Monte Carlo modelling and experimental verification of a high resolution silicon diode array performance in proton beams and magnetic fields

Brad Oborn[1,2], T. J Causer[2,1], S. M. Schellhammer[3,4], S. Gantz[3,4], A. Luhr[3,4,5], A. L. Hoffmann[3,4,6], P. E. Metcalfe[1,7], S. Guatelli[1], M. Petasecca[1], A. B. Rosenfeld[1]

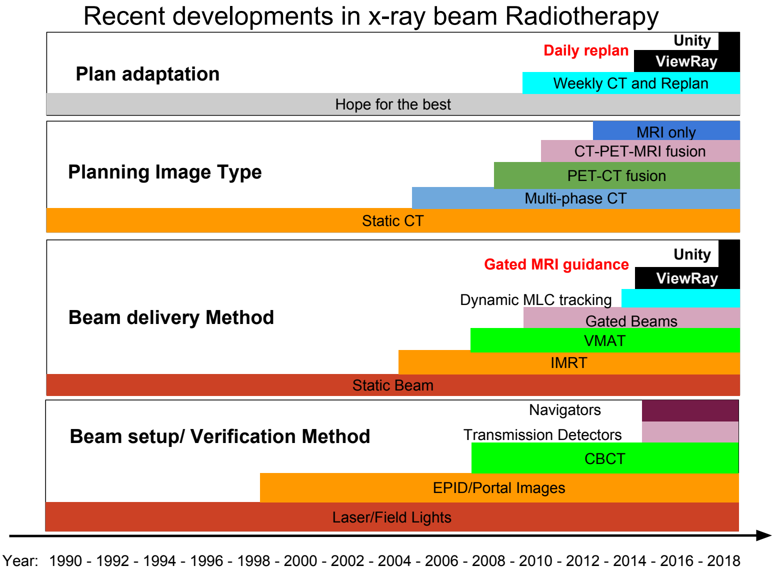
[1]Centre for Medical Radiation Physics (CMRP), University of Wollongong, NSW 2522 Australia
[2]Illawarra Cancer Care Centre(ICCC), Wollongong Hospital, NSW 2500 Australia
[3]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Radiooncology, Dresden, Germany
[4]OncoRay - Nat. Center for Rad. Research in Oncology, Dept. Med. Rad. Phys., Dresden, Germany
[5]German Cancer Consortium DKTK, Partner Site Dresden, Dresden, Germany
[6]Faculty of Medicine and University Hospital Carl Gustav Carus at the Technische Universität Dresden, Dept. Radiation Oncology, Dresden, Germany
[7]Ingham Institute for Applied Medical Research, Liverpool, NSW 2170 Australia

CENTRE FOR MEDICAL RADIATION PHYSICS

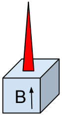
MCMA: Naples, Oct 15th-18th 2017

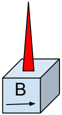
University of Wollongong

Increasingly complex radiotherapy.... MRI guidance is here..



MRI guided X-ray Therapy Systems



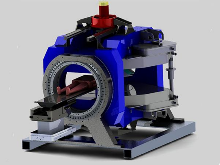


Inline

Rotate Magnet and Gantry

Alberta Inline: Magnettx ***Aurora-RT***

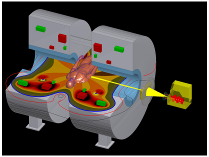
0.5 T
6MV



Rotate Patient

Sydney Inline: (Australian MRI-linac)

1.0 T
6MV

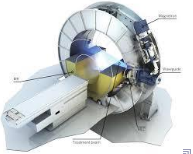


Perpendicular

Rotate Gantry

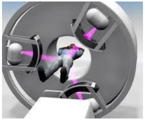
Utrecht: Philips-Elekta: ***Unity***

1.5 T
7MV

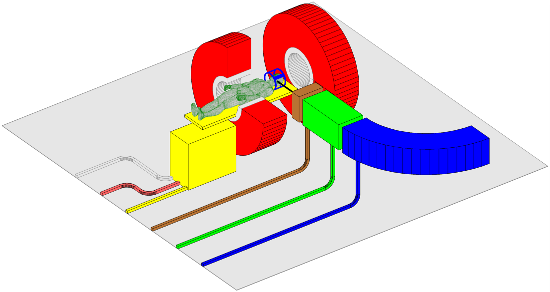


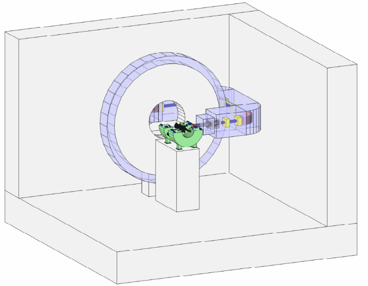
ViewRay: ***MRIdian***

0.35 T
Co60
& 6MV



Real-time MRI-guided Proton beam therapy?





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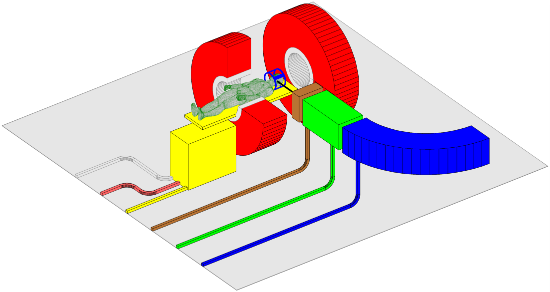
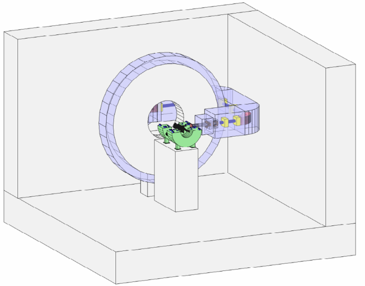
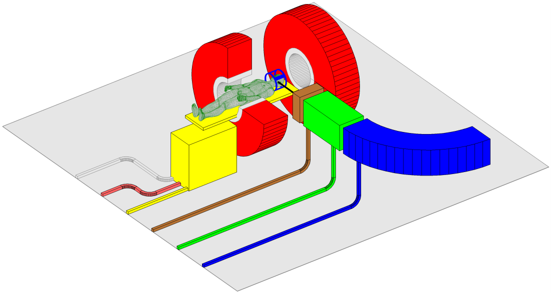
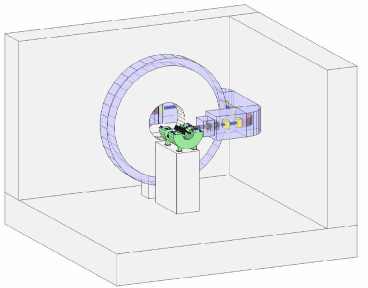




A challenging concept...

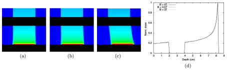
Real-time MRI-guided Proton beam therapy?





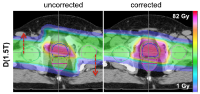
A challenging concept... but various studies already exist....

Deflection in B



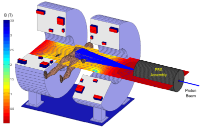
- Raaymakers *et al.*, Phys. Med. Biol. 53 (2008) 5615-5622.
- Wolf and Bortfeld, Phys. Med. Biol. 57 (2012) N329-N337

Planning Studies



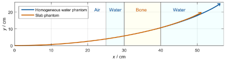
- Moteabbed *et al.*, Med. Phys. 41, 111713 (2014)
- Hartmann *et al.*, Phys. Med. Biol. 60 (2015) 5955-5969

Beam delivery



- Oborn *et al.* Med. Phys. 42, 2113 (2015)

Fast numerical model



- Schellhammer and Hoffmann, Phys. Med. Biol. 62 (2017) 1548-1564

MRI-guided Proton therapy.....

MRI-guided Proton therapy.....

Future of medical physics: Real-time MRI-guided proton therapy

Bradley M. Oborn[a)]
Illawarra Cancer Care Centre (ICCC), Wollongong, NSW 2500, Australia
Centre for Medical Radiation Physics (CMRP), University of Wollongong, Wollongong, NSW 2500, Australia

Stephen Dowdell
Shoalhaven Cancer Care Centre, Nowra, NSW 2541, Australia

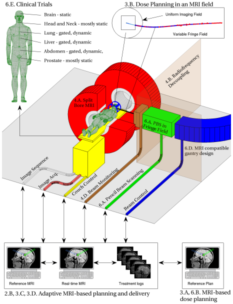
Peter E. Metcalfe
Centre for Medical Radiation Physics (CMRP), University of Wollongong, Wollongong, NSW 2500, Australia
Ingham Institute for Applied Medical Research, Liverpool, NSW 2170, Australia

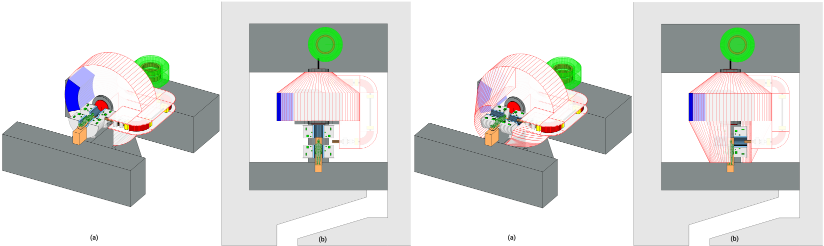
Stuart Crozier
School of Information Technology and Electric Engineering, University of Queensland, QLD 4072, Australia

Radhe Mohan
Department of Radiation Oncology, MD Anderson, Houston, TX 77030, USA

Paul J. Keall
Sydney Medical School, University of Sydney, NSW 2006, Australia
Ingham Institute for Applied Medical Research, Liverpool, NSW 2170, Australia

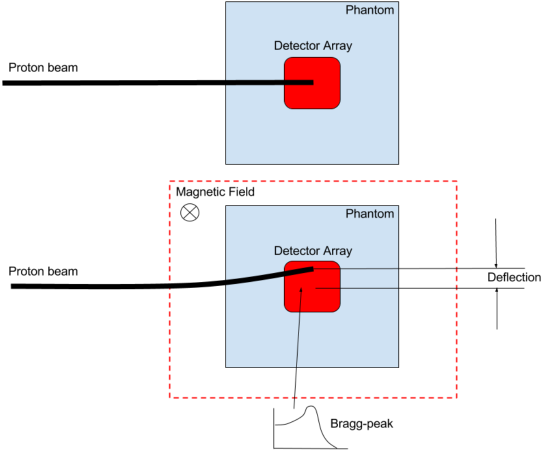
(Received 11 December 2016; revised 12 March 2017; accepted for publication 15 May 2017; published 4 July 2017)





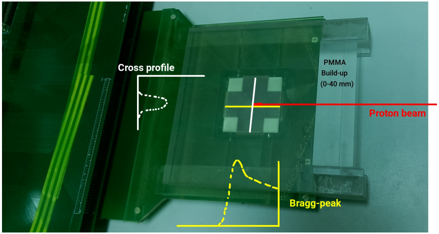
Experiment Aims

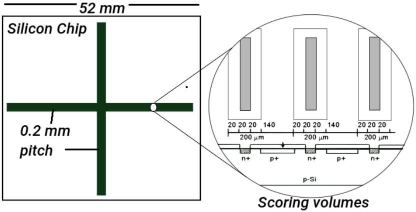
- To assess the operation of a high resolution dosimeter in magnetic fields for proton beams
  - Deflections
  - Bragg-peak
  - High resolution
- To setup Geant4 Monte Carlo simulations of the experiment
  - Complex geometry and beamline
  - Verify experimental results

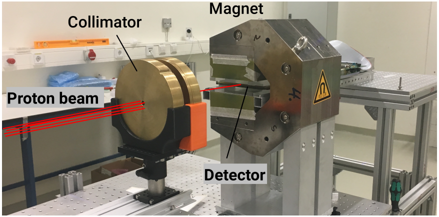


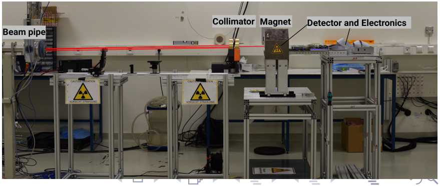
Methods: Experimental Setup

- Silicon based diode array: 'DUO'[a]
  - 0.2 mm pitch cross-hair
  - 52x52 mm range
  - 256 pixels in each cross-hair
  - 0-40 mm thick PMMA build-up
- 0.95 T magnetic field
  - OncoRay permanent magnet
- 90, 109, 125 MeV proton beams
  - Dresden research beamline





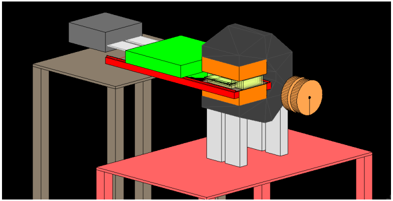




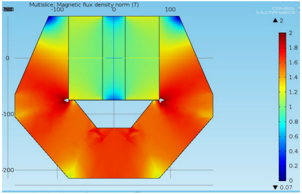
[a]CMRP, University of Wollongong, Australia

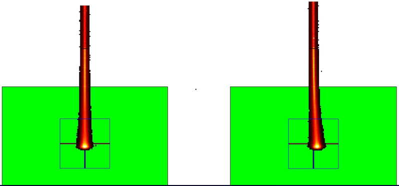
Methods: Monte Carlo Setup

- Geant4
  - Full detector geometry
  - Full magnetic field map from COMSOL simulation
  - Parameterised proton beamline
  - 10 mm collimated beams

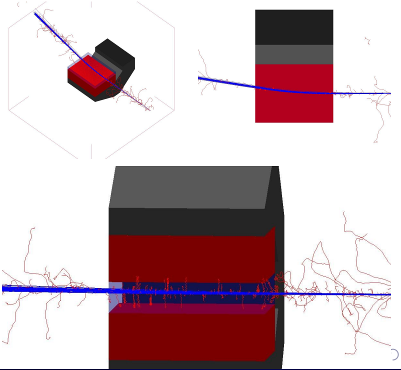


COMSOL MODEL



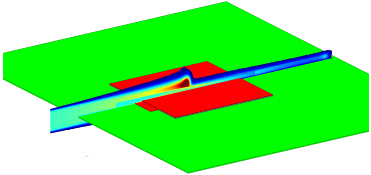


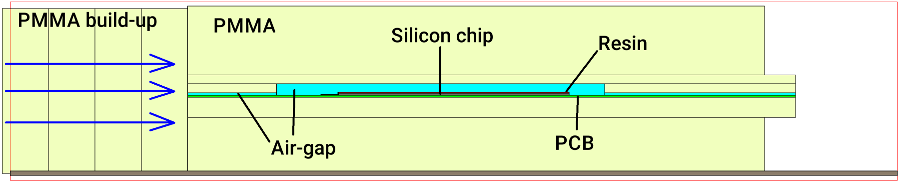
70 MeV Pencil Beam in Air



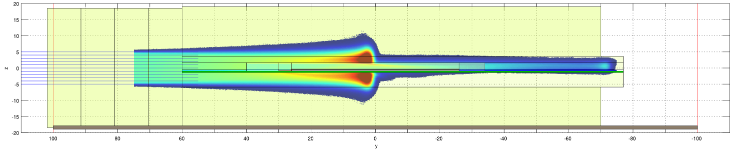
Results: simulation basics

- The proton beam travels through various media:
  - PMMA, Air gaps, PCB (printed circuit board), resin, silicon chip
  - Protons will scatter between mediums before stopping somewhere
  - Hence the Bragg-peak is spreadout
  - Size/shape of the air-gap most important

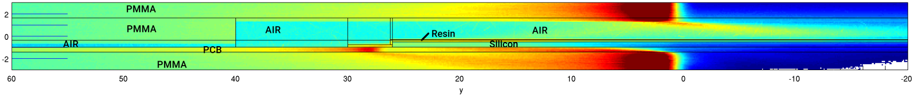




Results: simulation basics - dose distributions



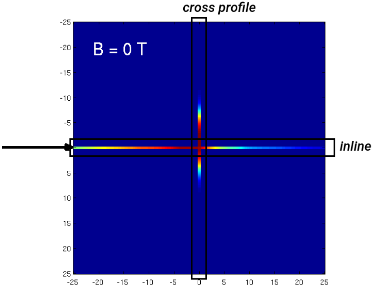
A sideview of the spread-out Bragg-peak components

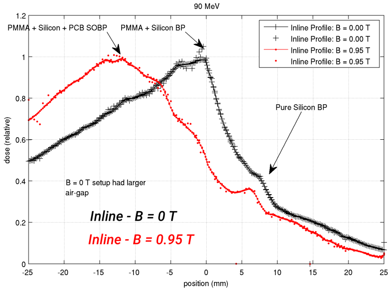


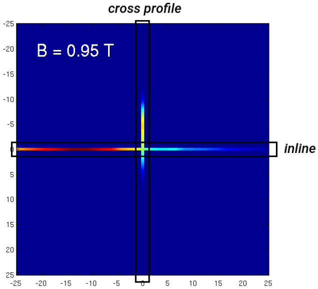
A close-up of the dose in the silicon chip: multiple B-P are observed

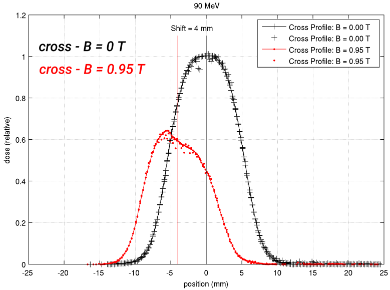
- PMMA + Silicon path
- Air + Silicon path
- PBC + Silicon path
- Various media path = SOBP/background...

Exp results: 90 MeV Edge-on

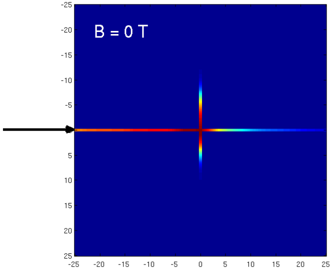


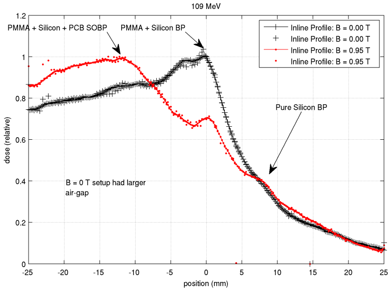


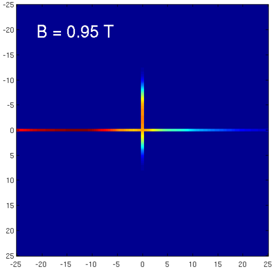


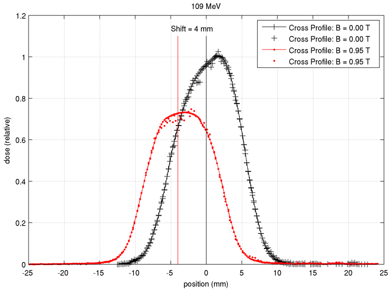


Exp results: 109 MeV Edge-on

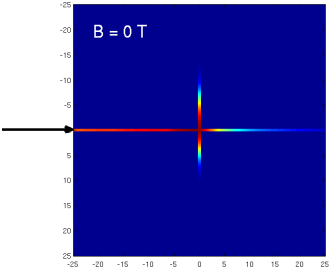


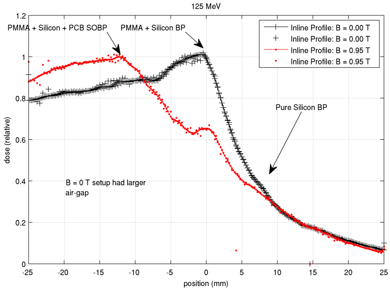


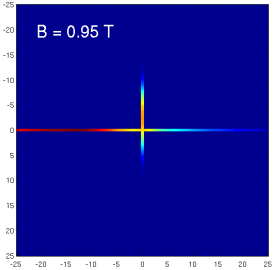


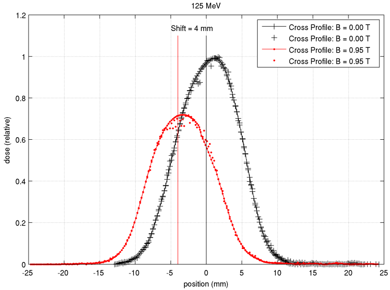


Exp results: 125 MeV Edge-on



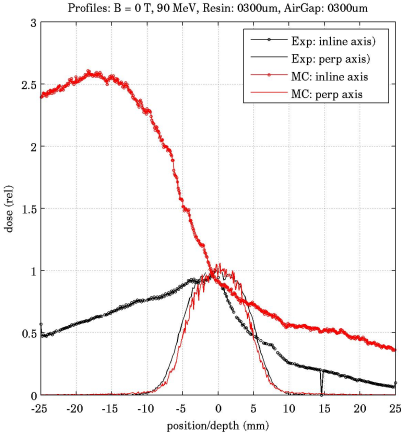


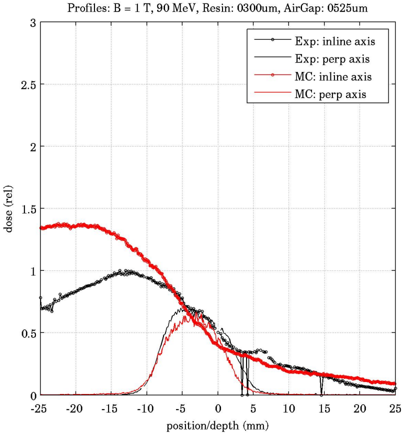




Results: Simulation vs Experiment

- Good agreement with the deflection amount observed: $\approx$ 4 mm for a beam which reaches the cross-hair
- We don't have a good match inline direction: air-gap squashed/relaxed





Discussion/Conclusions

- A complex multiple Bragg-peaked depth-dose profile was observed
  - Monte Carlo helps to explain, but completely accurate model not found
  - Multiple Bragg-peaks can be used for energy verification
- A changing beam cross-profile was observed for different energies
  - A unique Monte Carlo beam model will be required for each energy
  - direction, spread, FWHM....
- Real-time MRI guided proton therapy will require robust dosimetry
  - Pencil beam scanning only for MR-PT
  - Real-time requirements
  - Proton deflections
- Another field ready for Monte Carlo!

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Thanks for your attention!