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Polymer gel dosimetry: a promising 3D quality assurance tool for magnetic resonance-image guided radiotherapy

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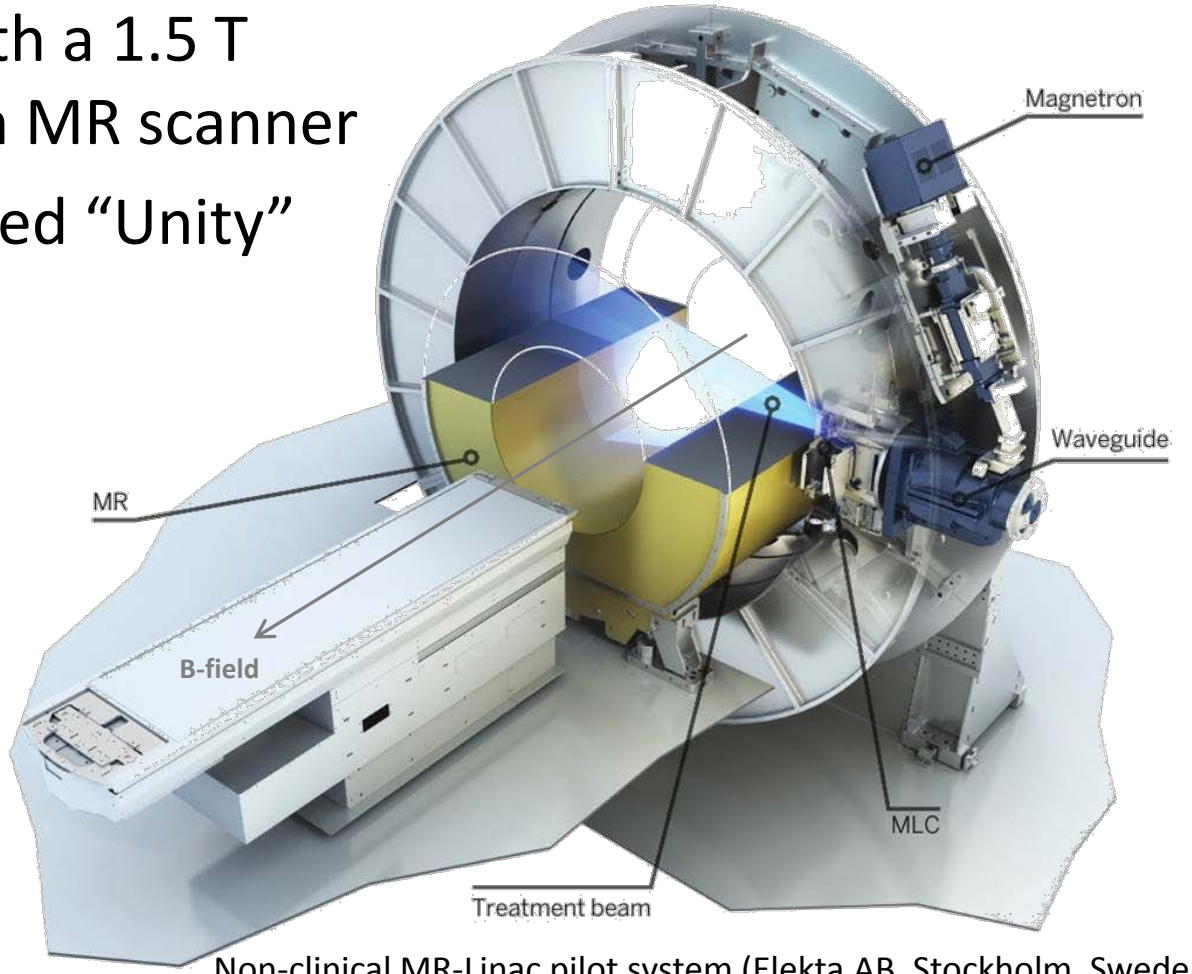
Outline

- Introduction of Elekta Unity (MR-Linac)
- Why we need 3D QA measurements
- Representative clinical irradiation
- Results
- Conclusion

Disclosure:
MD Anderson Cancer Center is an Elekta MR-Linac consortium member.

MR-Linac: non-clinical pilot system

- A 7 MV linear accelerator combined with a 1.5 T Philips Marlin MR scanner
- MR-Linac called “Unity”



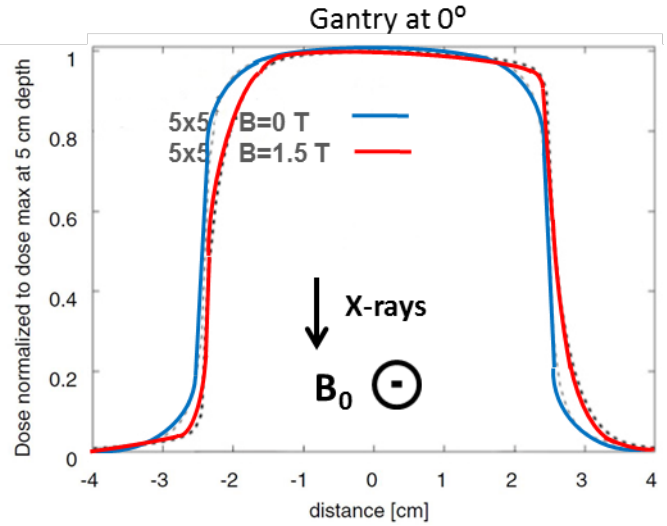
Non-clinical MR-Linac pilot system (Elekta AB, Stockholm, Sweden)

MR-Linac: non-clinical pilot system

Non-clinical MR-Linac pilot system (Elekta AB, Stockholm, Sweden)

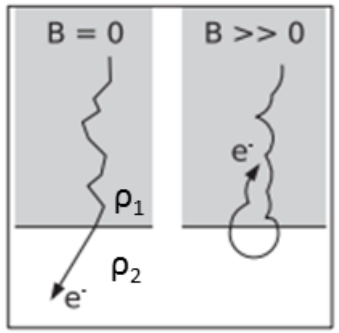
Influence of Magnetic Field

- Deflection of electrons due to Lorentz force
  - Shift in cross-plane beam profile



Adapted from Raaymakers, Phys. Med. Biol. 49 (2004)

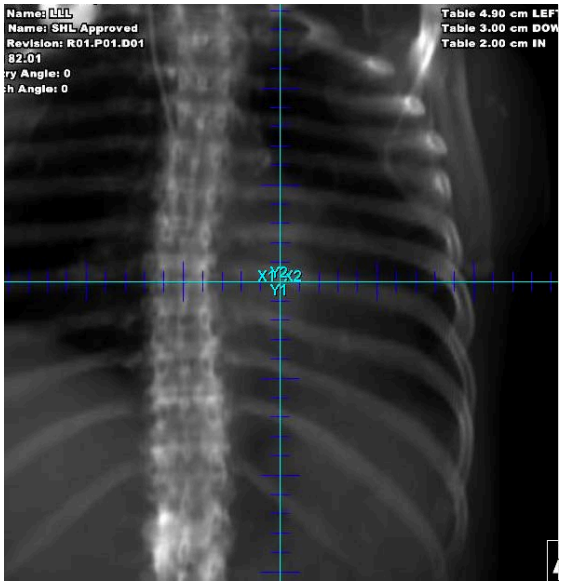
- Electron return effect (ERE) dose enhancement at media interfaces



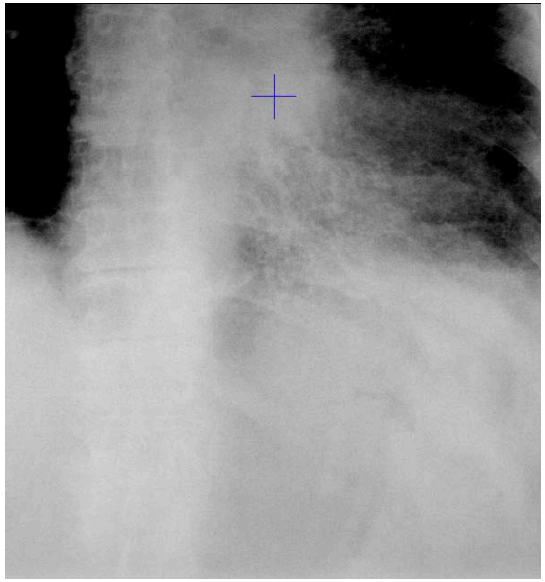
Adapted from Raaijmakers, PhD Dissertation (2008)

Why MR-Linac?

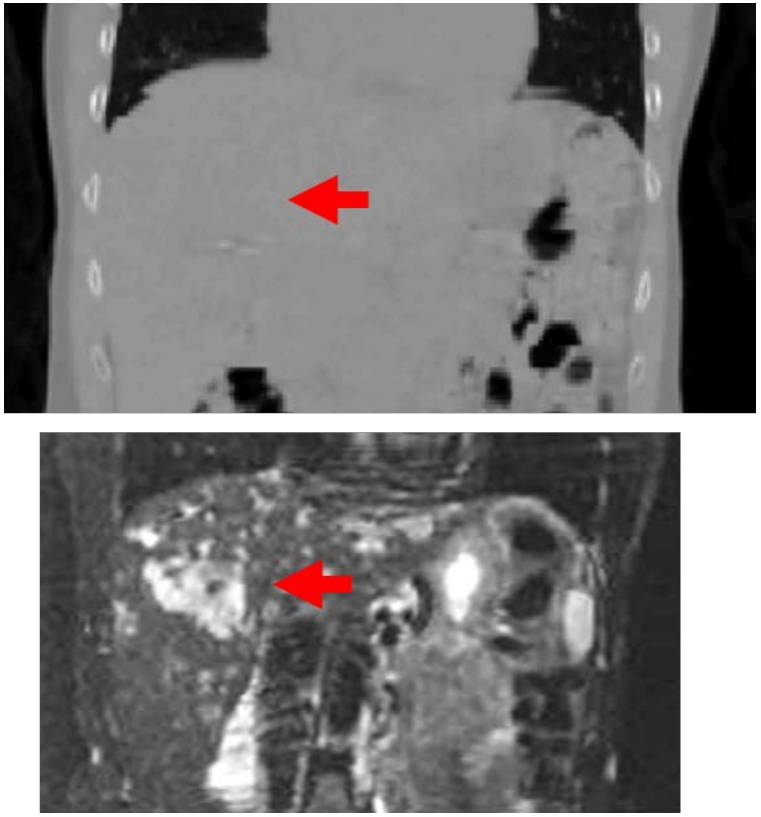
- Current kV image guidance relies on bony anatomy
- MR shows improved soft-tissue contrast



kV pre-treatment image



MV portal image



CT image (top)
MR image (bottom)

QA measurements

- Need to ensure accurate delivery of prescribed radiation treatment plans with new system
- QA standards for MR-Linac are being developed

⊗ Point measurements (0D): ion chambers, TLDs etc
→ Concerns at interfaces between different densities

⊗ Planar measurements (2D): film, arrays
→ dose information might be missed in 0D and 2D
→ MR compatibility?

✓ Volumetric measurements (3D): polymer gels
→ Can address all concerns

Polymer Gels

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- BANG™ polymer gels
  - BANG3Pro prepared by MGS Research (Madison, CT) and poured into glass vessels of our design

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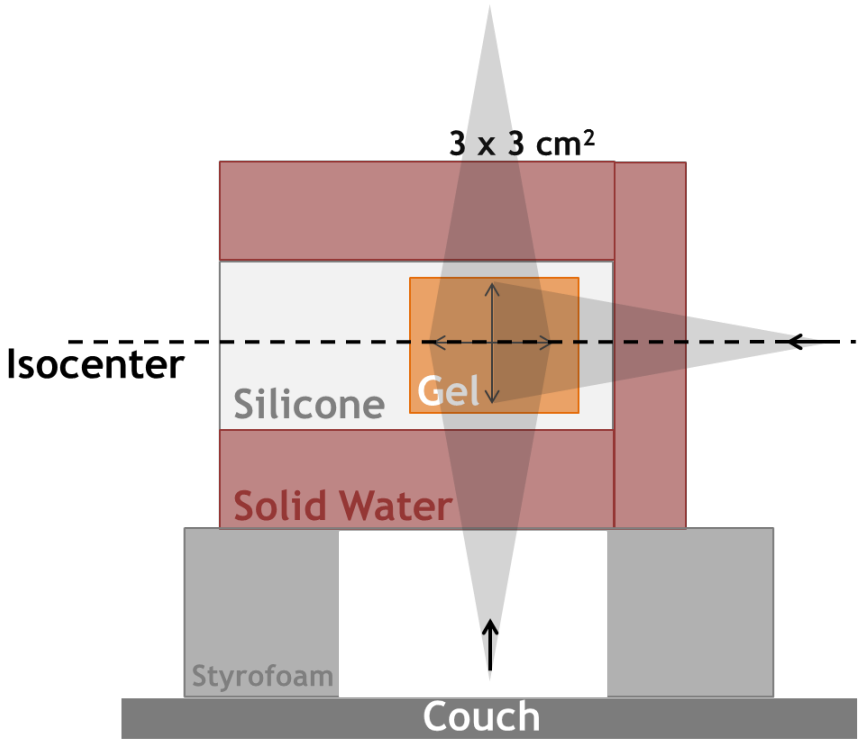
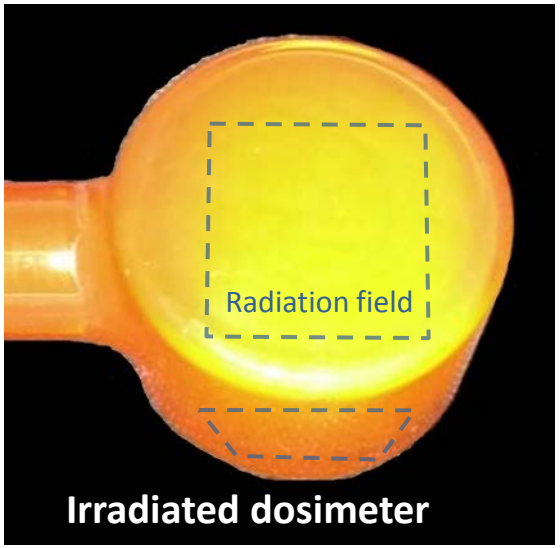
- Value of polymer gels to measure 3D dose distributions in the presence of a strong magnetic field

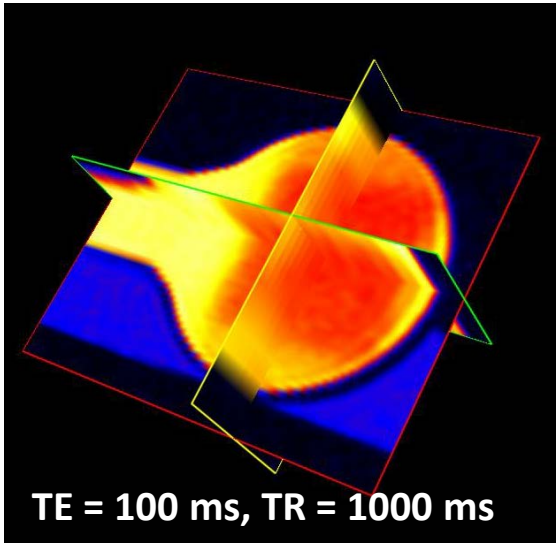
Setup: 3-field irradiation, B_0 = 0 T

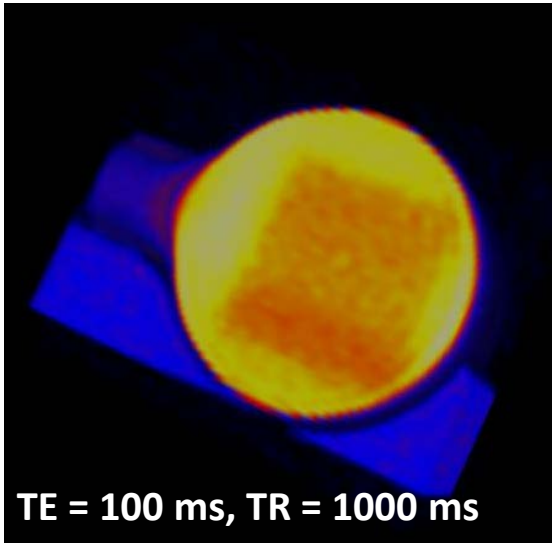
- Clinically relevant dose distribution



Results: 3-field irradiation



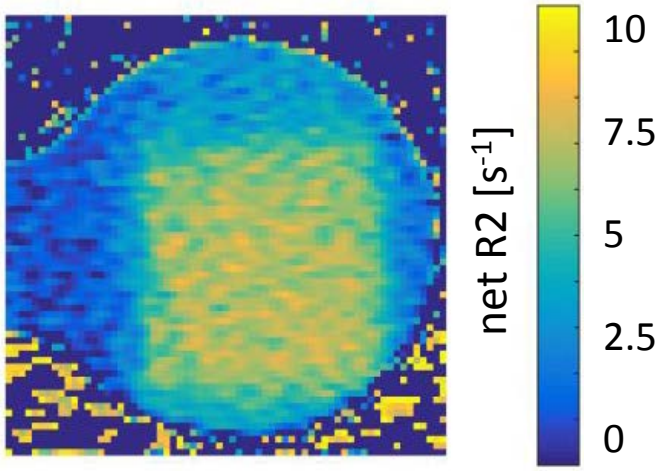




Results: 3-field irradiation, B_0 = 0 T

R2 map – coronal, B_0 = 0 T

Gantry at 0° and 180°

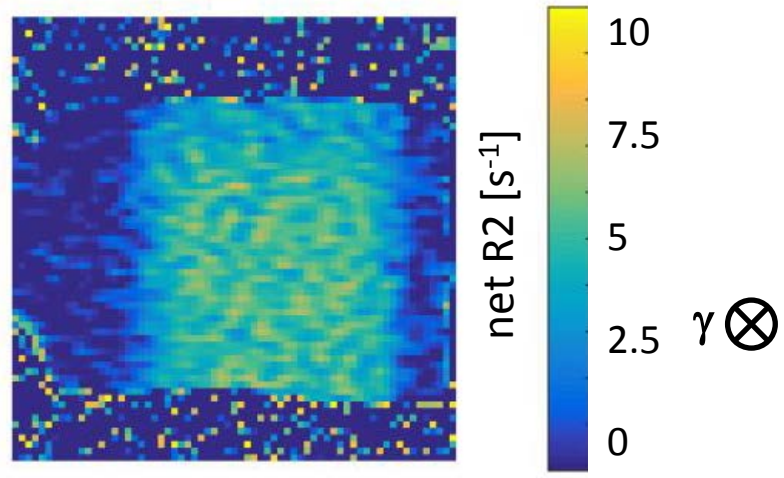


Profile width (in-plane) = 28 mm

Profile width (cross-plane) = 30 mm

R2 map – sagittal, B_0 = 0 T

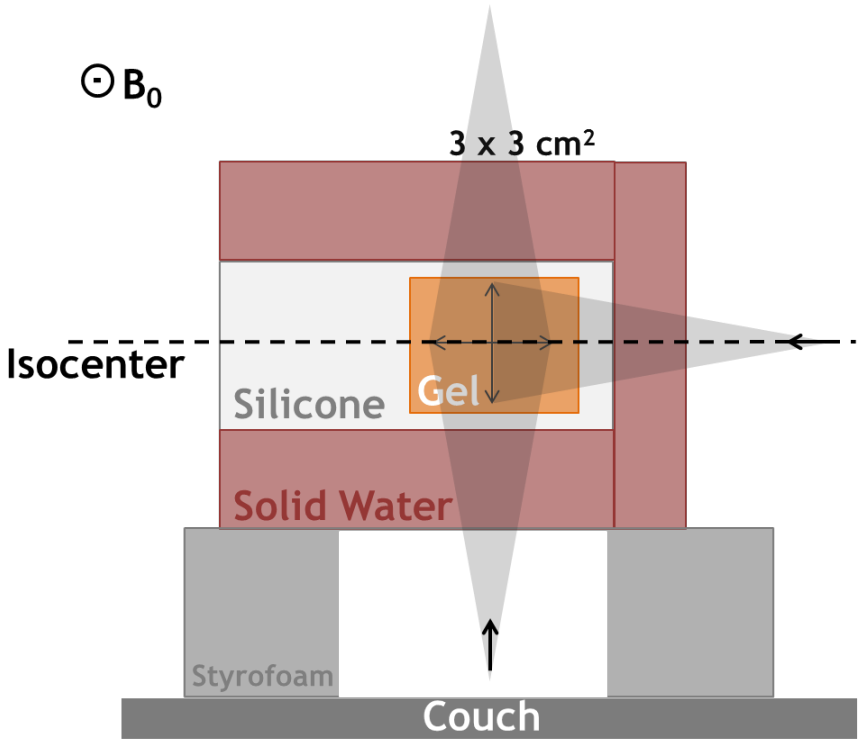
Gantry at 90°



Profile width (in-plane) = 28 mm

Setup: 3-field irradiation, B_0 = 1.5 T

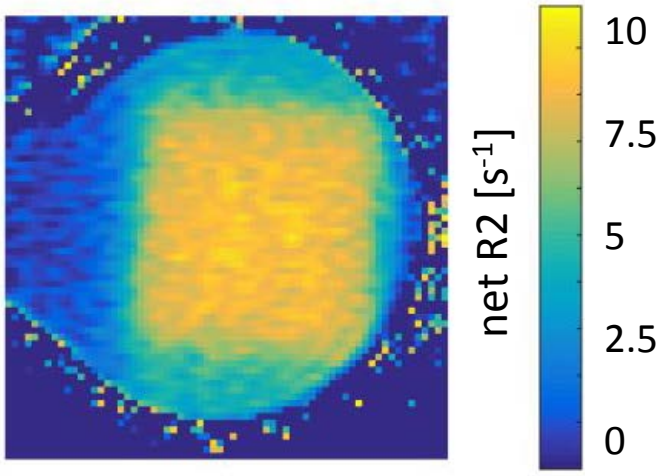
- Clinically relevant dose distribution



Results: 3-field irradiation, B_0 = 1.5 T

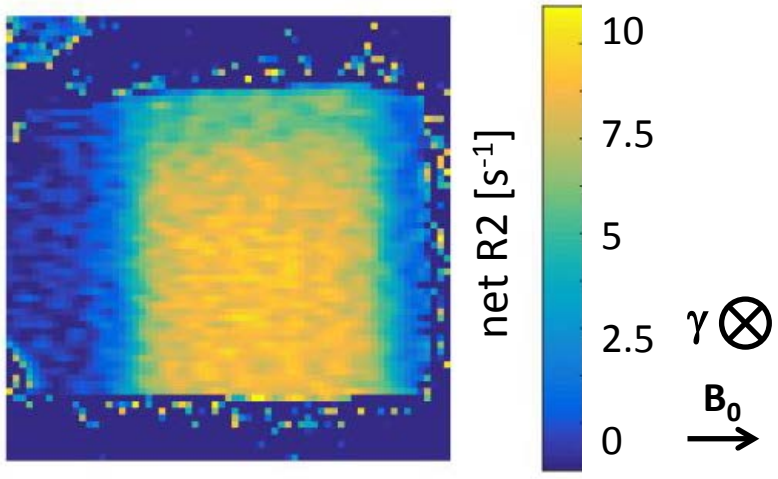
R2 map – coronal, B_0 = 1.5 T

Gantry at 0° and 180°



R2 map – sagittal, B_0 = 1.5 T

Gantry at 90°



Profile width (in-plane) = 31 mm

Profile width (cross-plane) = 30 mm

Profile width (in-plane) = 31 mm

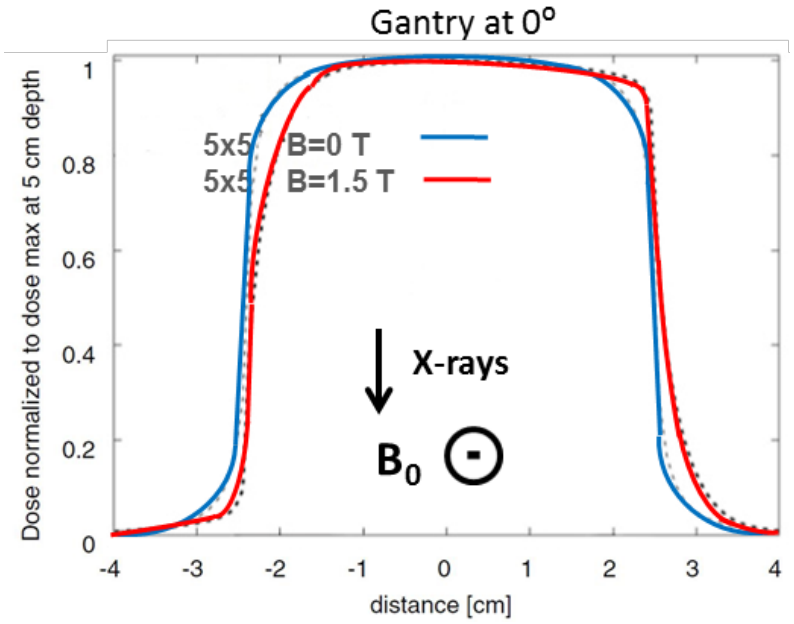
- Coronal view: opposing beams minimize effect of Lorentz forces on profiles
- Sagittal view: asymmetry in single beam profile

Influence of Magnetic Field

- Lorentz force $\mathbf{F_L}$ acting on secondary e^- → deflection orthogonal to the plane containing velocity $\mathbf{v_e}$ and magnetic field **B** vectors

$$\mathbf{F_L} = q\,(\mathbf{v_e} \times \mathbf{B})$$

- Trajectories of e^- altered → change in dose distribution



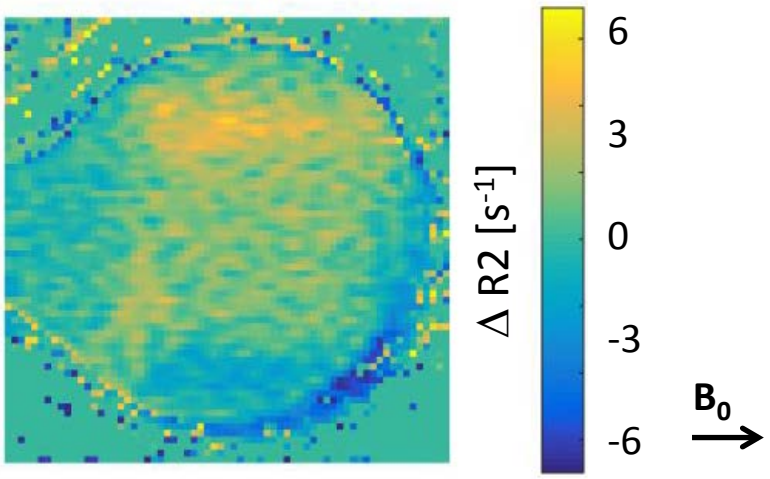
Adapted from Raaymakers, Phys. Med. Biol. 49 (2004)

→ How does the magnetic field affect 3D dose distribution?

Results: 3-field irradiation difference

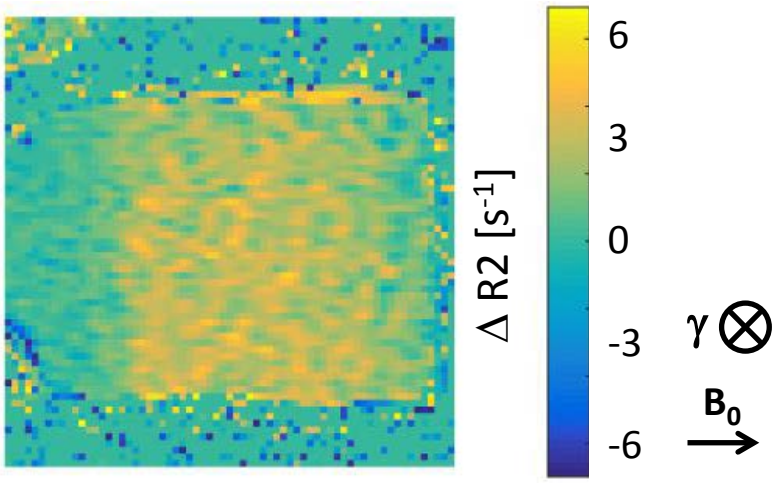
Difference map - coronal

Gantry at 0^o and 180^o



Difference map - sagittal

Gantry at 90^o



$$\Delta\ R2 = \text{net } R2_{B=1.5T} - \text{net } R2_{B=0T}$$

- Max Δ R2 at edges due to errors in registering images
- Coronal view: small setup error resulted in large Δ R2
- Sagittal view: +Δ R2 indicated deflection e^-

Conclusion

- Polymer gels – excellent means to measure 3D dose distributions delivered with an MR-Linac
- Effect of Lorentz force appeared to be minimized when using multiple field angles
- Further study of polymer gels encouraged for measuring 3D dose distributions in the presence of magnetic fields

Acknowledgements

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  - Geoffrey Ibbott
  - Hannah Lee
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  - Gary Bosco (Elekta)
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Thank you for your attention!