The Danish Centre for Particle Therapy

Jacob G. Johansen

The Danish Centre for Particle Therapy

Jacob G. Johansen

The facility

The research

A potential collaboration with FOOT

Jacob Johansen (my background)

Associate professor
Department of Clinical Medicine
Department of Physics and Astronomy
Aarhus University

Experience:

2008-2012: PhD in experimental nuclear physics (Aarhus, DK)

2013-2014: Postdoc in experimental nuclear physics (Darmstadt, De)

2015-2016: Postdoc in experimental nuclear physics (Aarhus, DK)

2016-2020: Research assistant (DCPT, DK)

2020 - : Associate professor (DCPT, DK)

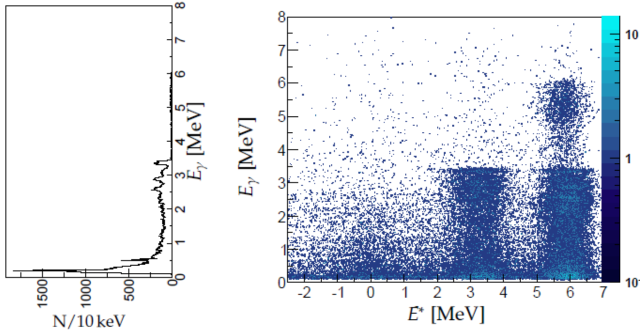
PhD project

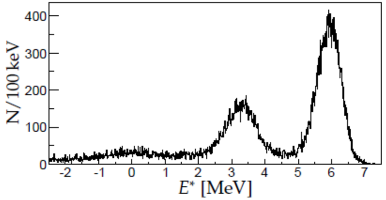
Investigation of neutron-rich Beryllium isotopes through transfer reactions in inverse kinematics

The Miniball setup at ISOLDE, CERN

8 segmented HpGe + 16 ΔEE Si-strip

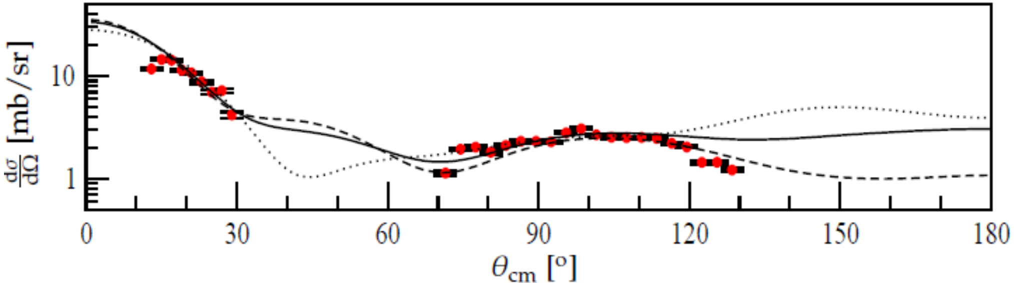
Coincidence measurements





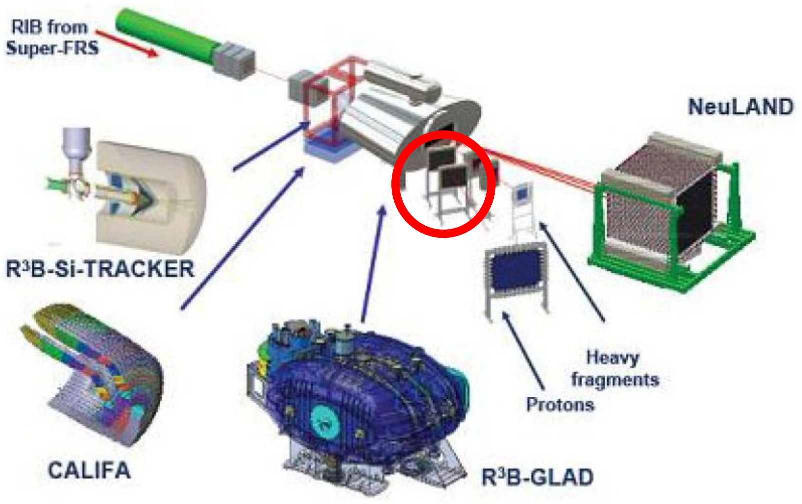
$^{11}Be(d,t)^{10}Be$

Differential cross sections



Post doc position (Germany)

R3B (Reactions with Relativistic Radioactive Beams) at GSI



Mini-fiber grid detector for proton tracking

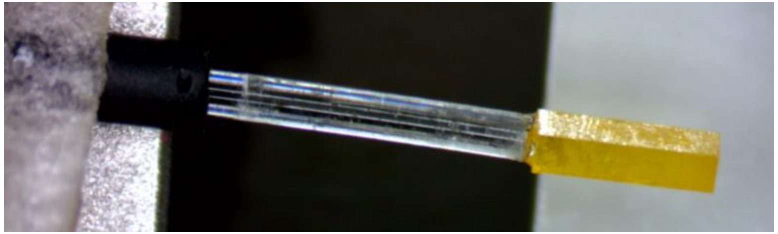
- Method to mount parallel fibers
  - 2x1024 100um thick plastic fibers
- Testing of different photodetectors
  - Silicon Photomultiplier
  - Multipixel PMT (256 pixels)
- Testing of different DAQ-systems
  - NXYTER (GSI)
  - FEBEX (GSI)
- Prototype developed and tested

Associate professor position

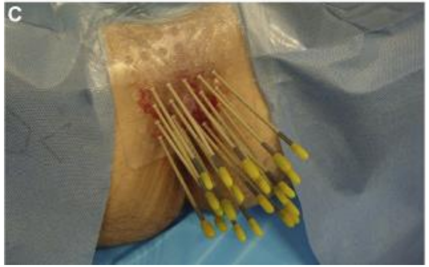
Time-resolved dosimetry using an inorganic scintillator-based point detector

The detector

0.5x0.5x(0.5-2)mm^3 ZnSe(O) + 15 m optical fiber

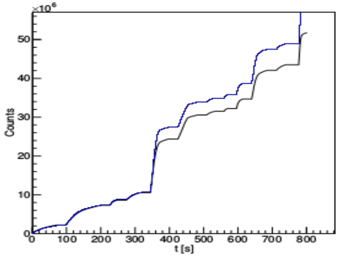


Brachytherapy (cancer treatment wiht radioactive sources)

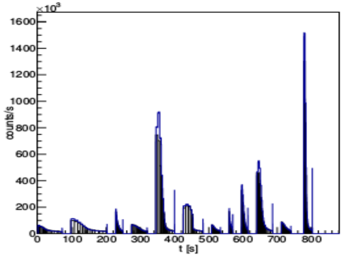


Avalanche photodiode

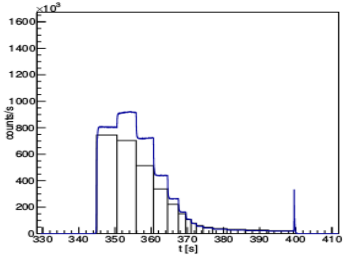
Accumulated dose



Dose rate



Dose rate of one needle



Associate professor position

Time-resolved dosimetry using an inorganic scintillator-based point detector

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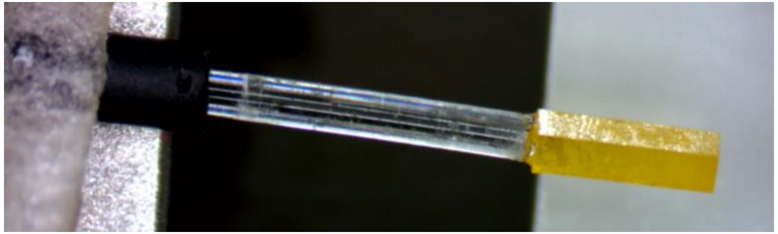
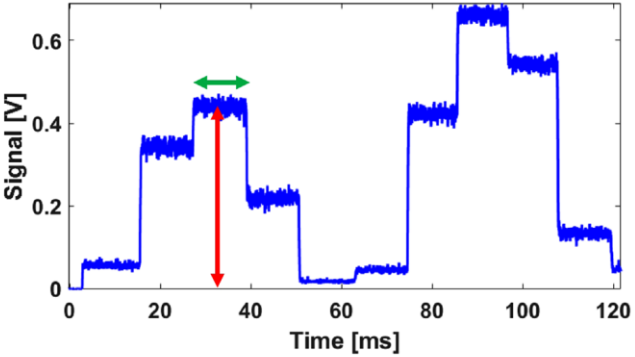
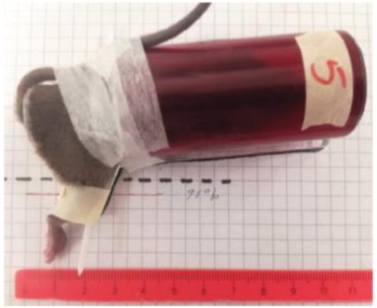
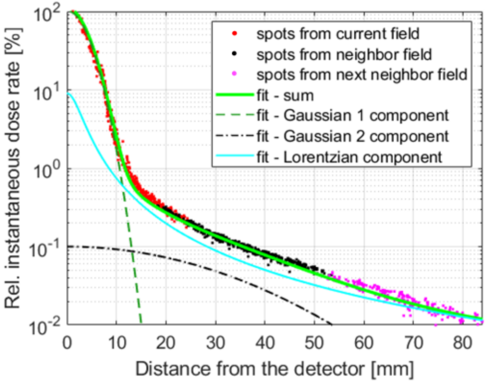


SiPM



Proton therapy (Murine studies)





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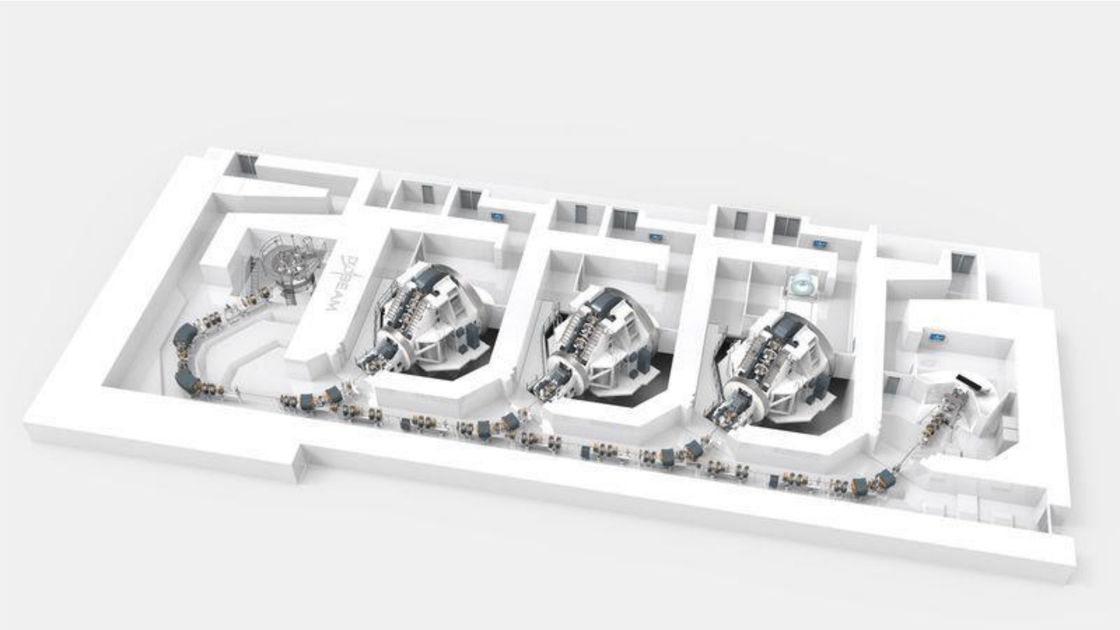
The danish Centre for Particle Therapy

Key numbers:

- First patient treated in 2019
- Today 300 patients/year
- Only proton facility in Denmark

- 1 cyclotron
- 3 gantries (patient treatment)
- 1 fixed beam (research)



The cyclotron

Key numbers:

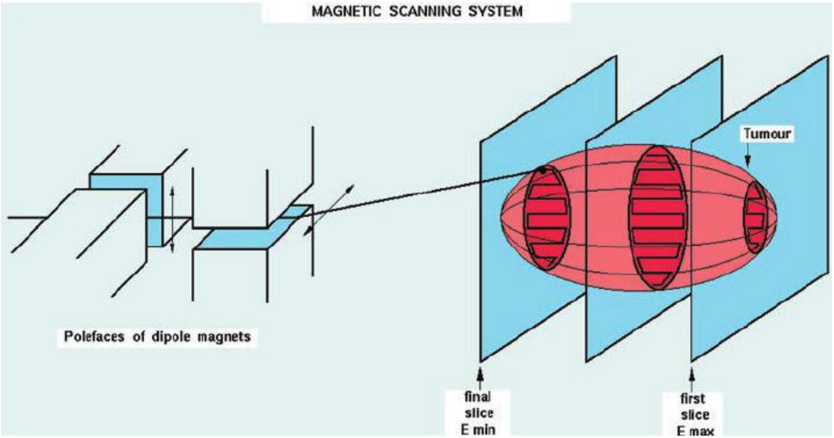
- Weight: ~90 tons
- Diameter: Ø3.1 meter
- Operating T: 4.2 K
- Magnetic field: 2.4 T

- RF frequency (beam pulse frequency): 72.8 MHz
- Pulse width: 4-6 ns
- E_{beam}: 70 MeV – 250 MeV
- I_{beam}: 10 nA – 800 nA
- Yield: 0.1 % (70 MeV) – 1 % (170 MeV)
- Minimum protons/pulse: ~10 (every 14 ns)

The Gantries

Key numbers:

- 360º rotation
- Pencil beam scanning
- Spread out Bragg peak by changing E_{beam}



The Gantries

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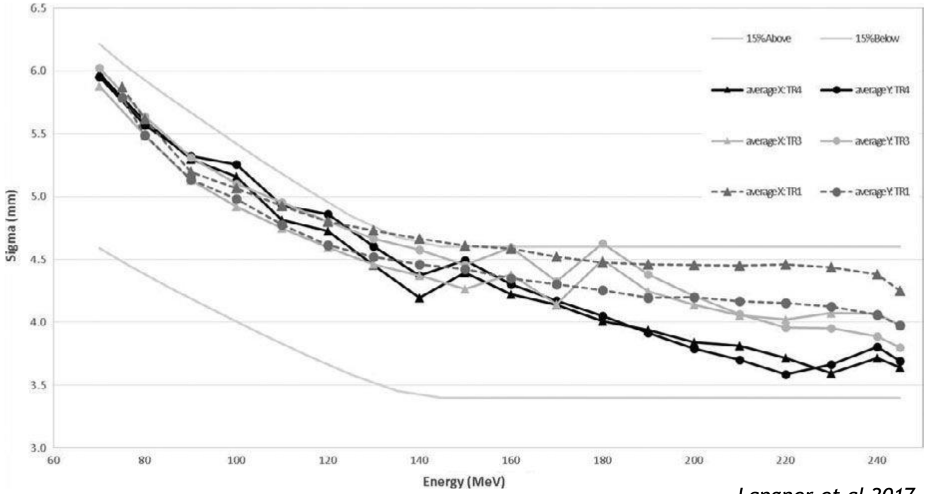
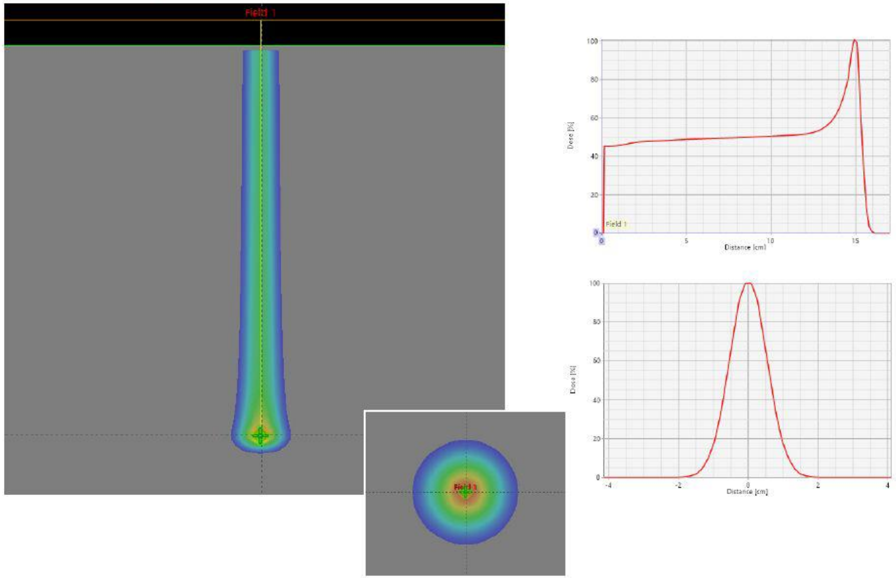


Langner et al 2017

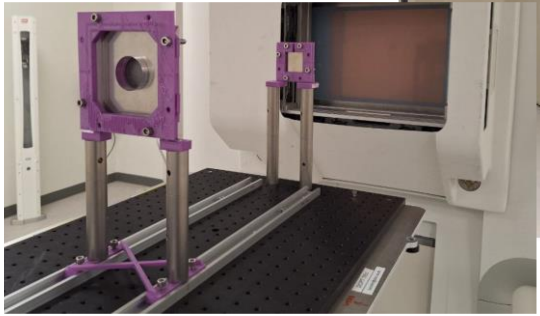
147 MeV, Range = 15 cm

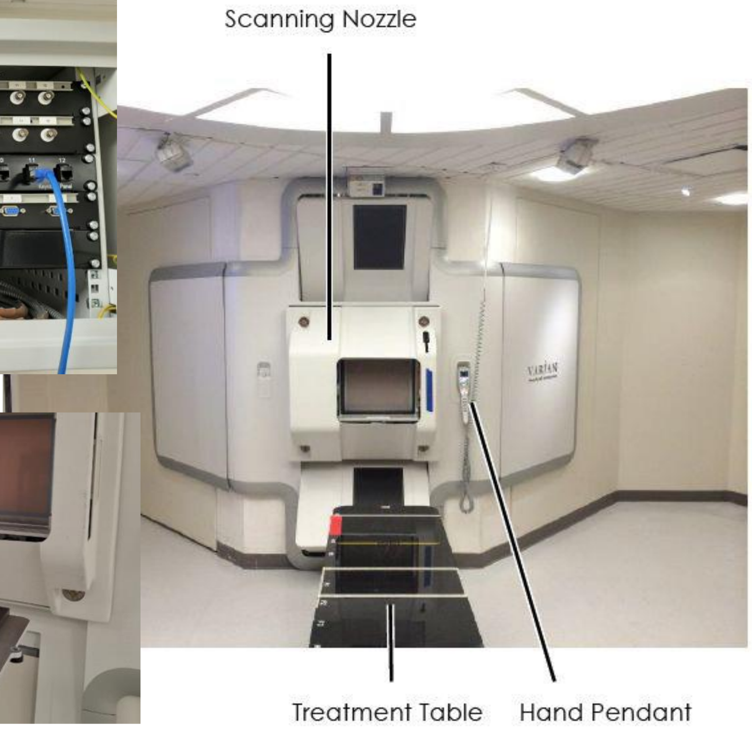


The experimental beam line

<u>Key numbers:</u>

- Fixed 90º beam line
- Treatment couch
- Dedicated setups for murine studies
- Easy access to mouse stable
- Breadboard available (fitted to couch)
- Passive beam line (N. Bassler)
- Room available 24-7
- Beam normally available working days after 18 (may vary)
- Possible to apply for beam time





https://www.en.auh.dk/departments/the-danish-centre-for-particle-therapy/research/research-facilities/

The Danish Centre for Particle Therapy

Jacob G. Johansen

The facility

The research

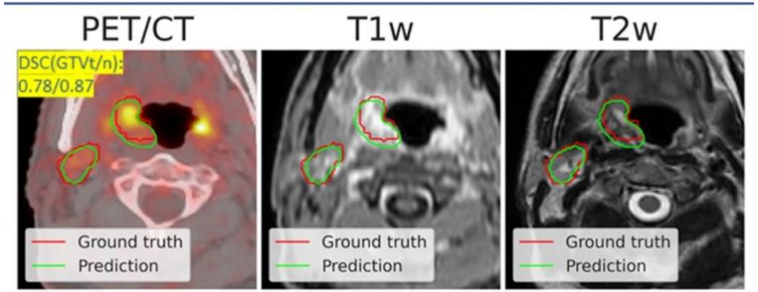
A potential collaboration with FOOT

The research staff

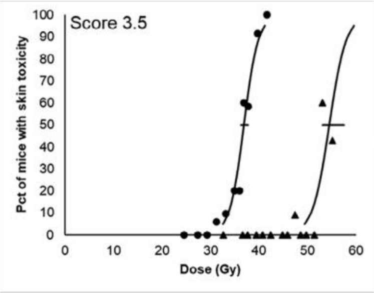
- 18 Senior scientists
  - 8 Medical doctors
  - 8 physicists
  - 1 Data scientists
  - 1 biologist
- 9 Postdocs
- 33 PhD students
- ~10 undergraduate students

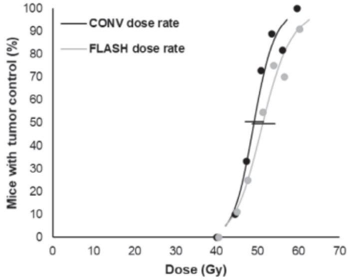
Research project examples

Artificial intelligence in radiohterapy

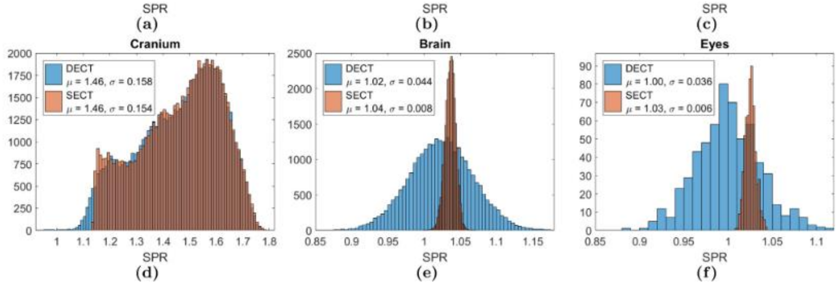


FLASH radiotherapy





CT number to proton stopping power



Clinical studies

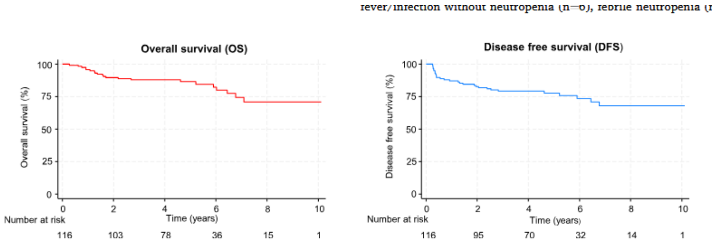


Fig. 1. Kaplan-Meier survival curves **A)** Disease free survival (DFS), 5-year DFS was 77.7% (95%CI 68.7%;84.5%) **B)** Overall survival (OS), 5-year OS was 8
(95%CI 78.3%;91.7%).

https://www.en.auh.dk/departments/the-danish-centre-for-particle-therapy/research/research-groups/

Niels Bassler and his research

Professor
Department of Clinical Medicine
Aarhus University

Experience:

2003-2006: PhD in applied physics (Aarhus, DK)

2006-2009: Post.doc. German Cancer Research Center, Heidelberg (DE)

2009-2013: Senior Scientist/Research Group Leader, Aarhus University (DK)

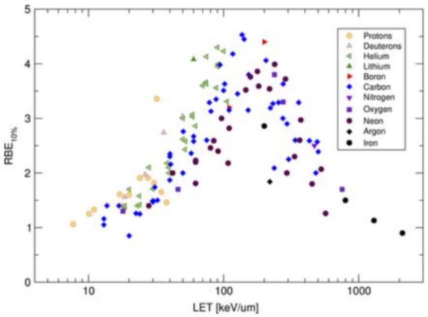
2013-2016: Associate professor, Aarhus University (DK)

2016-2020: Associate professor, Stockholm University (SE)

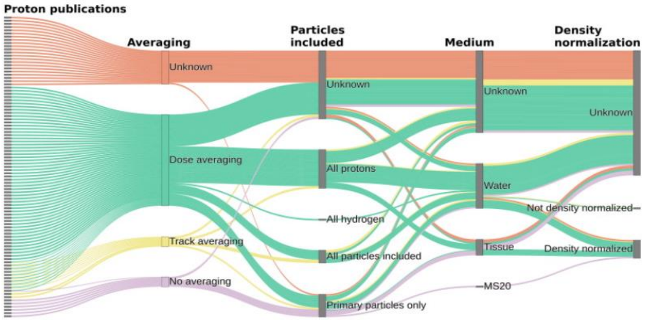
2020 - : Professor (DCPT, DK)

Example of studies from Niels Bassler's group

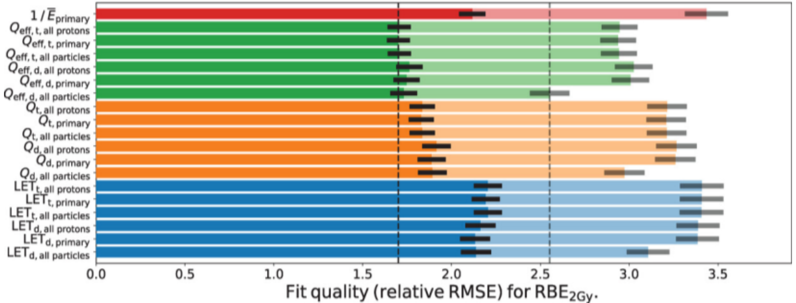
The relation between biological effect (RBE) and linear energy transfer (LET)



Schuemann J, Bassler N, Inaniwa T. Computational models and tools. Medical physics. 2018 Nov;45(11):e1073-85.



Kalholm F, Grzanka L, Traneus E, Bassler N. Radiotherapy and Oncology. 2021 Aug 1;161:211-21.



Kalholm F, Grzanka L, Toma-Dasu I, Bassler N. Modeling RBE with other quantities than LET significantly improves prediction of in vitro cell survival for proton therapy. Medical Physics. 2023 Jan;50(1):651-9.

Boron-proton/neutron capture therapy for increased LET

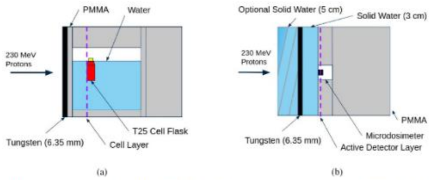


Figure 2. Graphical illustrations of the experimental setup for NCEPT *in vitro* measurements (a) and microdosimetric measurements (b).

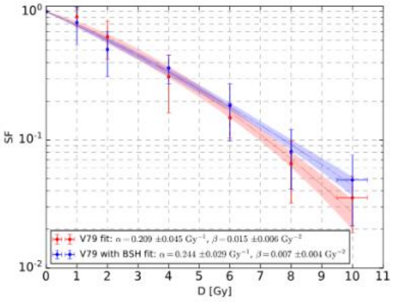


Figure 5. Cell survival curve for three biological replicas of V79 cells exposed to BSH prior and during irradiation (blue curve) and non-exposed cells (red curve).

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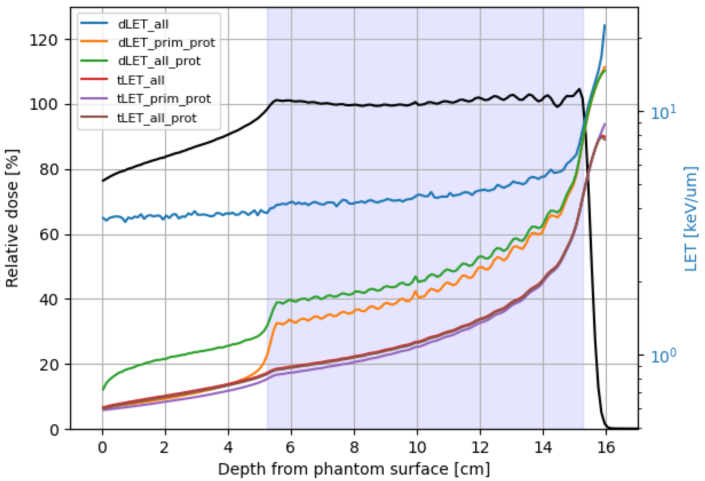
The facility
The staff
The research

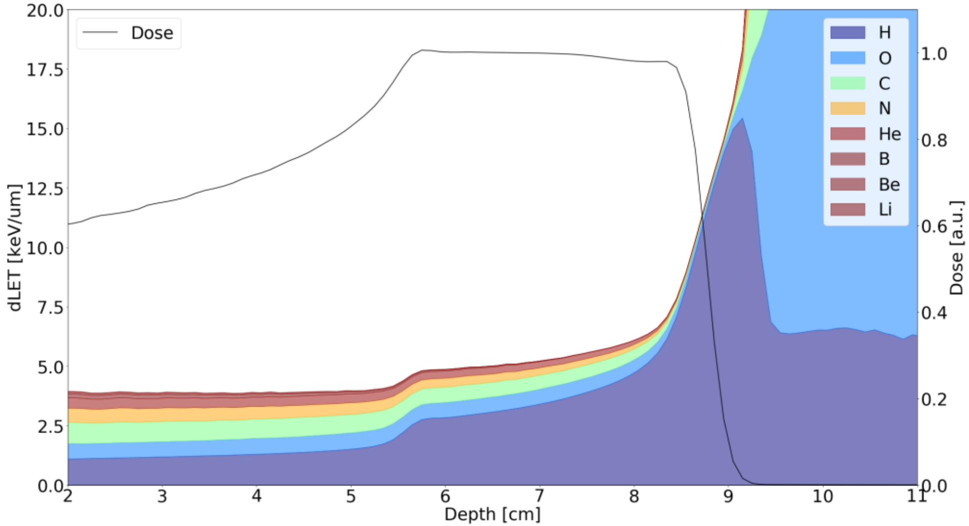
A potential collaboration with FOOT

Impact of reaction cross section uncertainties

Impact of averaging on LET.

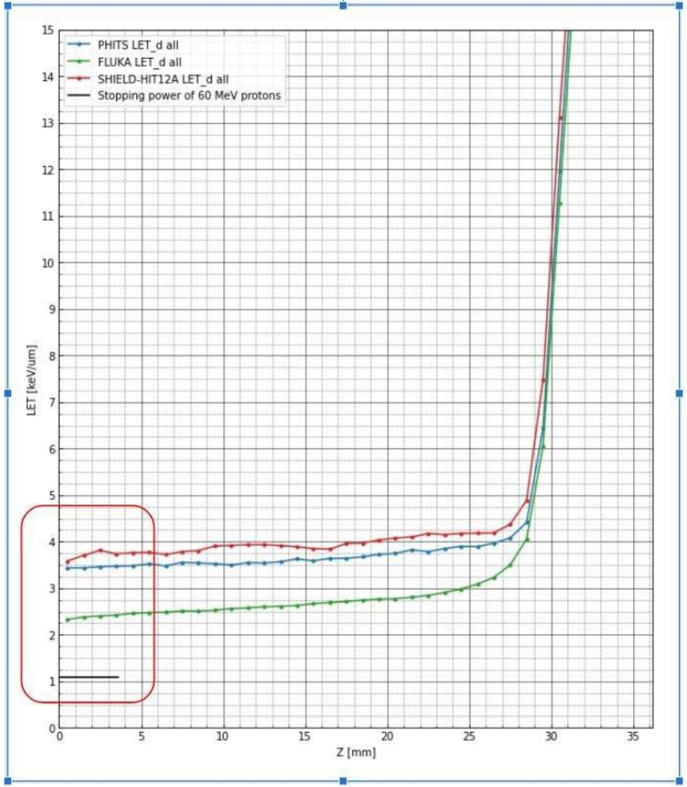


Fragment contribution to dose-averaged LET.



(Figure and MC calculation by Leszek Grzanka, SHIELD-HIT12A)

Impact of reaction cross section uncertainties



LETd (all particles) depth profile:

FLUKA predicts much lower LETd_all in entrance channel than PHITS/SHIELD-HIT12A

Experimentally measured y_d in CATANA is ~**3.5 keV/um**

LETd_all for **PHITS** and **SHIELD-HIT12A** close to LETd_total calculated by Geant4 in [6].

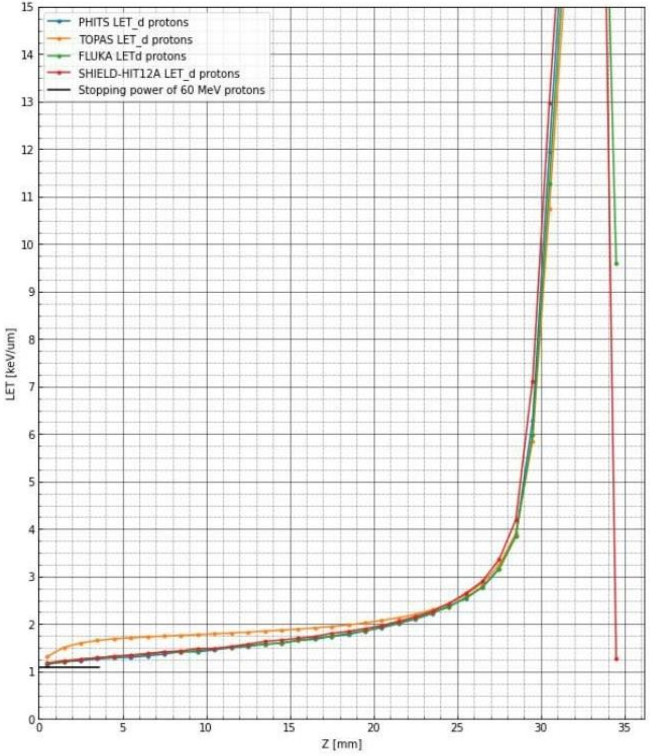
LETd_all **FLUKA** compatible with results from [5]
2.1 keV/um in entrance channel of 150 MeV proton beam

TOPAS excluded from further analysis: default scorer non capable of calculating the LETd_all

[5] Embriaco, A., et al. "FLUKA simulation of target fragmentation in proton therapy." Physica Medica 80 (2020): 342-346.
[6] Romano, Francesco, et al. "A Monte Carlo study for the calculation of the average linear energy transfer (LET) distributions for a clinical proton beam line and a radiobiological carbon ion beam line." Physics in Medicine & Biology 59.12 (2014): 2863.

(Figure and MC calculation by Leszek Grzanka, SHIELD-HIT12A)

Impact of reaction cross section uncertainties



LETd (protons) depth profile:

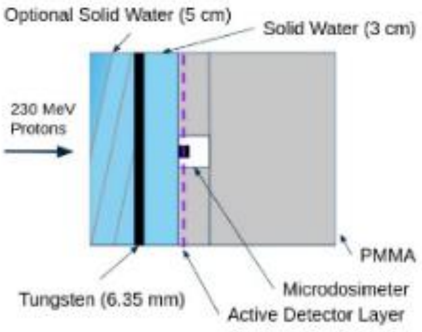
- Very good agreement between various MC codes, **except TOPAS**
- Most differences in the entrance channel

Note: custom user-compiled scorer for FLUKA, based on GETLET function [4]

[4] Johnsen, Kine. Simulations of a Therapeutic Proton Beam with FLUKA Monte Carlo Code and Varian Eclipse Proton Planning Software. MS thesis. The University of Bergen, 2013.

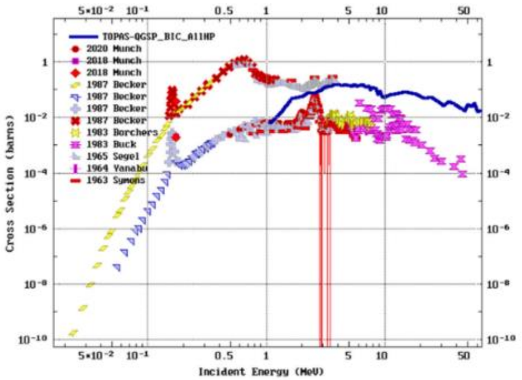
(Figure and MC calculation by Leszek Grzanka, SHIELD-HIT12A)

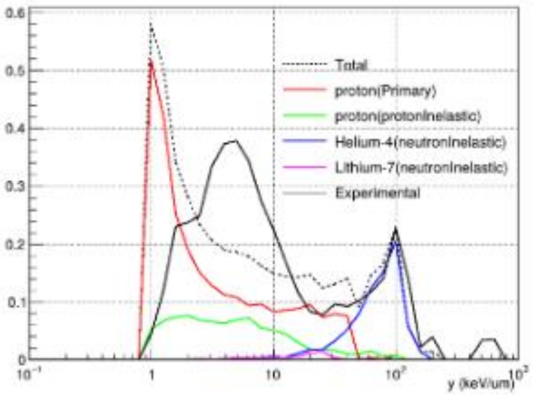
Comparison of MC simulation and microdosimetry



(b)

Jacobsen VL, Pan VA, Tran LT, Vohradsky J, Bønnelykke J, Herø CS, Johansen JG, Frederiksen A, Sørensen BS, Busk M, Sauerwein WA. Physics in Medicine and Biology. 2025 Feb 3.





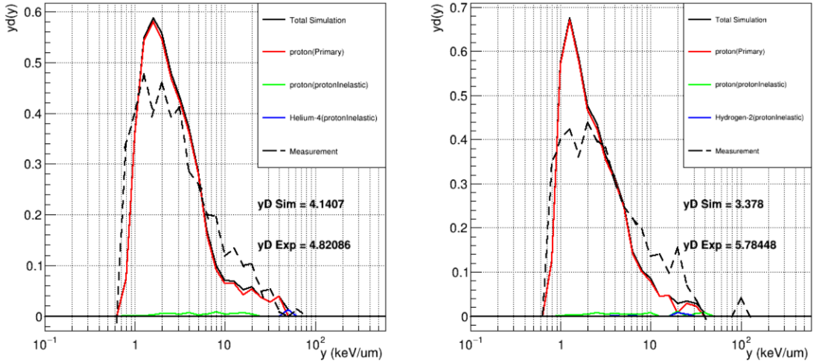
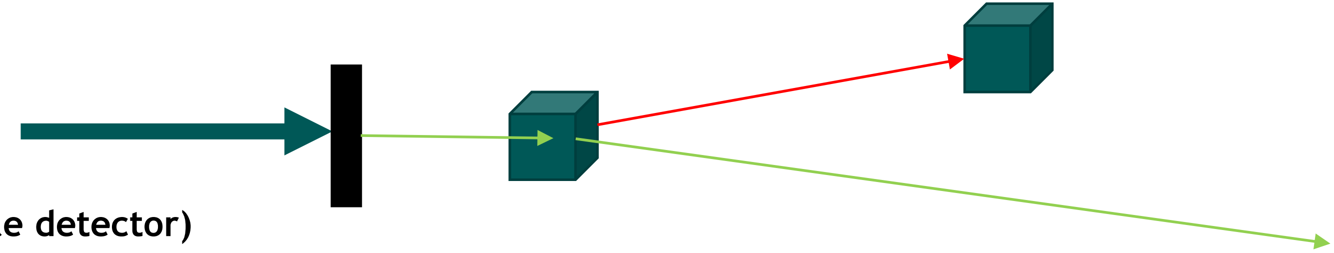


Figure 2: Comparison of Monte Carlo simulations and experimentally determined energy-deposition spectra for protons on a Silicon-On-Insulator microdosimeter.

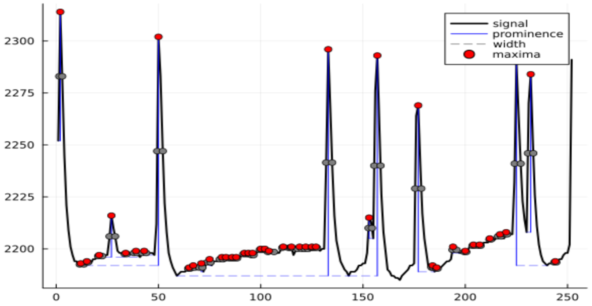
A fast neutron detector (master project)

Neutron detection

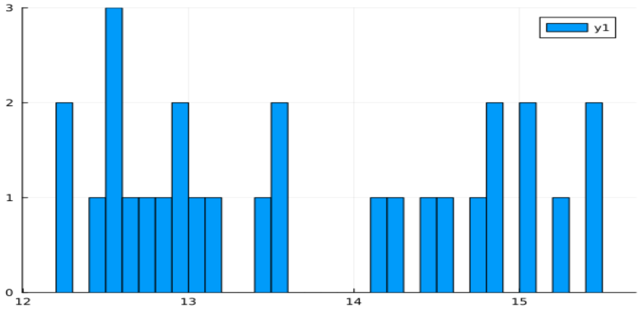
- Coincidence events in two detectors after each other
- Neutron interact with first scintillator, creating a proton, which will be detected in the second
- Energy from time-of-flight
- Picosecond temporal resolution and distances of meters



First tests (single detector)



Raw signal



Measured times between pulses

Examples of projects with FOOT

- 12C(p,alpha) or 16O(p,alpha) reaction cross section measurements
- Development of neutron detector
- Neutron production cross section measurements (angular dependence)
- Facilitating clinical beam or proton beam line

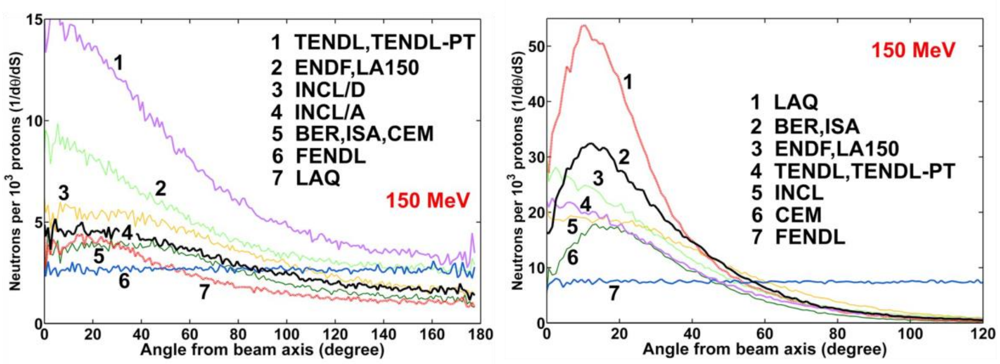


Figure 1: Plots showing the angular distribution of emitted neutrons for a proton beam traveling through a cube of water. The plots are made from simulations using different physics lists as noted in the figure. Top: High-energy neutrons (>10MeV). Bottom: Low-energy neutrons (<10MeV). Plots are taken from [6]