

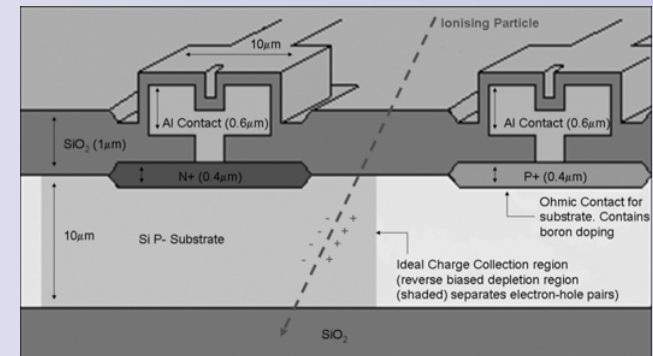
# Geant4-based studies to characterise the tissue-equivalence of SOI and diamond microdosimetric detectors, under development at CMRP

S. Dowdell, S. Guatelli, P. Lazarakis, and A. B. Rosenfeld

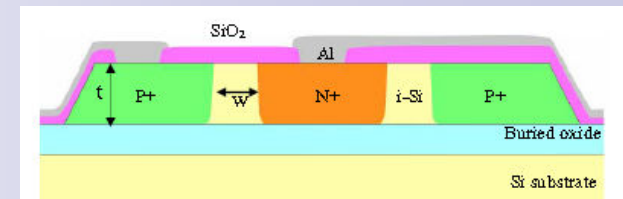
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# Silicon microdosimetry

- Microdosimetry measures energy deposition on a cellular scale
- Silicon On Insulator (SOI) microdosimeters have been under investigation at CMRP for the past ten years as a possible alternative to tissue equivalent gas counters
- Applications in radiation protection in space and dosimetry in medical physics
- Collaboration of CMRP with
  - Australian Nuclear Science and Technology Organisation
  - University of New South Wales, Australia



*First generation SOI detector*



*Second generation SOI detector*



# Geant4 for microdosimetry

- **Characterisation of SOI microdosimeter**
  - Response of the detector in radiation fields of interest
    - Proton therapy
    - Fast neutron therapy
    - Radiation protection in terrestrial, aviation and space
  - Chord length distribution
  - Tissue equivalence
    - Methodology to convert microdosimetric spectra in silicon to tissue

# Geant4 for microdosimetry

- Advanced capability in physics and geometry modelling
- Good agreement between experimental and simulated microdosimetric spectra

A. B. Rosenfeld, A. J. Wroe, I. M. Cornelius, M. Reinhard, and D. Alexiev, "Analysis of inelastic interactions for therapeutic proton beams using Monte Carlo simulation", *IEEE Trans. Nucl. Sci.*, vol. 51, no. 6, pp. 3019-3025, 2004.

A. B. Rosenfeld, A. Wroe, M. Carolan, and I. Cornelius, "Method of Monte Carlo simulation verification in hadrontherapy with non-tissue equivalent detectors", *Rad. Prot. Dosim.*, vol. 119, pp. 487-490, 2006.

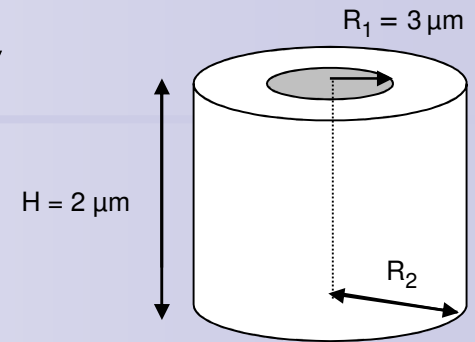
D. A. Prokopovich, M. I. Reinhard, I. M. Cornelius, and A. B. Rosenfeld, "SOI microdosimetry for mixed field radiation protection", *Rad. Meas.*, vol. 43, pp. 1054-1058, 2008.

# Characterisation of SOI microdosimeters by means of Geant4

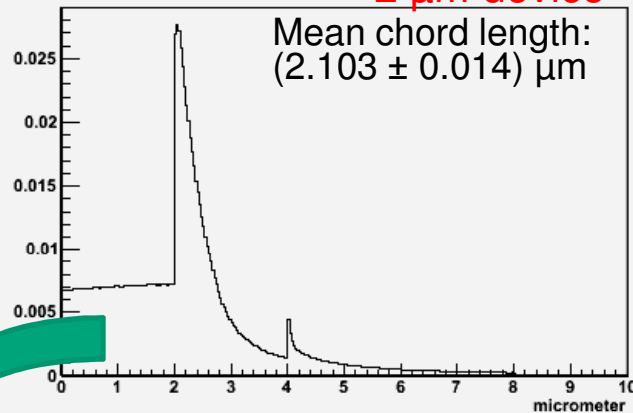
Chord length distribution  
Tissue-equivalence of silicon

# Chord Length Distribution study

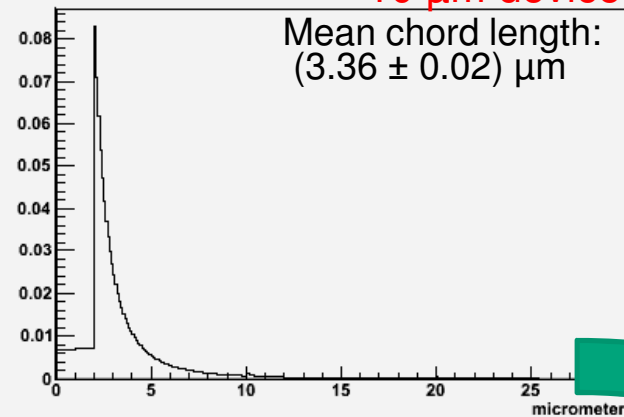
The detector concept is exposed to a uniform isotropic field of infinite straight lines



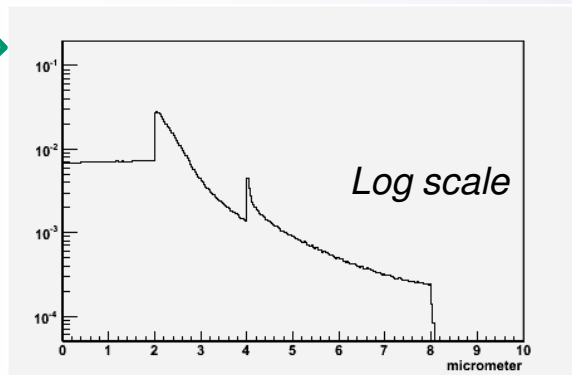
2  $\mu\text{m}$  device



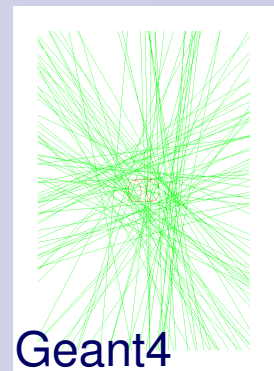
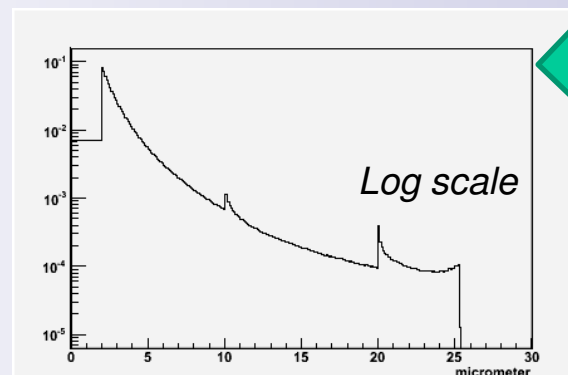
10  $\mu\text{m}$  device



Log scale



Log scale



# Characterisation of SOI microdosimeters by means of Geant4

Chord length distribution

Tissue-equivalence of silicon

S. Guatelli, et al., "Tissue equivalence correction in silicon microdosimetry for protons characteristic of the LEO space environment", IEEE Trans. Nucl. Sci., vol. 55, pp. 3407-3413, 2008

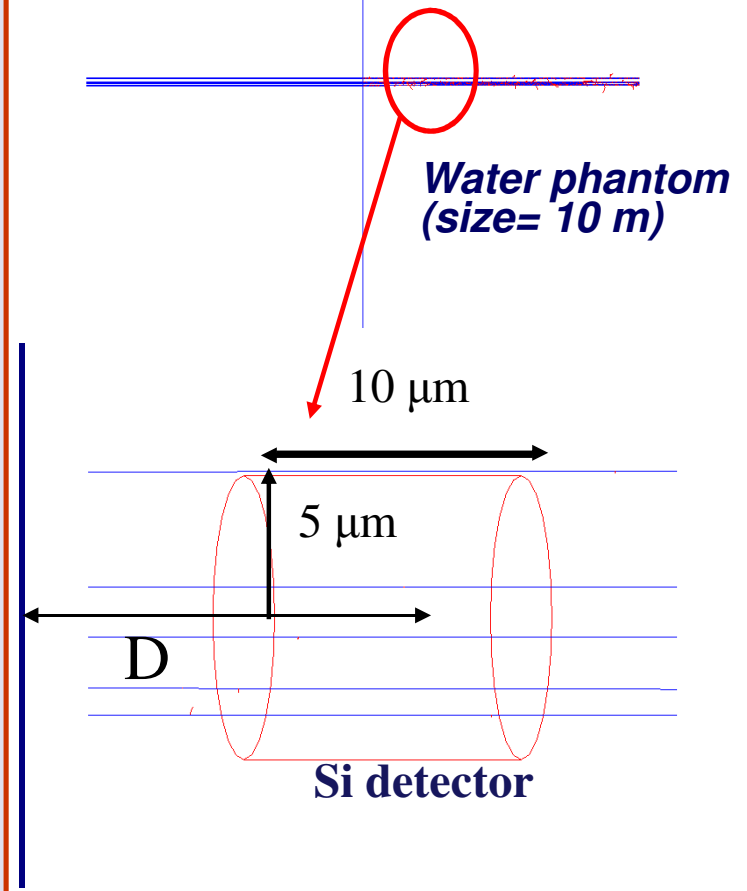
# Geant4 simulation

## How to convert Si based microdosimetric measurements to tissue

- Microdosimetric energy deposited spectra along the proton Bragg peak
  - in a simplified model of the Si SV
  - in a cylinder of water
- Experimental set-up
  - 50, 100, 150, 200 MeV proton pencil beam
  - Electromagnetic and hadronic physics active for primary and secondary particles
  - Calculate the energy deposit per event in the detector

## Experimental set-up

Blue tracks: proton tracks  
Red tracks: e- tracks



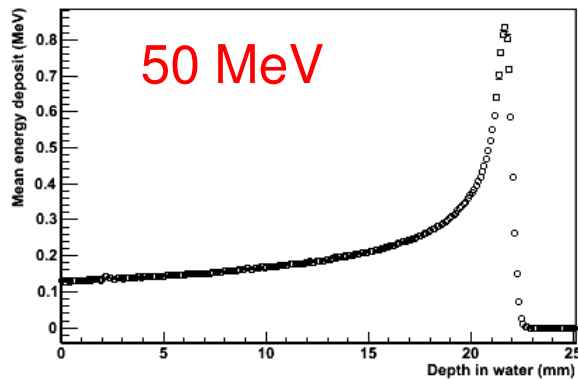


# Geant4 simulation: Physics List

- Electromagnetic physics: G4 Standard Package
  - Threshold of production of secondary particles: 1 micrometer
- Hadronic physics for protons, neutrons and pions:
  - Geant4 elastic process
    - Parameterised Elastic Model
  - Inelastic hadronic processes
    - Bertini cascade model
  - Fission and capture processes
- Inelastic hadronic scattering for deuteron, triton and  $\alpha$  particle
  - Low Energy Parameterized model
- The Binary Ion Model was active in the case of other ions

# Proton Bragg peak in water

50 MeV proton Bragg peak in water



100 MeV proton Bragg peak in water

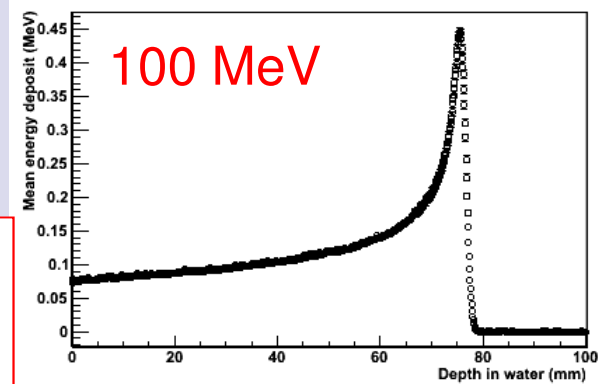
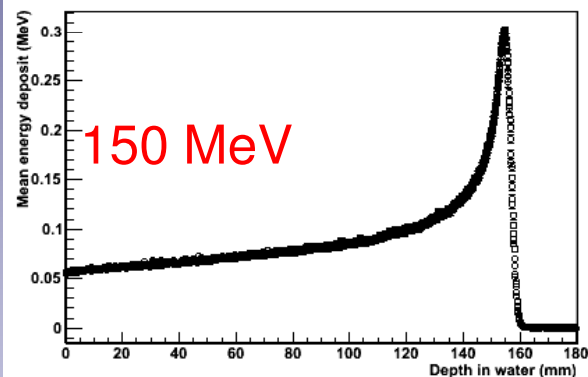


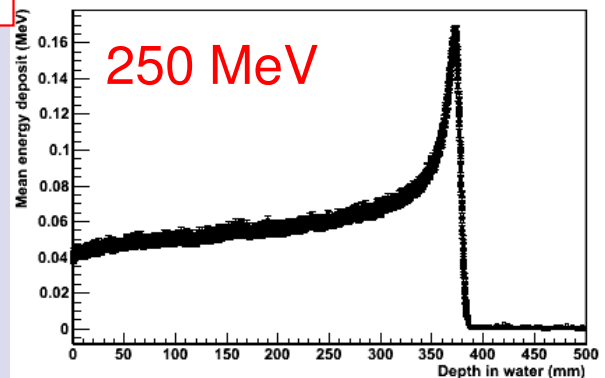
TABLE I  
DEPTHS AT WHICH THE MICRODOSIMETER SITE WAS SET IN THE WATER PHANTOM, ALONG THE BRAGG PEAK CURVE, WITH RESPECT TO THE INCIDENT PROTON BEAM ENERGY

Proton Energy (MeV)	Position I	Position II	Position III	Position IV
50	1 cm	2 cm	2.1 cm	2.2 cm
100	4 cm	7.2 cm	7.5 cm	7.7 cm
150	8 cm	15 cm	15.5 cm	15.75 cm
250	20 cm	35 cm	37 cm	38 cm

150 MeV proton Bragg peak in water



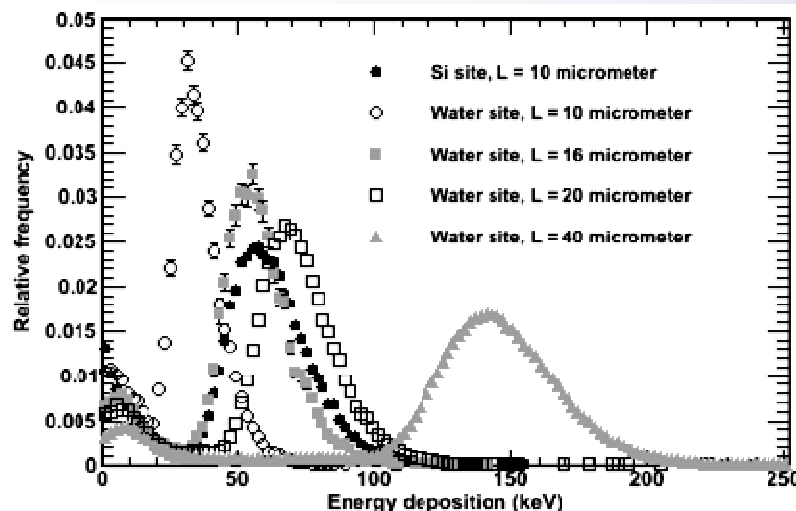
250 MeV proton Bragg peak in water



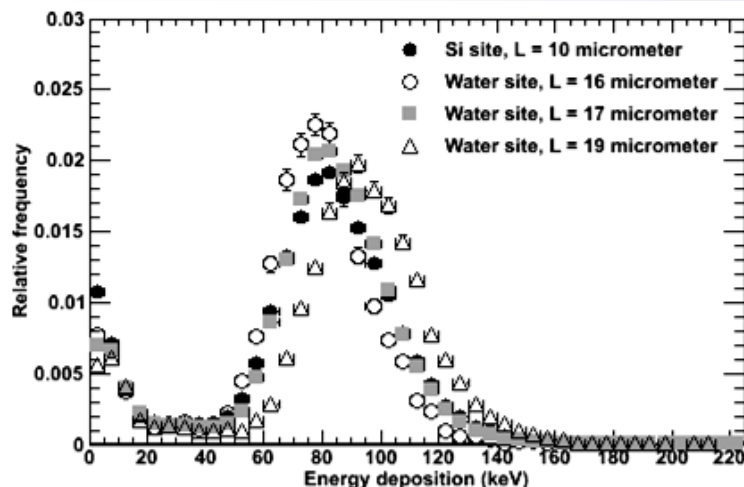
The result of the study is the factor  $C$ , corresponding to the best agreement of the energy deposition spectra in the Si and in the water microdosimeter sites.

For a water cylinder with height  $h$  and diameter  $d$ , the required scaling is  $C \cdot h$ ,  $C \cdot d$  of silicon.

# Results



Energy deposition spectra resulting from a 50 MeV at 2 cm depth in the water phantom. (raising part of Bragg curve)



Energy deposition spectra resulting from a 50 MeV proton beam at 2.1 cm depth in the water phantom. (Bragg peak)

- Statistical analysis by means of Kolmogorov-Smirnov test

	Water microdosimeter site	Left branch <i>p</i> -value	Right branch <i>p</i> -value
Position I	$L = 17 \mu\text{m}$	0.8730	0.9955
Position II	$L = 17 \mu\text{m}$	0.9897	0.8384
Position III	$L = 17 \mu\text{m}$	0.6172	0.9996
Position IV	$L = 17 \mu\text{m}$	0.8580	1.0000

- Linear coefficient  $C^* = (0.56 \pm 0.03)$  was determined to convert microdosimetric spectra from silicon to water for incident proton energies between a few MeV and 250 MeV
- For a water cylinder with height  $h$  and diameter  $d$ , the required scaling is  $C^* \cdot h$ ,  $C^* \cdot d$  of silicon

# Work in progress

- We are investigating a **general methodology** to convert silicon microdosimetric spectra to tissue equivalent spectra **in any arbitrary mixed radiation field**
- Study of the tissue equivalency of diamond
  - Diamond proposed as alternative to silicon for microdosimetry because of better tissue-equivalency

# Secondary neutrons in proton therapy

- Secondary neutrons are generated through nuclear interactions of the primary beam with the beamline and **inside the patient**
- Neutrons deposit energy through secondary charged particles, often of high LET, and are important for second cancer calculations
- Accurate determination of secondary neutron dose delivered **in tissue** is vital
- Using different phantoms may lead to different secondary neutron doses

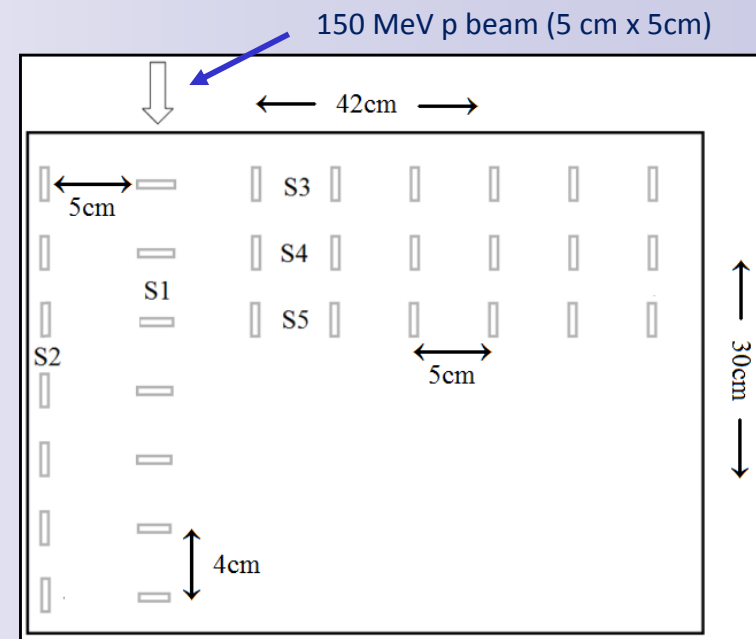
Geant4-based study of secondary neutron dose in different materials  
*S. Dowdell, et al., "Tissue equivalence of phantom materials for neutron dosimetry in proton therapy", Med Phys, accepted for publication*

The materials considered were: A150, brain, cranium, lucite, muscle, water

# Geant4 simulations

- Neutron absorbed dose scored in sensitive volumes ( $2.5 \times 25.0 \times 0.5 \text{ mm}^3$ ) throughout different materials
- Absorbed dose (D) combined with radiation weighting factor ( $w_R$ ) to give dose equivalent H
  - $H = w_R \times D$
- Physics list based on previous study by Zacharatou Jarlskog and Paganetti\*:
  - G4EmStandard
  - G4BinaryCascade
  - G4UHadronElasticProcess
  - Cut in material = 1mm
  - Cuts in sensitive volume =  $1\mu\text{m}$

\* C. Zacharatou Jarlskog, and H. Paganetti, "Physics Settings for Using the Geant4 Toolkit in Proton Therapy", IEEE Trans. Nucl. Sci., **55**, 1018-1025, (2008)



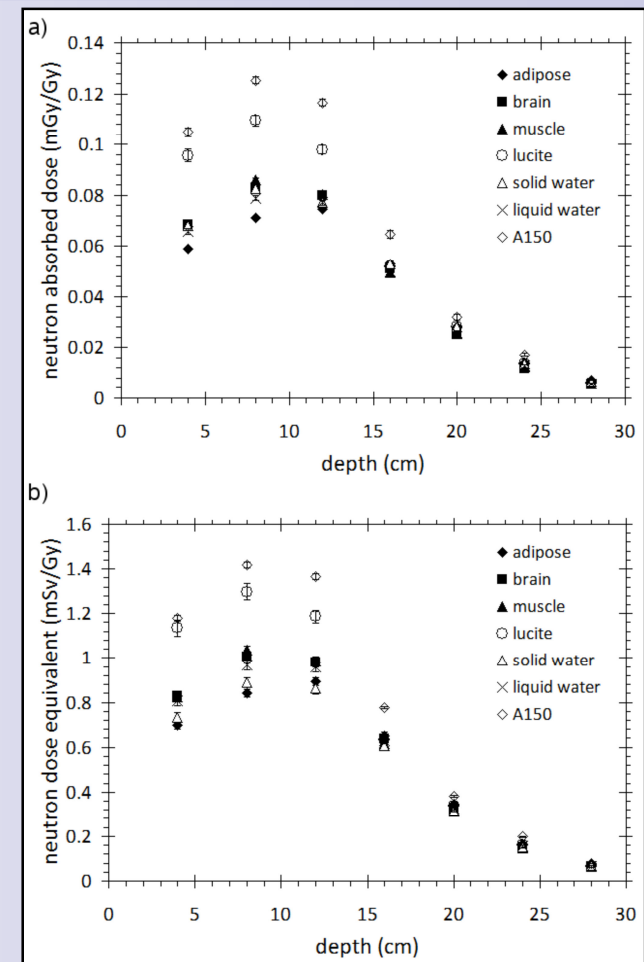
Simulation setup

# Results

- Magnitude of secondary neutrons doses out of field is less than along central axis, but larger differences exist between phantom and tissue
- **Secondary neutron dose in proton therapy is sensitive to the materials traversed**



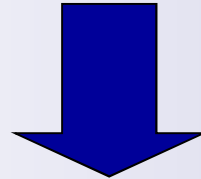
affecting out of field measurements where neutrons dominate the total dose equivalent



Neutron absorbed dose (a) and dose equivalent (b) along the central axis

# Next step: in progress

How different are microdosimetric spectra obtained by silicon microdosimeter in different phantom materials irradiated with the same proton beam?

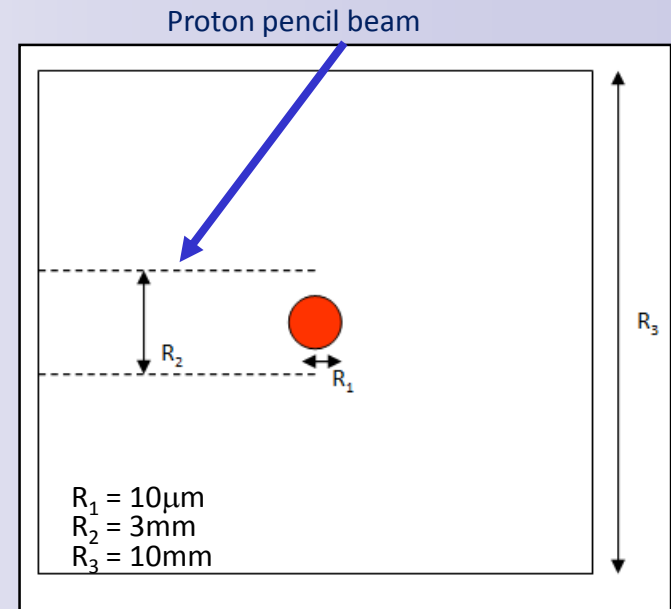


How similar are phantom materials to tissue of interest for modelling of radiobiological properties of the proton beam?



# Geant4 simulation experimental setup

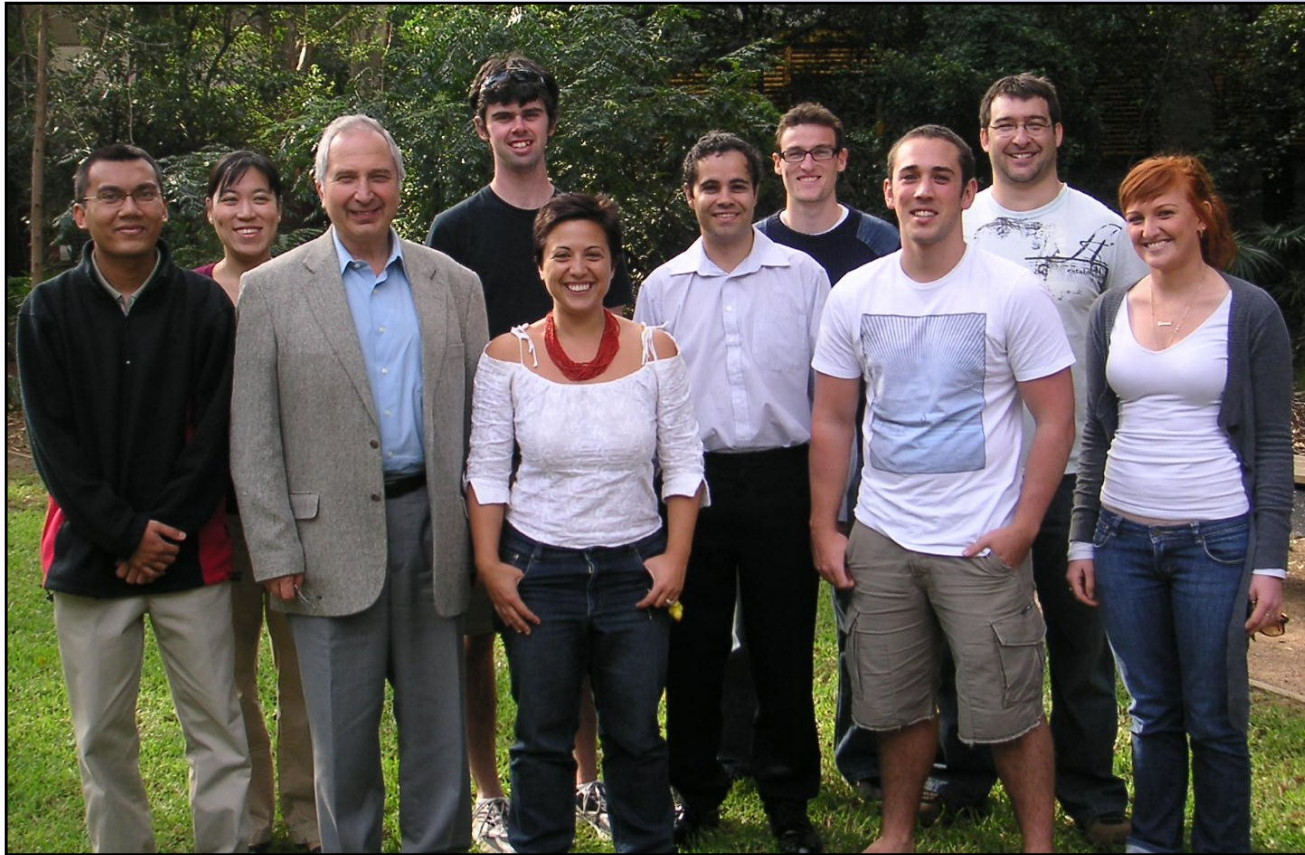
- 150 MeV and 250 MeV proton beams simulated
- Energy deposition spectra collected in Si sensitive volume (red sphere), at multiple depths in different phantoms and tissues
- The energy deposition spectra will be converted to microdosimetry spectra in Si
- Significance of any variation in the spectra will be ascertained using the Kolmogorov-Smirnov statistical test
- This study will show any effect that the phantom material has on a microdosimetric level



Geant4 simulation experimental setup

# Summary

At the CMRP we are intensively using Geant4 as a simulation toolkit to characterise novel detectors in radiation fields of interest for medical physics and radiation protection



## Thank you