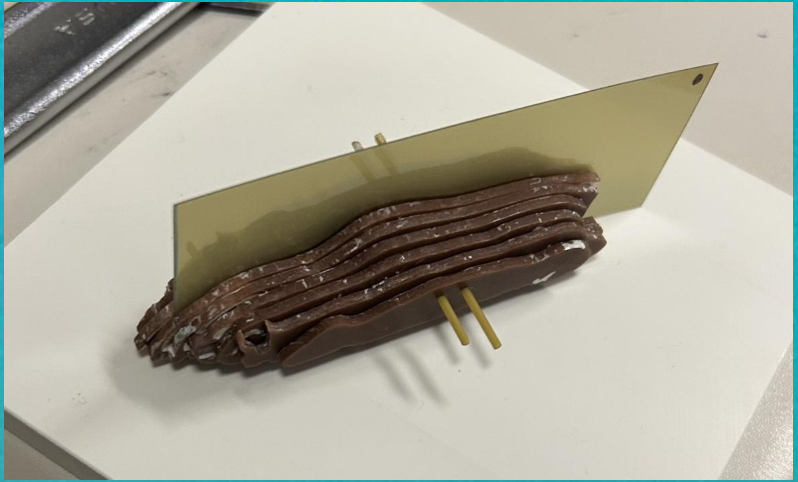


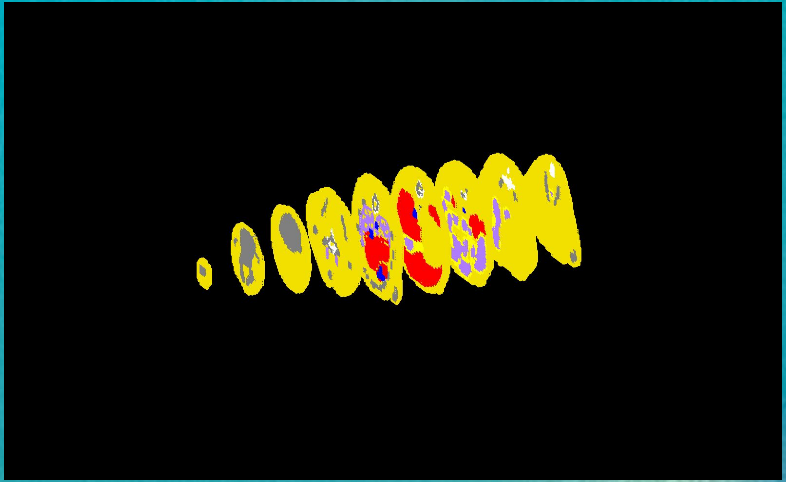
- Instantaneous vs. Average Dose Rate

Future Plans

- Next Steps in Pencil Beam Scanning
  - Moving the motor while beam is pulsing
  - Test different distances between scans to improve uniformity of dose
- Improve Circuitry for extended range in potentiometers

Simulations





- Mouse phantom simulation and CRR physical mouse phantom
- Different density materials allow accurate simulation of dose depth and distribution in mice

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