Geant4 coupled with heat transfer simulations to determine correction factor of a novel micro-calorimeter

Kamran Fathi, S. Galer, H. Palmans, J. Gallop, L. Hao, K. Kirkby and A. Nisbet

16th of Feb 2016

UNIVERSITY OF SURREY

Royal Surrey County Hospital NHS
NHS Foundation Trust

NPL National Physical Laboratory

Content

- Motivation
- Background
  - Relative Biological Effectiveness (RBE)
  - Microdosimetry
  - Detectors
- Methodology
  - Monte Carlo simulations
  - Thermal simulations
- Results
- Summary and Planned work

Motivation

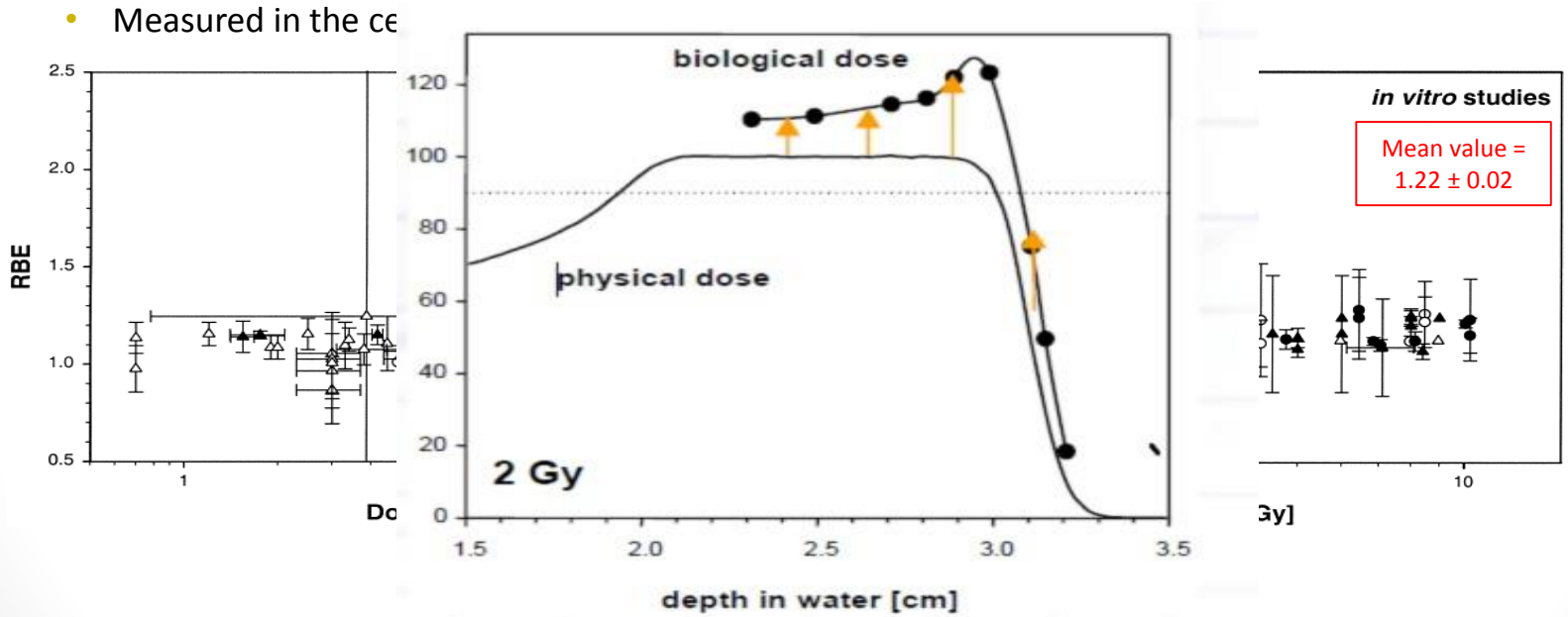
- Increase use of Proton and Ion therapy in cancer therapy[1]
  - 62 in operation
  - 64 under construction
  - 31 in Planning stages
- Over 100,000 cancer patients were treated with proton therapy by 2013[2]
- High uncertainty in Relative Biological Effectiveness (RBE) value

[1] Particle Therapy Co-Operative Group. Current centres. http://ptcog.web.psi.ch/newptcentres.html, 2016

[2] H. Paganetti, "Advancing (Proton) Radiation Therapy," International journal of Radiation Oncology Biology Physics, vol. 87, no. 5, pp. 871-873, 2013

RBE value

- Definition
  - Ratio of the doses required by two radiations to cause the same level of effect. (ref radiation ^{60}Co). RBE = D_{ref} / D_{rad}
  - $Dose_{RBE\ Adjusted}$ (Gy) = Physical dose (Gy) × RBE
- In-vivo and in-vitro studies
  - Measured in the ce

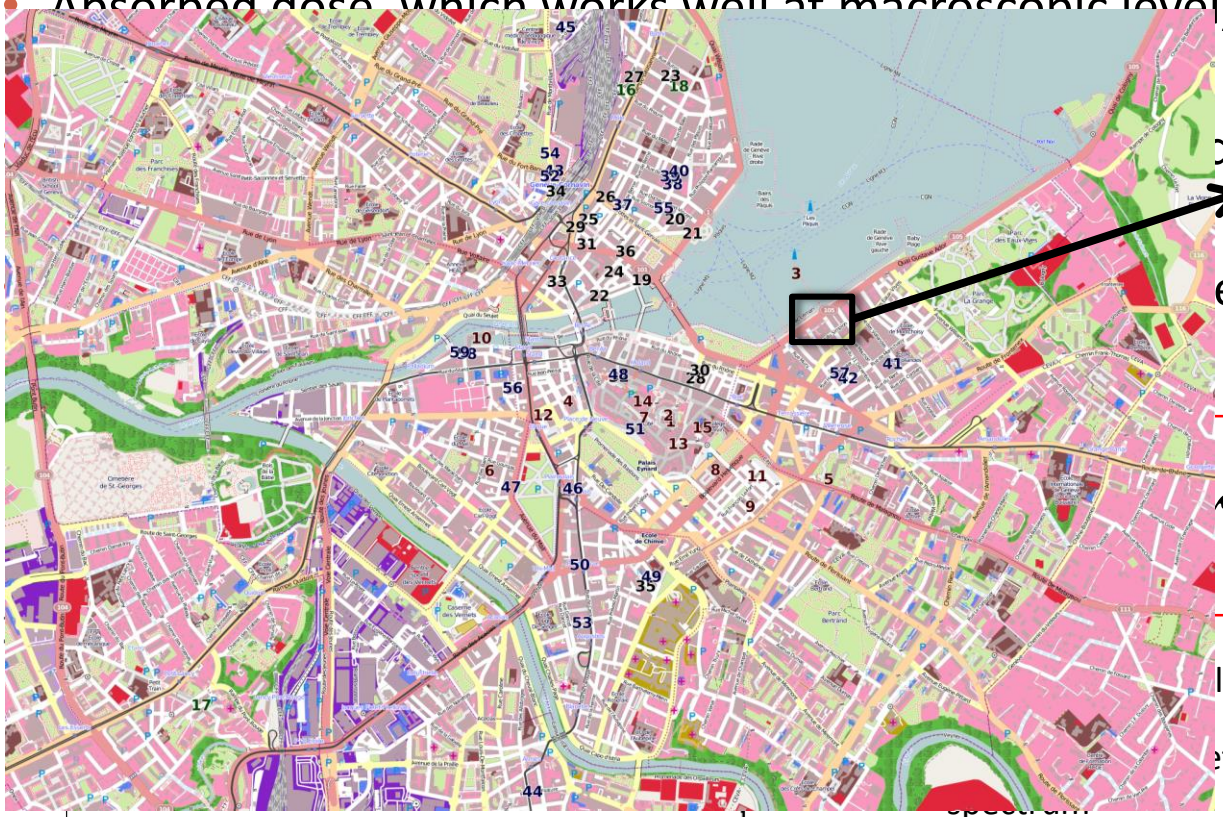


Paganetti *et al. RBE value for proton beam therapy. Int J Rad Onc Bio Phy, vol 53, 2002.*

- Generic RBE of 1.1 used for all proton therapy treatments

Microdosimetry

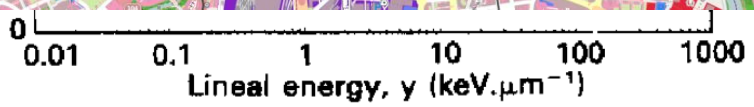
- Absorbed dose, which works well at macroscopic level, fails at



$r(y)d(y)dy$

logical response function

etric single event

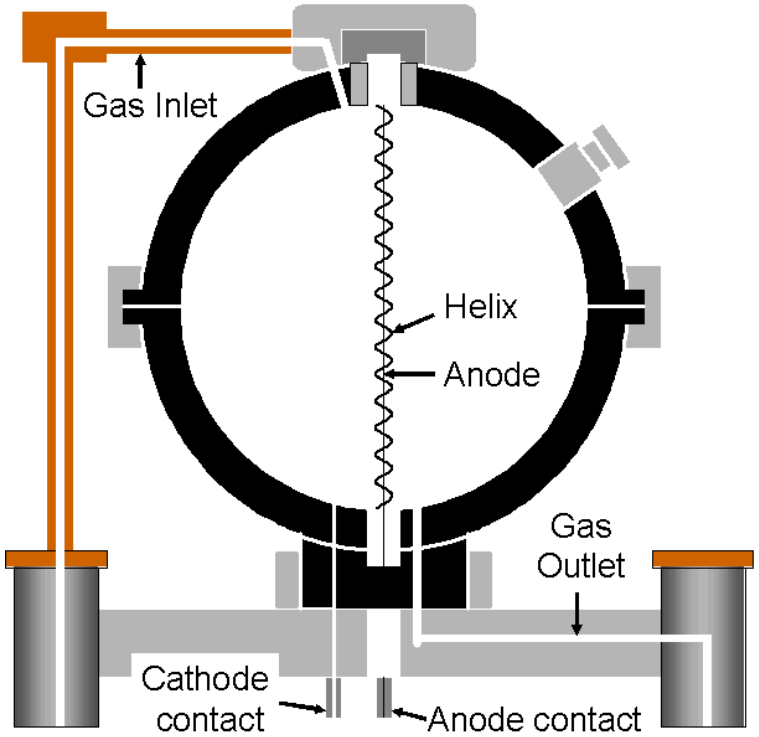


Loncol *et. al*, 1994 Rad Prot Dosim Vol 52. pp 347-352

Pihet *et al. 1990* Biological weighting function for RBE specification of neutron therapy beams. Rad Pro Dos. Vol 31. pp 437-442

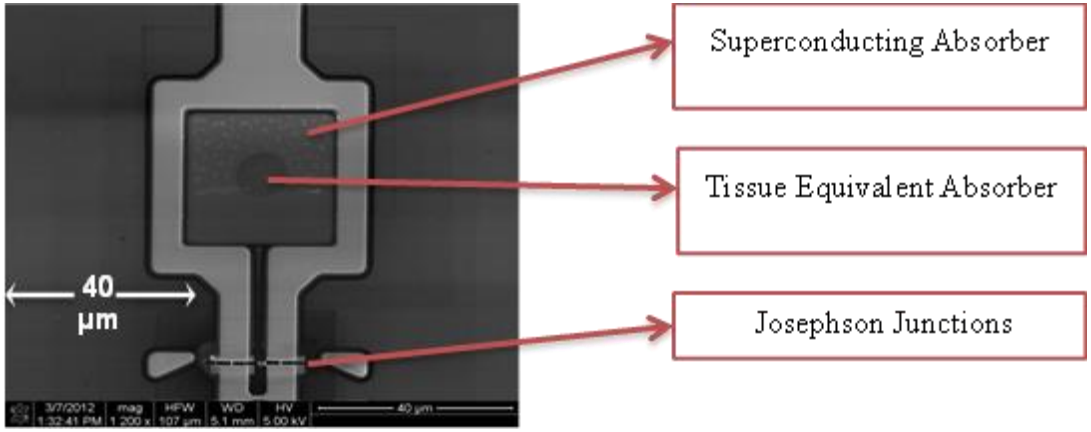
Detectors

- Ionisation chambers
  - Tissue Equivalent Proportional Counter (TEPC)
  - Miniaturised TEPC (mm)
- Semiconductor Detectors
  - Silicon
- Other detectors
  - Cloud Chambers
  - Optical Ionisation Chamber
- Calorimetry
  - Micro-calorimeter
  - Direct measurement
  - Comparable volume size



Our Detector

- Modified **I**nductive **S**uperconducting **T**ransition **E**dge **D**etector **(ISTED)**



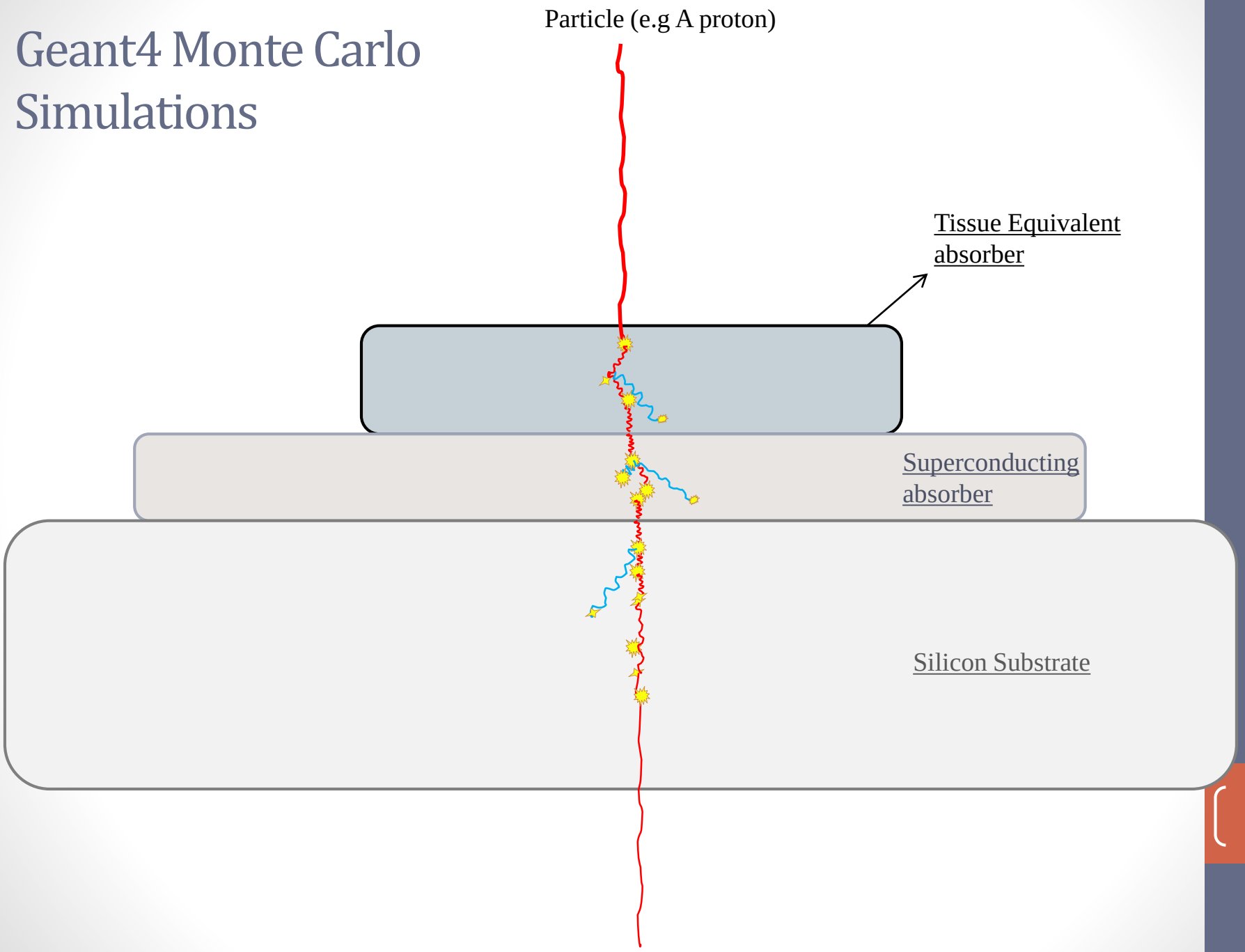
T rise in the absorbers > Change in penetration depth of the Superconducting absorber > change in SQUID's loop inductance > Voltage read out due to SQUID's altered response to an applied magnetic field

- Sensed by the transient change in inductive coupling, rather than a change in resistance.

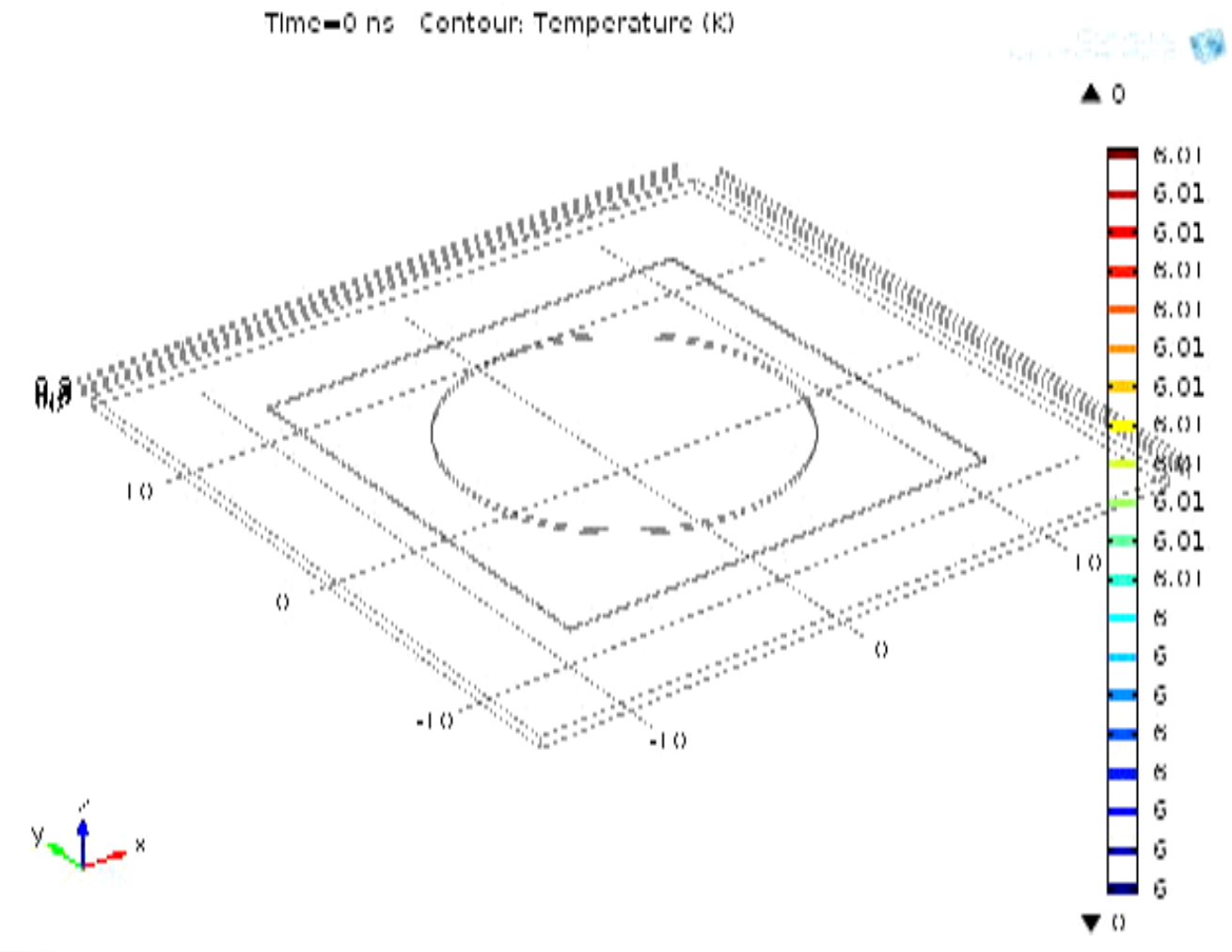
$$\lambda(T)= \lambda(0)/ [1-(T/T_c)^4]^{1/2}$$

- Temperature rise of 1µK are detectable

Geant4 Monte Carlo Simulations



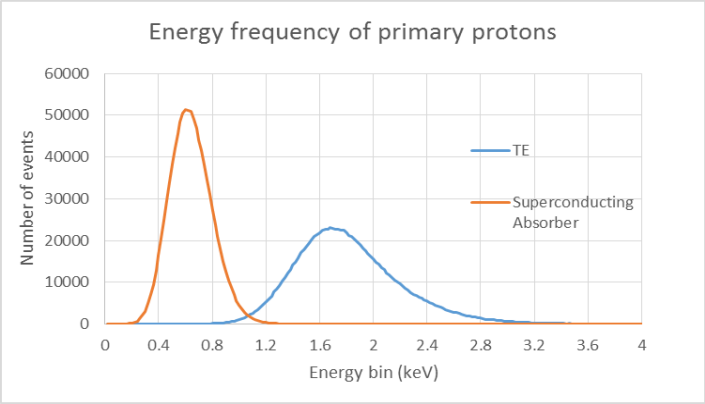
COMSOL Heat transfer representation



Geant4 Monte Carlo Simulations

- Each particle track is unique, resulting in different detector response depending on the energy it deposits
- For each particle interacting with the detector, the spatial position (x, y, z) and energy deposited is recorded.
- Impractical to analyse thermal contribution of each track hence particle tracks are categorised into:
  - Most common
  - Least common (at both extremes)
- As an example, the following is the track selection criteria for a 3.8 MeV proton beam:

Absorber	Particle type	Energy range (keV)
Tissue Equivalent	Primary	$1.5 \leq E \leq 1.7$
	Secondary	$0.2 \leq E \leq 1.5$
Superconducting	Primary	$0.4 \leq E \leq 0.8$
	Secondary	$0.5 \leq E \leq 3.5$



Multiple tracks

- Coupling Geant4 Monte Carlo output into COMSOL Multiphysics software
- Matlab script to run COMSOL
  - Extract information only at specific times
  - Simulation time has be improved significantly ×15!

Results

- 5 proton tracks (3.8 MeV) were thermally simulated and analysed using COMSOL Multiphsyics
- Average temperature rise, caused by the interacting particle was measured
- Temperature rise due to conduction and direct energy deposition was determined

Selected Track	I	II	III	IV	V
Percentage contribution from TE to Superconducting absorber (%)	**24.2**	**23.0**	**18.2**	**31.1**	**17.3**
Uncertainty (%)	6.5				

Conclusion and planned work

- Monte Carlo information > Heat transfer simulations
- The method can be used to determine the correction required to the signal
- The correction can be applied to determine the expected microdosimetric spectra which can be compared to the experimental measurements.
- Initial results show that on average **23%** of the signal is due to heat conduction from the TE absorber
- By atomising the process a large number of particle tracks can be simulated and analysed
- The simulations will be performed for particles:
  - 2.0, 3.8, 10, 62 and 230 MeV
  - Large number of particle tracks (over 1000)

Acknowledgements

- NIHR funding
- EPSRC funding
- AIR Dosimetry group _ NPL