Detecting nuclear reaction products from markers as a range verification technique in proton therapy

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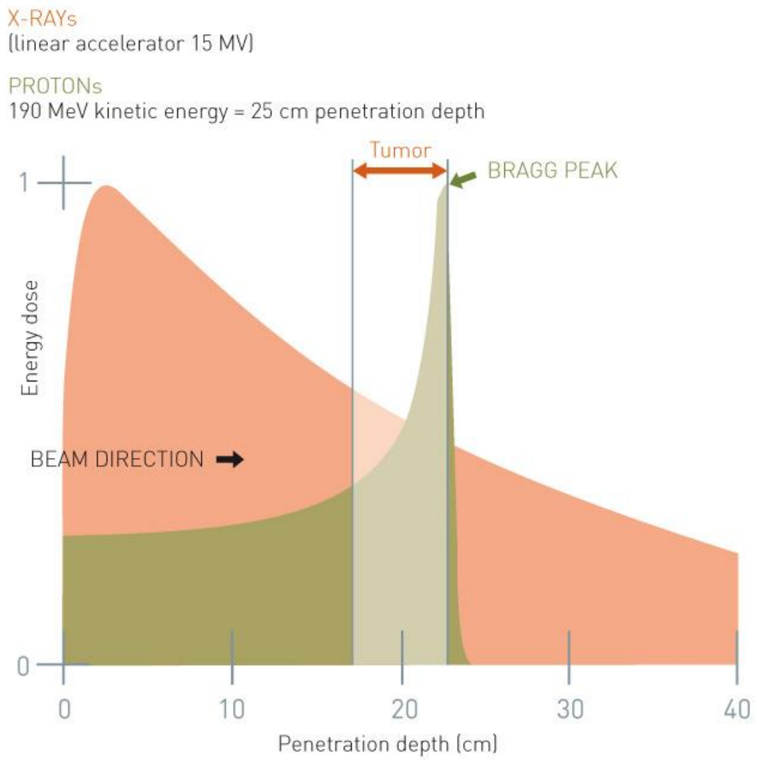
Advantages of Proton Therapy

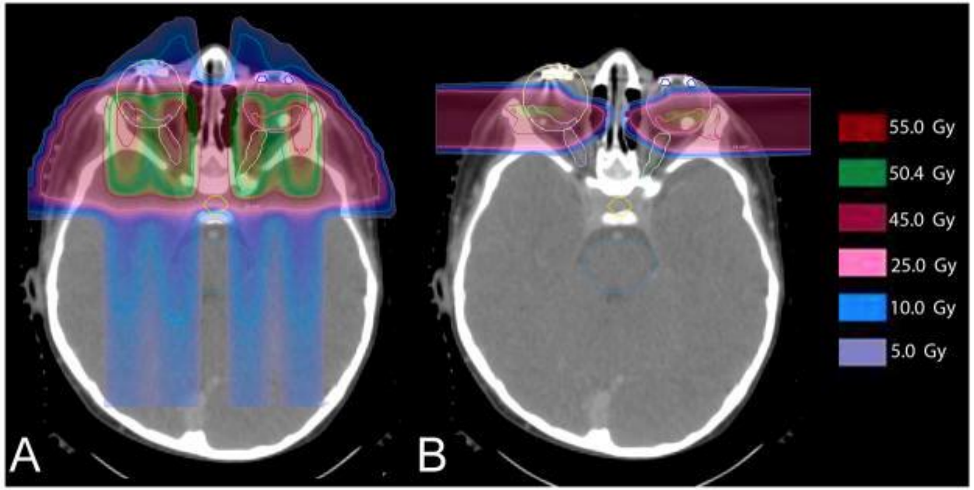
- Protons deposit the majority of their energy at the end of their trajectory
- Less radiation is delivered to healthy tissue compared to conventional therapy



Proton Therapy at TRIUMF

TRIUMF hosts a 500 MeV cyclotron and is the only Canadian proton therapy institution

Photon Plan (IMRT) **Proton plan (same patient)**



A dose as low as 5 Gy significantly increases risk of second malignancy

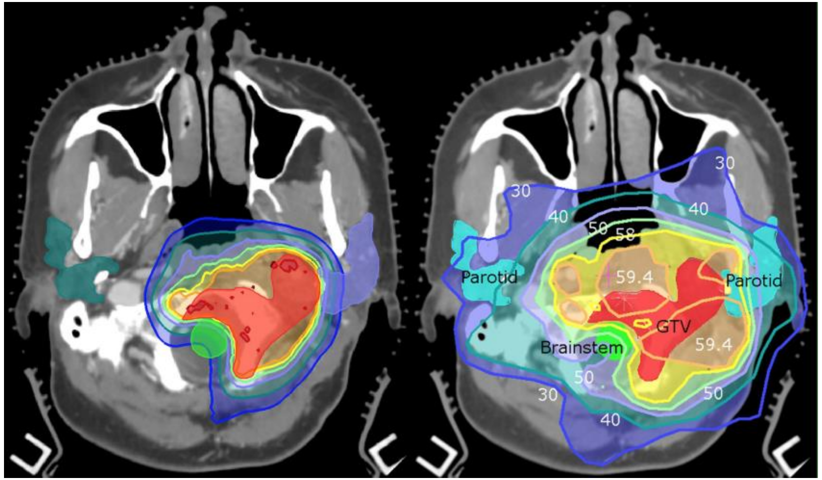
V. S. Roshan et al. Cancer. 2014 January 1; 120(1): 126–133

Dose-Monitoring and Range Verification

- **Range Verification**
  - Range precision of proton therapy dependent on the accuracy of proton stopping powers in tissue
- **Dose Monitoring**
  - γ, proton and neutron flux all contribute to total dose to patient

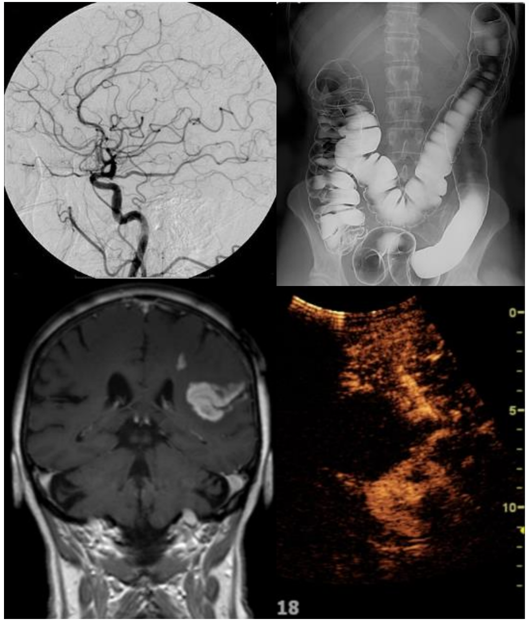
<u>Expected range uncertainties:</u>

- brain (10cm) -- 0.14cm
- prostate (15cm) -- 0.33cm

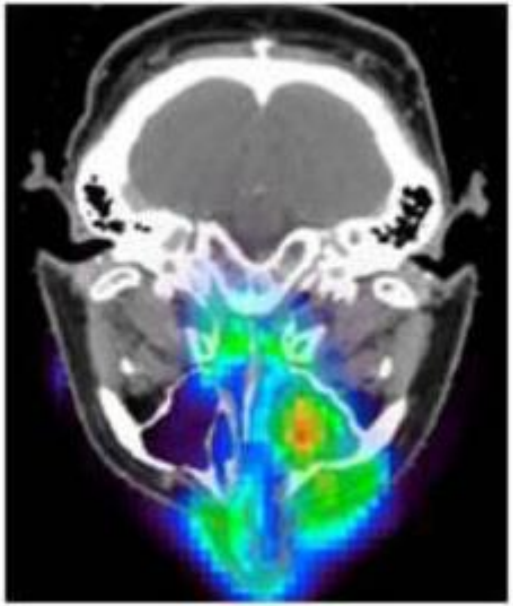


B. Schaffner and E. Pedroni. Phys. Med. Biol. 43 (1998) 1579–1592

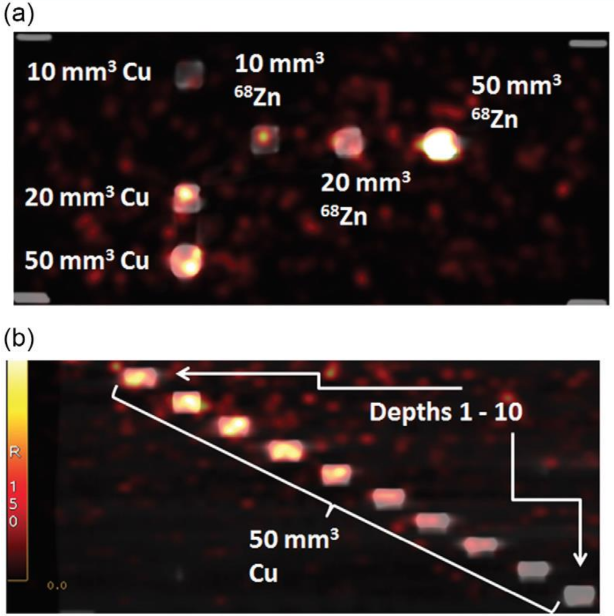
Markers & Contrast Agents



Contrast agents in Medical Imaging Modalities

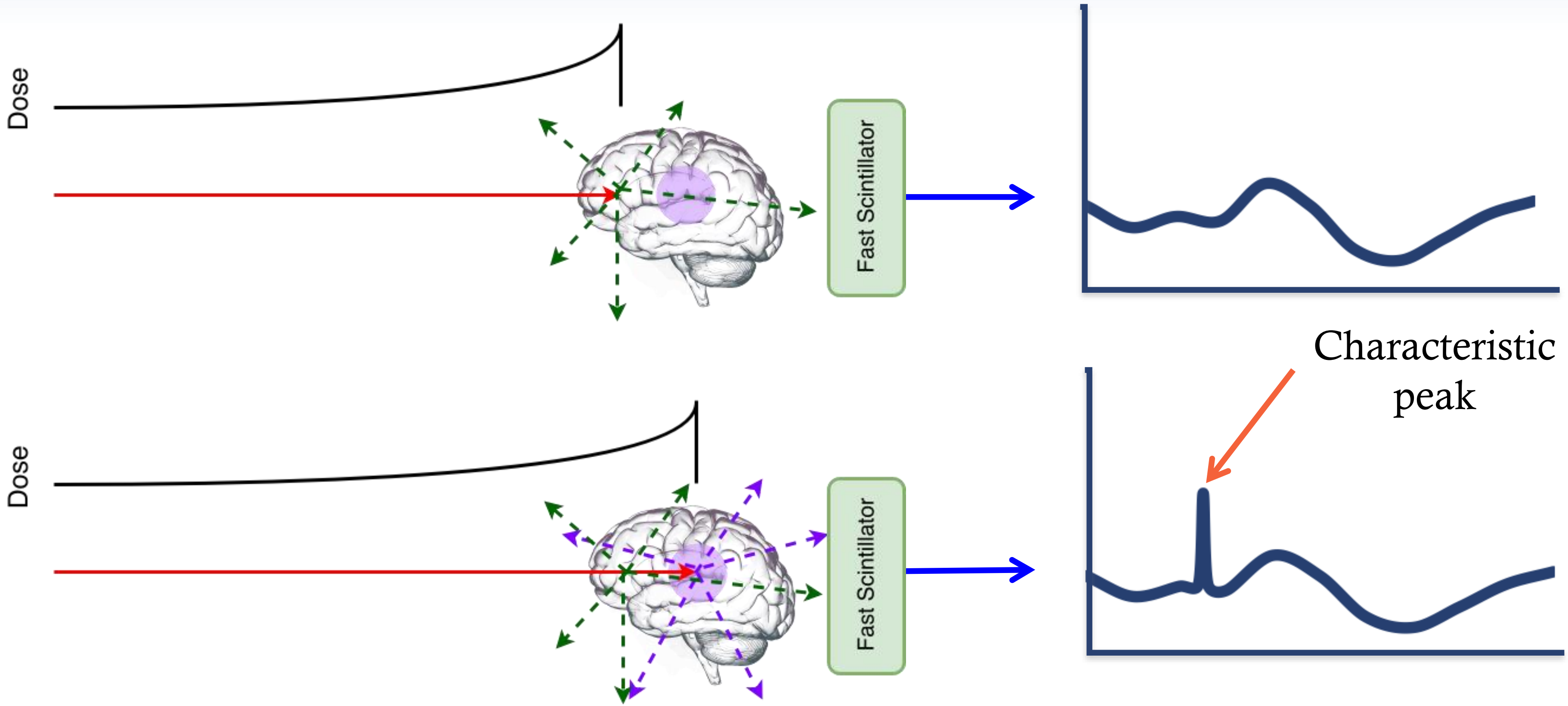


Tissue PET-activation for range verification in proton therapy

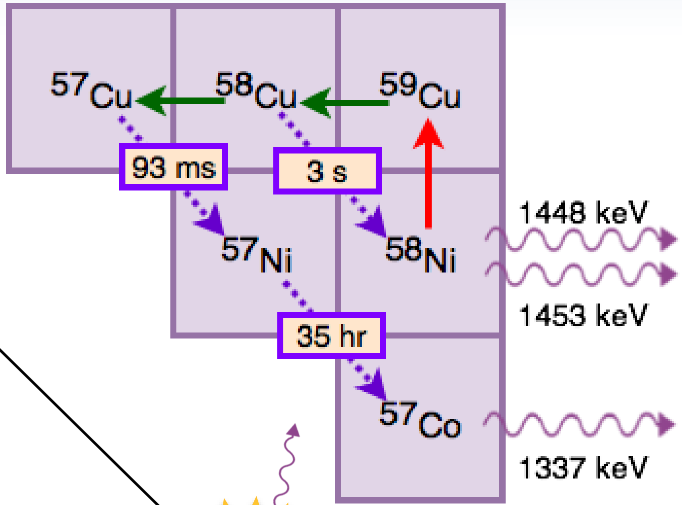


Marker PET-activation for range verification in proton therapy

Using prompty-spectroscopy to measure range



Approaches to γ-detection

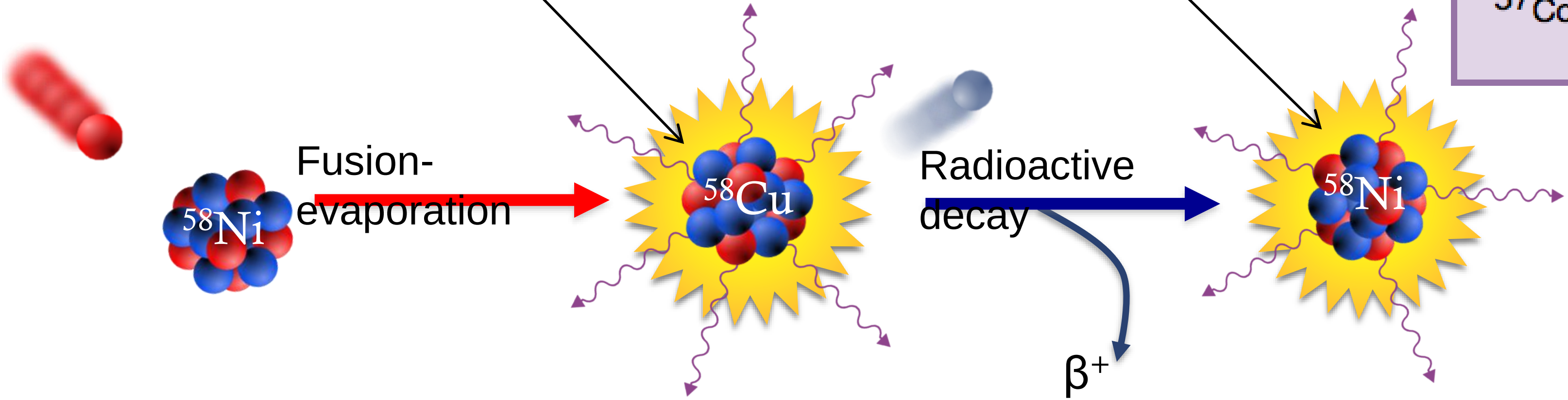


Prompt gamma rays:

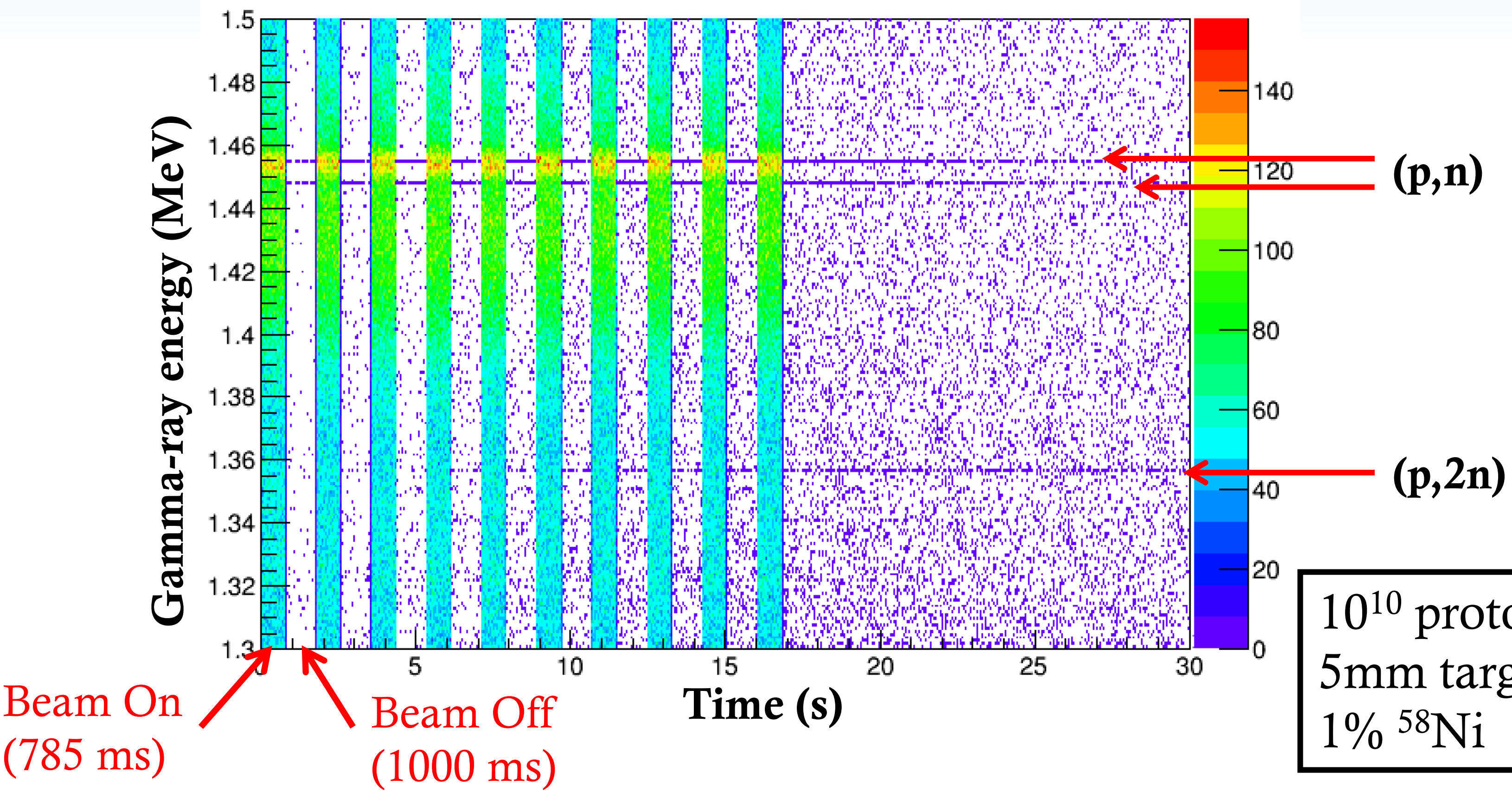
- measured when beam is online

β-delayed gamma rays:

•measured between beam pulses or after treatment

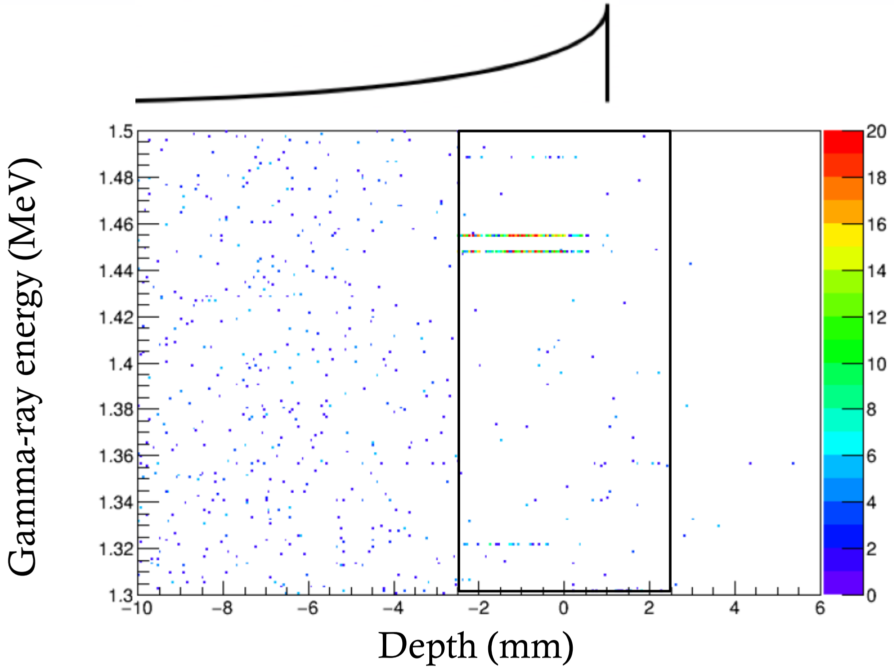


Time structure of Beam

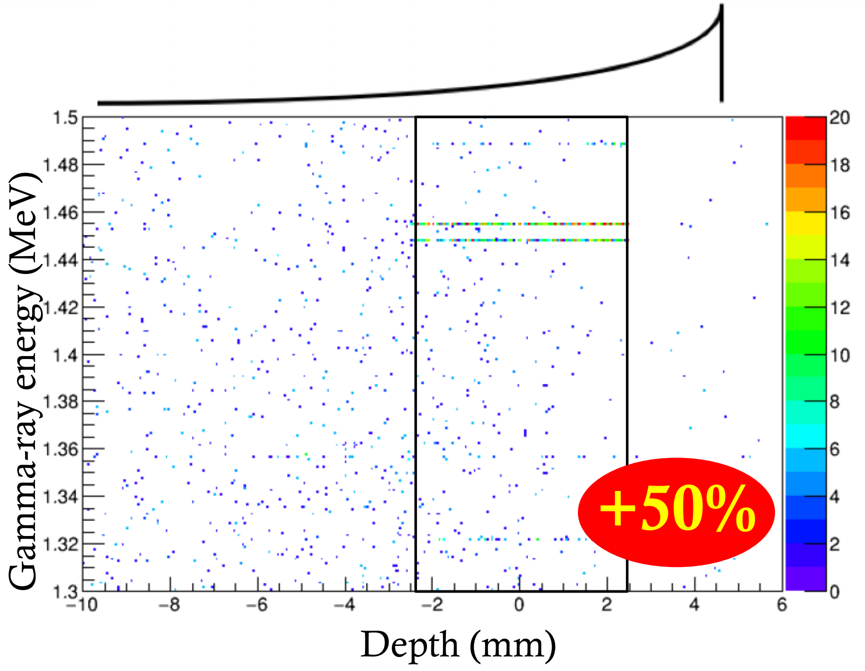


10^{10} protons
5mm target
1% ^{58}Ni

Range-dependence of ^{58}Ni reactions

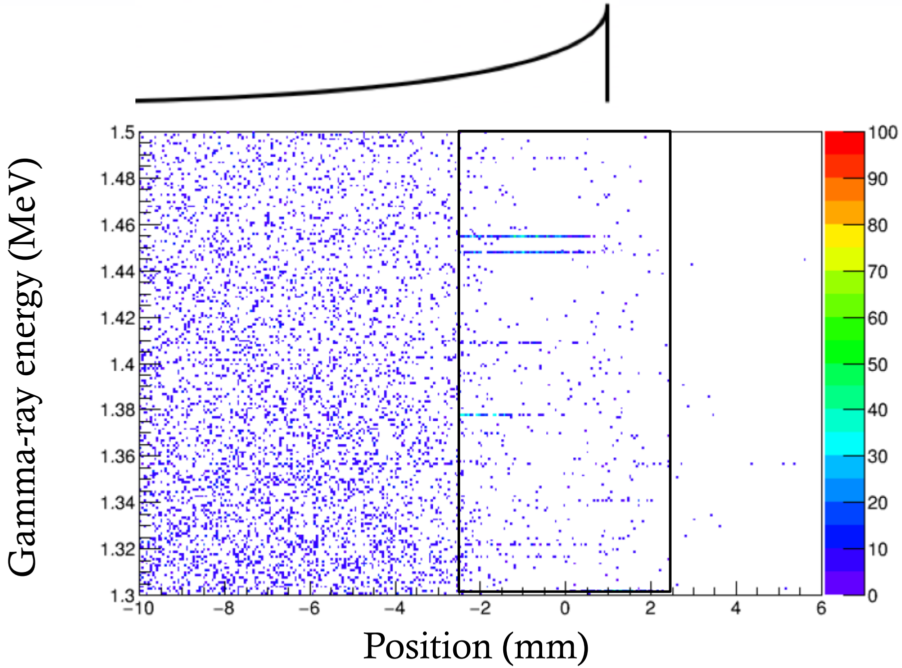


77 MeV beam, 1% concentration of ^{58}Ni in target, 20s measurement period

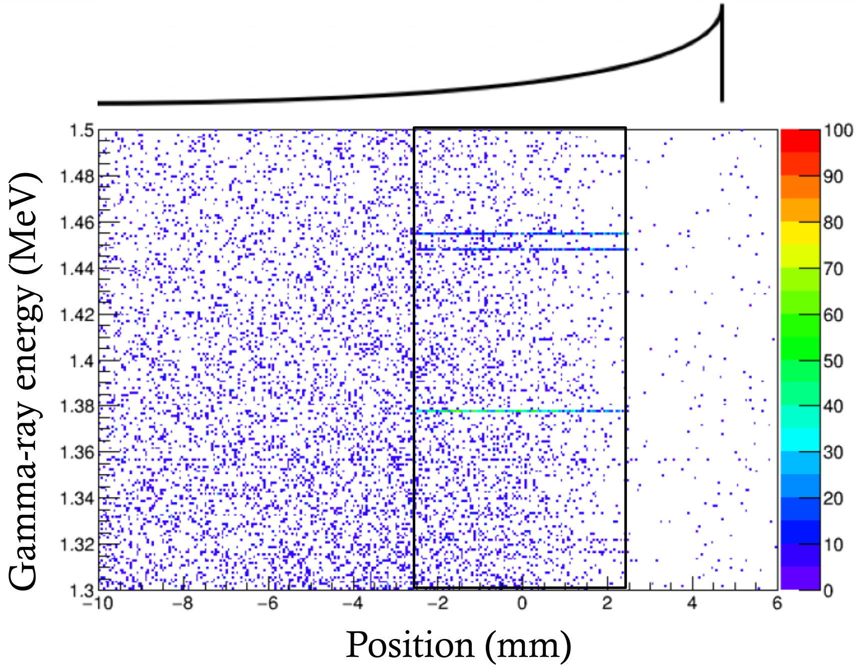


81 MeV beam, 1% concentration of ^{58}Ni in target, 20s measurement period

Long-term Range Dependence

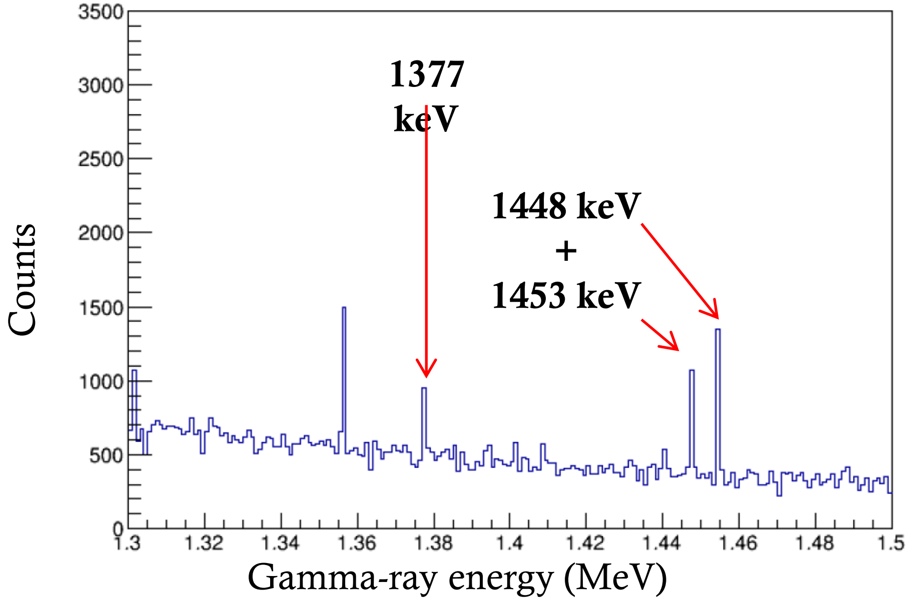


77 MeV beam, 1% concentration of ^{58}Ni in target, 1hr measurement period

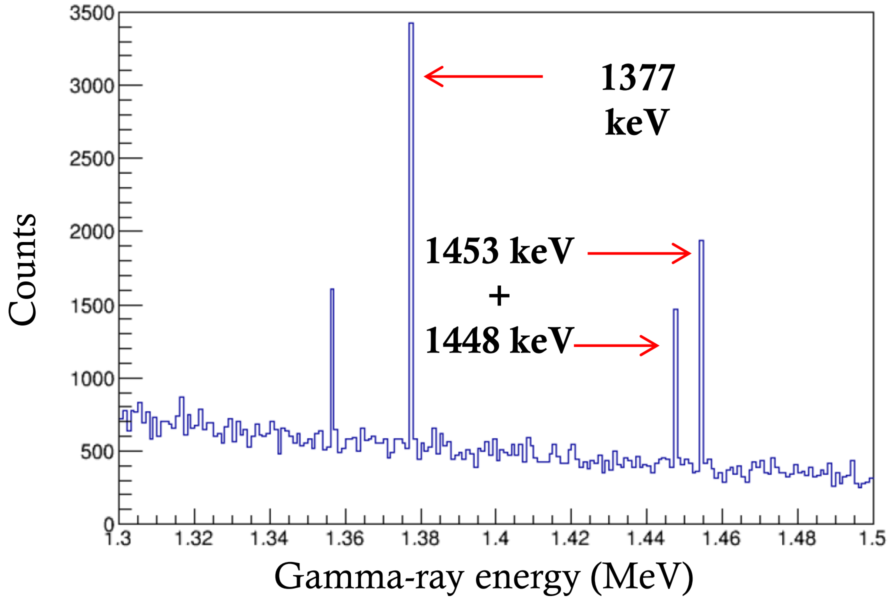


81 MeV beam, 1% concentration of ^{58}Ni in target, 1hr measurement period

Energy Spectra for different beam ranges



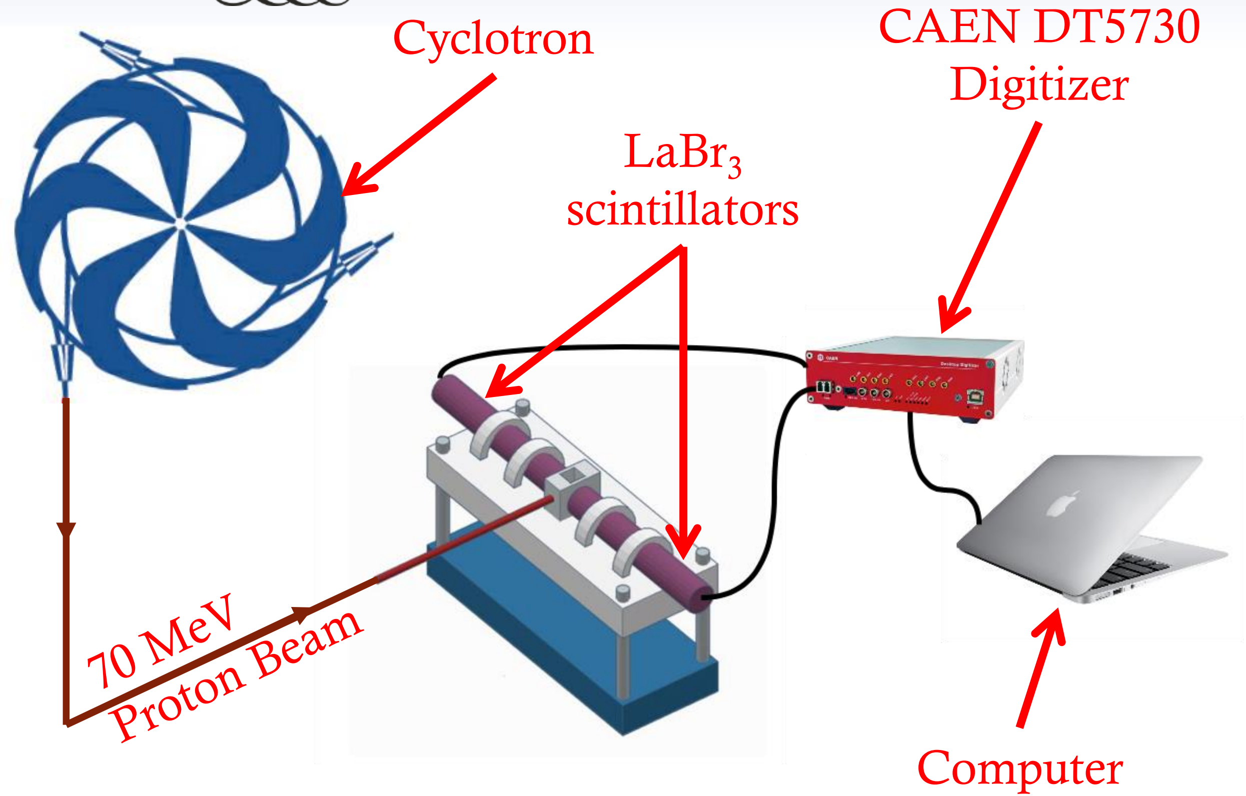
77 MeV beam



81 MeV beam

Experimental Setup at TRIUMF proton treatment facility

- Experiment proposal M1780 approved at TRIUMF:
  - Test different contrast agents and concentrations
  - Compare to simulation
  - Determine expected SNR



Acknowledgements

Muecher, D., Bildstein, V., Turko, J., Hoehr, C., Burbadge, C., Hymers, D., Olaizola, B.

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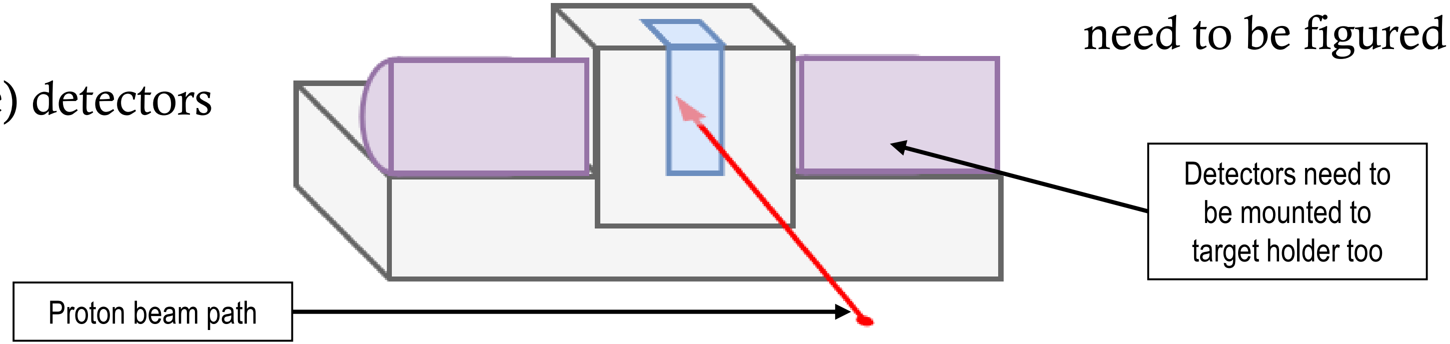
TRIUMF

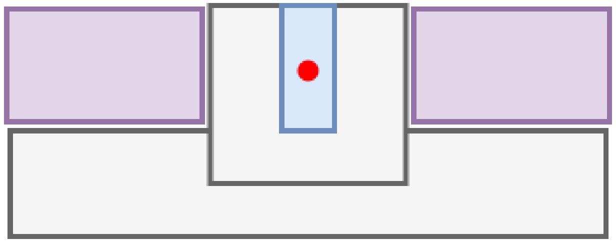
Building a Target & Mount

- PMMA
- $LaBr_3(Ce)$ detectors
- Sample

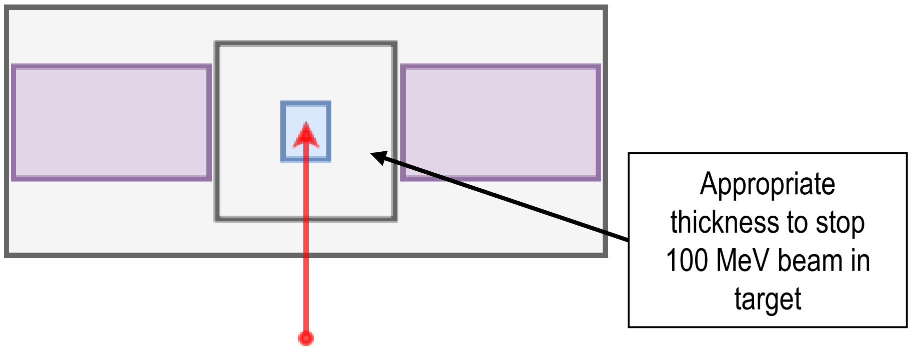
*actual dimensions still need to be figured out



Side View (bisection)

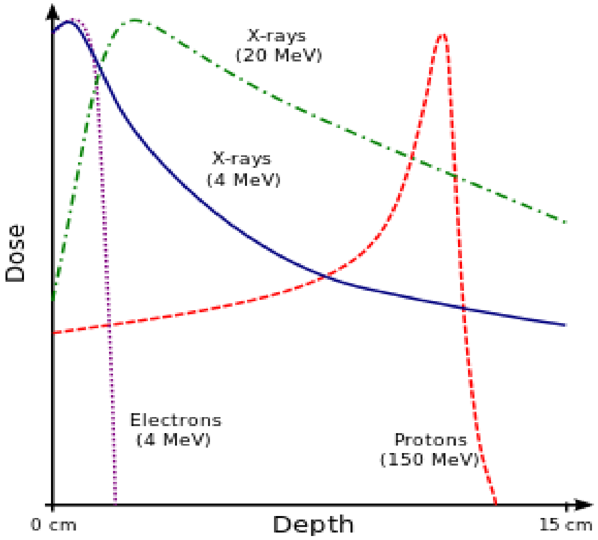


Top View

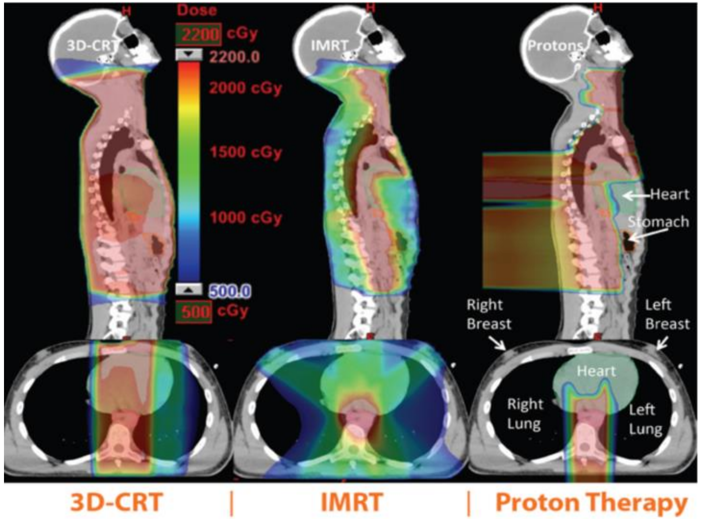


Range verification in Proton Therapy

$$\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi}{m_e c^2} \cdot \frac{n z^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\epsilon_0} \right)^2 \cdot \left[\ln \frac{2 m_e c^2 \beta^2}{I\,(1-\beta^2)} - \beta^2 \right]$$



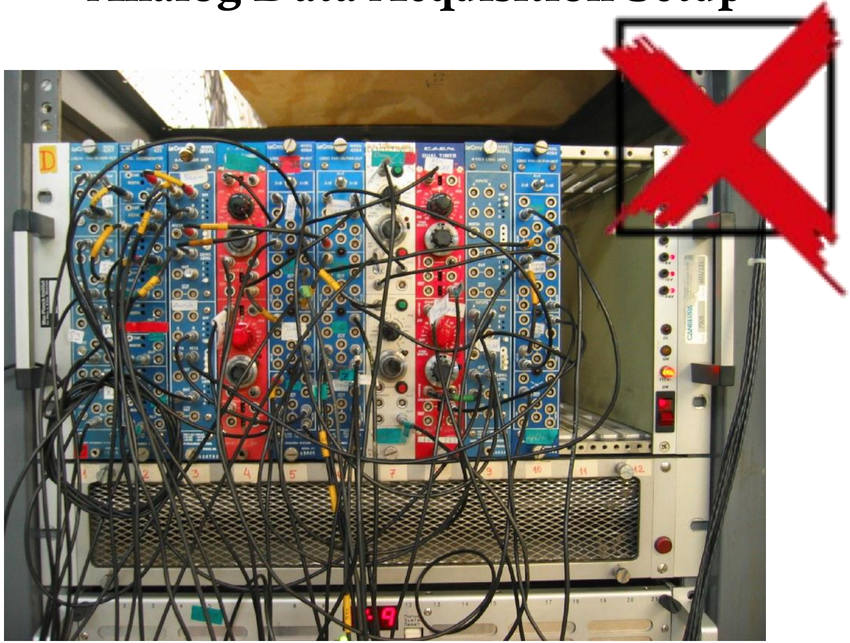
Zhu, X., and Fakhri, G. Proton therapy verification with PET imaging. Theranostics 3, 10 (2013).



UF Health Proton Therapy Institute. Proton Therapy for Hodgkin Lymphoma And Non-Hodgkin Lymphoma, Jacksonville, Florida, 2017.

Data Acquisition

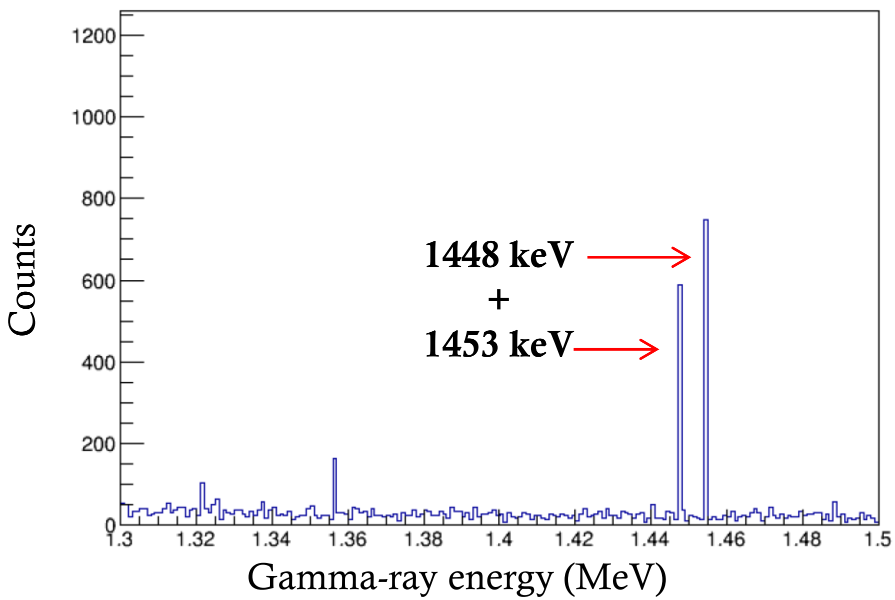
Analog Data Acquisition Setup



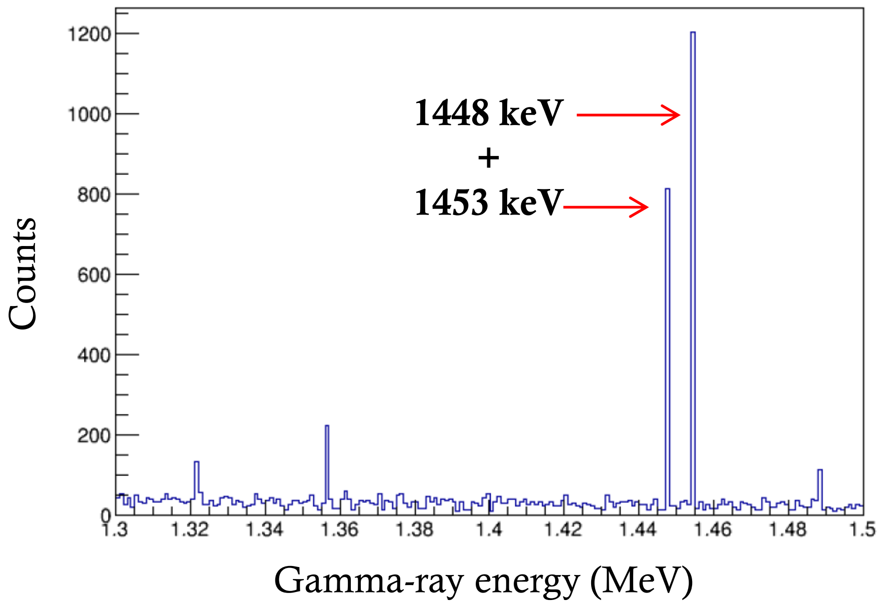
CAEN DT5730 Digitizer

(Christina Burbadge)

Energy Spectra for different beam ranges



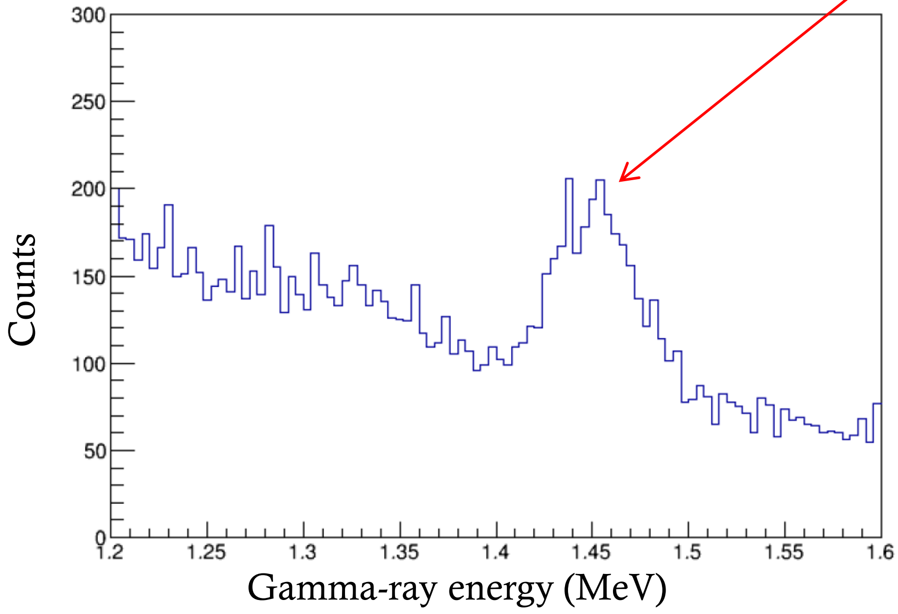
77 MeV beam



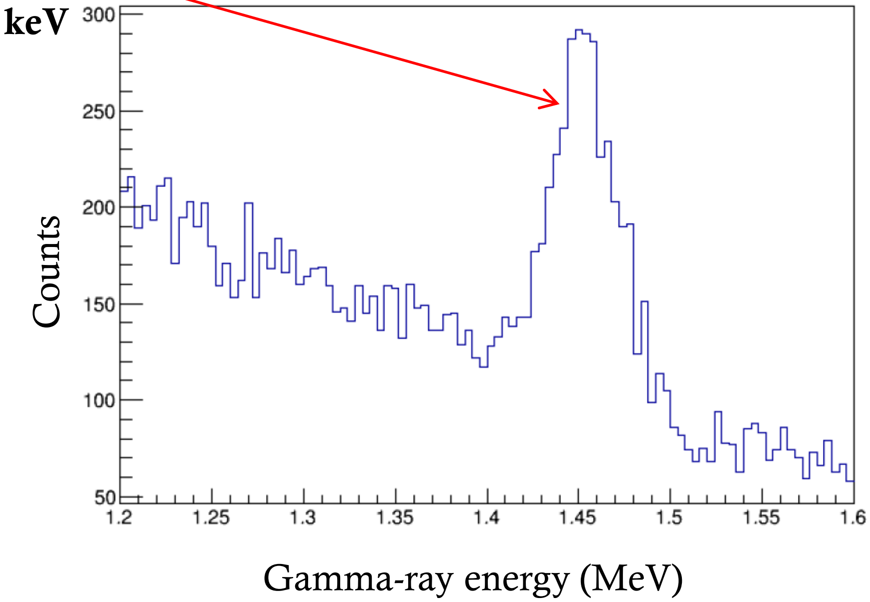
81 MeV beam

Adding a realistic detector to the mix

1448 keV
+
1453 keV

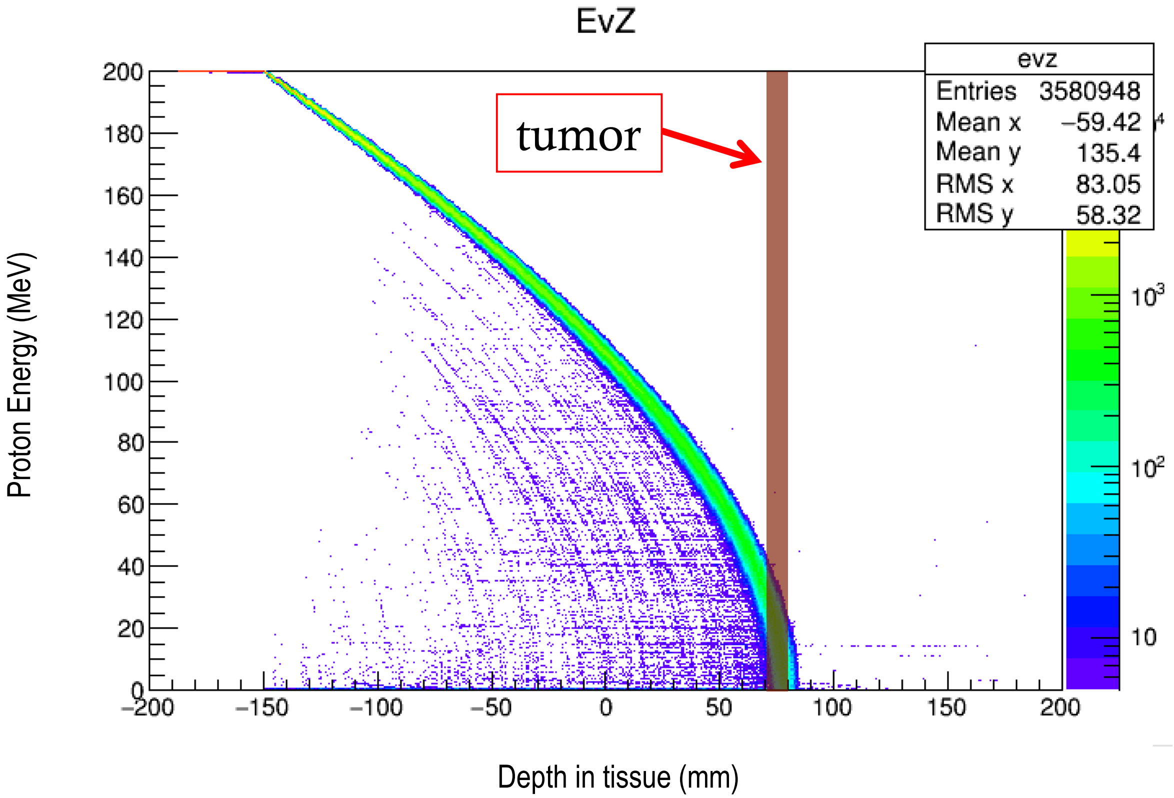


77 MeV beam



81 MeV beam

Geant4 Simulation Results



- Energy distribution of protons against depth in tissue.
- 10 000 events

Fusion-evaporation Reactions

$$^{98}Tc + p^{+} \rightarrow \; ^{97}Ru^{*} + 2n$$

Cross-section of ^{98}Tc fusion-evaporation reactions against proton energy