Simulation of Synchrotron-based Microbeam Radiation Therapy using Geant4

CENTRE FOR MEDICAL RADIATION PHYSICS | UNIVERSITY OF WOLLONGONG

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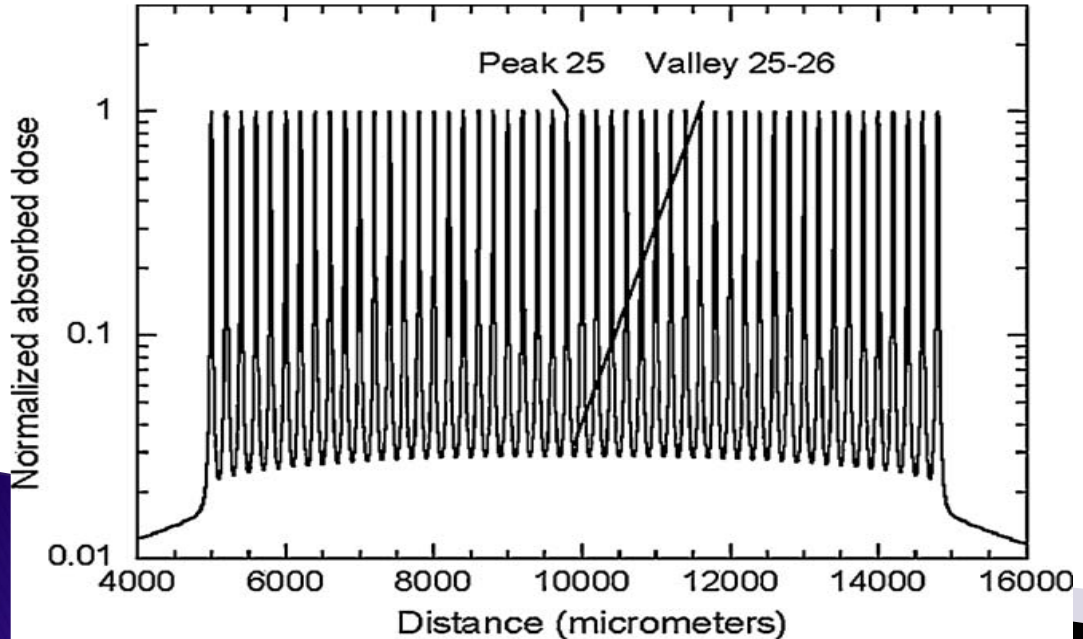
Microbeam Radiation Therapy

- High intensity (up to 10kGy/s) , low divergence, polarised, pulsed photon beam
- Use of micron sized beams to deposit very large doses

Braüer-Krisch, E. Serduc, R. Siegbahn, et al. 2010. ***Mutat . Res. 704. 160-166.***



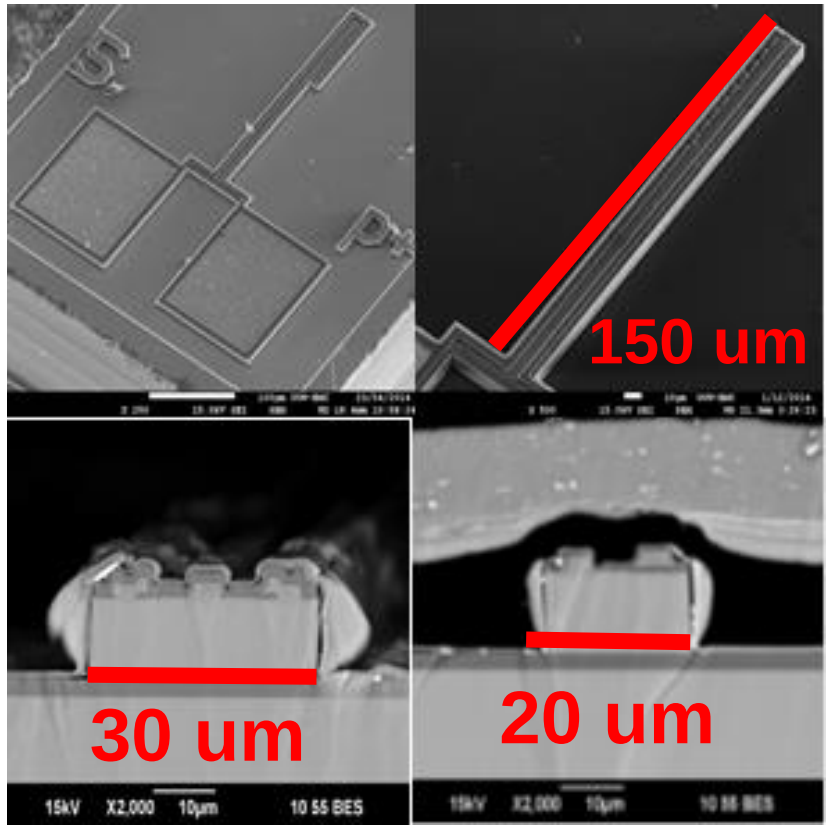
- Preferential damage to tumors
- Preclinical research, promising for paediatric patients, head and neck tumors, other radiosensitive tumors

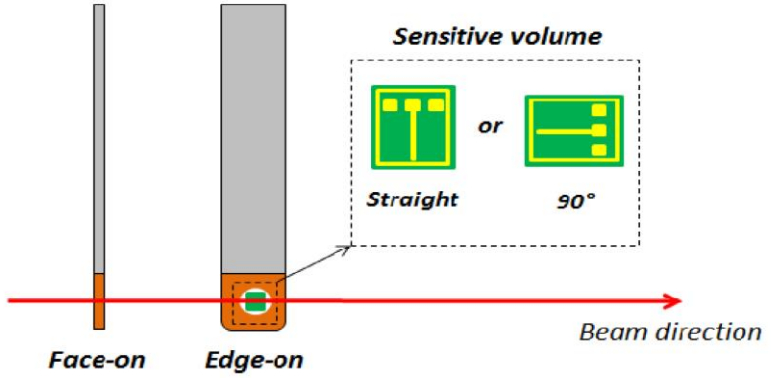
Laissue, J. Blattmann, H. Grotzer, M. Slatkin, D. 2007. **Develp. Med. Child Neurol. 49, 577-581.**

Aim of the project

- Development of Geant4 simulations for characterisation of detectors designed
  - At the Centre For Medical Radiation Physics, University of Wollongong
  - for use in Quality Assurance of Microbeam Radiation Therapy (MRT) at the Australian Synchrotron Imaging and Medical Beamline (IMBL)

- Requirements:
  - Modular design – experiments have differing beamline configuration
  - Geant4 based
  - Time-dependent geometry – mimic experimental phantom motion
  - Efficient – maximum accuracy for minimum execution time





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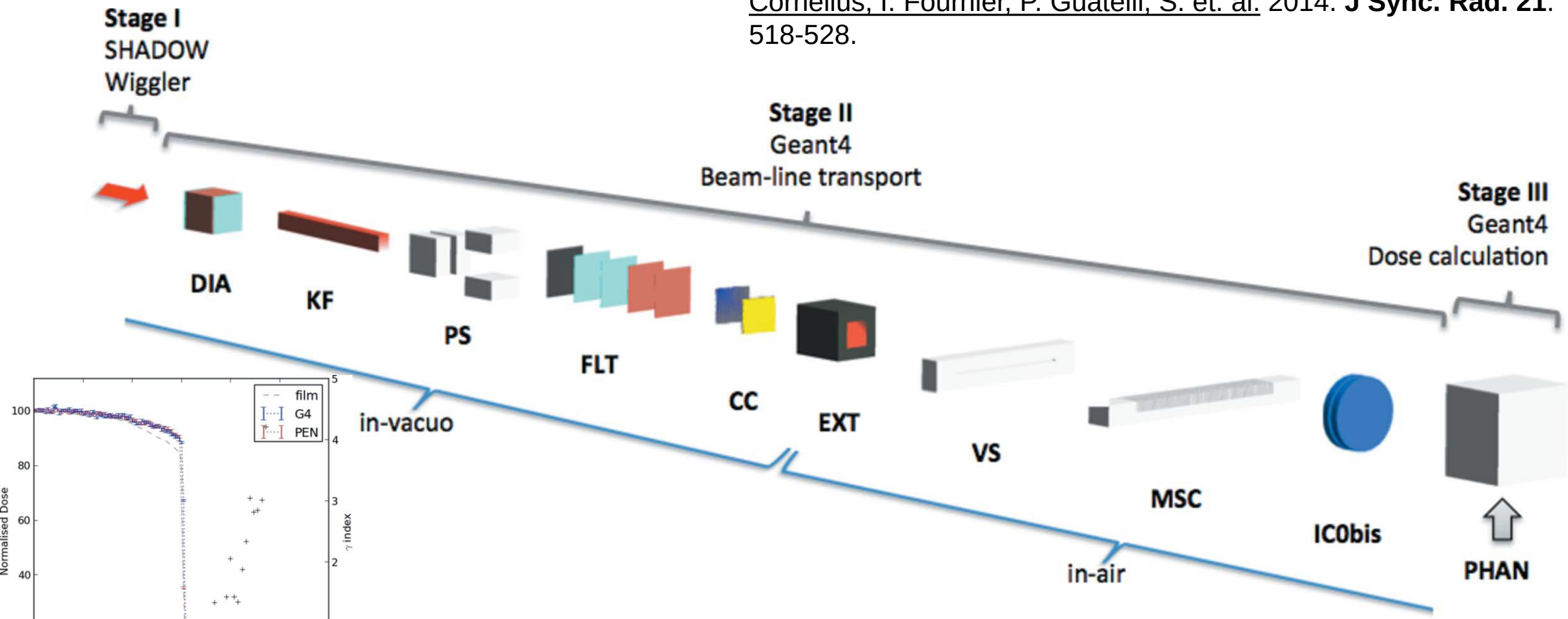
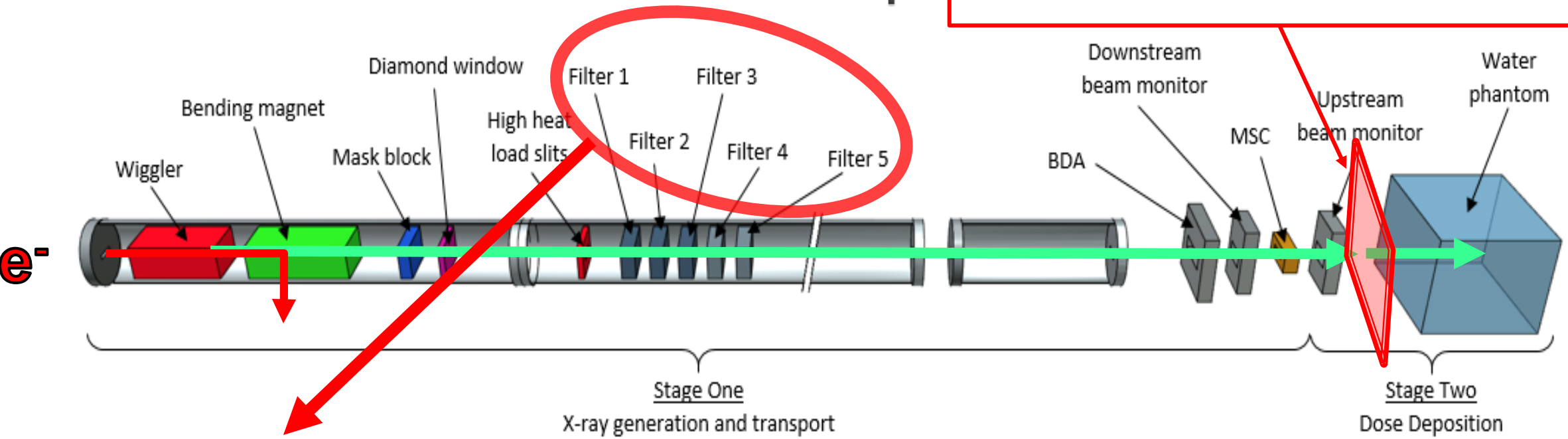
Geant4 modelling of the ESRF ID17 beamline

Cornelius, I. Fournier, P. Guatelli, S. et. al. 2014. **J Sync. Rad. 21**. 518-528.



Geant4 IMBL simulation set-up

Phase Space Position, Momentum, Polarisation, Energy, Weighting



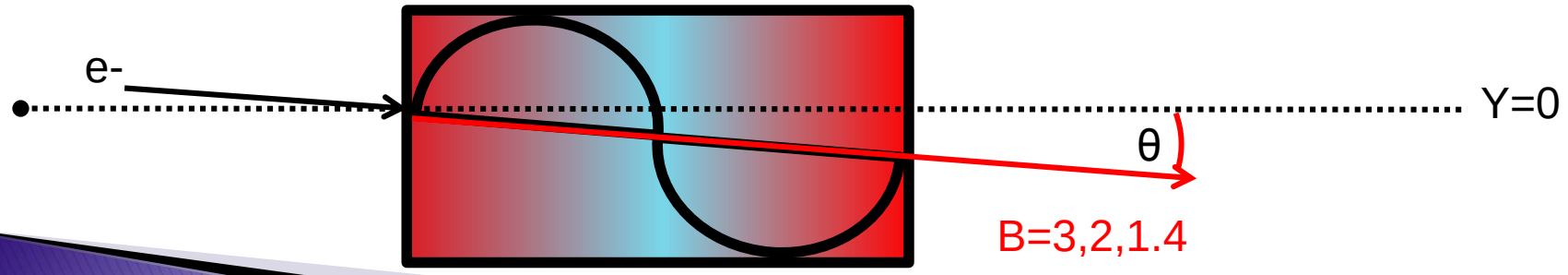
	High Dose Rate (HDR)	Medium Dose Rate (MDR)	Low Dose Rate (LDR)
Filter 1	C (0.45 mm)		
Filter 2	C (1.49 mm) 45º		
Filter 3	C (10 mm) 45º		
Filter 4	Al (2 mm) 45º	Cu (1 mm) 45º	Al (2 mm) 45º
Filter 5	Cu (1 mm) 45º	Cu (1 mm) 45º	Mo (2 mm) 45º

Livermore Polarised Physics, Geant4 9.6.patch4

Specific aim of the simulation–increase stats:
Maximise the number of generated photons

- Find the best steering angle of e^- to maximise the intensity of the photons
  - W.r.t. magnetic field

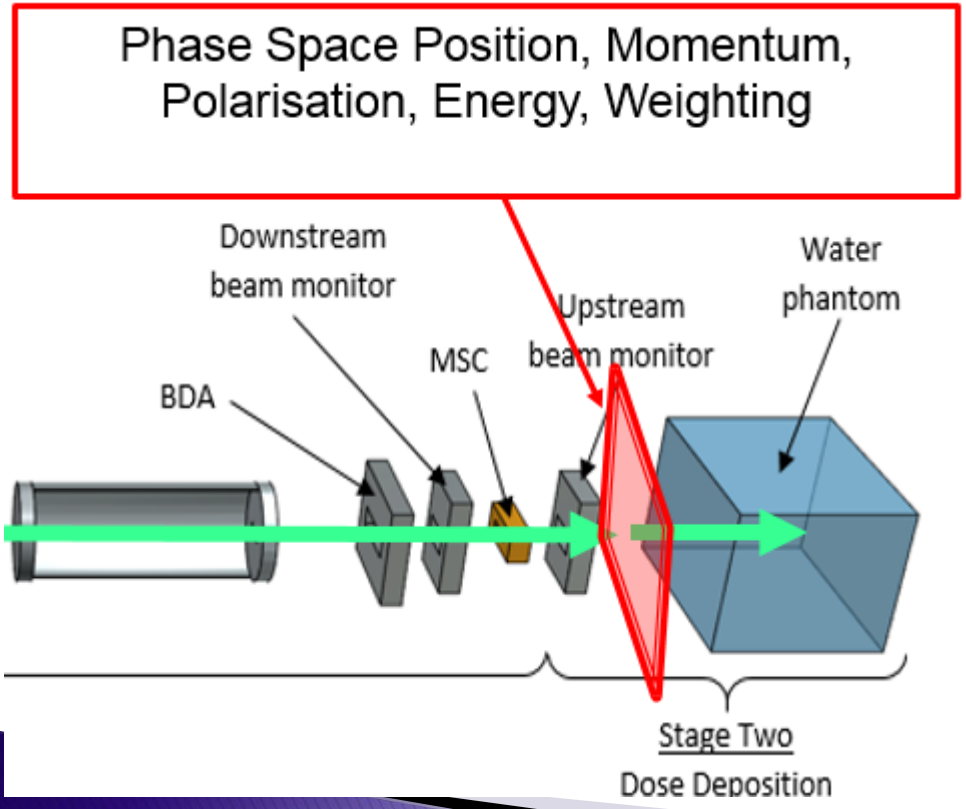
- Optimisation of the photon splitting w in G4Synchrotron:
  - Increase photon generation per step in wiggler
  - Optimised to w=5000
  - The photon is recorded in the PSF with weighing number of $\frac{1}{number\_electrons\_job \cdot w}$

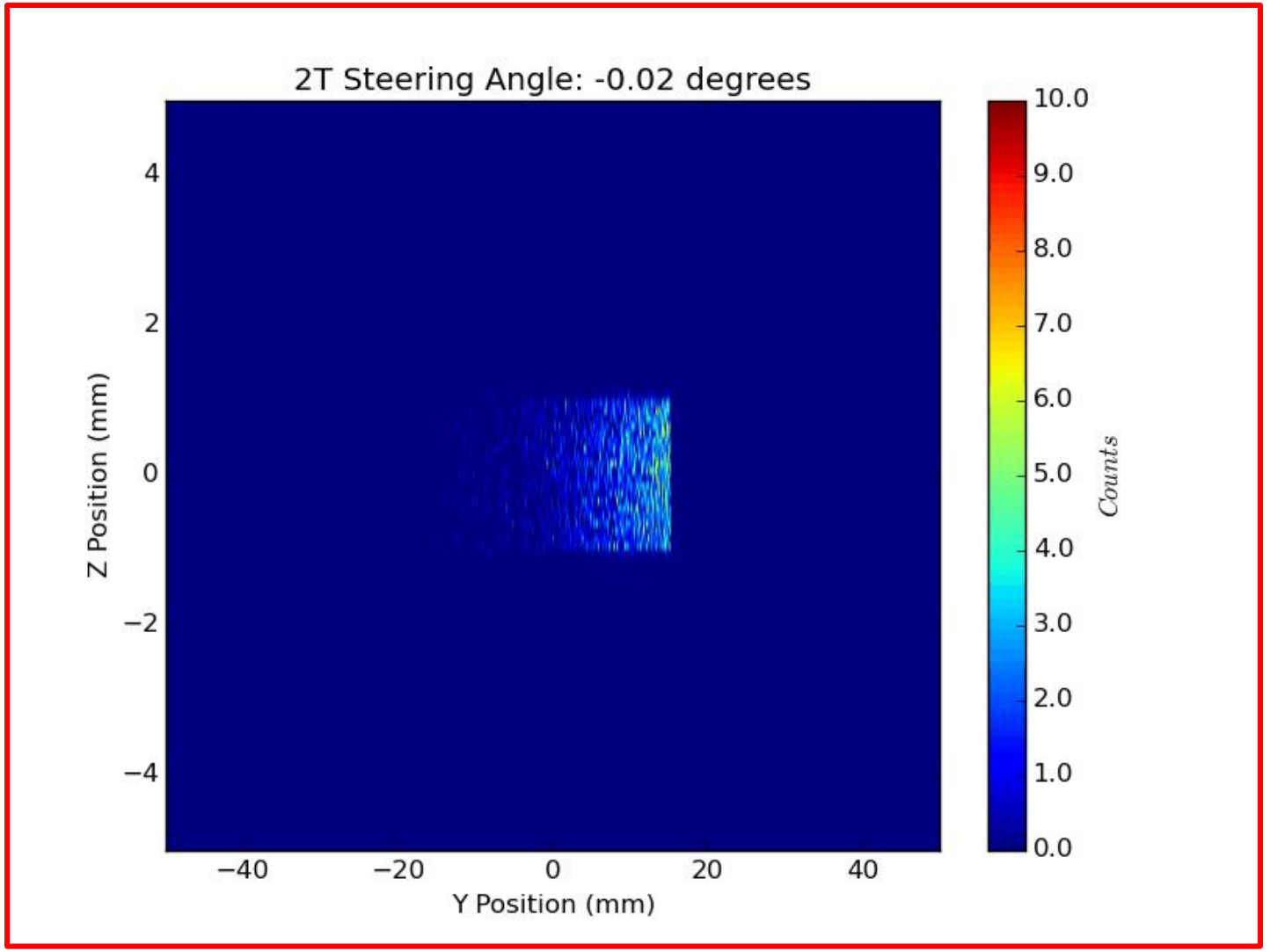


Optimisation of photon flux for 2T Wiggler

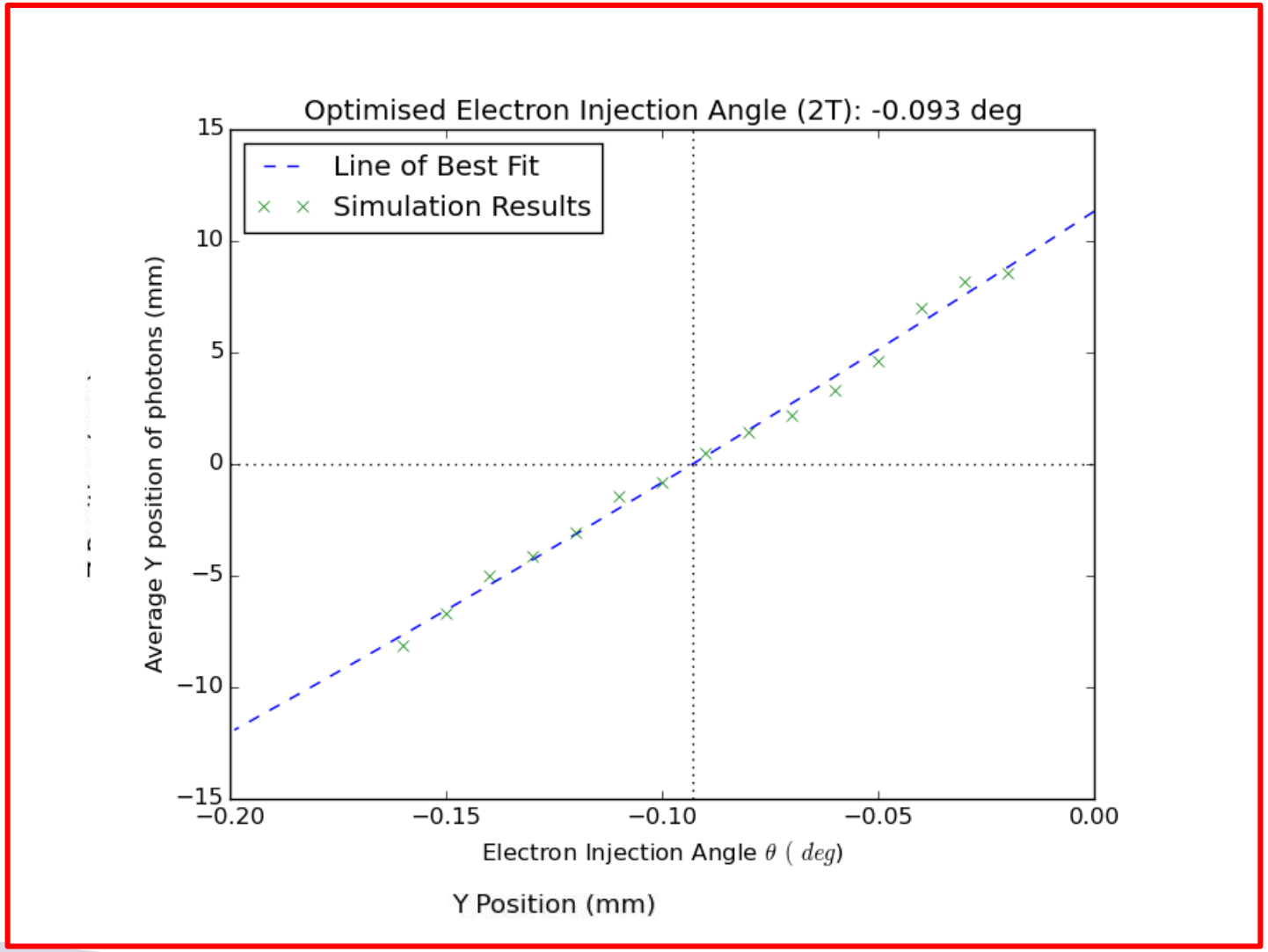
Photon intensity map 10 cm from Phantom

Pixel size= 0.1x0.1 mm^2

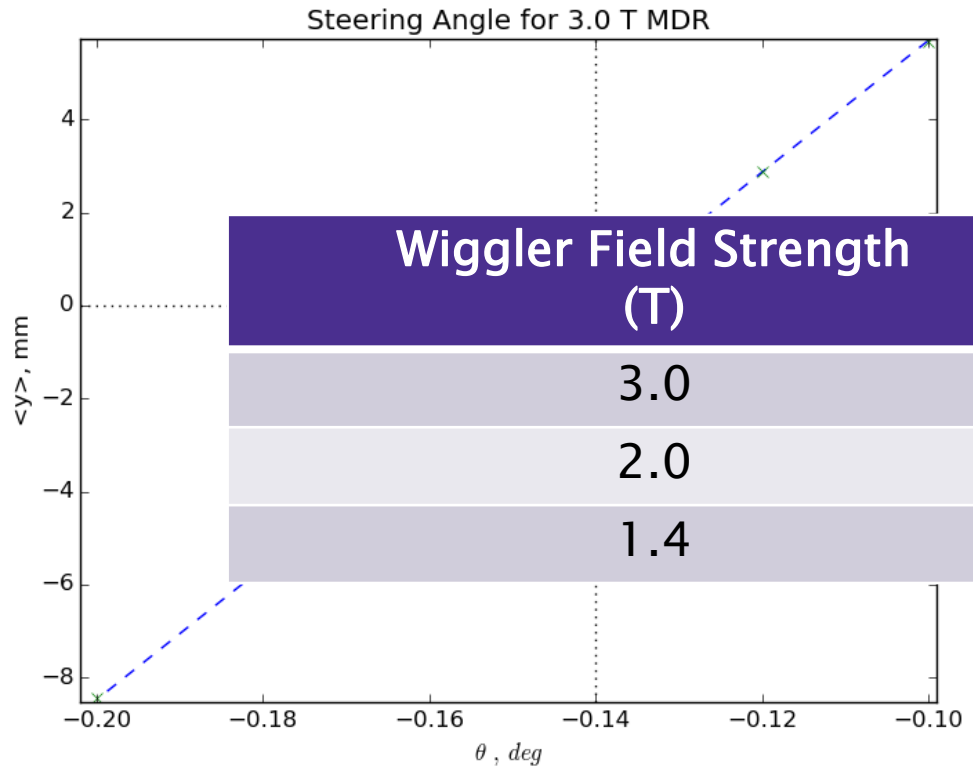


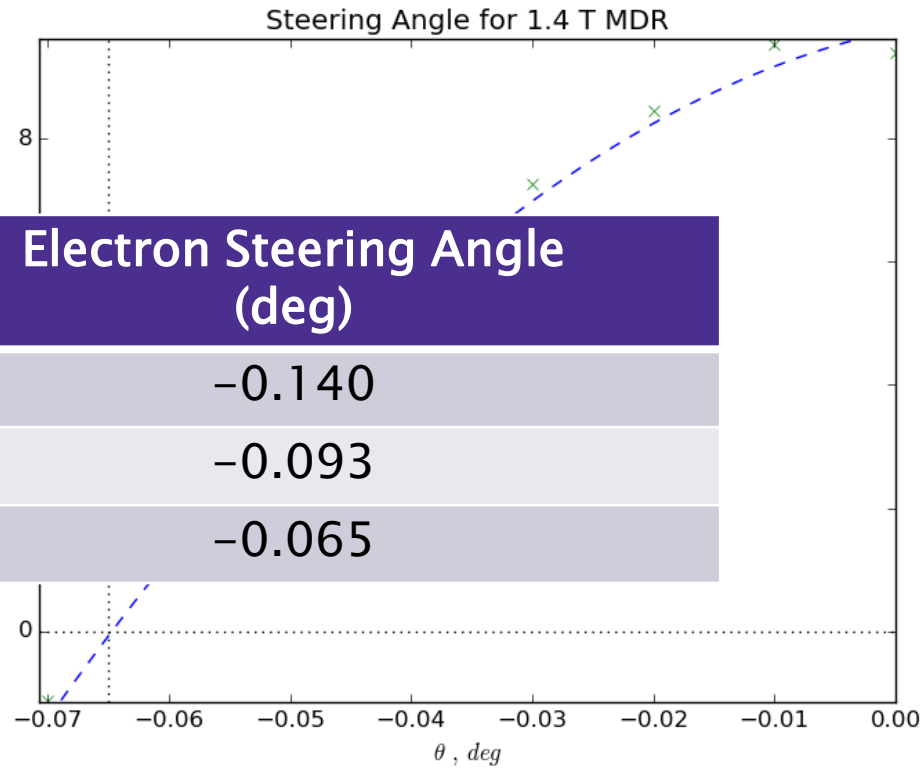


Steering 2T expectation -0.093 deg



Steering angles of 3 T and 1.4 T





Wiggler Field Strength (T)	Electron Steering Angle (deg)
3.0	-0.140
2.0	-0.093
1.4	-0.065

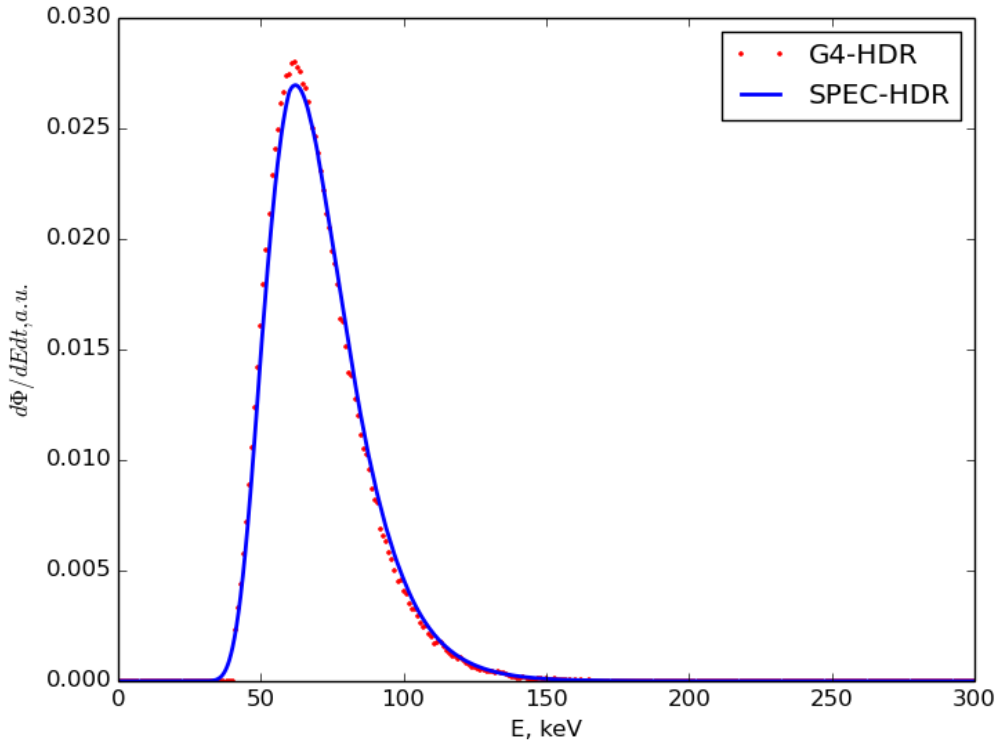
3.0 T steering angle = -0.140 deg

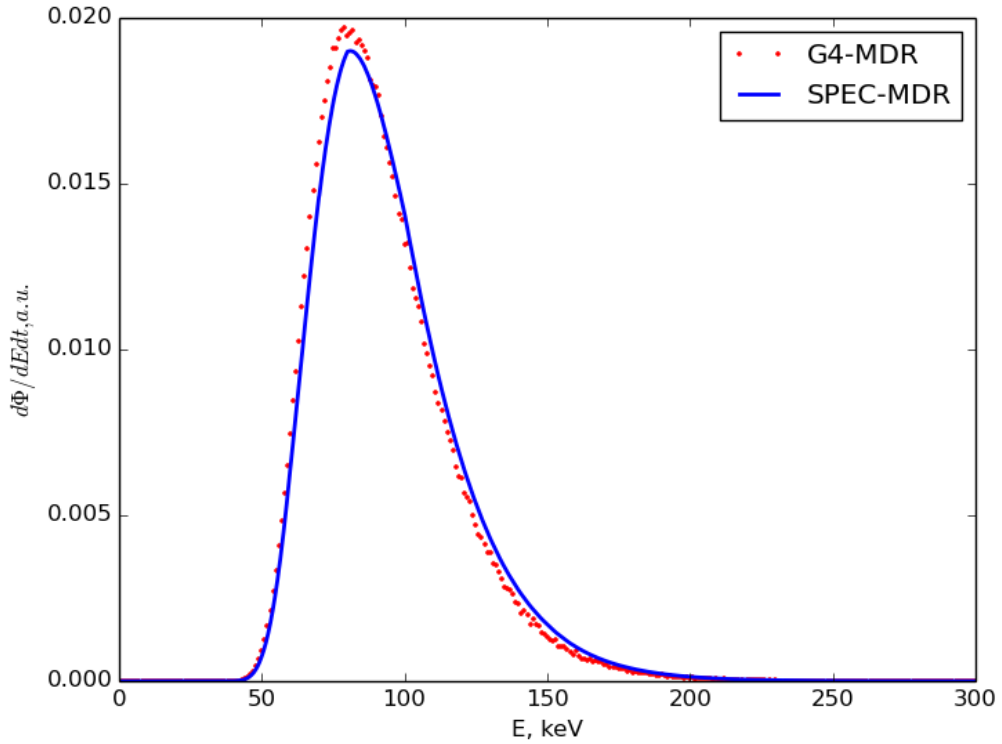
1.4 T steering angle = -0.065 deg

Verification of the simulation

Comparison to theoretical (SPEC) Energy Spectra

Stevenson et al. 2017. **J. Sync. Rad.** ***24. 110-141.***





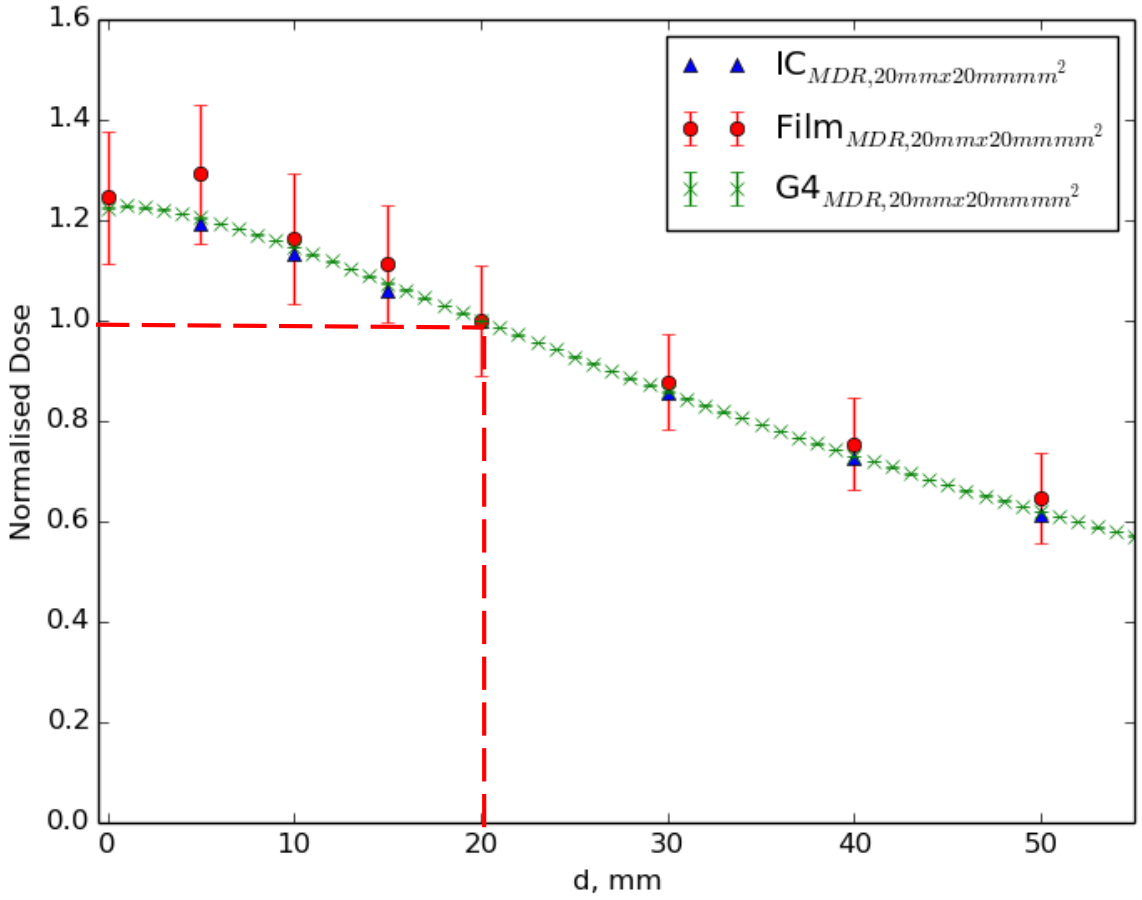
2.0T HDR ~70keV mean

3.0T MDR ~90keV mean

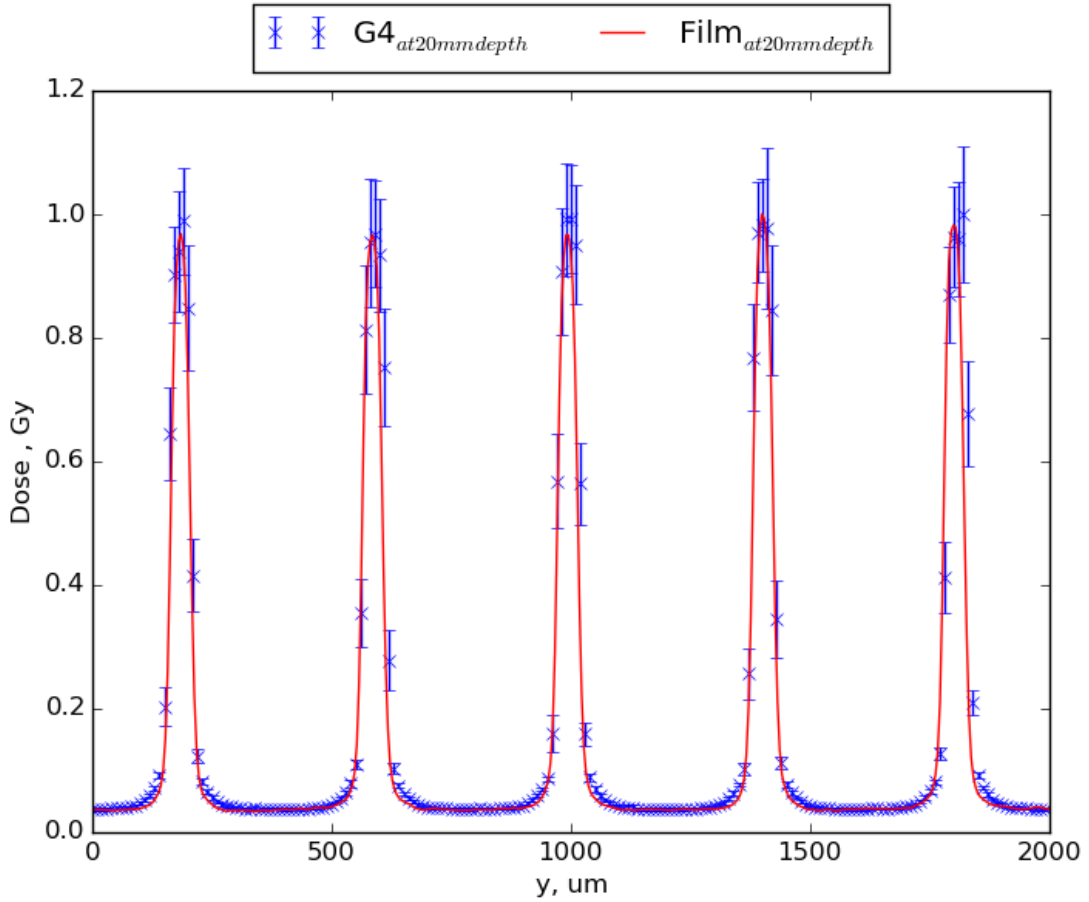
Validation of the simulation

Relative dose profiles – 3T MDR 20 x 20 mm² field

Broad beam 1 x 1 x 1 mm^3 resolution



Microbeam 1 x 0.01 x 0.1 mm^3 resolution



Execution times

Broadbeam configuration

- Stage I PSF filling: variable depending on beam defining aperture size – 4800 hrs in total (~ 200 days)

- Stage II edep for broad beam configuration: ~50 hours

Microbeam configuration (with multislit collimator)

- Stage I: ~1600 days
- Stage II: ~100 hours

- Supercomputing facility: Massive, Monash or Raijin, NCI, Canberra

Summary and conclusions

- An entirely Geant4-based model of the Australian Synchrotron IMBL has been developed
- Good agreement of simulated energy spectra against reference analytical data
- Benchmarking in progress against experimental Ion Chamber and GafChromic film measurements for a variety of configurations
- Future work includes:
  - Investigation into 4T mode
  - Migration to Geant4 Multithreaded
  - Test alternative physics lists of Geant4 – how polarisation affects the simulation results
  - Test the polarisation models of Geant4

The Team – Centre For Medical Radiation Physics, UOW

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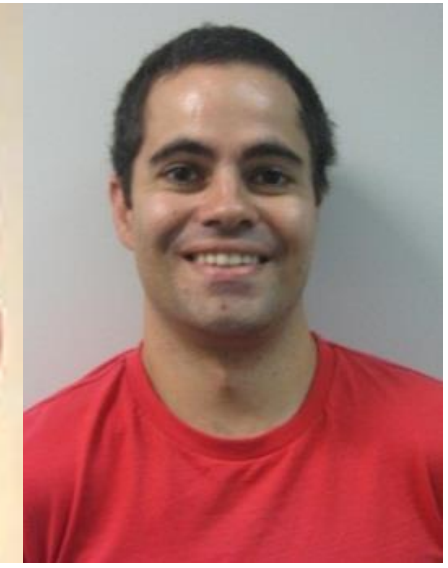

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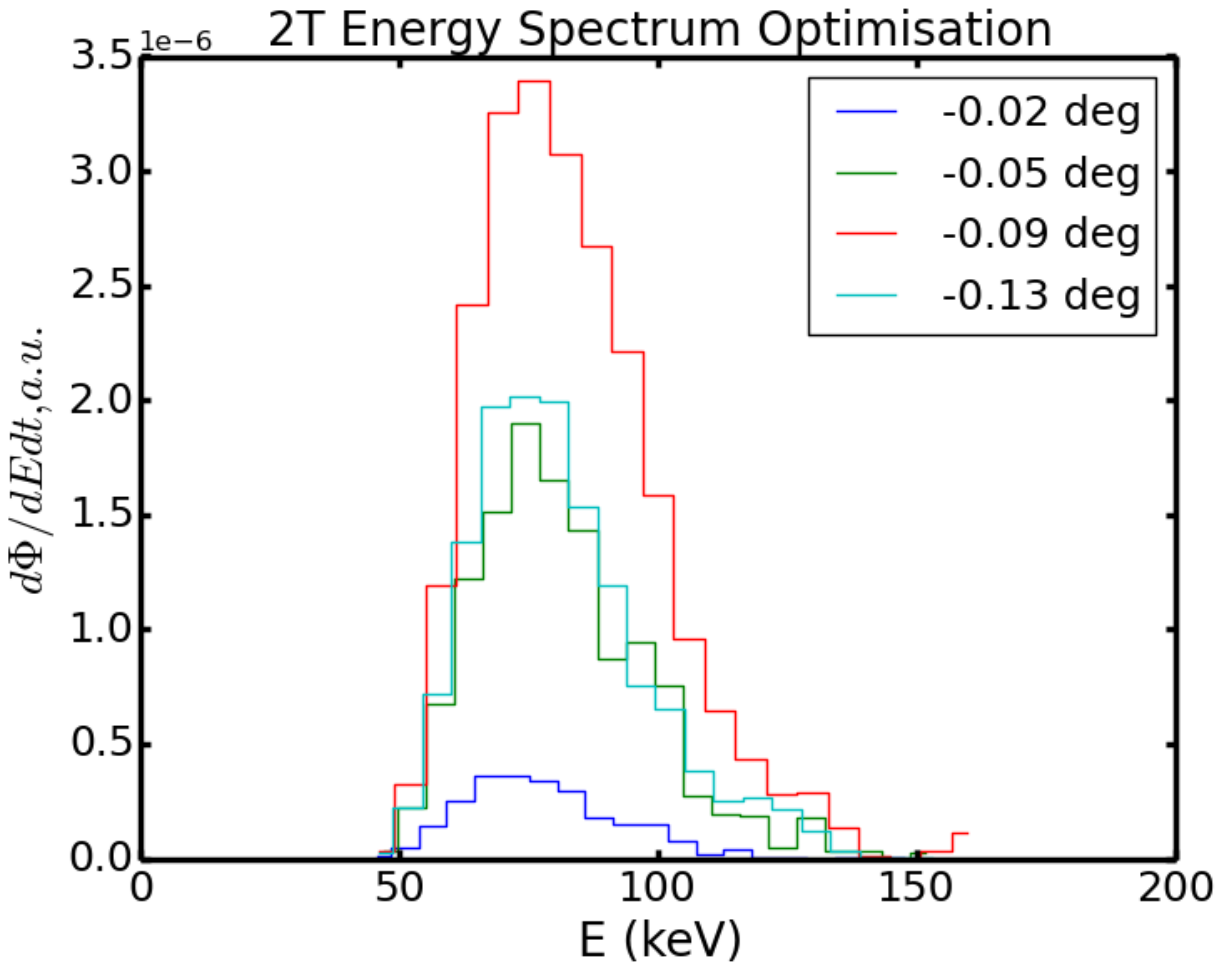
Optimisation of photon flux for 2T Wiggler–Energy Spectra



Angle (deg)	MDR Mean Energy (keV)	Std. Dev. Of the Mean (keV)	Max Relative Intensity (%)
-0.02	74.77	14.32	11.58
-0.05	78.73	16.70	54.95
-0.09	80.30	17.75	100.0
-0.13	78.20	16.66	61.45