Detecting fusion-evaporation reaction products from contrast agents as a range verification technique in proton therapy

Presented by Eva Kasanda

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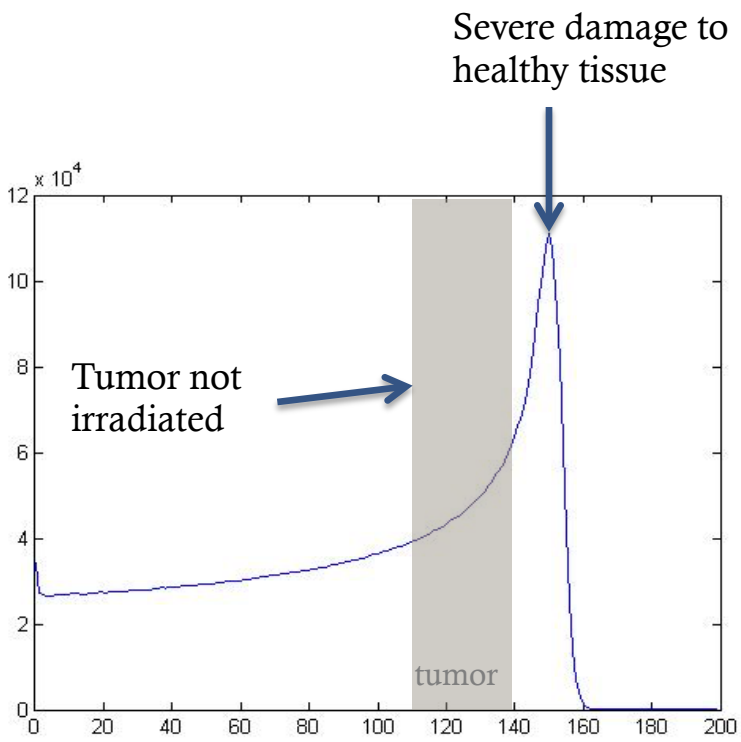
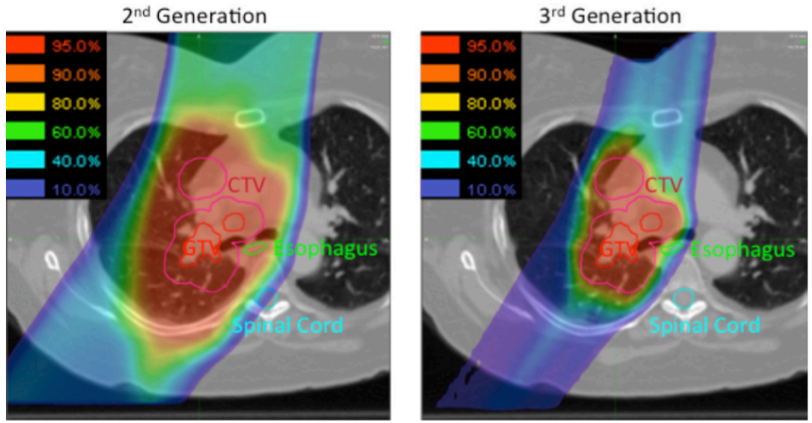
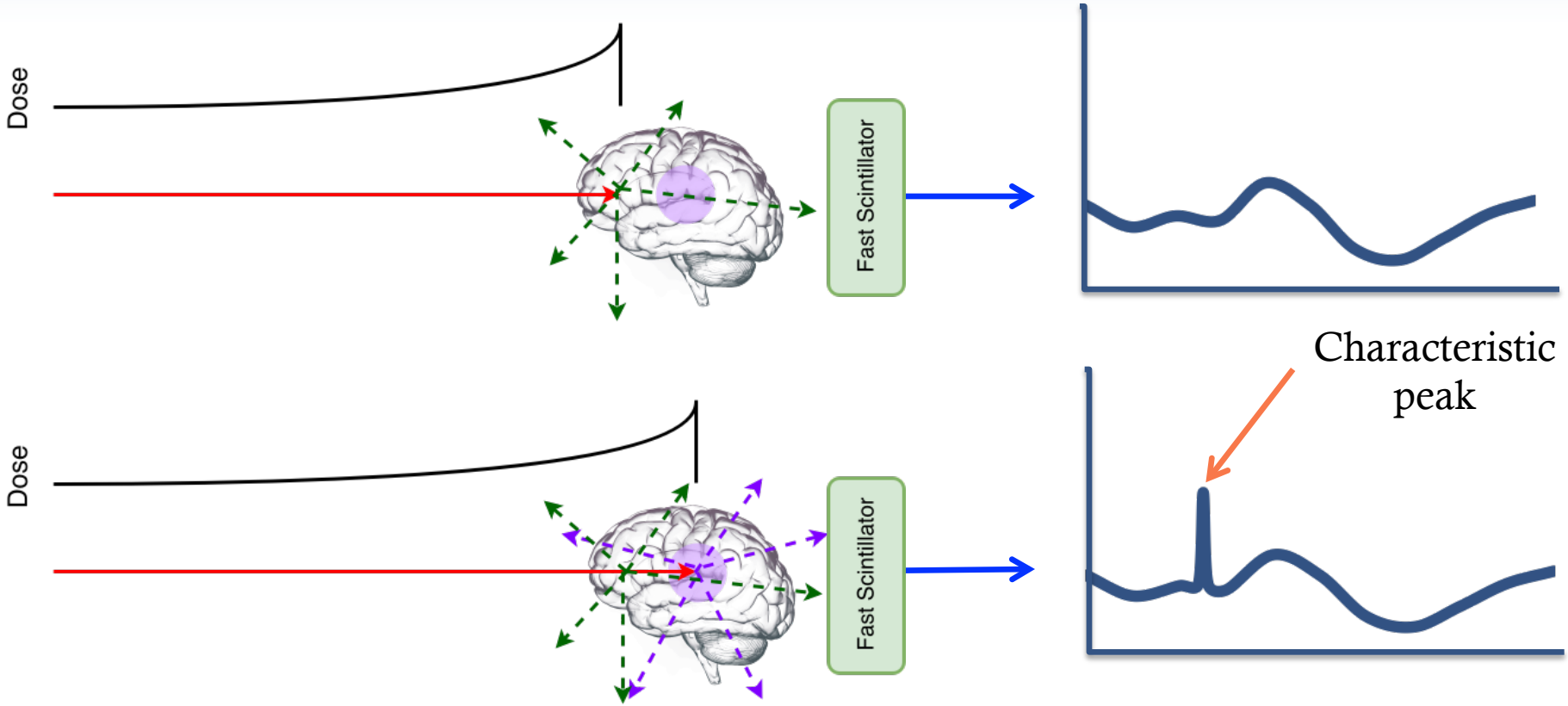
Range Verification in Proton Therapy



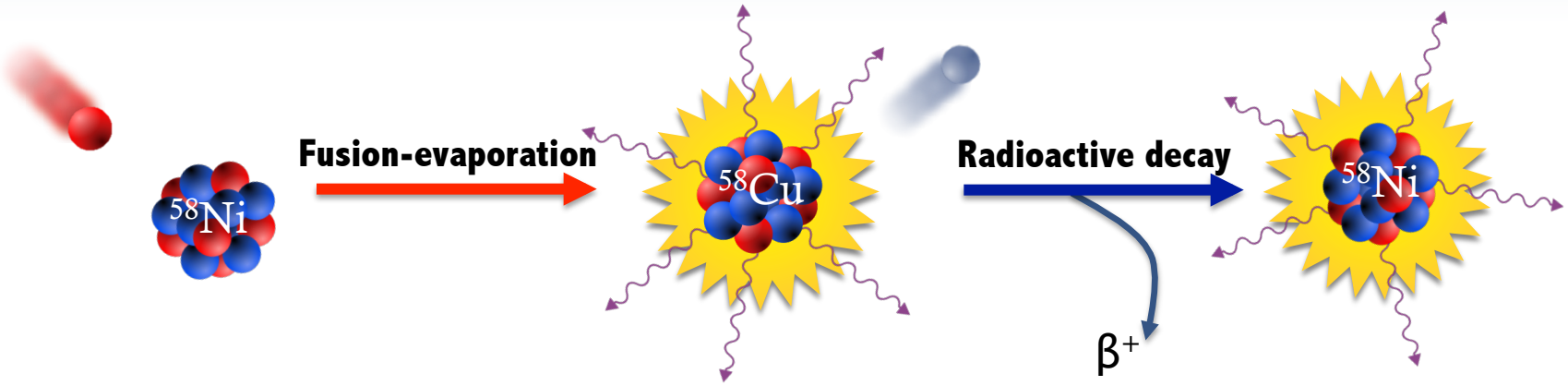
- Uncertainties from stopping powers, patient movement, etc. result in larger area needing to be irradiated

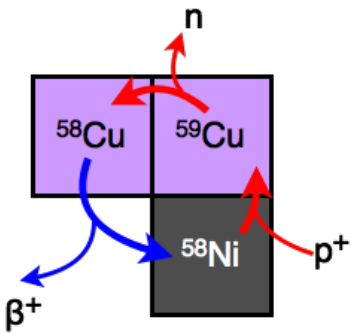


Using prompt γ -spectroscopy to measure range



Approaches to γ-detection





Prompt gamma rays:

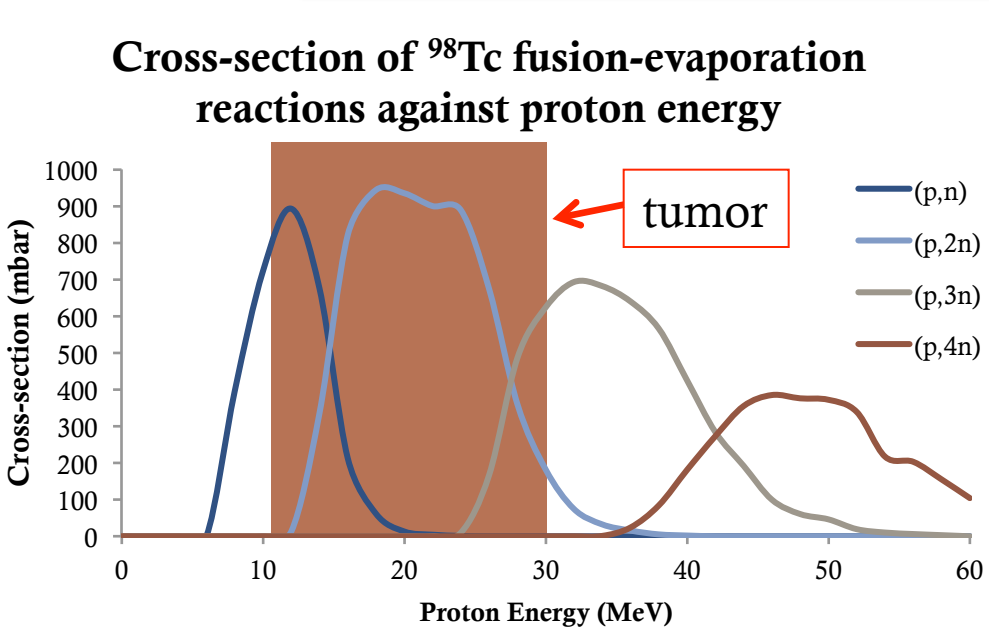
- ~ps-ns lifetimes
- measured when beam is online

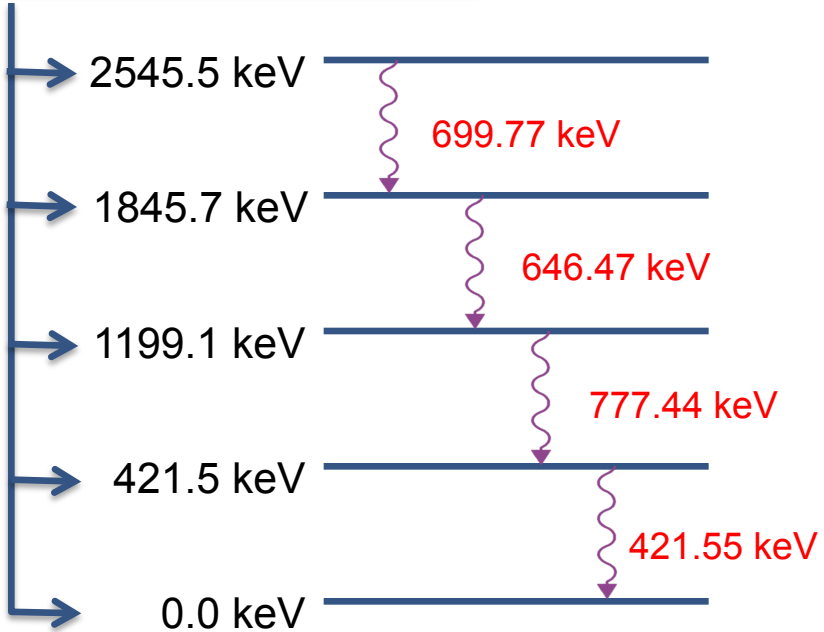
β-delayed gamma rays:

- ~s-min lifetimes
- measured between beam pulses or after treatment

Fusion-evaporation Reactions

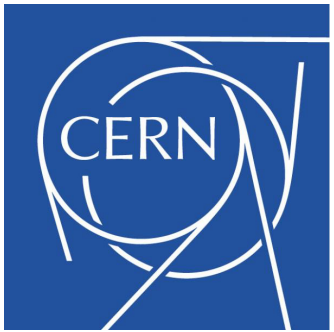
$$^{98}Tc + p^{+} \rightarrow {}^{97}Ru^{*} + 2n$$

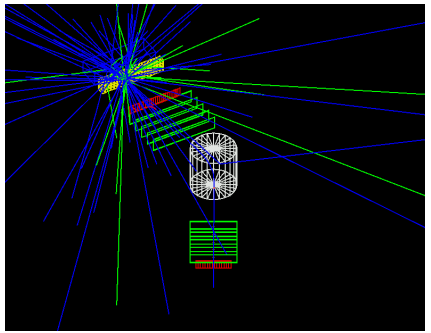




Geant4

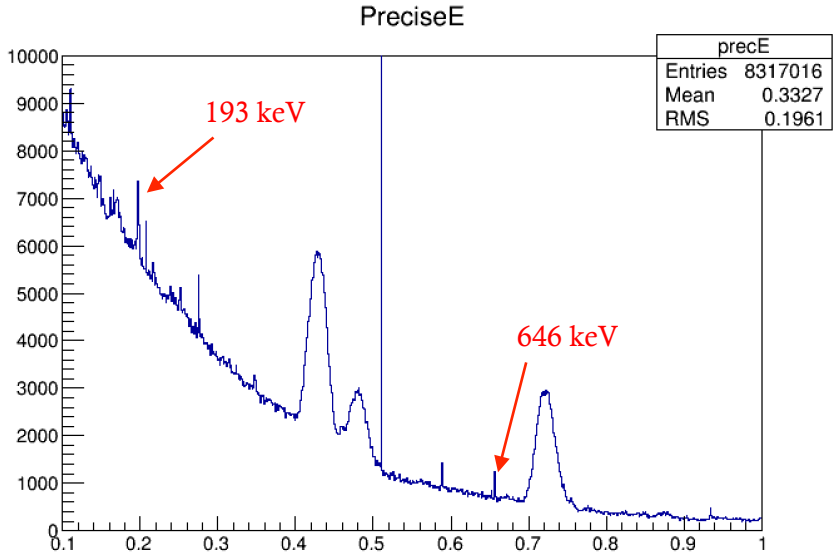
- Physics List: G4RadiationPhysics
- Current runtime for 1% of typical fraction dose:
  - ~300 computing hours
- Using “SharcNet” to obtain higher statistic run.



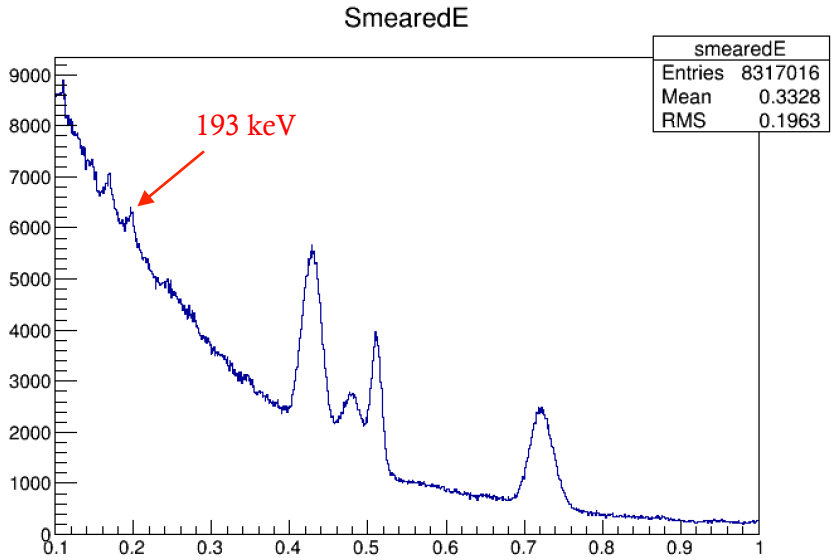


Background Suppression

1 second of treatment at 10% concentration of ^{98}Tc in the tumor, single gamma



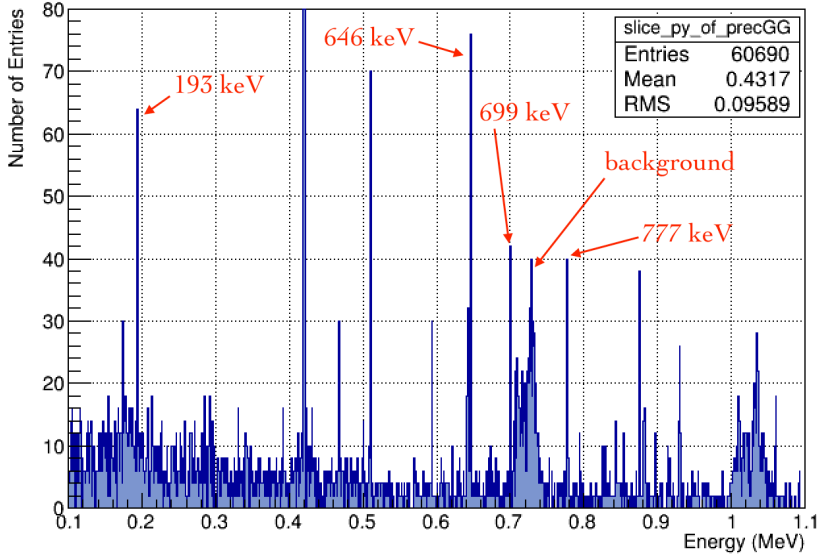
Detector with near-perfect time and energy resolution



$LaBr_3$(Ce) detector

Simulated γ - γ spectra for ^{98}Tc

1 second of treatment at 10% concentration of ^{98}Tc in the tumor



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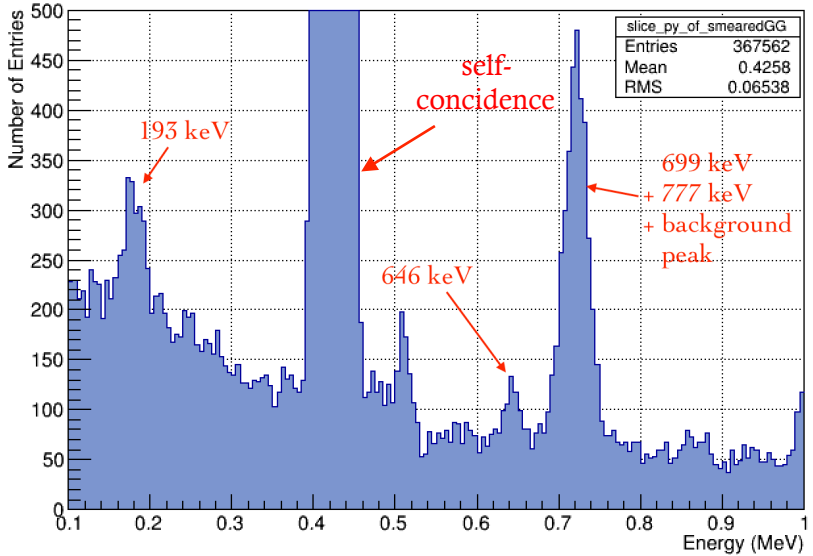
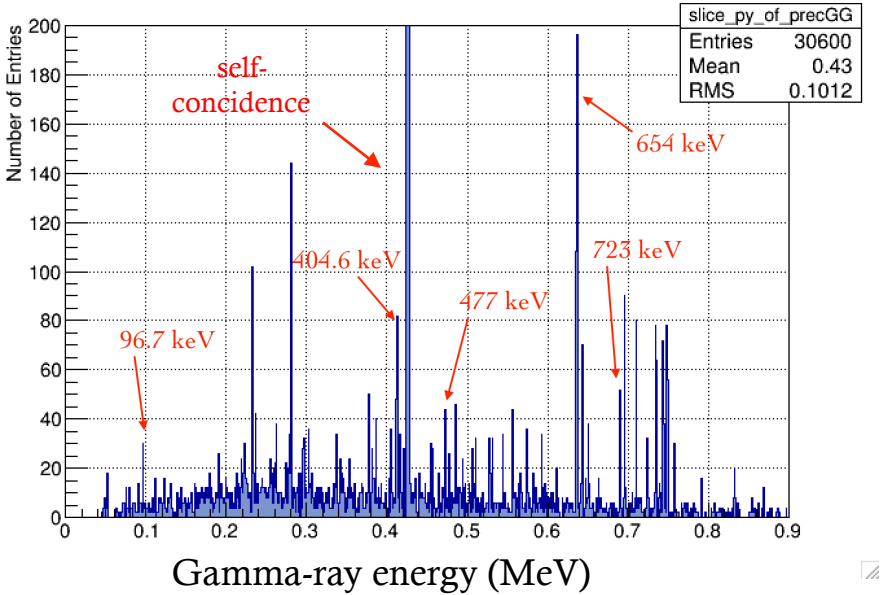
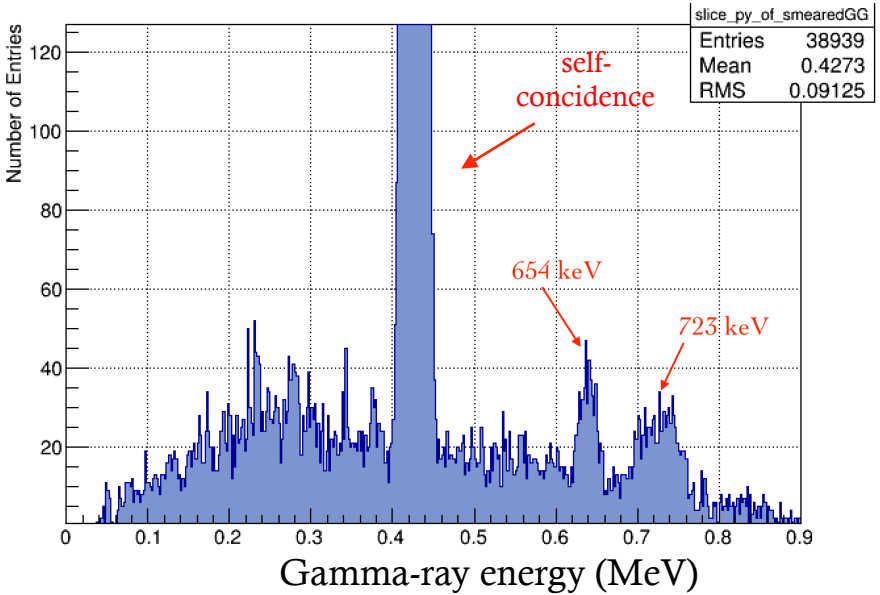


$LaBr_3$(Ce) detector

Simulated γ - γ spectra for ^{197}Au

1 second of treatment at 1% concentration of ^{197}Au in the tumor.



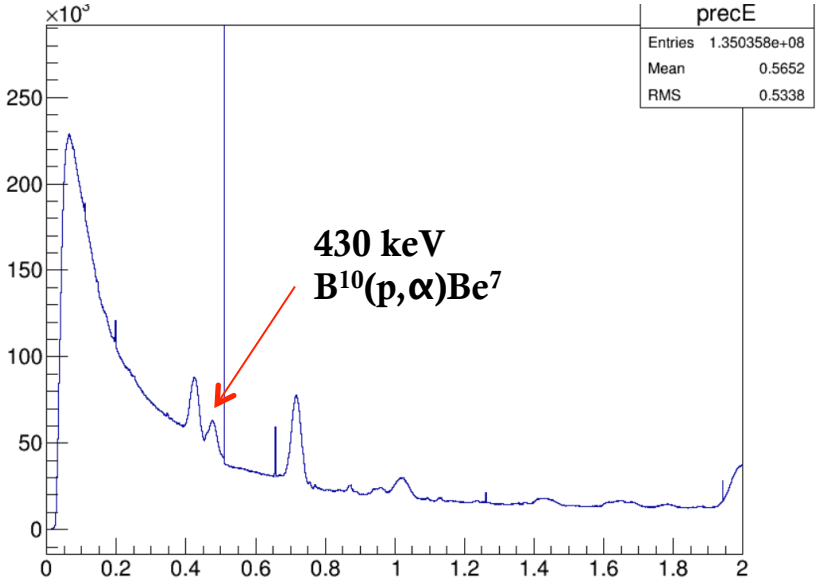


Detector with near-perfect time and energy resolution

$LaBr_3$(Ce) detector

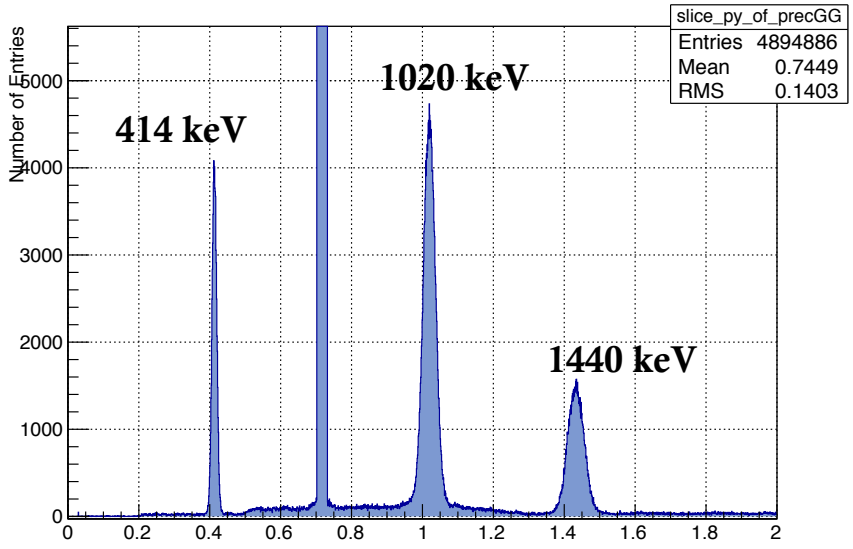
Simulated spectra for ^{10}B

1 second of treatment at 1% concentration of ^{10}B in the tumor



Gamma-ray energy (MeV)

Single gamma spectrum

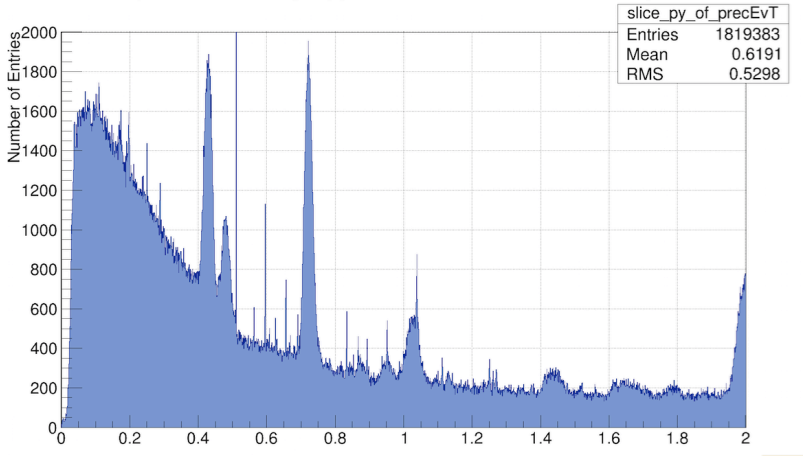


Gamma-ray energy (MeV)

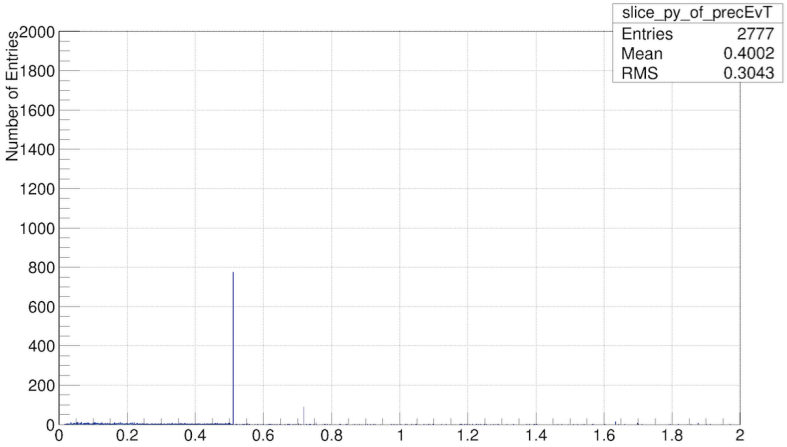
Gamma-gamma spectrum

Beta-delayed gamma spectra

Plots of single gamma background for a time period of 0.1s. **L. Carinci**



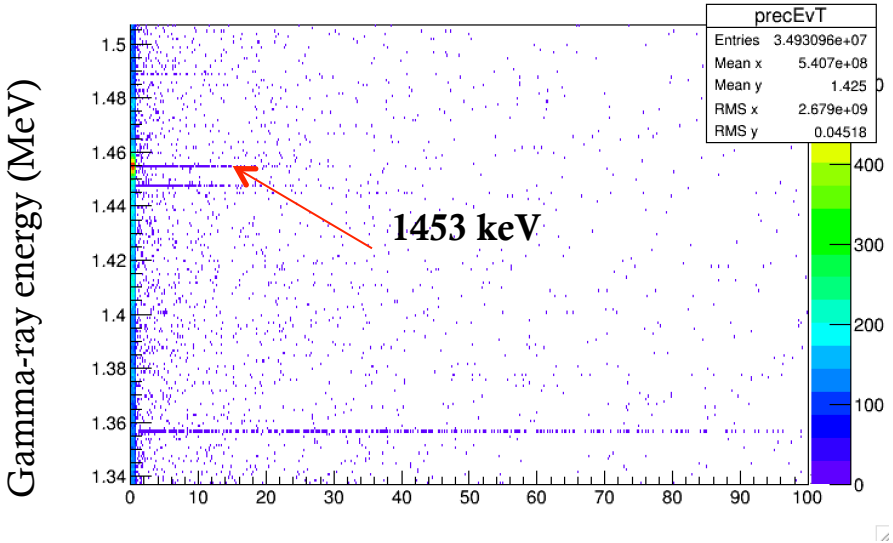
Beam-on



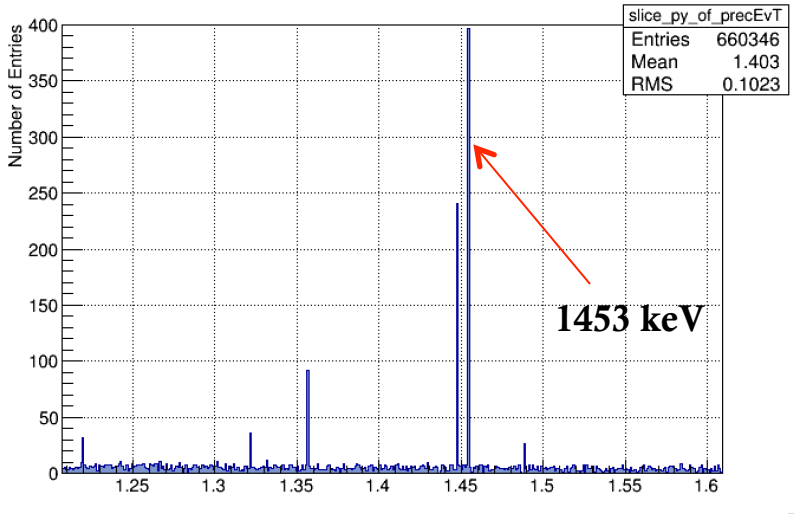
Immediately after beam is turned off

Beam on	Beam off

Simulated time-gated spectra for ^{58}Ni



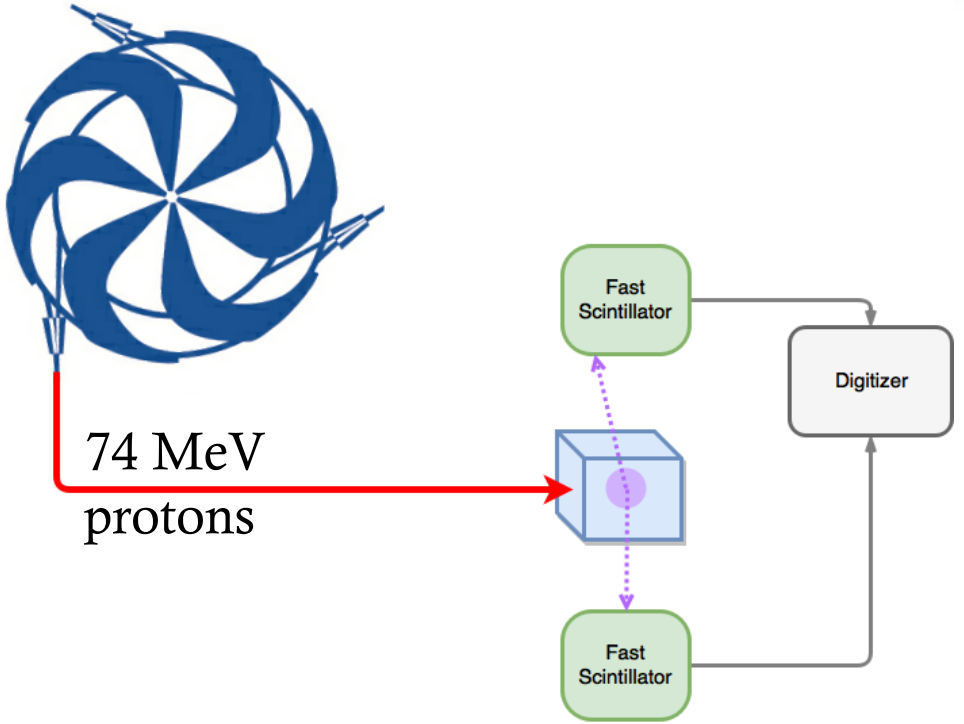
Gamma energy against time for 1 second of beam-on time.



Projection of first few beam-off seconds onto energy axis.

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., Hackman, G., Svensson, C. E., Burbadge, C., Hymers, D., Olaizola, B., Stachuta, M., Duzenli, C., Carinci, L., Tan, J.

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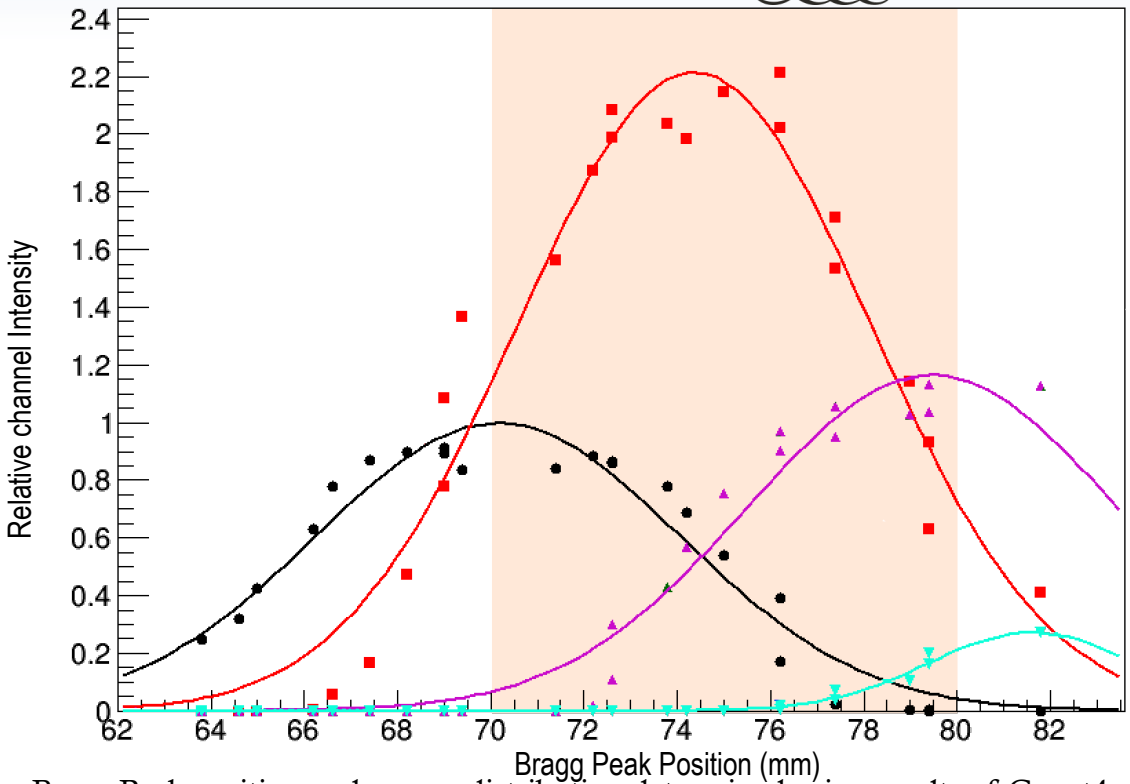
Geant4 Simulation Results

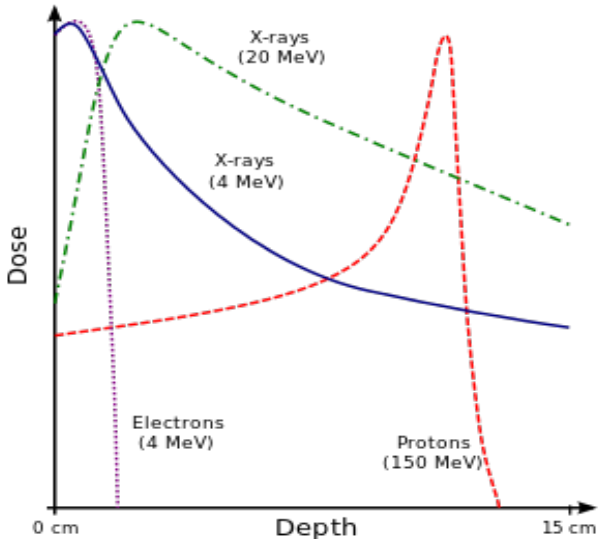


- $^{98}Tc(p,n)^{98}Ru$
- $^{98}Tc(p,2n)^{97}Ru$
- $^{98}Tc(p,3n)^{96}Ru$
- $^{98}Tc(p,4n)^{95}Ru$

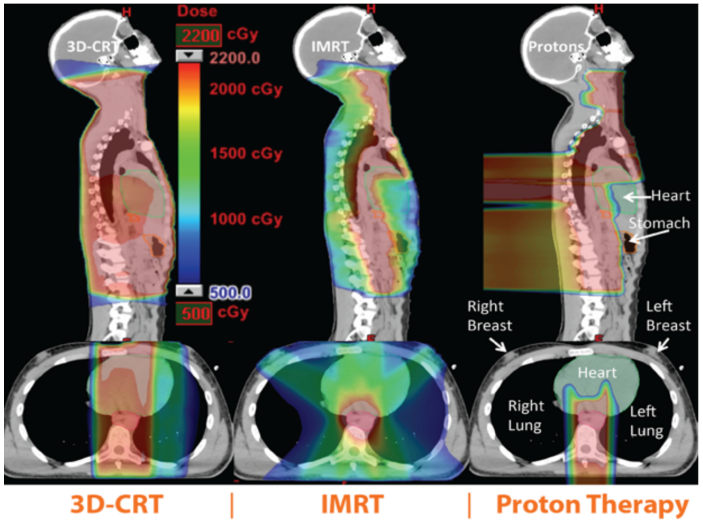
- Bragg Peak position and energy distribution determined using results of Geant4 simulation with 10 000 events.
- Channel intensity calculated by weighing theoretical cross section with number of protons in tumor

Range verification in Proton Therapy

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

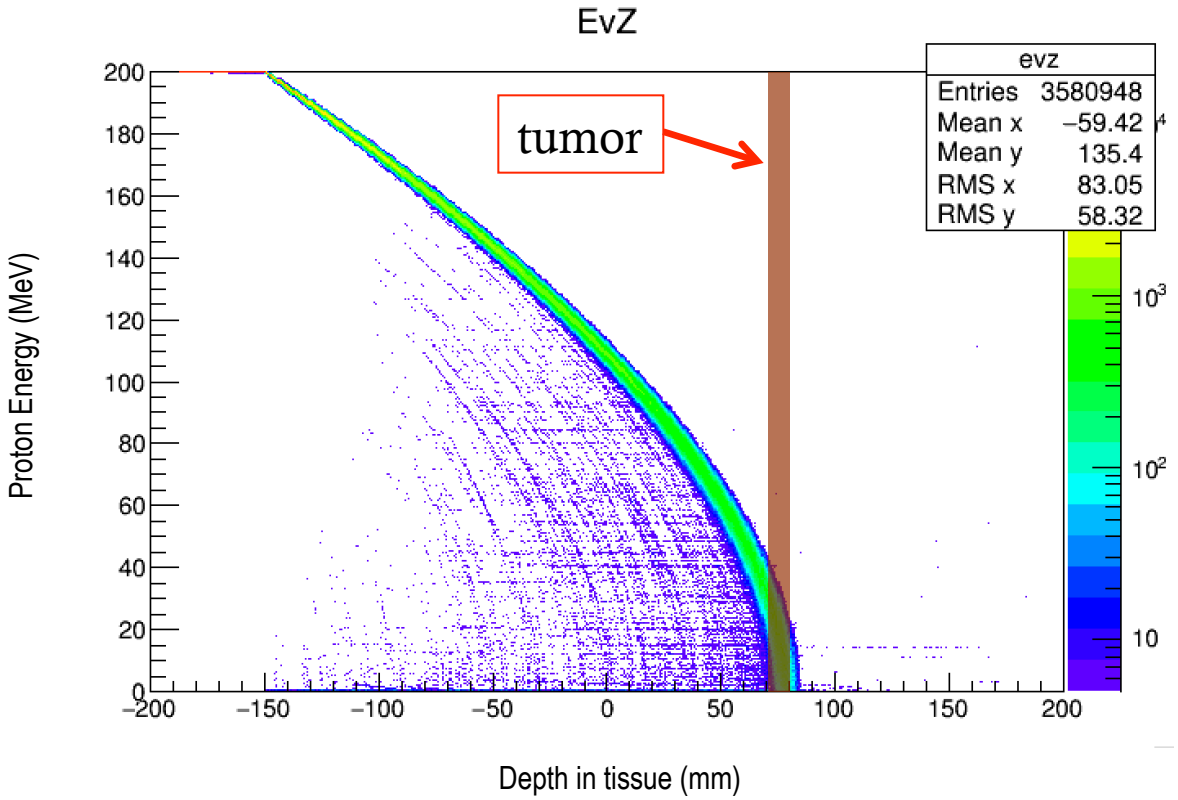


Zhu, X., and Fakhri, G. Proton therapy verification with PET imaging. Theranostics 3, 10 (2013).



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

Geant4 Simulation Results



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