Building An Electron Spectrometer: Characterizing Electron Beam for FLASH RT

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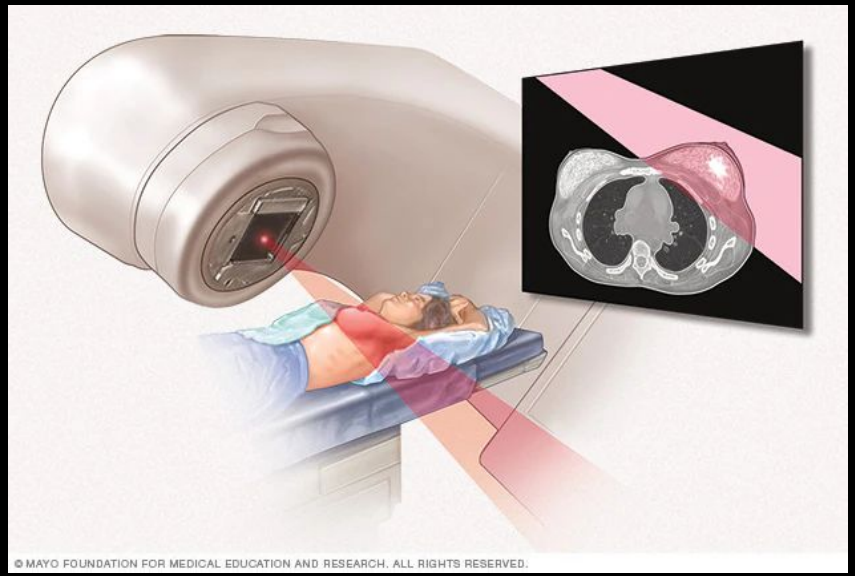
Radiotherapy

Definition:

Radiotherapy (RT) is a method of cancer treatment offered internally or externally using a high-energy beam.



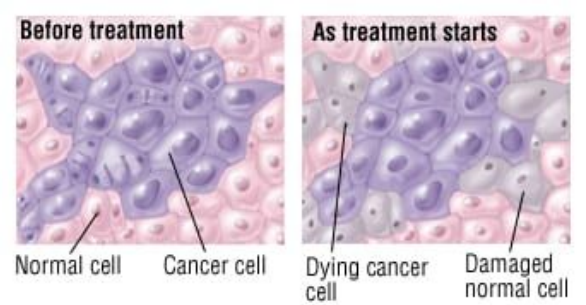
External Radiation

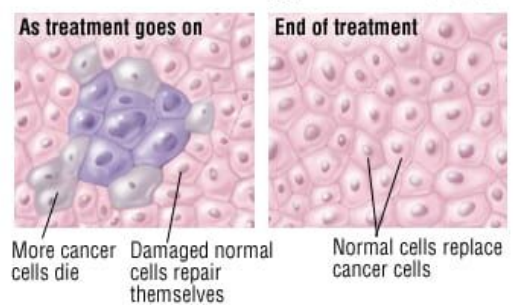
- Uses a linear accelerator
- Can deliver radiation from
  - **Electrons**
  - **X-rays**

Conventional RT

- Conventional RT directs irradiation at the tumor area with a typical dose* rate of 2-3 Gy/min
- Damage healthy tissue cells
  - **Disease**
  - **Pain**
  - **Mutation**
- Radiation in multiple sessions to reduce tissue toxicity

Dose: the measure of ionizing radiation per unit mass
- **1 Gy = 1 J/kg**



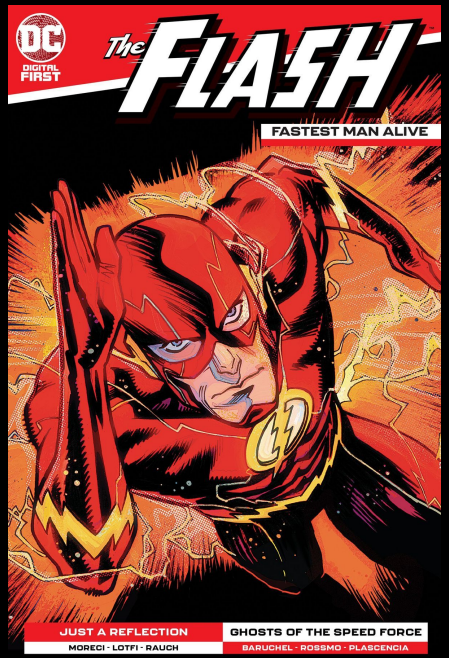


FLASH RT

Definition:

FLASH RT uses ultra-high dose rate irradiation (>40 Gy/s) to target tumors while reducing radiation effects on normal tissue

- The equivalent dose is the same as conventional RT



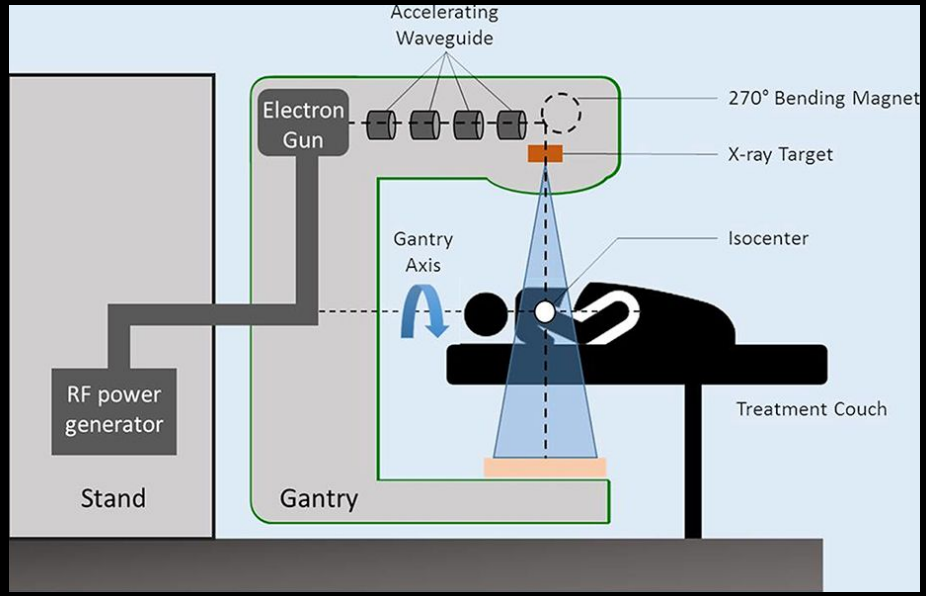
Why FLASH

- Reduction in normal tissue toxicity
  - **Biological reason is a mystery**
- Improved therapeutic index

Clinical Linear Accelerator (Clinac)

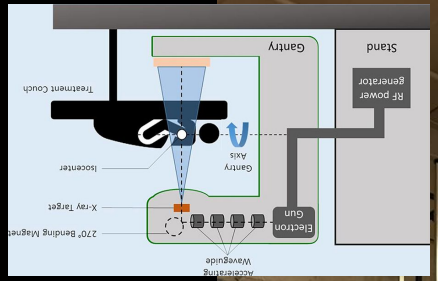
Components:

- Radiofrequency (RF) driver generates microwaves.
  - **Microwaves power the electron gun.**
- Accelerating waveguide and 270 degree magnet accelerate and focus the electrons at a target.
- With a target in place, electrons are converted into photons through the Bremsstrahlung process.



Modified Clinac

- RARAF Clinac operates in service mode with the option of firing photon and electron beams.
- Multiple energy levels (electron): 6 MeV, 9 MeV, 12 MeV, 16 MeV, and 20 MeV.
- Fixed gantry and a beam permanently pointing vertically up.
- Additional optical rails and platform for experimentation at different distances.



Characterizing the Electron Beam

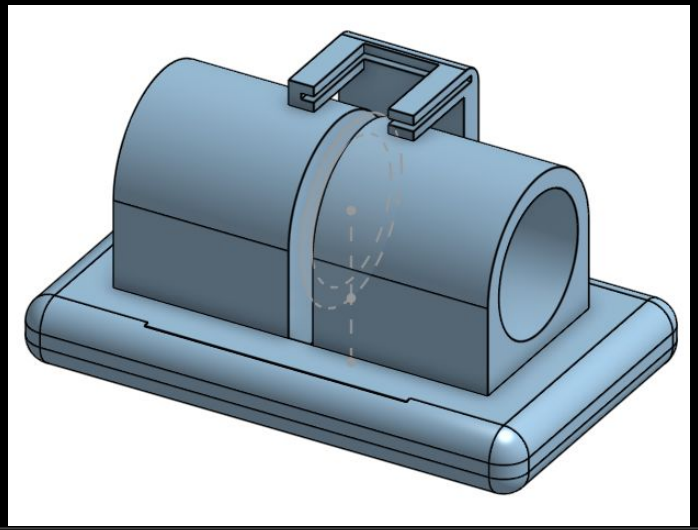
Purpose:

- Improving the understanding of FLASH RT is by characterizing the energy of the electron beam.
- To accurately measure and analyze the beam properties and their effects, in addition to ensuring consistent results.

Building and Designing the Electron Spectrometer

Definition:

This electron spectrometer is an instrument used to measure the energy of an electron, specifically the deflection of the beam.

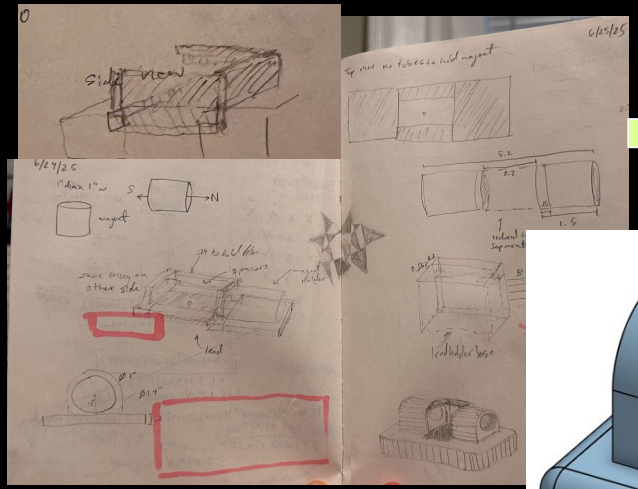


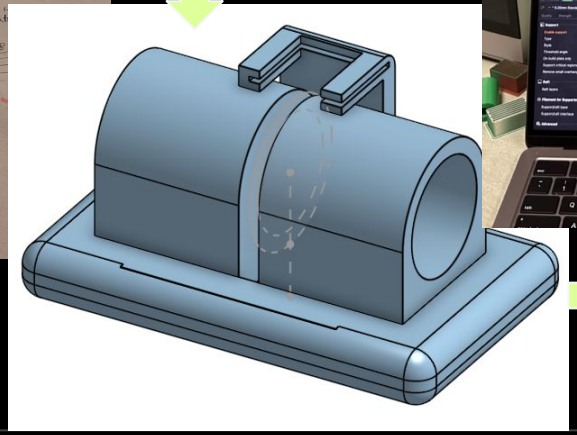
Components:

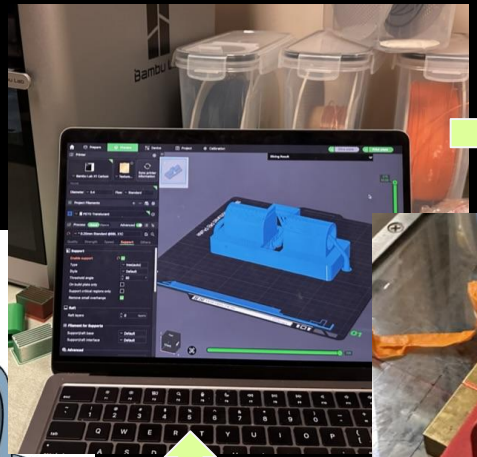
- 3D printed mount
- Magnets
- Lead aperture
- Gafchromic EBT3 Film

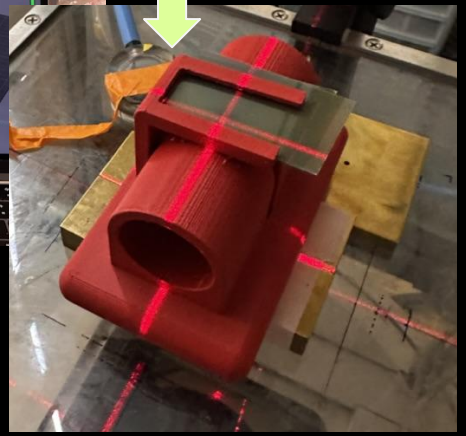
Building and Designing the Electron Spectrometer

This project was approached using the engineering design process!





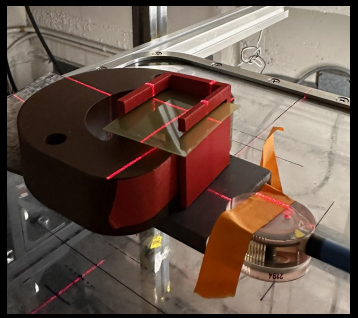
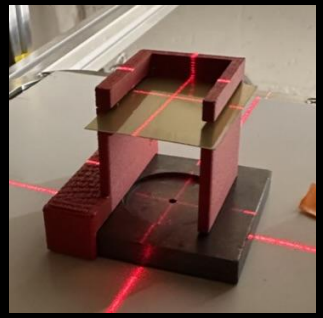
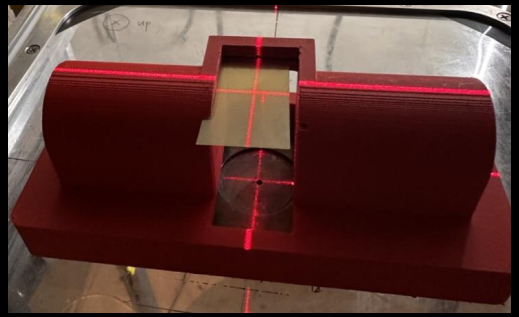
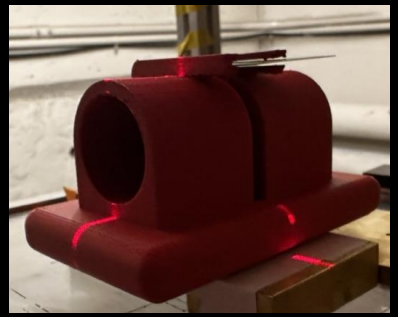




Building and Designing the Electron Spectrometer

Components:

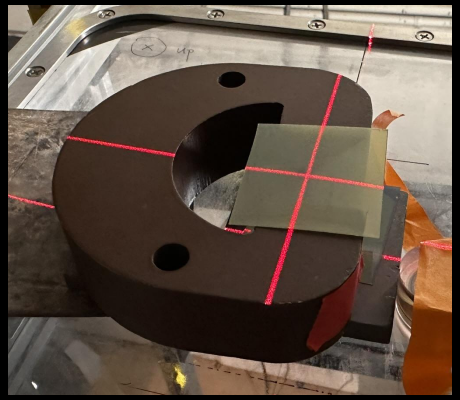
- **3D printed mount**
- Magnets
- Lead aperture
- Gafchromic EBT3 Film

Building and Designing the Electron Spectrometer

Components:

- 3D printed mount
- **Magnets**
- Lead aperture
- Gafchromic EBT3 Film

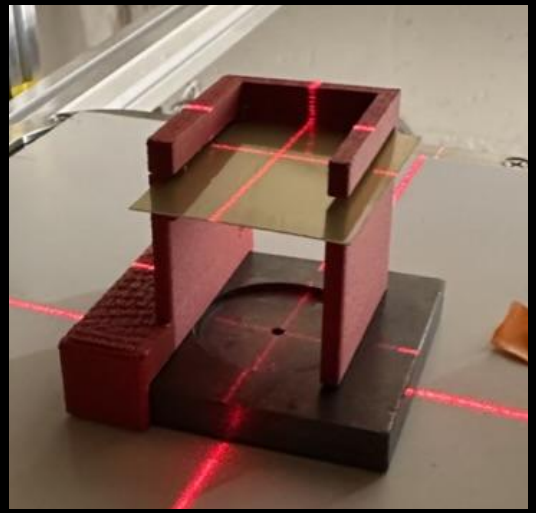


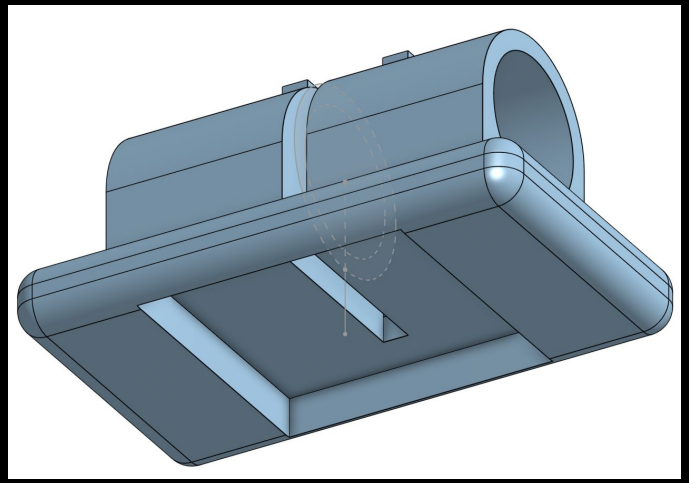
The initial magnetic field was 105 mT which created an insignificant deflection. The final 570 mT magnetic field had a measurable deflection.

Building and Designing the Electron Spectrometer

Components:

- 3D printed mount
- Magnets
- **Lead aperture**
- Gafchromic EBT3 Film



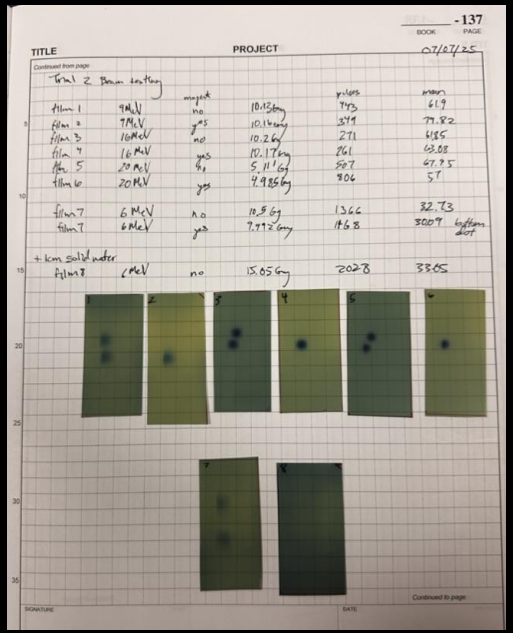


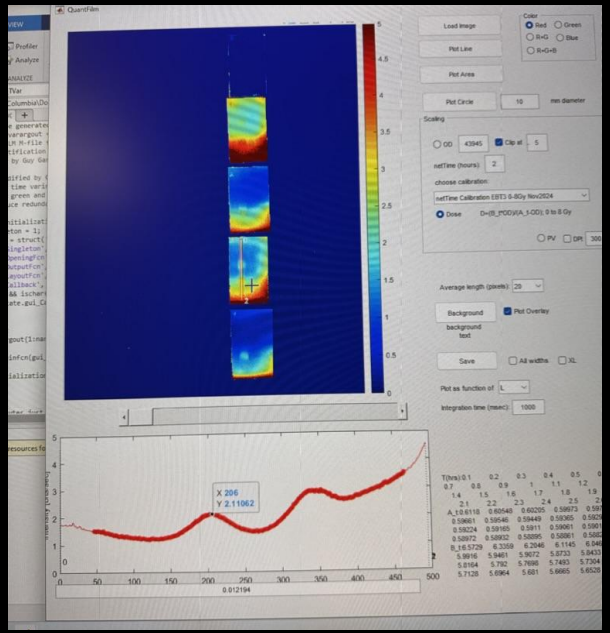
The collimator used has a 1 mm circle of beam creating a measurable dot on the film

Building and Designing the Electron Spectrometer

Components:

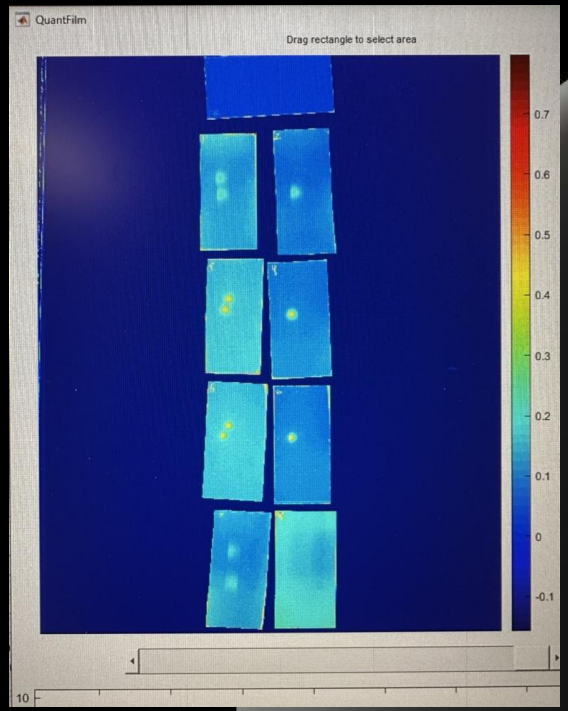
- 3D printed mount
- Magnets
- Lead aperture
- **Gafchromic EBT3 Film**





Used to measure deflection and dose

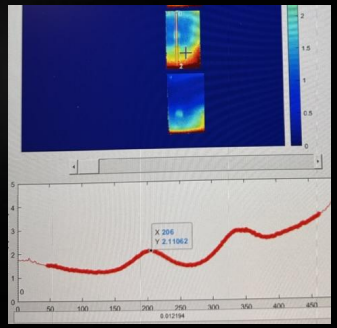
Film Dosimetry



- Irradiated films change in opacity.
- Optical density is converted into dose measurements:

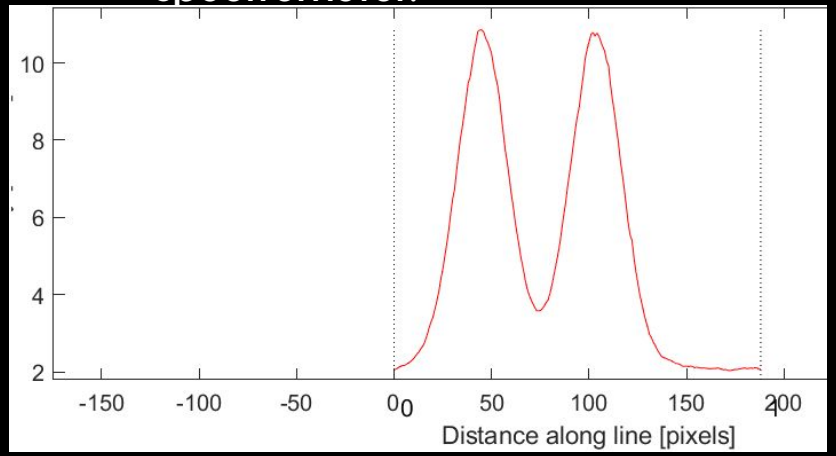
Optical Density = $-\log_{10}$(Pixel Value Irradiated/Pixel Value Control)
Dose = (0.7404*Optical Density)/(0.818-Optical Density)

- Using a line tool to highlight a strip of film, each film can be plotted in a dose versus pixel graph.

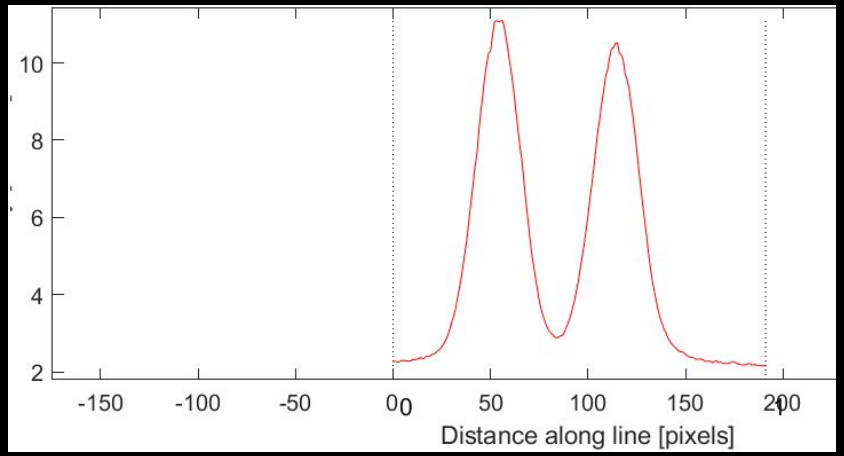


Measuring Dose

- The dose can be used to cross-check the beam intensity with the deflection accuracy
- During experimentation, the dose (10 Gy) was recorded after each film's irradiation period.
  - **The dose was measured using a dosimeter placed next to the electron spectrometer.**

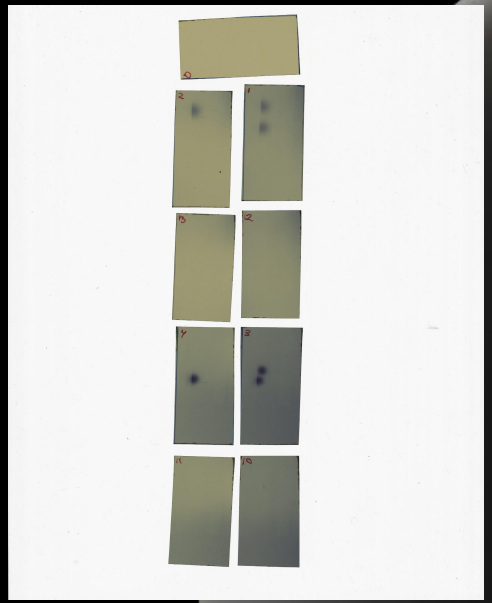


16 MeV

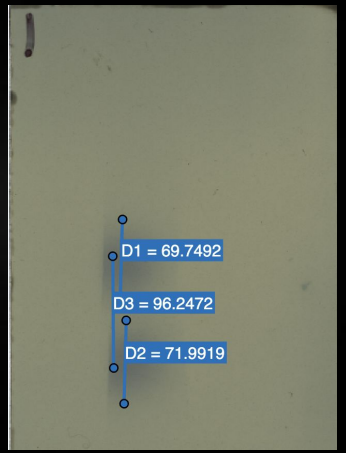


20 MeV

Measuring Deflection



- Using Image Viewer, a MATLAB app the deflection and diameter are manually counted in pixels.
- The diameter of each is also measured and used to calculate error.



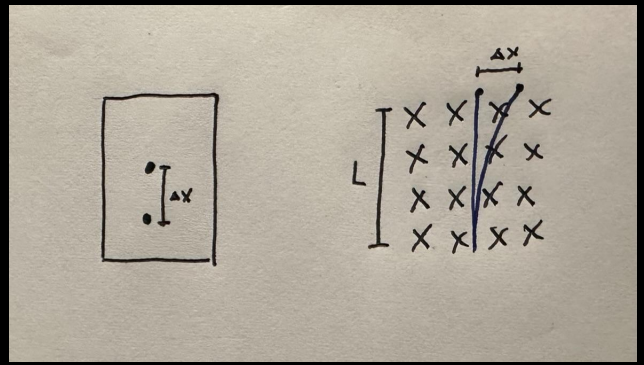
Calculating the Energy of the Electron Beam

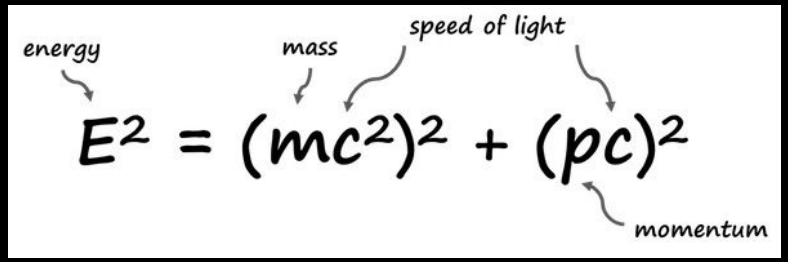
To use the relativistic energy equation, the deflection (x) is manipulated into radius

r = L^2/2x

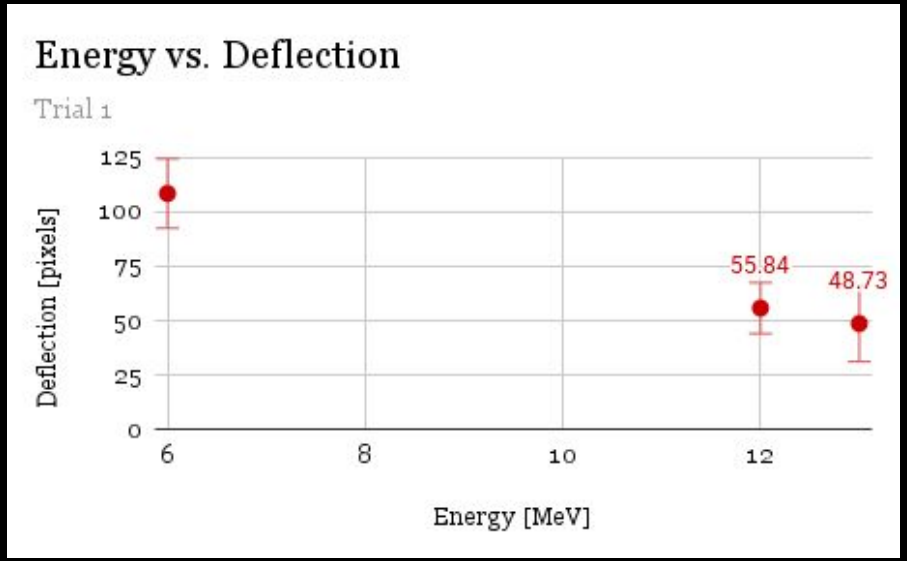
and then plugged into the momentum equation

p = qBr





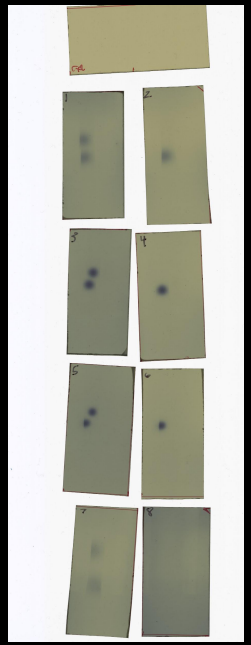
Energy Plotted Against the Deflection

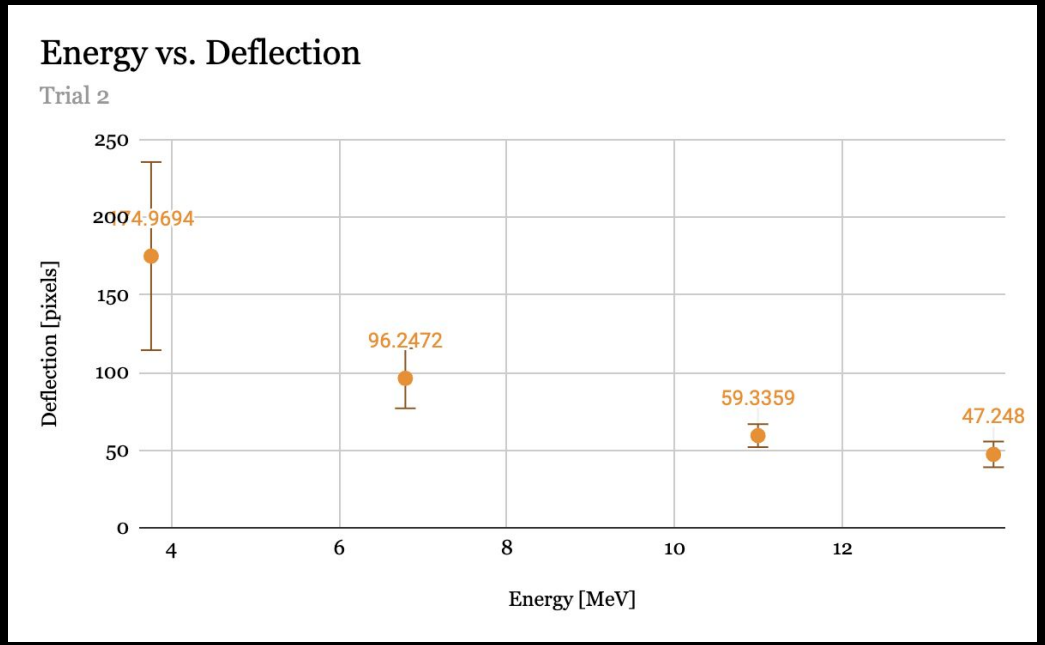


Nominal Energy (MeV)	Measured Energy (MeV)
20	13
16	11
9	6

Energy Plotted Against the Deflection

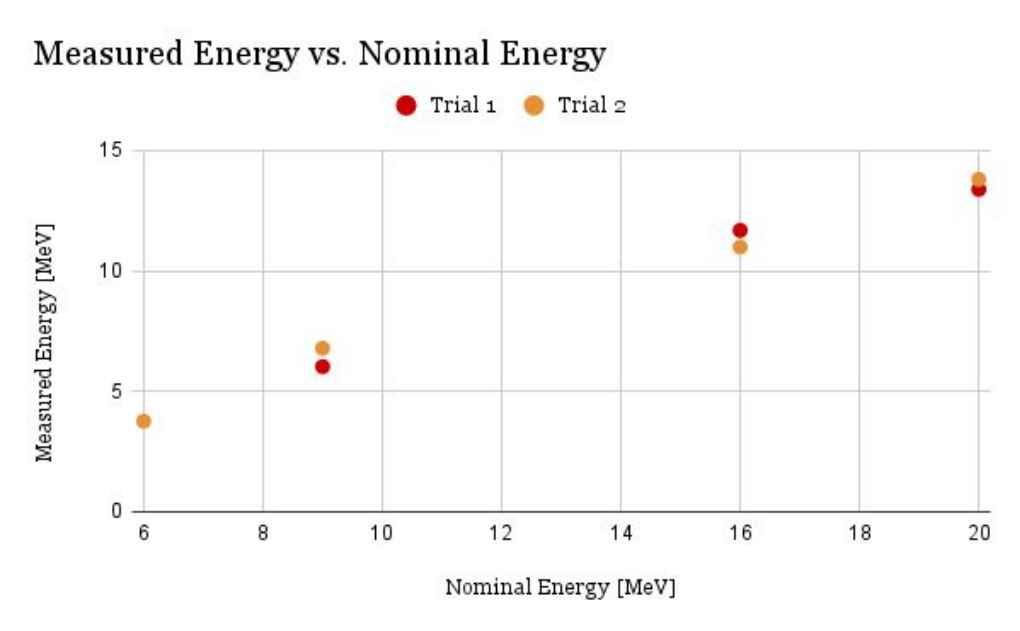
Nominal Energy (MeV)	Measured Energy (MeV)
20	13
16	10
9	6
6	3





Takeaways:

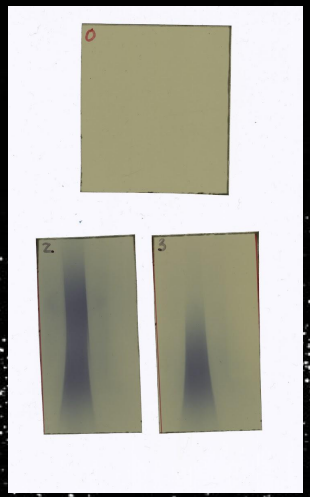
- The nonlinearity highlights the difference in the measured and nominal energy.
- The energy that is assumed to be fired is not the same as the energy received.
- Interpreting experimental results and understanding the system's behavior.

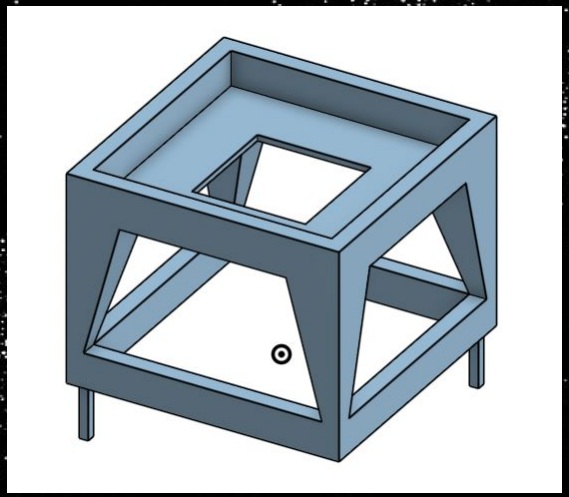


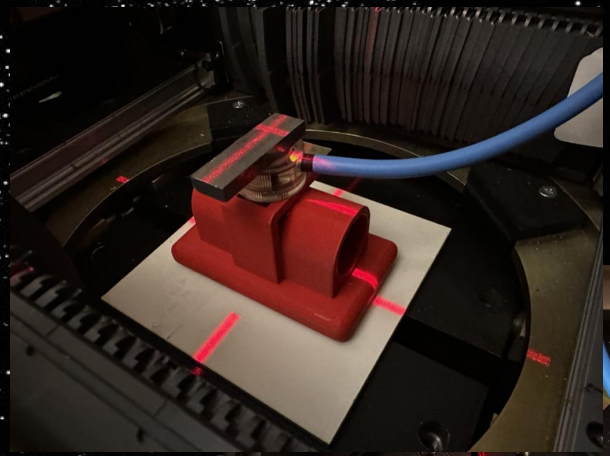
Nominal Energy (MeV)	Trial 1 Energy (MeV)	Trial 2 Energy (MeV)
20	13	13
16	11	10
9	6	6
6		3

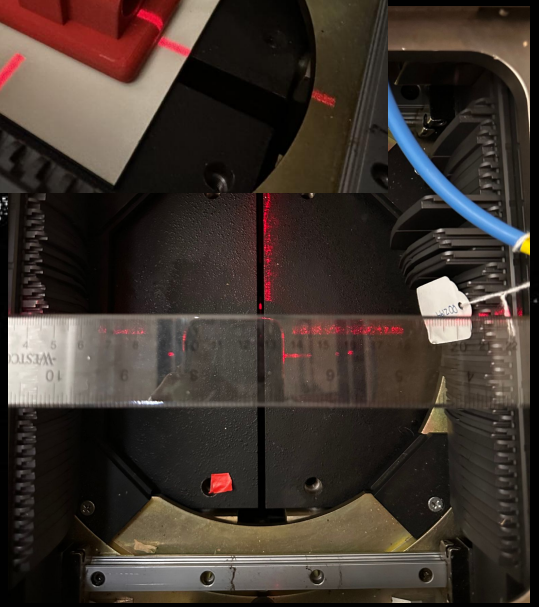
Future Studies

- Characterizing a degraded beam.
  - Using a slab of solid water plastic
- Align and collimate beam to reduce background
  - Using stacked apertures and jaws









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