MRI

+

LINAC

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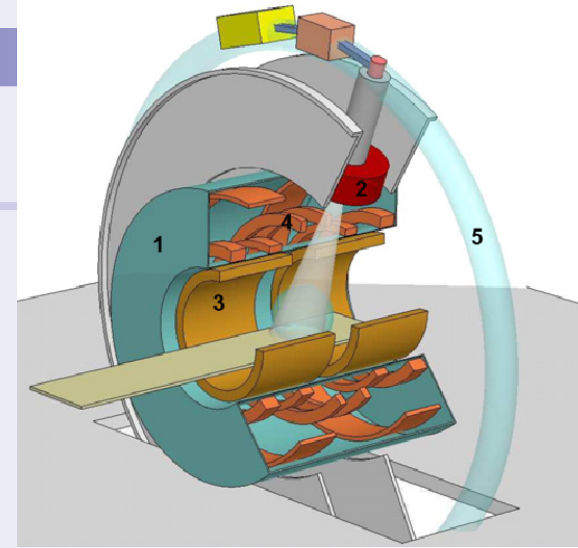

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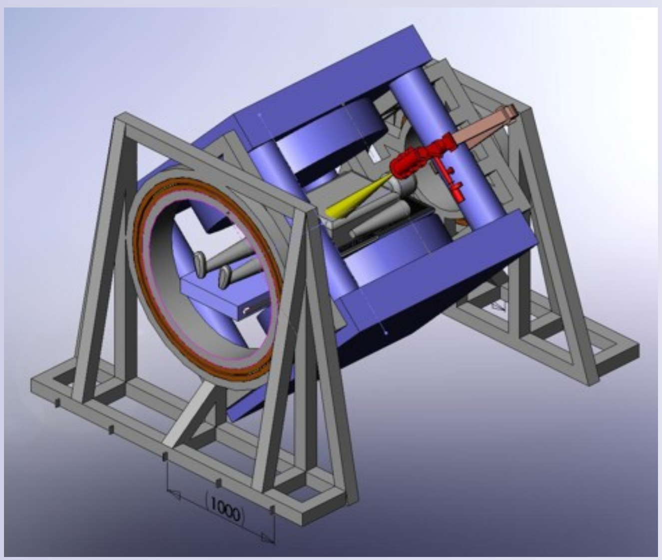
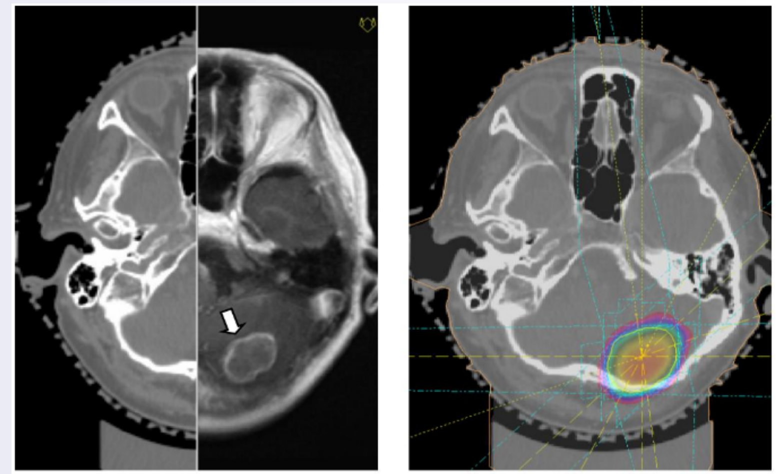


Skin Dosimetry in MRIgRT (MRI-guided-Radiotherapy)

Bradley Oborn
PhD Candidate
Centre for Medical Radiation Physics (CMRP)
University of Wollongong, Australia

Introduction

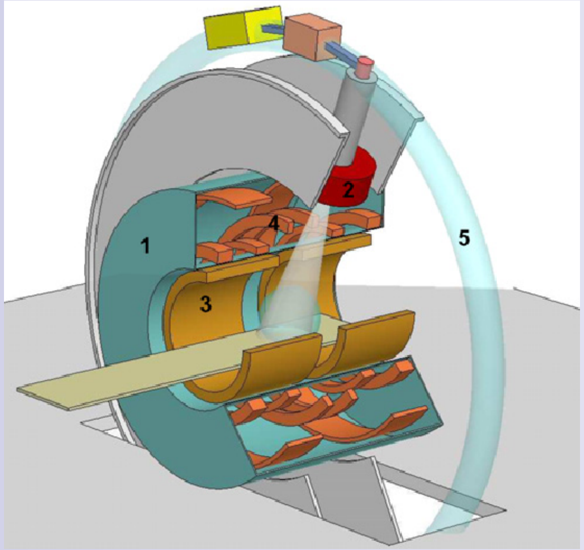
- MRI-guided-Radiotherapy (MRIgRT) is an experimental stage modality.
- Shows great promise for healthy tissue sparing and dose escalation to tumours
  – treatment delivered to MR quality images!
- Downsides:
  – Complex machines
  – Over/underdosing at boundaries
  – Skin dose increases
  – Complex treatment planning
- Most likely arrangement:
  – 6 MV Linac + transverse magnetic field
  – 0.2 – 1.5 T range
- Two working prototypes: Raaymakers et al[1], and Fallone et al[2].
- Quote from Talking Point (medicalphysicsweb.org, 23 Jul 2008, Kevin Brown, Elekta's Research Director) on the next big developments in radiotherapy:
  – "VMAT ....and the use of MR imaging during radiation therapy."

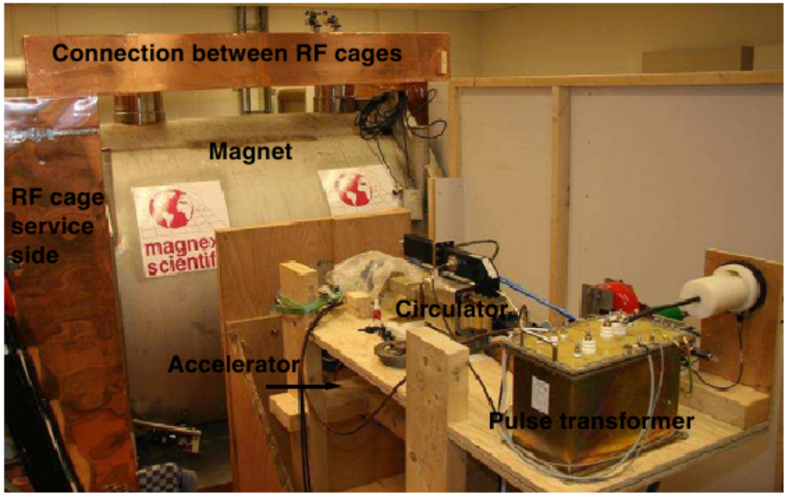


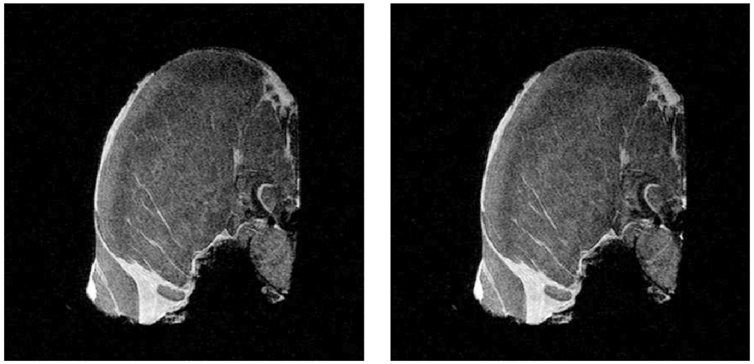
CT MRI

Working Prototypes 1

- Raaymakers et al, (Netherlands),
- 1.5 T "Fixed Cylindrical" (FC)
- B-field ⊥ to beam Central Axis (CAX)



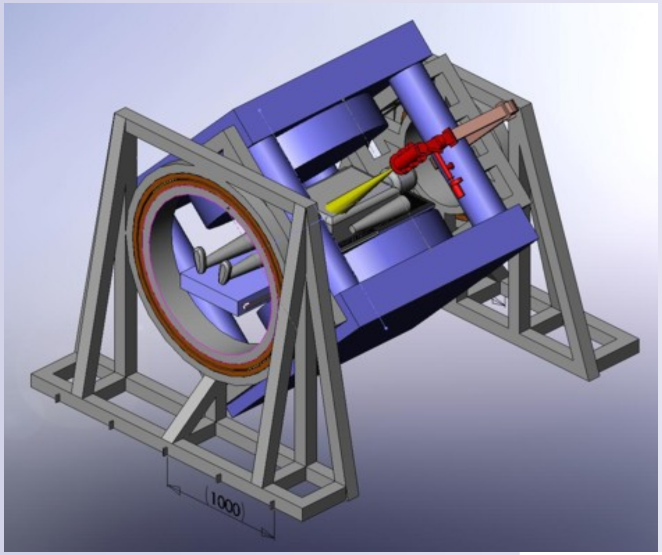




(a) Without radiation. (b) With radiation.

Working Prototypes 2

- Fallone et al, (Canada)
- 0.2 T "Rotating Bi-Planar" (RBP)
- B-field ⊥ to beam CAX



Left: MR axial image without 6 MV linac irradiation
Right:MR axial image during 6 MV irradiation of object imaged.
Linac is without flattening filter and radiation was monitored during imaging.

Aims

- Using Geant4 predict the ICRP 60 recommended 70 micron depth skin dose values in MRIgRT with focus on:
  - 6 MV transverse field system
  - effect of surface angle orientation
  - 0.2 – 3 T range systems

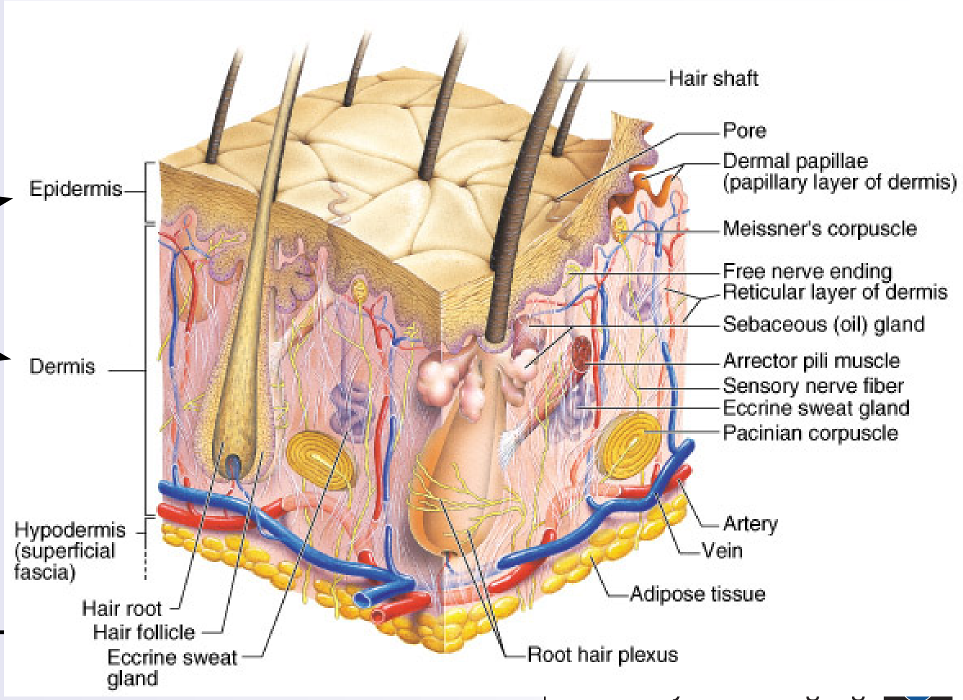
ICRP Publication 59:

Epidermal effects: 20-100 μm

Dermal effects: 300-500 μm

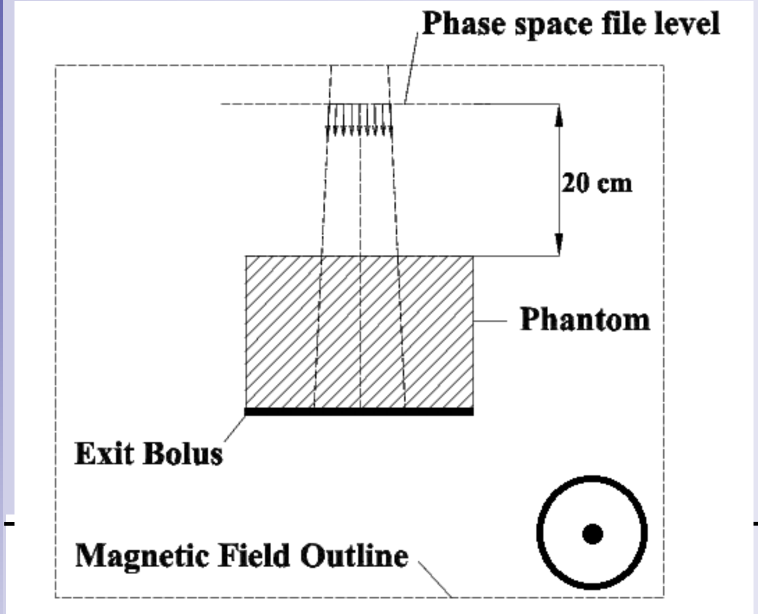
ICRP Publication 60:

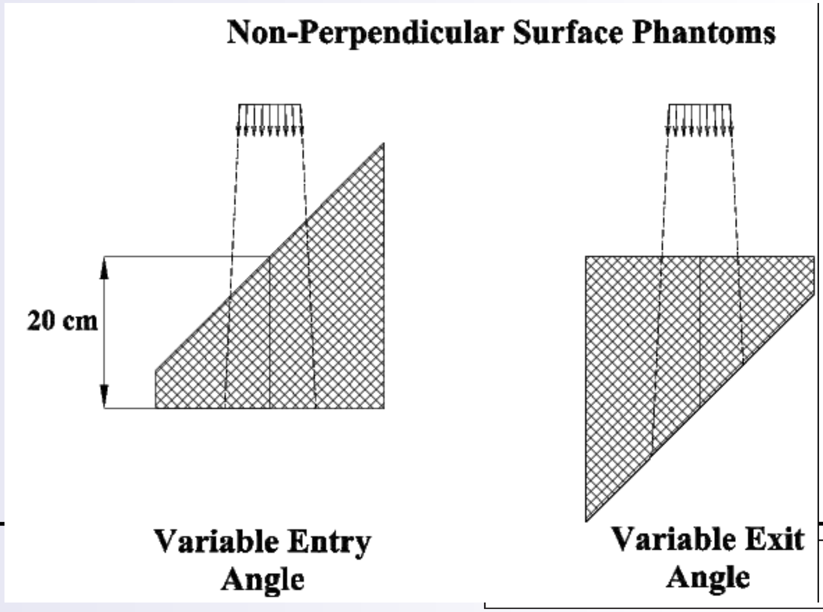
Skin dose: 70 μm



Geant4 Simulations

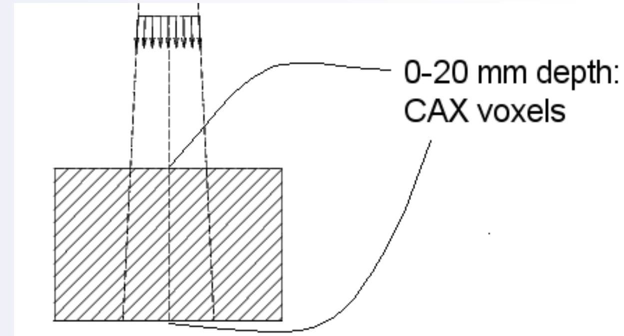
- Medical Linac (Varian 2100C 6MV) + Uniform Magnetic Field.
  - Geant4.9.2
  - PhysicsLists: Low Energy Electromagnetic (standard).
  - 4th order Runge-Kutta for B-field transport (standard)
  - Phantoms:
    - 30x30x20 cm^3 water phantom (perpendicular beams)
    - Modified 30x30x20 cm^3 water phantom (non-perpendicular beams)
  - 1 cm thick Exit Bolus simulations are performed.
  - Linac head simulated to make phase space files (20 cm above phantom).
  - B-field extent is 80x80x70 cm^3 (25 cm buffer in all directions).
  - Step and Cuts values are 5 um in scoring volumes, 0.2 mm otherwise.



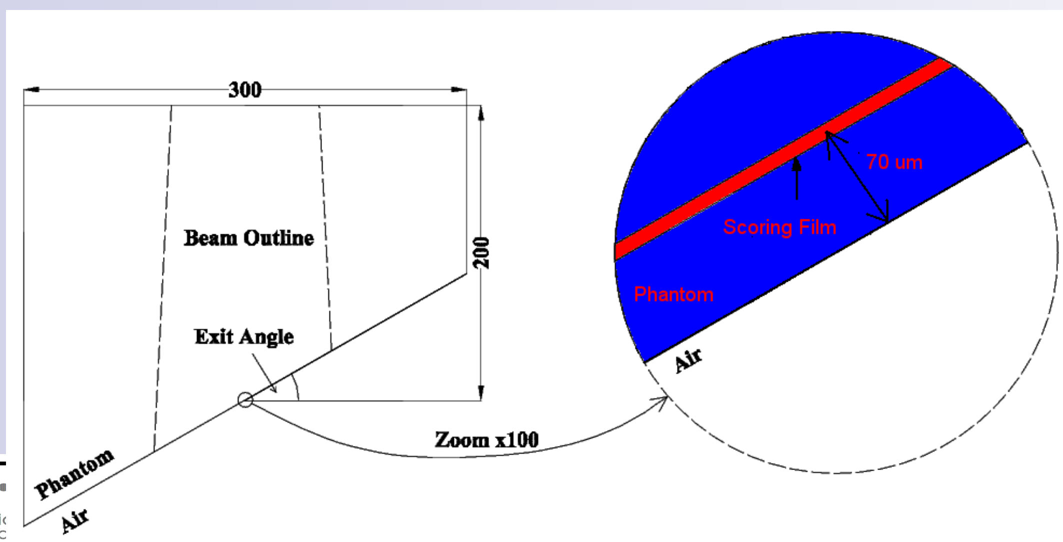


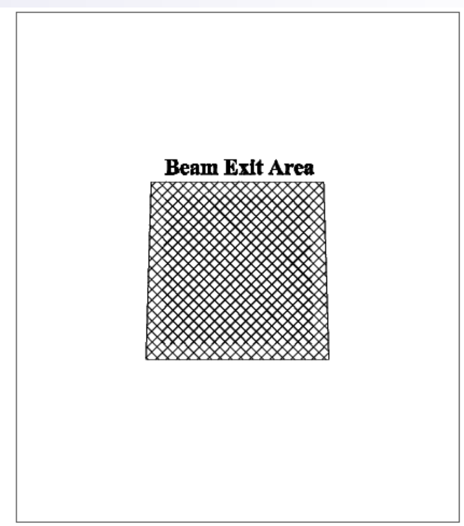
Geant4 Simulations – High resolution scoring

- CAX voxels:
  - 10x10x0.01 mm^3 in size
  - 2000 in entry region, 2000 in exit region
  - Used to generate CAX PDD curves



- Entry and Exit "Virtual" Films:
  - 10 μm thick layer between 65 and 75 μm depth
  - Entire exit face is covered
  - 1x1x0.01 mm^3 resolution

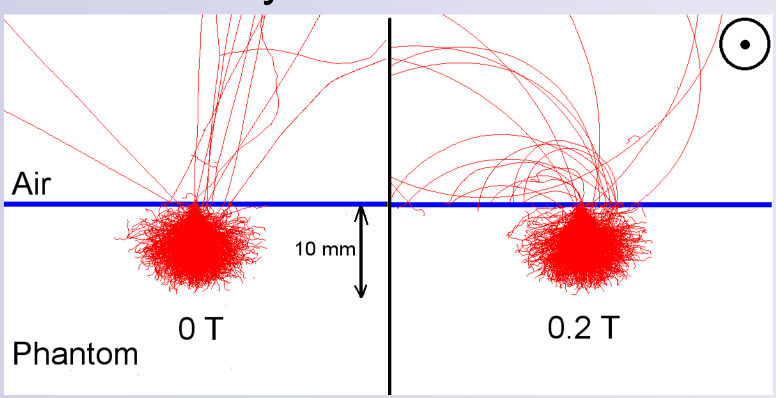




Theory: The Electron Return Effect (ERE)

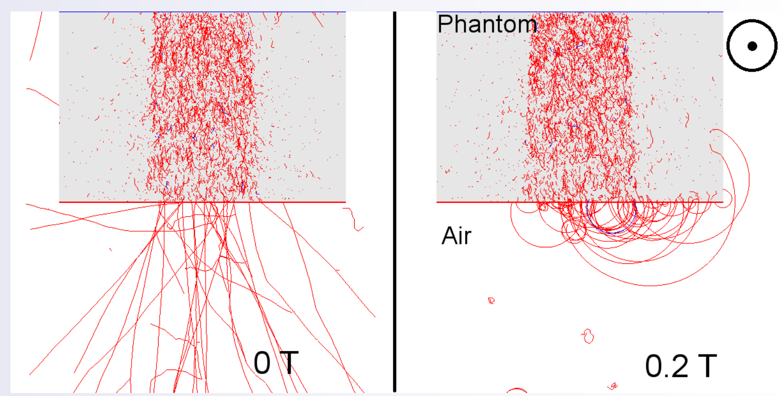
- Every electron that exits the phantom (any surface) will be forced to return.
- The ERE is mostly responsible for skin dose changes.
- The ERE changes with surface angle.

Entry Side ERE



2 MeV pencil e-beam starting at surface

Exit Side ERE

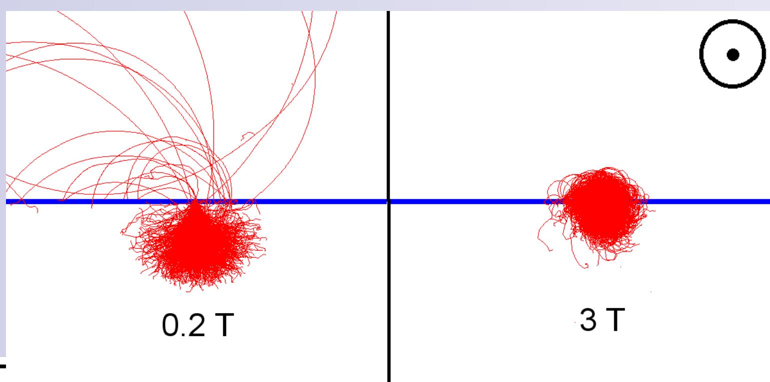


10x10 cm 6MV beam exit side

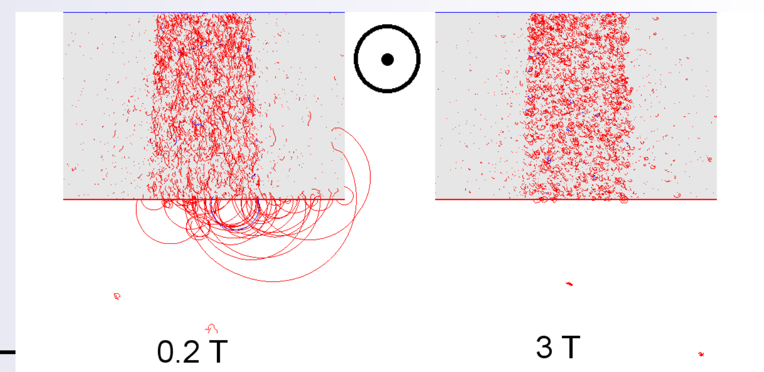
ERE for perpendicular beams

- Entry region:
  - Lepton contamination purged and minor ERE
  - Skin dose reductions until B-field becomes strong enough that secondary electrons are stopped in very short distances.
- Exit region:
  - ERE at all B-fields.
  - Shifting of skin dose maximum away from CAX.
  - Skin dose increases.

Entry Region

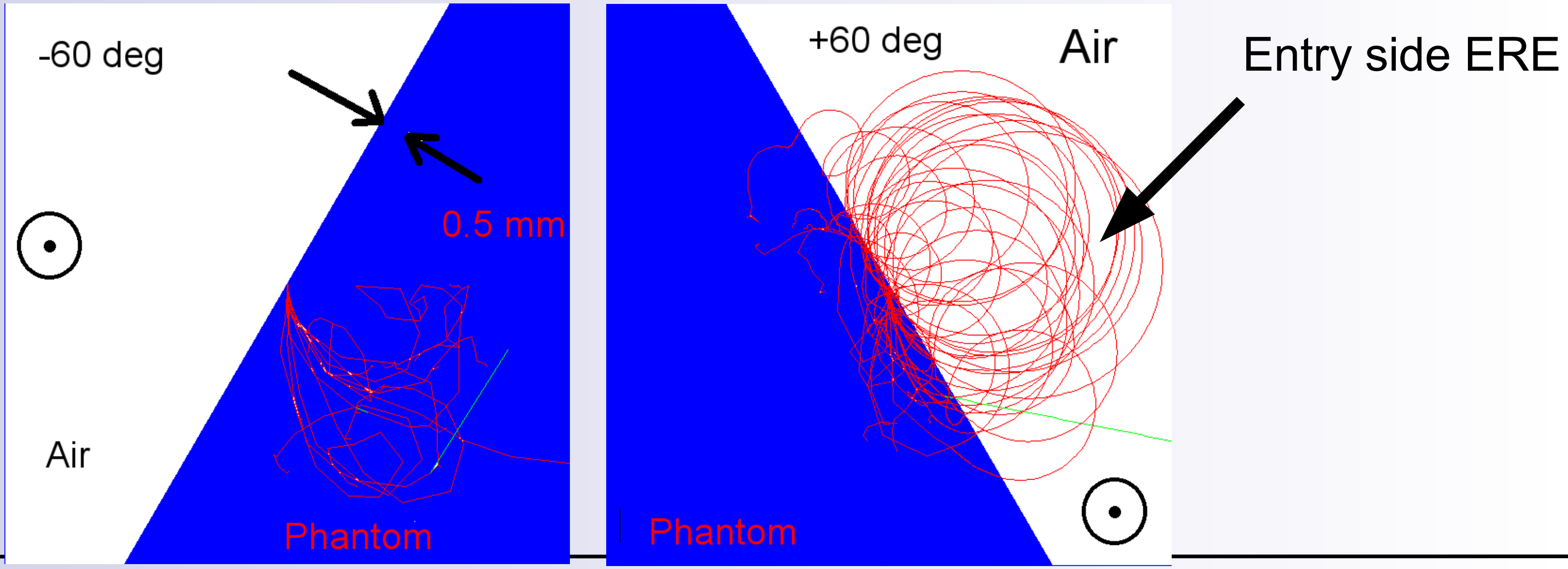


Exit Region



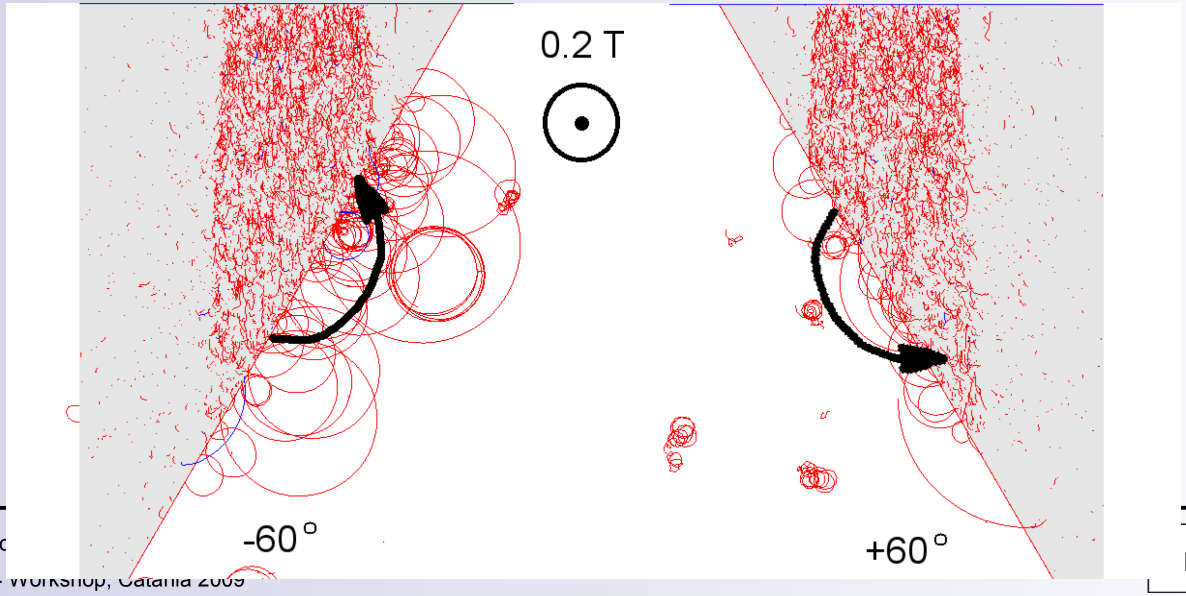
Entry surface ERE for non-perpendicular beams

- -ve angles: minimal ERE
- +ve angles: increased ERE
- Consider 10 x 2 MeV secondary electrons starting at the surface (3 T):
  - -ve angles: electrons encouraged to travel deep
  - +ve angles: electrons undergo ERE and barely travel below 1 mm depth → massive skin dose increase



Exit surface ERE for non-perpendicular beams

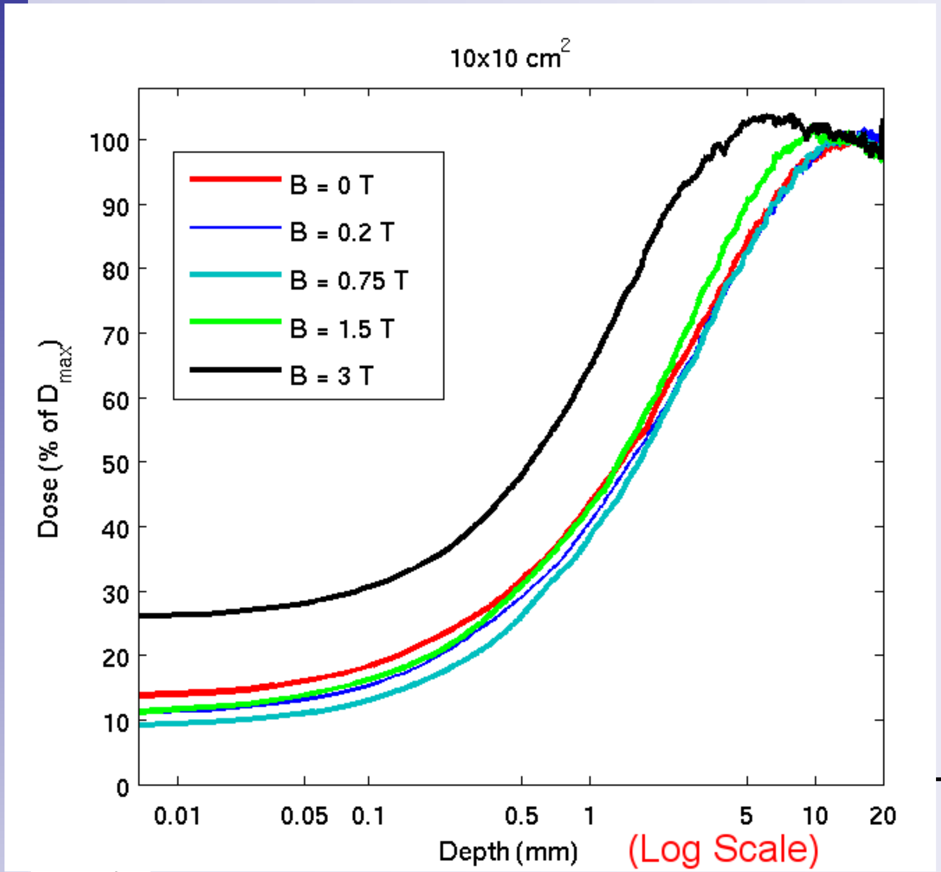
- -ve angles:
  - Increases ERE and lateral/transverse spreading
  - Electrons travel further (more lateral spread)
  - Increased skin dose
- +ve angles:
  - Decreased ERE
  - Electrons travel less (less lateral spread)
  - Decreased skin dose

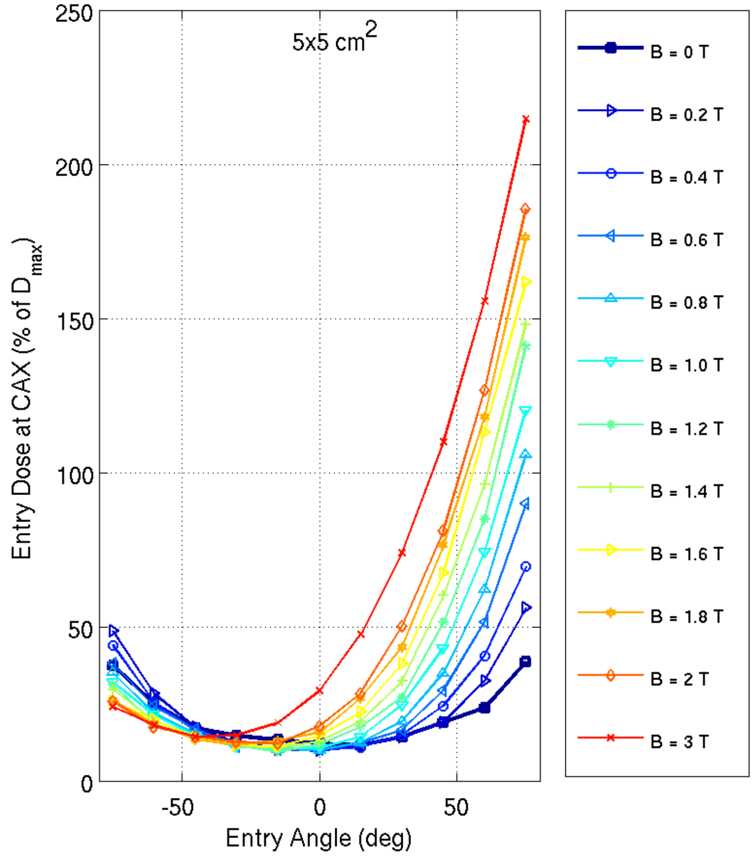


Results: Entry Side CAX

- CAX profiles (0-deg):
  - Minor reductions seen except at 3 T. (due to lepton purging)
  - D_{max} shifts to 5 mm at 3 T.

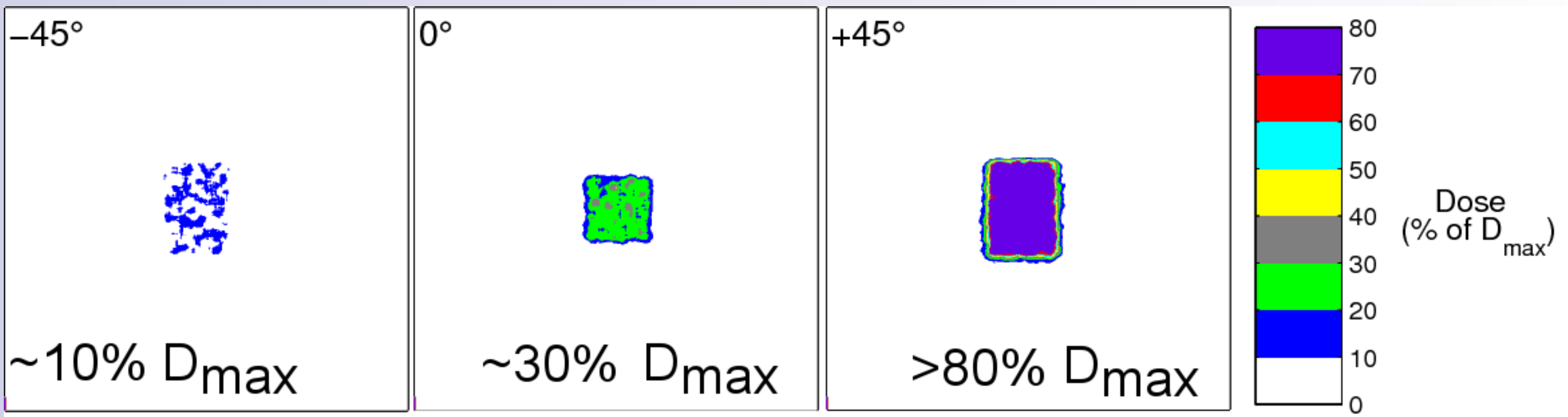
- CAX vs angle (70 um):
  - Large increases seen at +ve angles
  - Mild increases at -ve angles (greatest however for 0.2 T – opposite to +ve angles...)

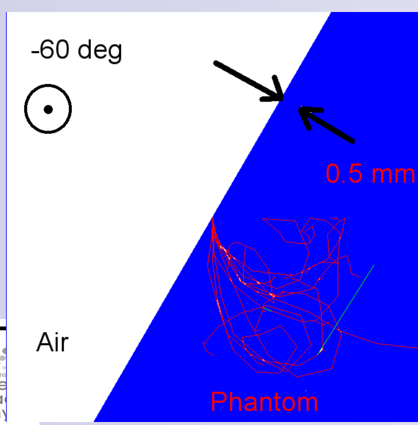




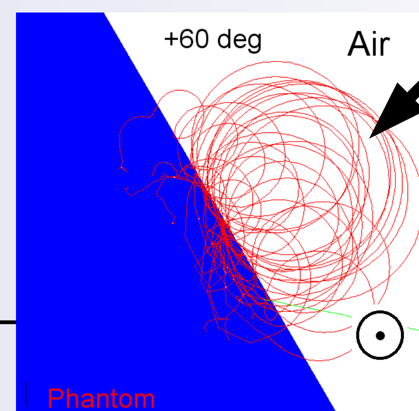
Results: Entry Side Films

- 70 micron depth "virtual" films (3 T):
  - Uniform dose across surface.
  - Generally, large increases at large +ve angles.
  - 5x5 cm^2 field shown.
  - Results still noisy (±4%) - some 2D smoothing applied.



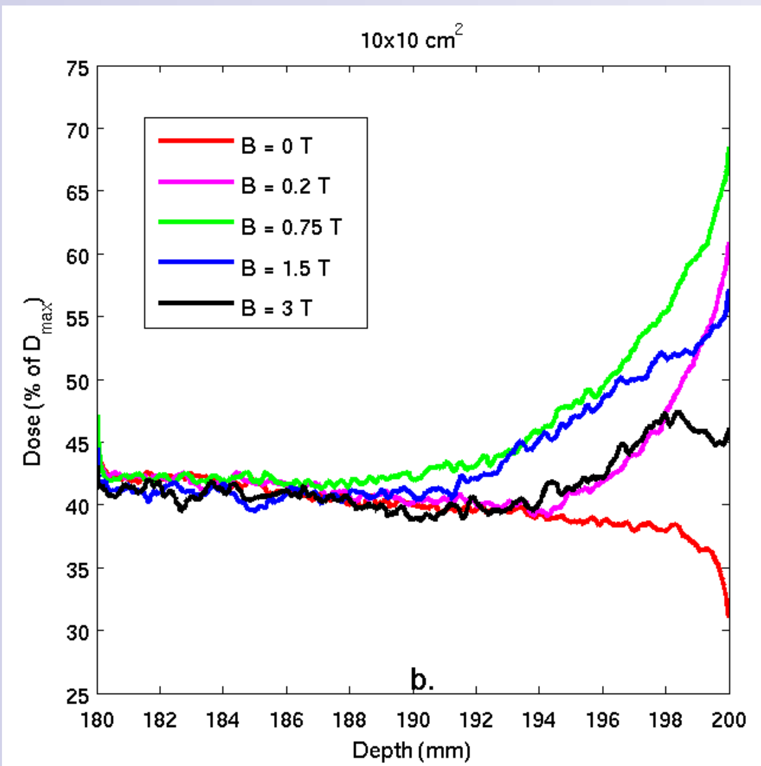


Entry side ERE

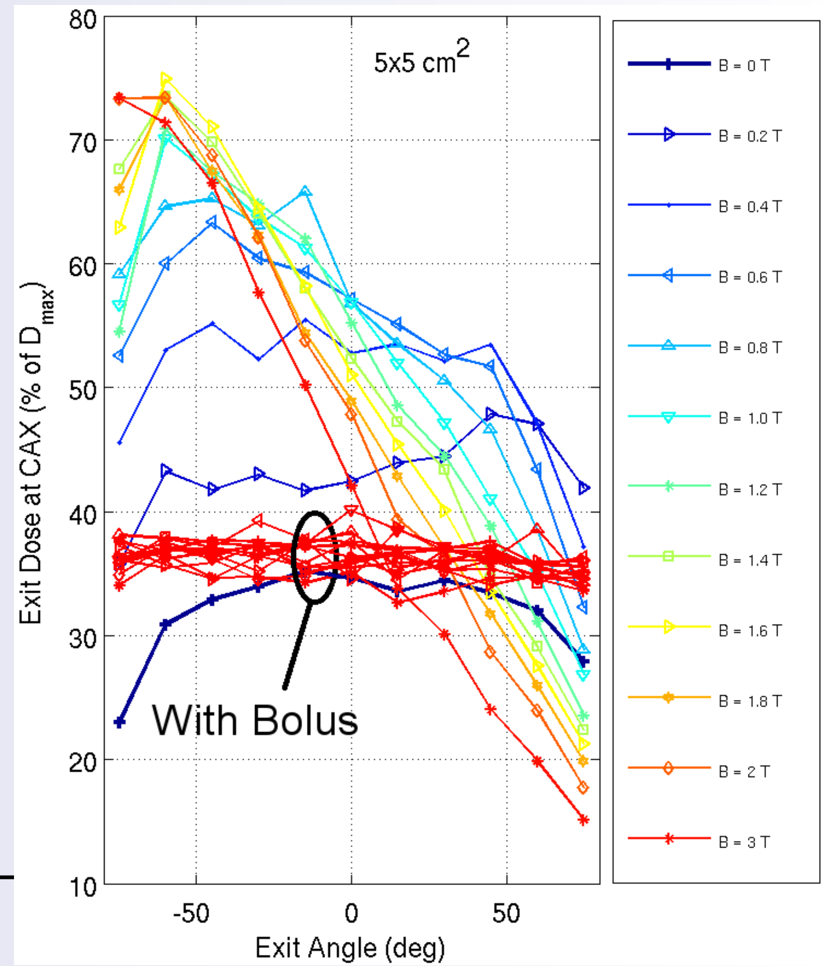


Results: Exit Side CAX

- CAX profiles (0-deg):
  - Large increases due to the ERE.
  - The increases are not directly related to B-field: ERE shift = 3-D problem.

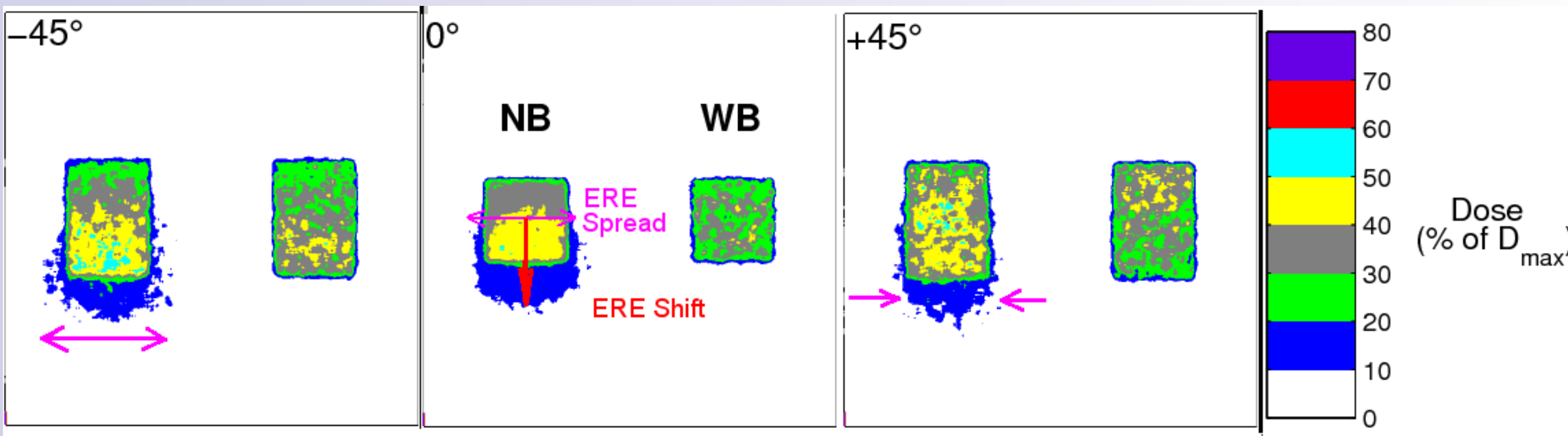


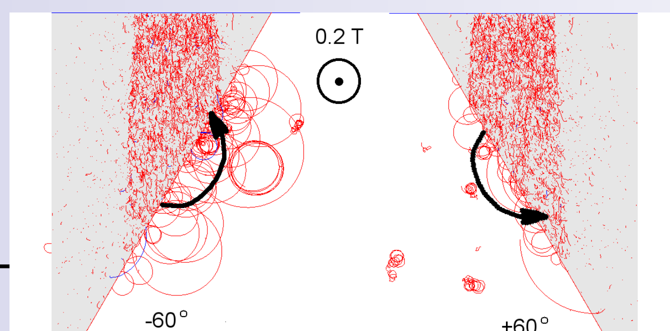
- CAX vs angle:
  - Large increases due to the ERE
  - Exit bolus very useful



Results: Exit Side Films

- 70 micron depth "virtual" films (0.2 T):
  - 5x5 cm^2 field shown.
  - Results still noisy (±4%) - some 2D smoothing applied.
  - Increases in surface area receiving low dose (< 20% of D_{max}) due to the lateral/ transverse spread.
  - Exit bolus (WB) prevents this low dose increase.





Conclusions

- Excess skin dose in MRIgRT is a real concern:
  - "Hot spots" expected.
  - Increased area of skin exposed to low doses.
  - Entry/Exit surface angles important.
  - Exit bolus may significantly lower exit skin dose.
  - IMRT treatments will help lower skin dose.

- Geant4 very powerful tool for this application:
  - B-fields: YES
  - High resolution scoring: YES

- Due to the complex nature of the ERE high resolution MC simulations may be the best method to characterize/study skin dose in MRIgRT → Geant4.

- Future Work:
  - Continue characterization of skin dose in MRIgRT for more realistic cases like IMRT, CT dataset phantoms.

References

- 1 Raaymakers et al, Phys., Med. Biol., (54) 2009, N229-237.
- 2 Fallone et al, Med. Phys., 35(3), 2008, p1019-1027.
- 3 Oborn et al, Med. Phys., 36(8), 2009, p3549-3559.

Catania

Mt Etna

University of Wollongong (CMRP)

Mt Keira (Extinct Volcano)