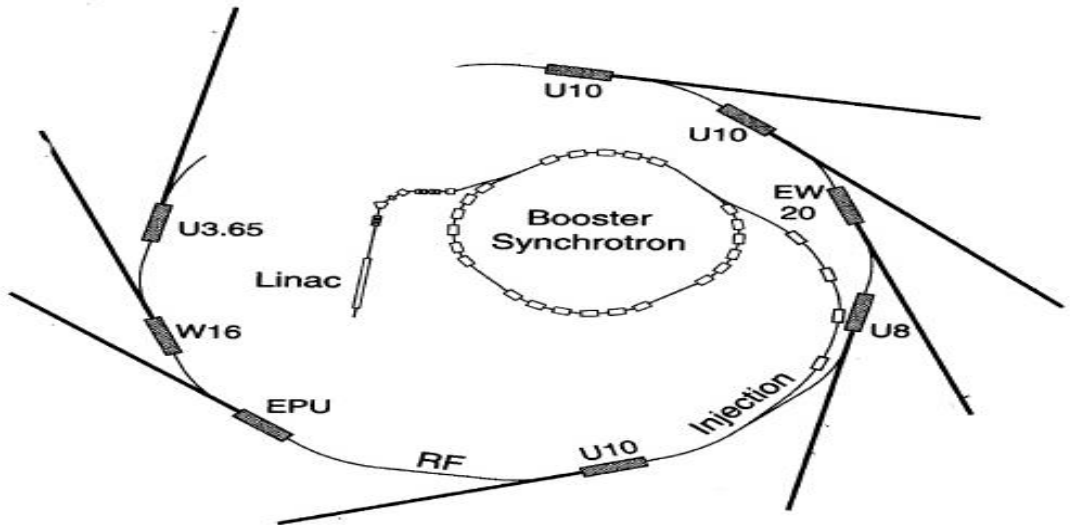
Validation of Geant4 for Microbeam Radiation Therapy

Matthew Cameron, Andrew Dipuglia, Dr. Iwan Cornelius,
Dr. Susanna Guatelli, Dr. Dean Cutajar, Dr. Jeremy Davis,
Dist. Prof. Anatoly Rosenfeld, Assoc. Prof. Michael Lerch

Synchrotron Radiation

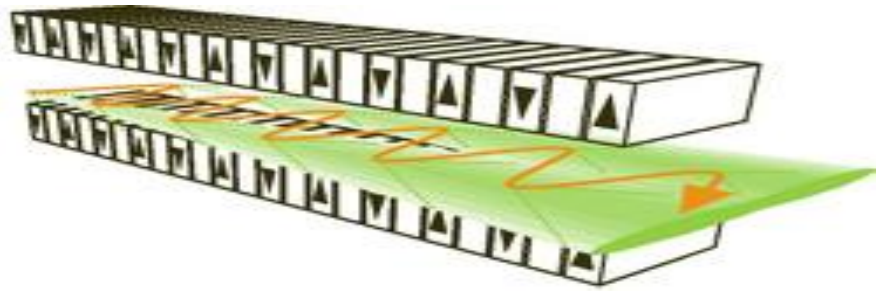
- Average energy ~ 100keV
- High intensity (up to 10kGy/s)
- low divergence
- polarised
- pulsed

Astrophysical Spring School. 2006. "**Synchrotron Radiation.**" Astrophysics Science Division, NASA/GSFC.
<http://asd.gsfc.nasa.gov/Volker.Beckmann/school/download/Longair_Radiation2.pdf



Australian Synchrotron

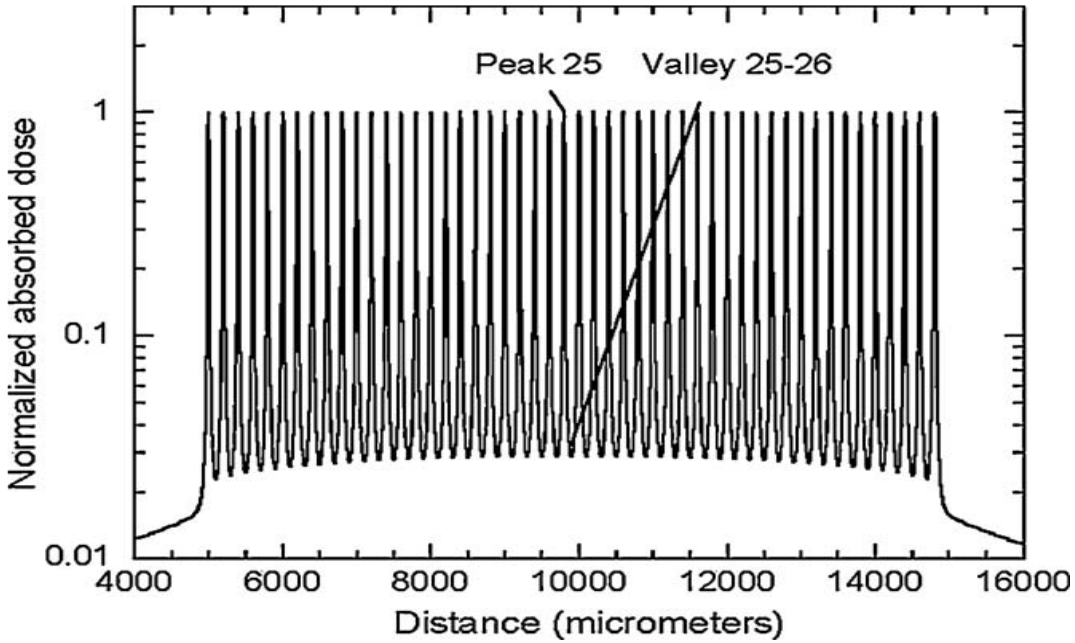
Australian Synchrotron. 2013. "**How Is Synchrotron Light Created?**"
http://www.synchrotron.org.au/index.php/synchrotron-science/how-is-synchrotron-light-created



Microbeam Radiation Therapy

- Preclinical modality of radiotherapy.

- Use of micron sized beams to deposit very large doses.



Braüer-Krisch, E. Serduc, R. Siegbahn, et al. 2010. ***Mutation Research, Vol. 704. Pgs. 160-166.***

Preferential damage to tumors.

- Promising for treatment of:
  - paediatric patients,
  - head and neck tumors
  - other radiosensitive tumors

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

Aim of the project

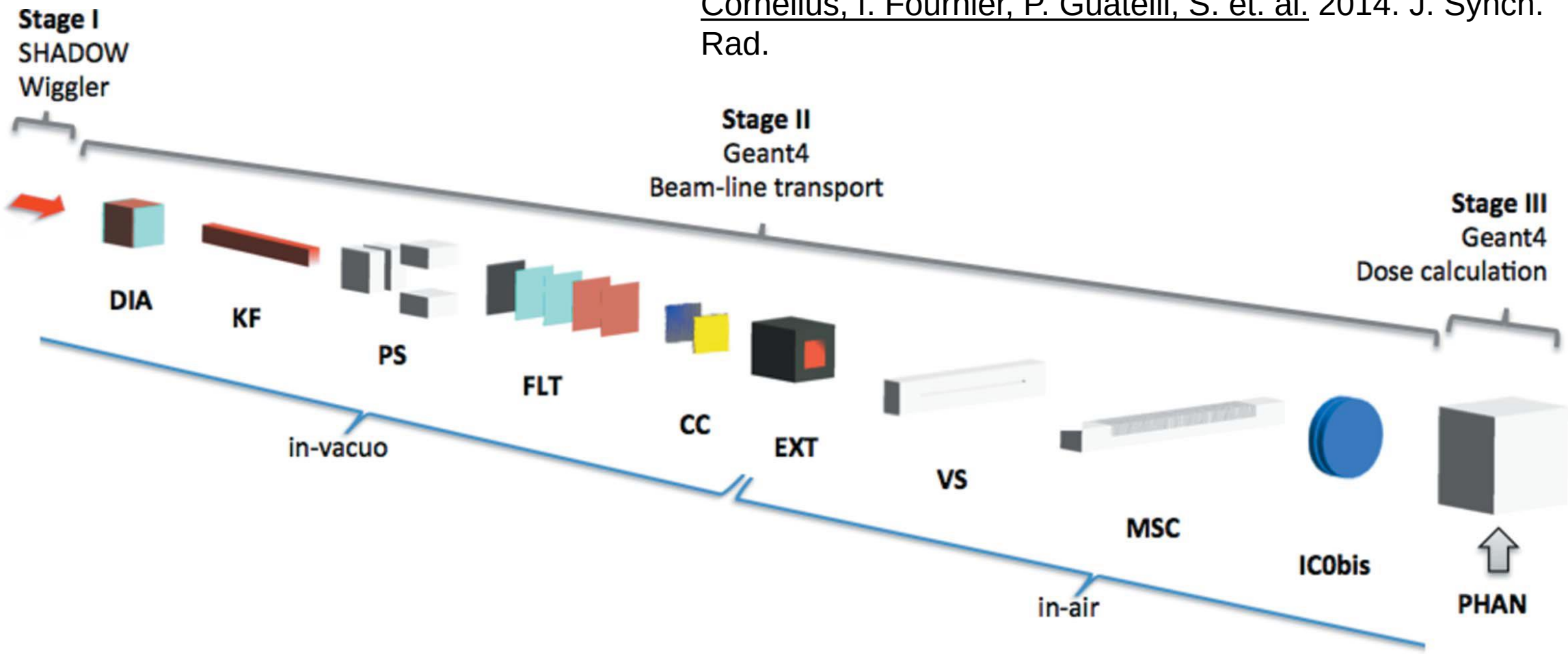
- Development of Monte Carlo simulations for characterisation of CMRP detectors designed for use in Microbeam Radiation Therapy (MRT) at the Australian Synchrotron Imaging and Medical Beamline (IMBL)

- Requirements:
  - Modular design – experiments have differing beamline configuration
  - Geant4 based – no third-party programs during run (python for analysis)
  - Time-dependent geometry – mimic experimental phantom motion
  - Efficient – maximum accuracy for minimum time

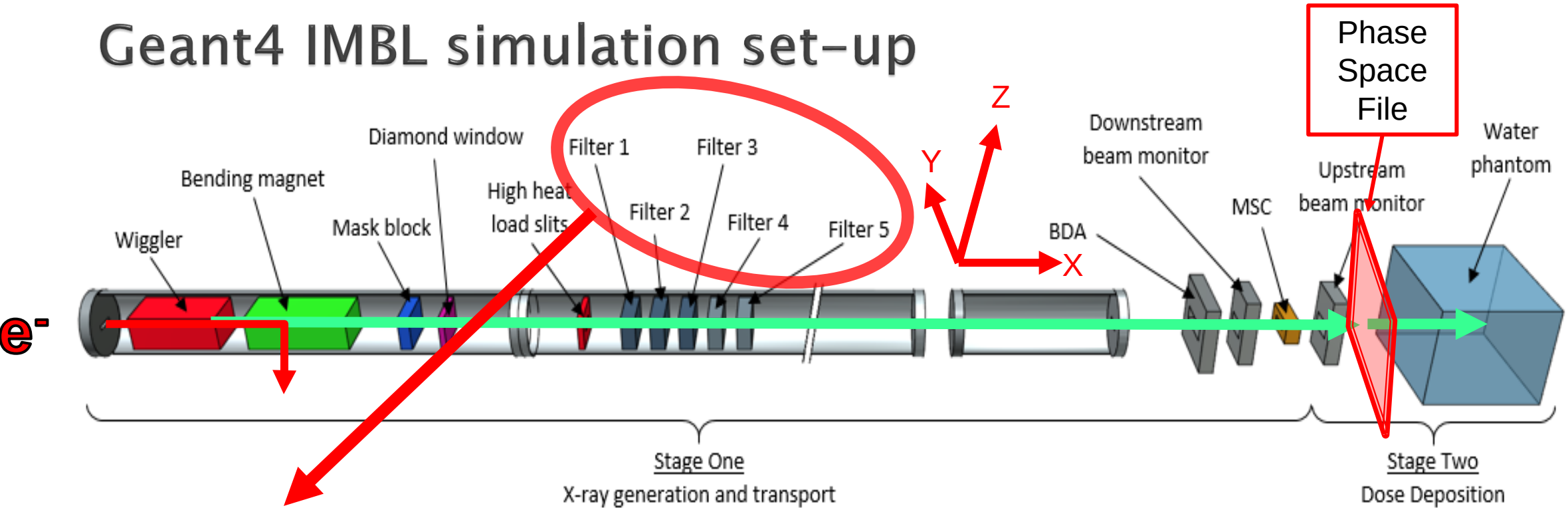
- G4LowEnergyLivermorePolarisedPhysics model
  - 250eV – 10 MeV
- G4SynchrotronRadiationAS process (Grichine ‘98,’05; Ivanchenko ’01, Burkhardt ‘06)
- Geant4.9.6 p04

Geant4 modelling of the ESRF ID17 beamline

Cornelius, I. Fournier, P. Guatelli, S. et. al. 2014. J. Synch. Rad.



Geant4 IMBL simulation set-up



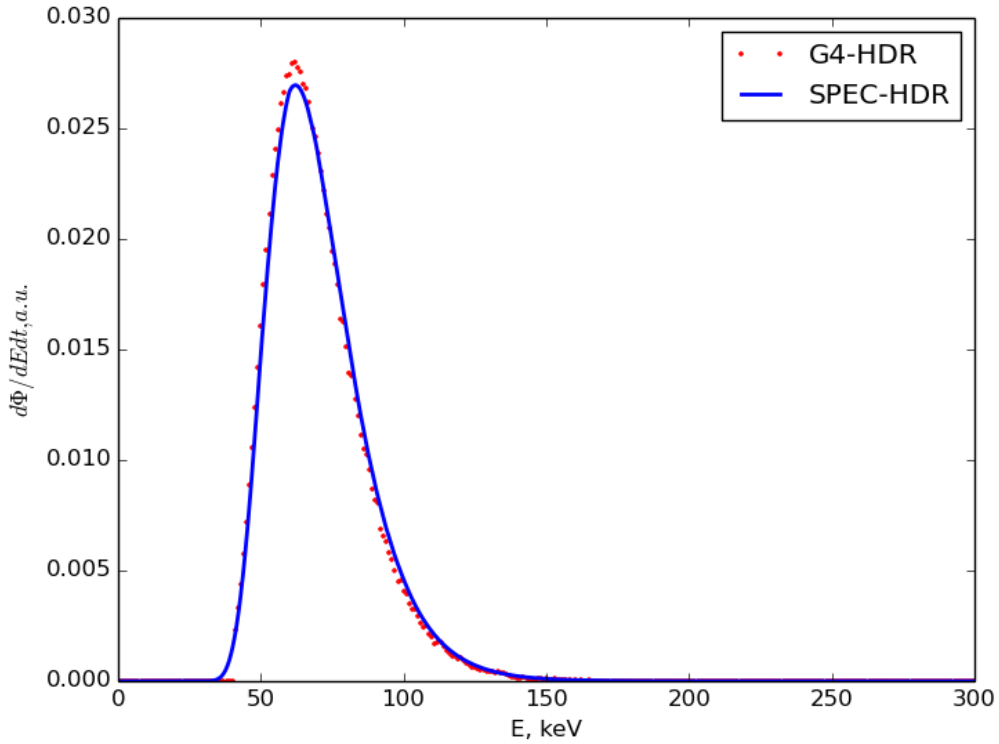
	High Dose Rate (HDR)	Medium Dose Rate (MDR)	Low Dose Rate (LDR)
Filter 1	C (0.45 mm)		
Filter 2	C (1.49 mm) 45°		
Filter 3	C (10 mm) 45°		
Filter 4	Al (2 mm) 45°	Cu (1 mm) 45°	Al (2 mm) 45°
Filter 5	Cu (1 mm) 45°	Cu (1 mm) 45°	Mo (2 mm) 45°

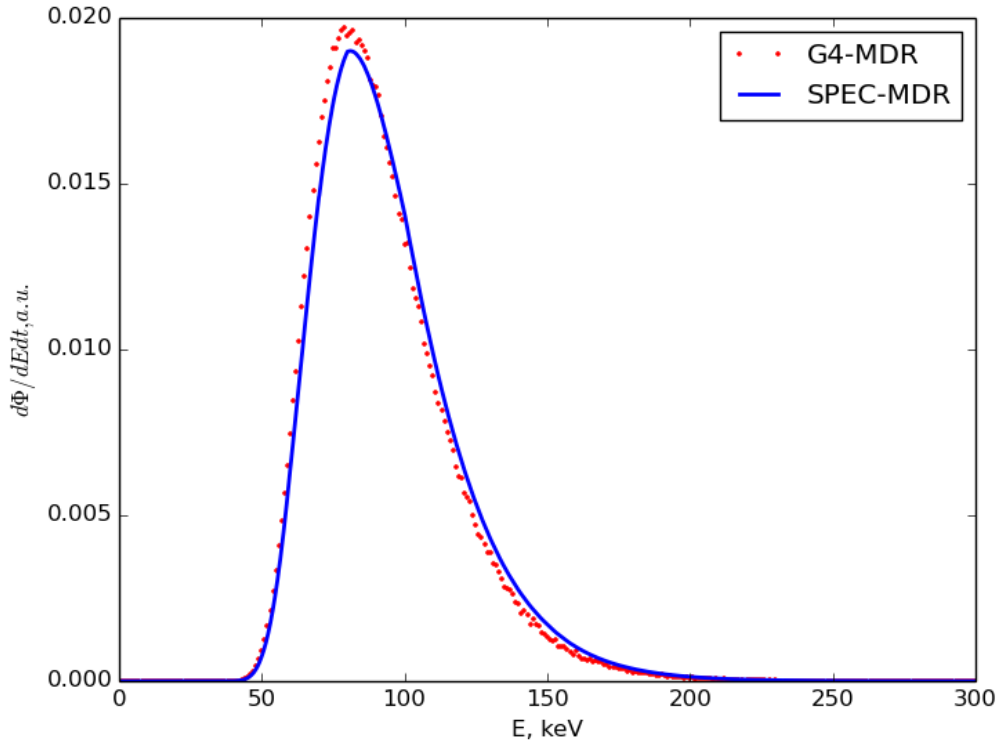
Stage I Validation

- **Phase Space File:** recording properties of particle as double-precision floating-point number
  - Position, Momentum, Polarisation, Energy, Weighting
- FWHM: BDA y and BDA z
- Comparison against theoretical energy spectrum
- Histogram energy bins: 1 keV
- PSF resolution: 1 x 0.1 mm^2 BB
- Production cut: 1 mm γ, 0.01mm e- 1
  - 1 m in Pb Wall, Cu Mask Block, and Cu High-Heat Load slits
- Step limit: 0.1 mm in the wiggler

Comparison to theoretical (SPEC) Energy Spectra

Stevenson, A. Crosbie, J. Hall, C. et al. 2017. **J. Sync. Rad.** ***Vol. 24. Pgs. 110-141.***

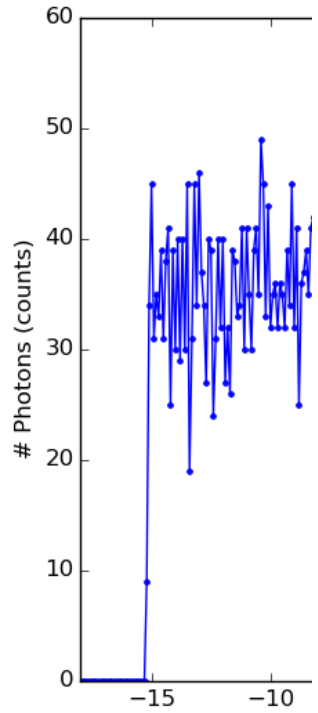


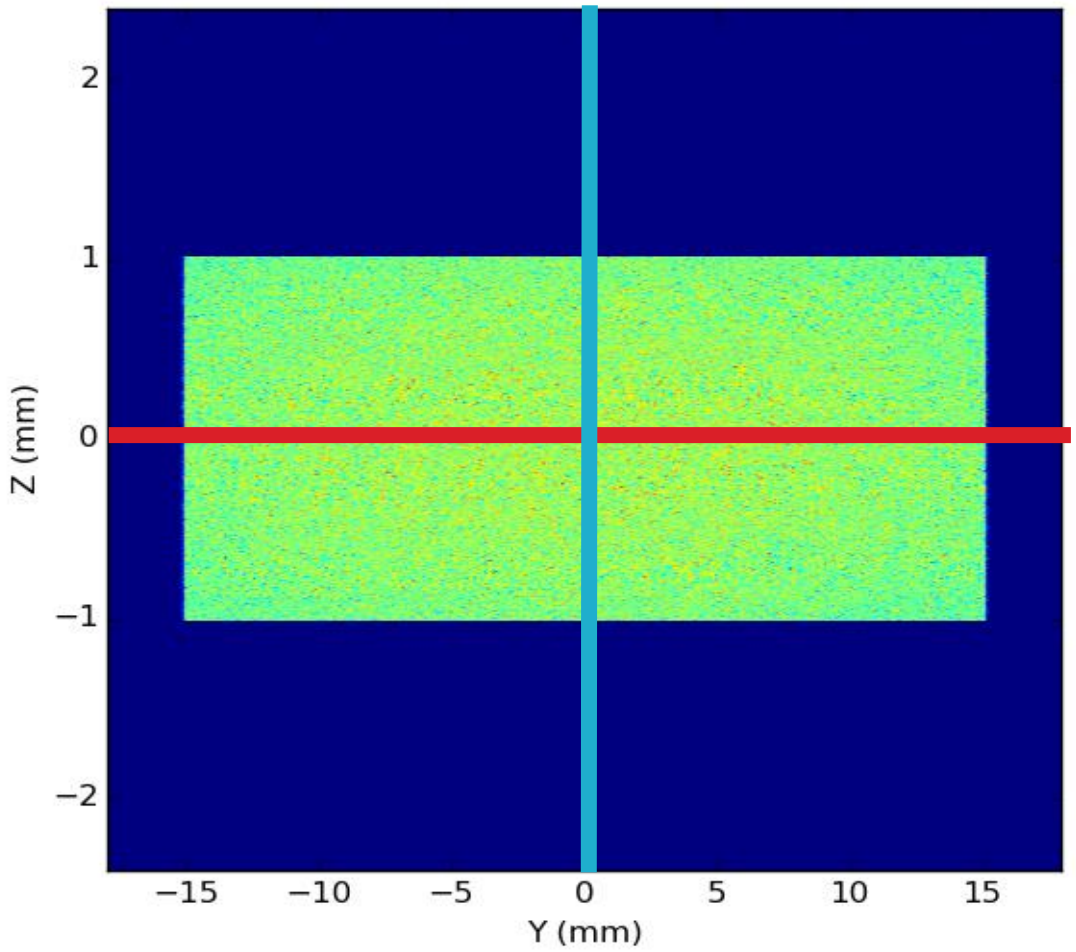


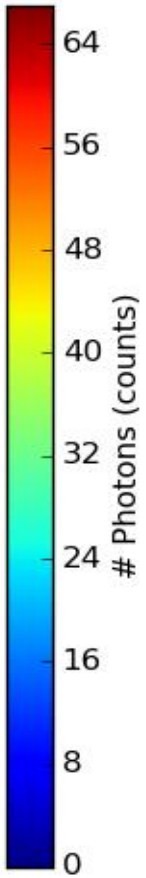
2.0T HDR ~70keV mean

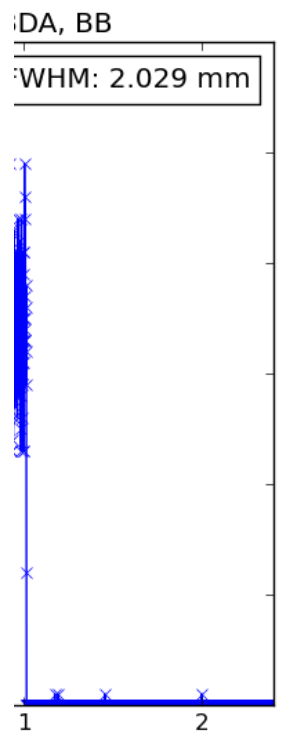
3.0T MDR ~90keV mean

Verification of BDA size





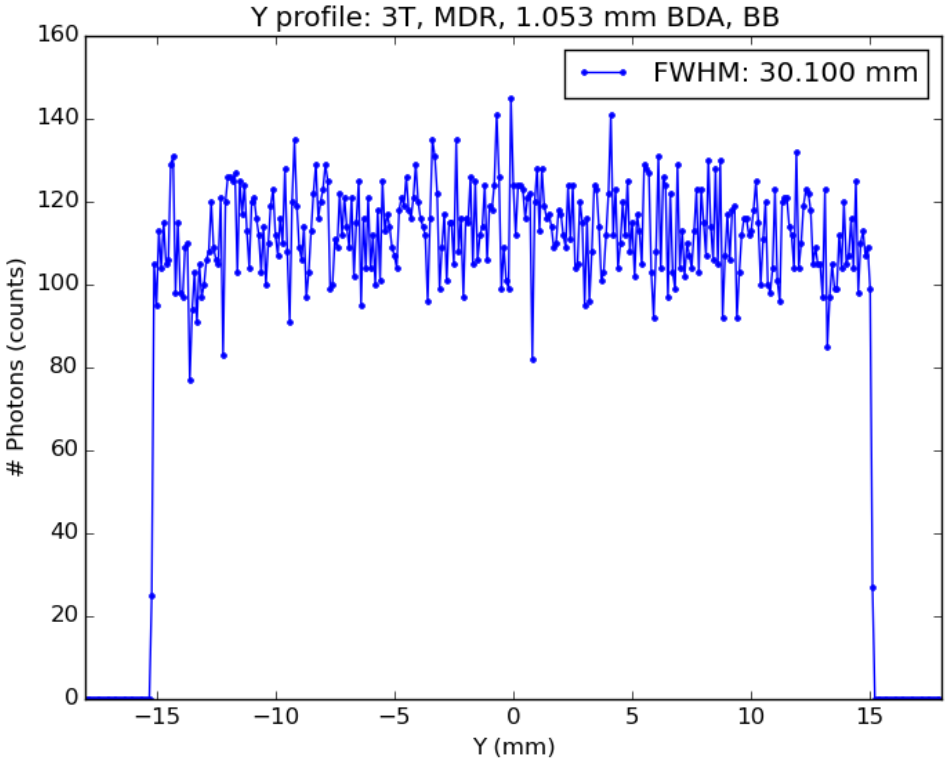




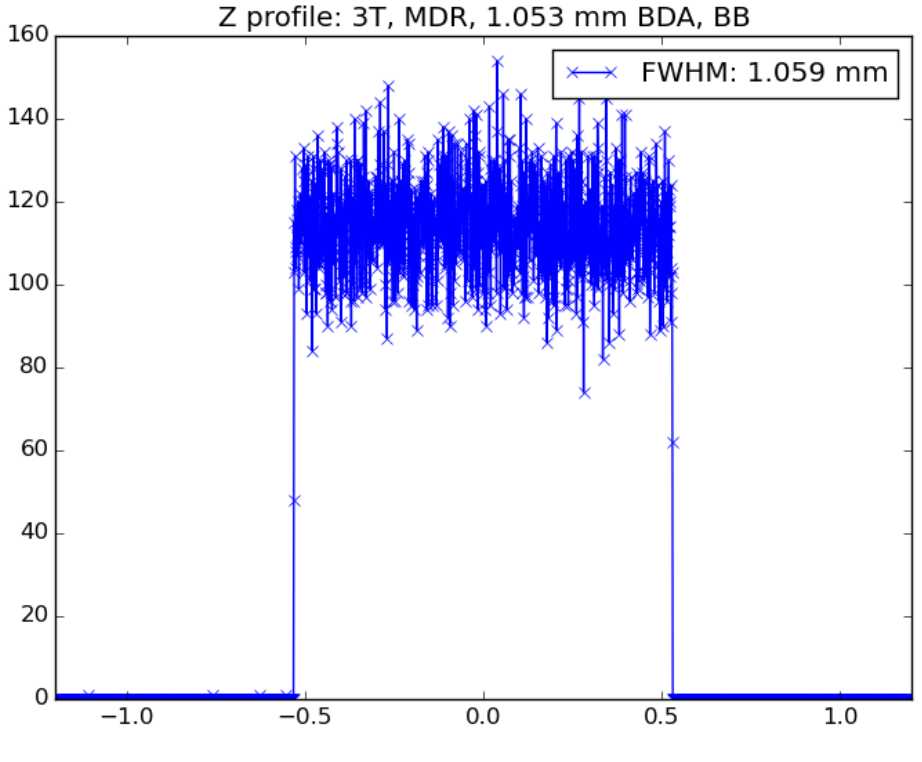
Y intensity pro

n BDA

Verification of BDA size

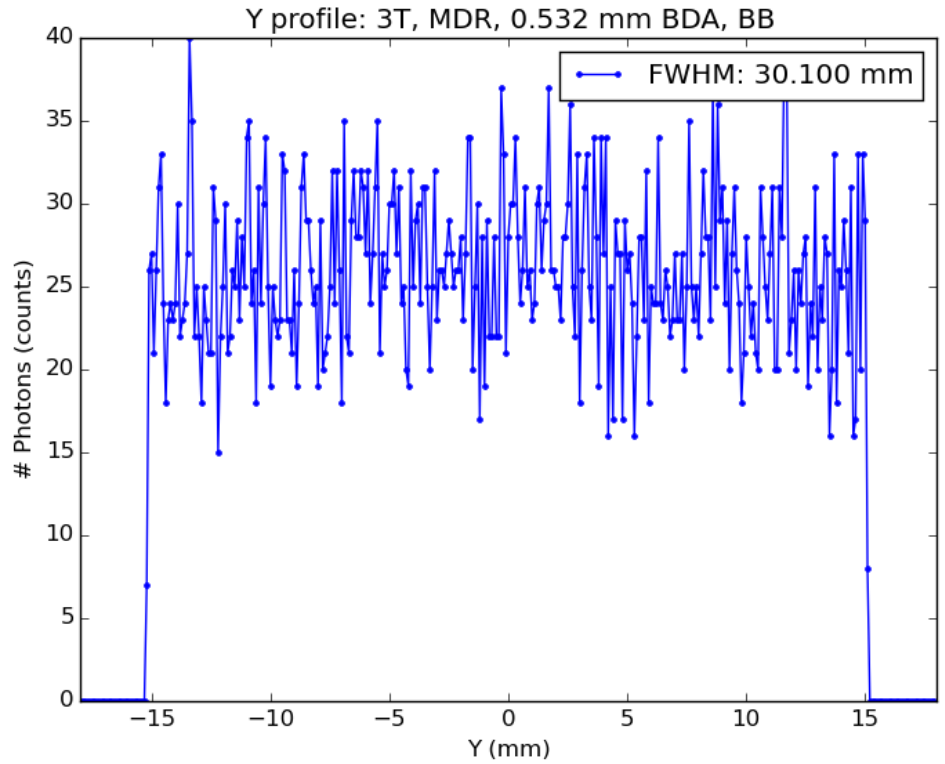


Y intensity profile of 1.053 mm BDA

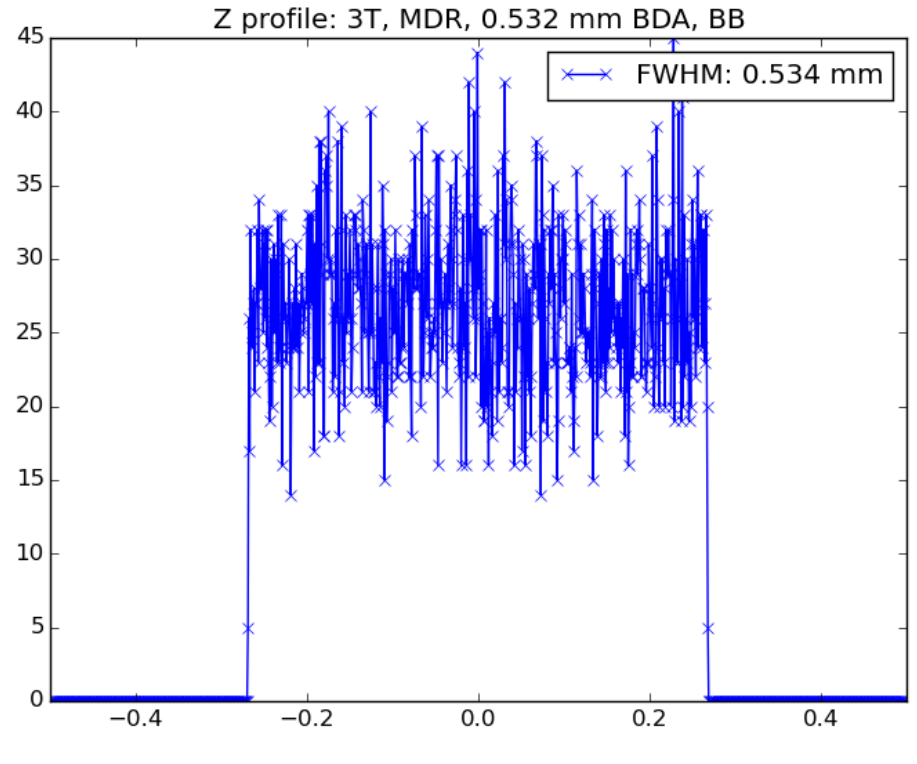


Z intensity profile of 1.053 mm BDA

Verification of BDA size



Y intensity profile of 0.532 mm BDA

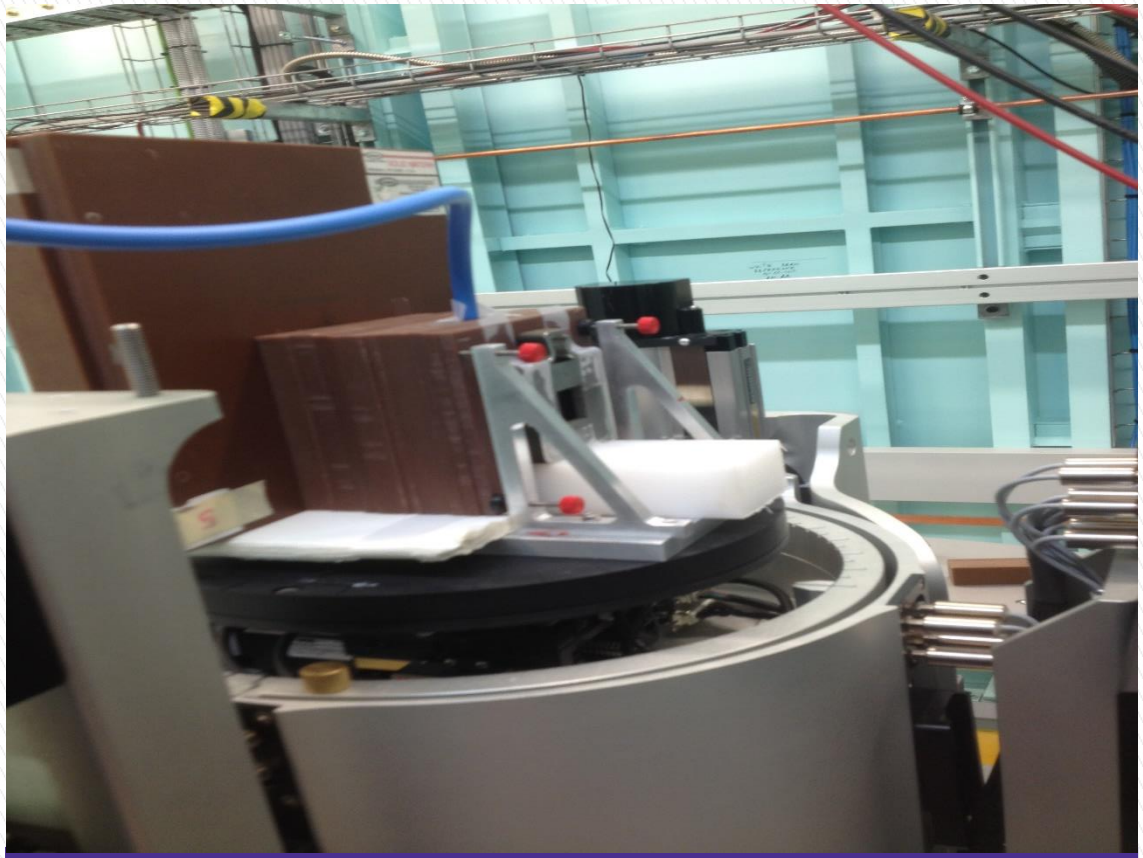


Z intensity profile of 0.532 mm BDA

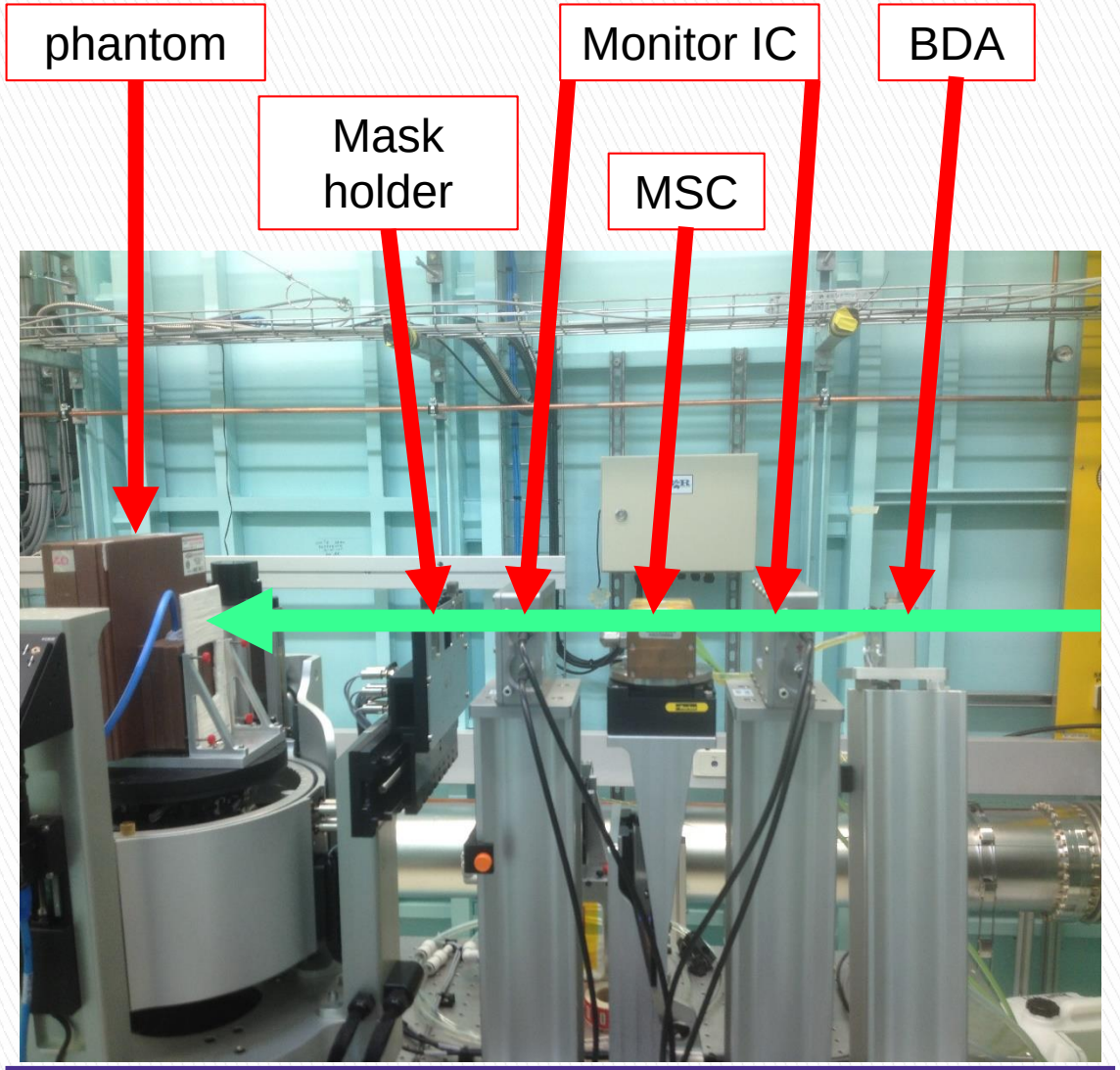
Stage II Validation

- Comparison against:
  - PinPoint 31014 Ion Chamber (PTW, Freiburg)
  - EBT3 GafChromic film (International Specialty Products, Wayne, NJ, USA)
  - RMI457 Solid Water (Gammex, Middleton, WI, USA) phantom (100 x 50 x 50 mm^3)
- Tungsten Mask with 20 x 20 mm^2 aperture placed flush against the surface of the phantom to define field size.
- Voxelisation of phantom
  - G4VSensitiveDetector scoring volume with user-defined dimensions and resolution
  - Energy deposition stored in 3D array based on position of step in scoring volume
- Broad-Beam: 1 x 1 x 1 mm^3 voxels; 100 x 30 x 30 mm^3 scoring volume
  - Production cuts: 1 mm γ, 0.01mm e-
  - Step limit: 10 µm in scoring volume
- Microbeam: 1 x 0.01 x 0.1 mm^3 voxels; 100 x 2 x 2 mm^3 scoring volume
  - Production cuts: 0.01 mm γ, 0.01mm e-
  - Step limit: 1 µm in scoring volume

Experimental Setup

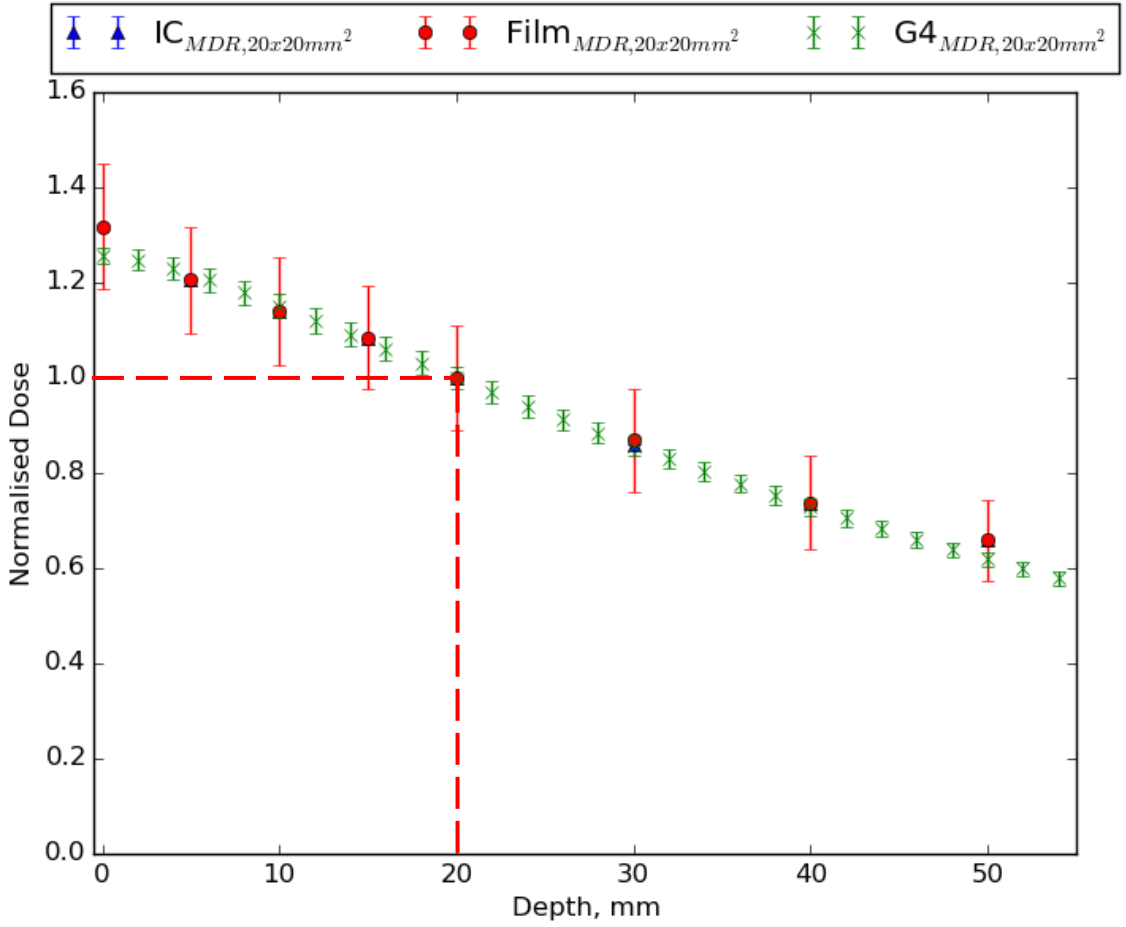


Phantom sample stage

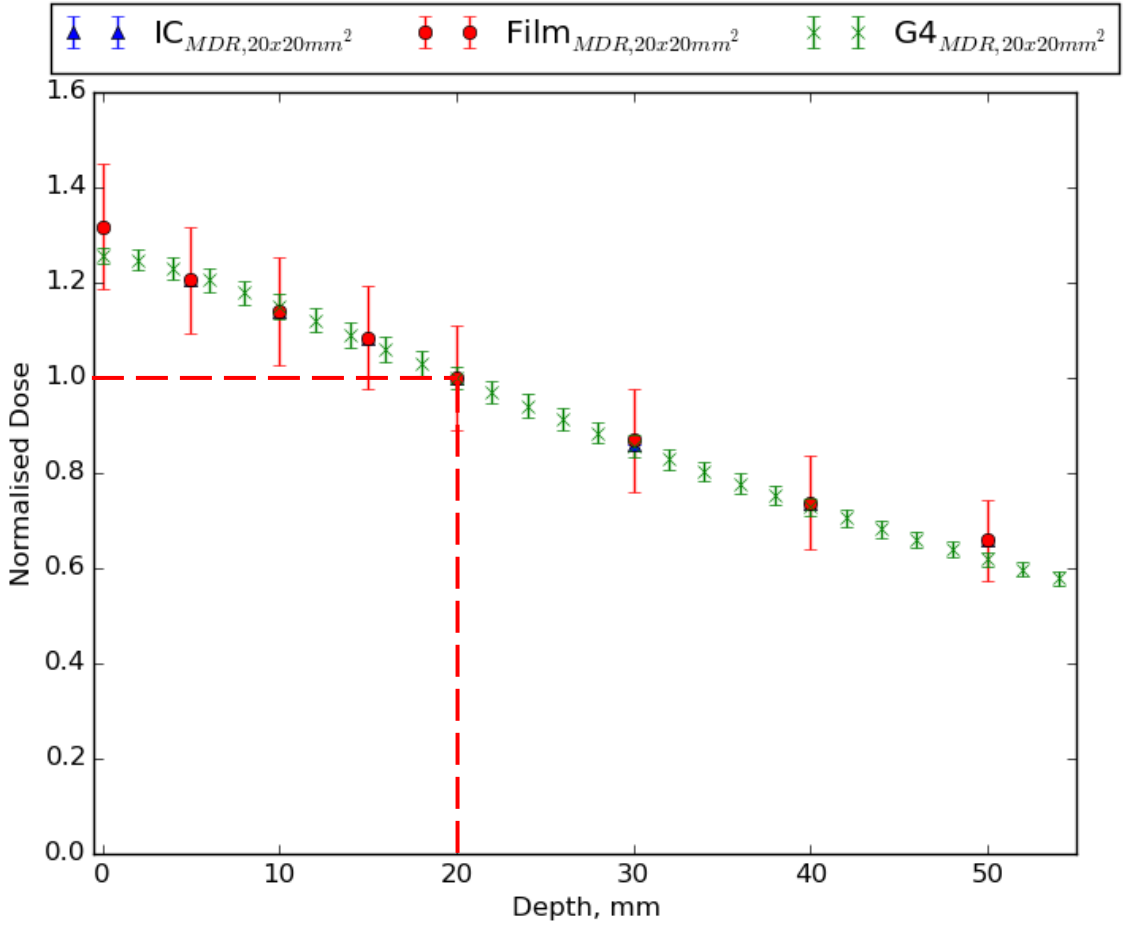


IMBL Hutch2B

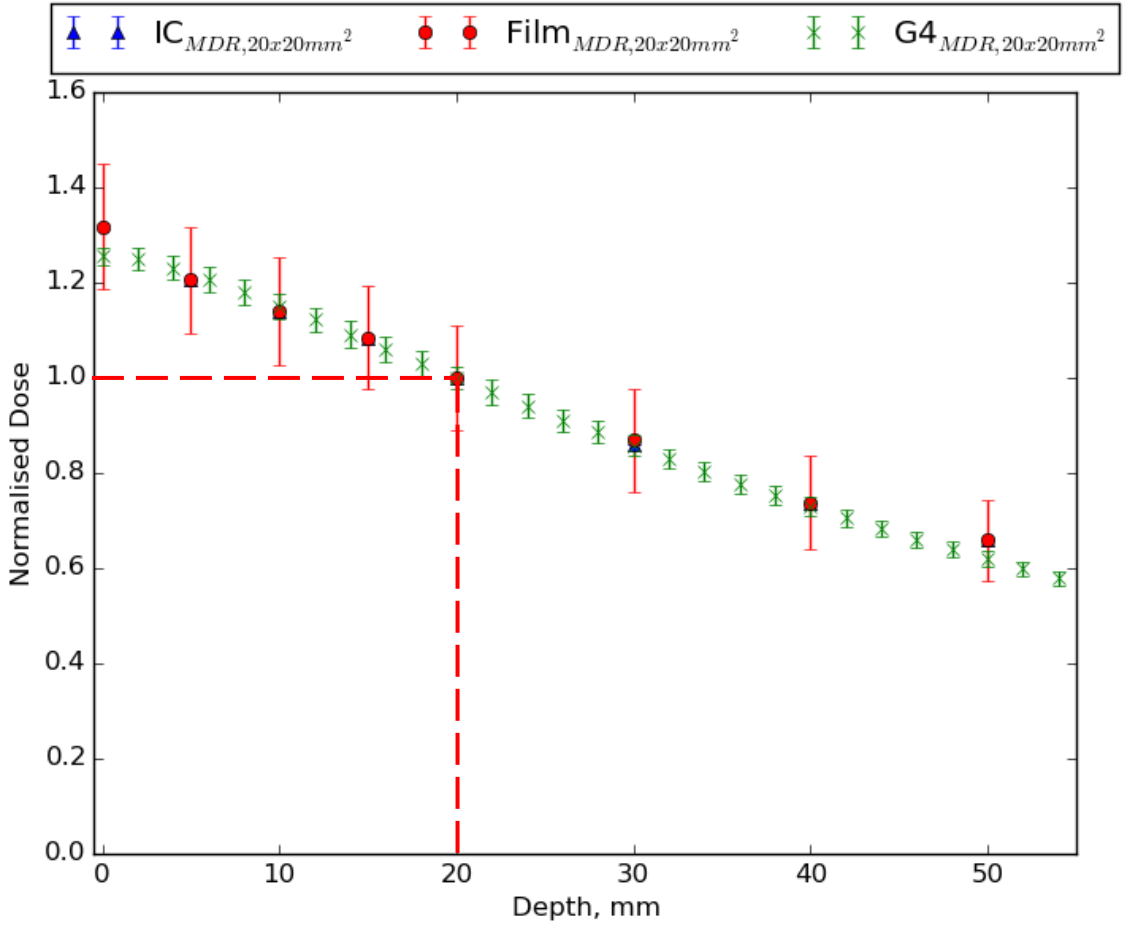
Relative dose profiles – 3T MDR 20 x 20 mm² field, 2.014mm BDA, BB



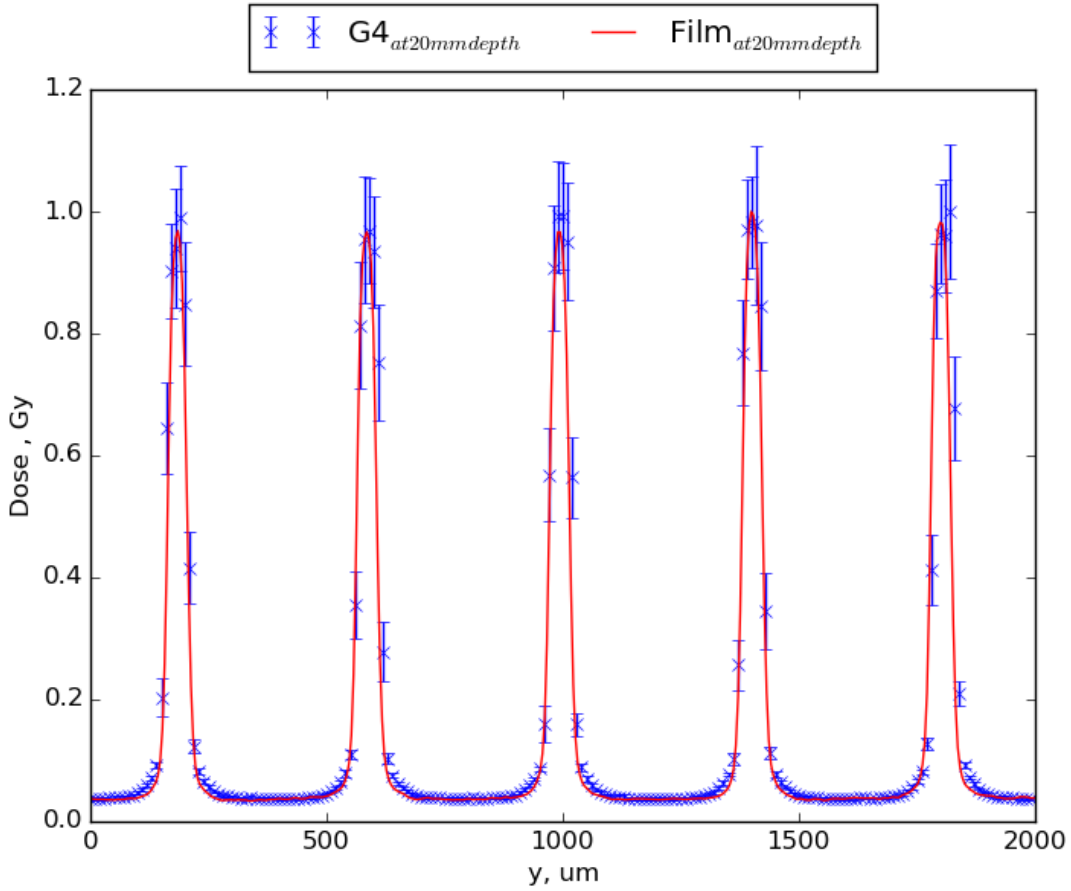
Relative dose profiles – 3T MDR 20 x 20 mm² field, 1.053mm BDA, BB



Relative dose profiles – 3T MDR 20 x 20 mm² field, 0.532mm BDA, BB



Relative Dose profile in yz plane at 20 mm depth in phantom – 1 x 0.01 x 0.1 mm^3 resolution, 2.014 mm BDA, MRT



Conclusions

- An entirely Geant4-based model of the Australian Synchrotron IMBL has been developed
- Good agreement of simulated energy spectra against SPEC data
- Good agreement for 3T MDR Relative Dose Profiles with experimental Ion Chamber and GafChromic film measurements for a variety of configurations
- Future work includes:
  - Further benchmarking
  - Investigation into 4T mode
  - Migration to Geant4 Multithreaded GPU

Acknowledgements

- This work was supported by the Multi-modal Australian ScienceS Imaging and Visualisation Environment (MASSIVE) (www.massive.org.au).
- We would like to thank the University of Wollongong Information Management & Technology Services (IMTS) for computing time on the UOW High Performance Computing Cluster.
- This research has been conducted with the support of the Australian Government Research Training Program Scholarship and the NH&MRC (APP1093256).
- Special thanks to the Australian Synchrotron Imaging and Medical Beamline staff for all of their assistance.