Measuring radiation dose through the detection of radiation-induced acoustic waves

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Dosimetry in radiation therapy

- Variety of dosimetry techniques and protocols required to ensure patients receive the correct dose in the desired location
- Development of advanced delivery techniques presents a dosimetry challenge
- Novel fast and accurate dosimetry techniques are required

Overview of x-ray acoustic computed tomography (XACT)

Pulsed photon beam deposits energy

↓

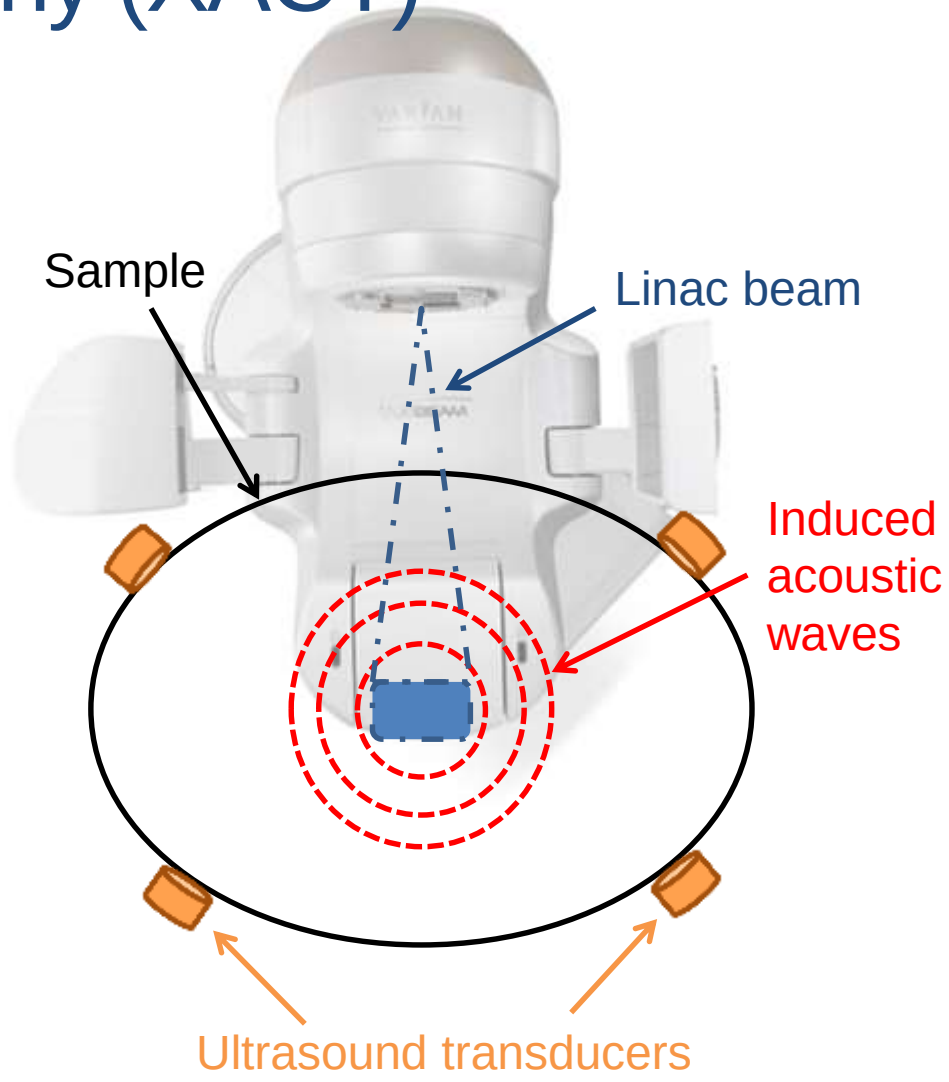
Acoustic waves generated through thermoacoustic effect

↓

Acoustic waves detected by ultrasound transducers

↓

Image of initial pressure distribution reconstructed



Bowen et al., Phys Med Biol 36(4), 1991
Xiang et al., Med Phys 40(1), 2013

Theory: Thermoacoustic effect

- Thermoacoustic wave equation:

$$\nabla^2 p(\mathbf{r},t) - \frac{1}{v_s^2}\frac{\partial^2}{\partial t^2} p(\mathbf{r},t) = -\frac{\beta}{C_p}\frac{\partial}{\partial t} H(\mathbf{r},t)$$

p = Pressure
v_s = Speed of sound
β = Isobaric expansion coefficient
C_p = Specific heat capacity
H = Heat energy
Γ = Grüneisen coefficient

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- Initial pressure distribution

$$p(\mathbf{r})|_{t=0} = H(\mathbf{r}) \cdot \Gamma(\mathbf{r}) \quad \text{where} \quad \Gamma = \frac{v_s^2 \beta}{C_p}$$

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- Initial pressure distribution

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- Relating pressure to dose

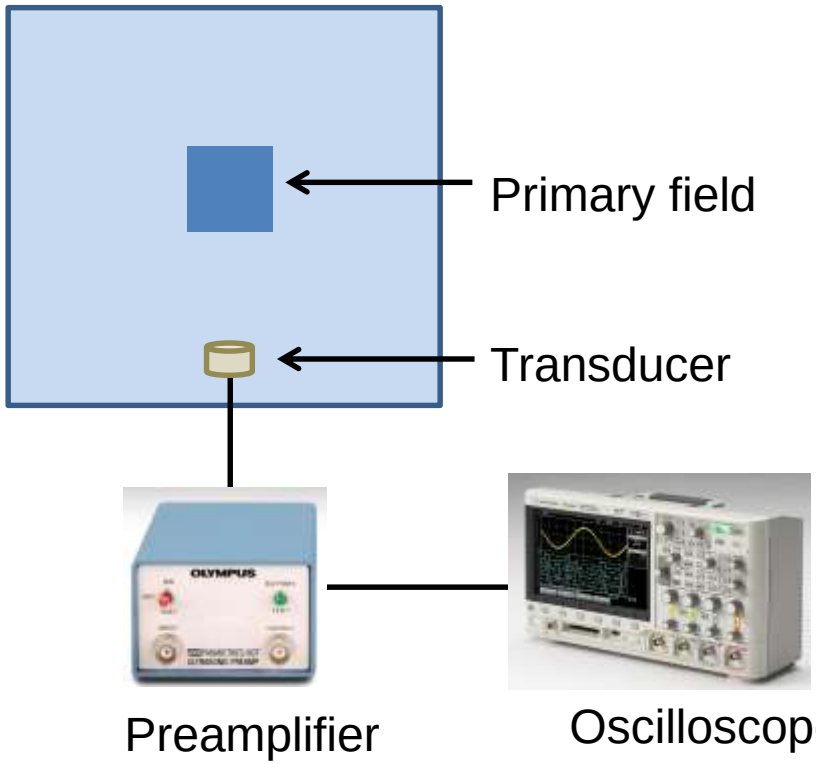
$$p(\mathbf{r}) = \mathrm{D}(\mathbf{r}) \cdot \rho(\mathbf{r}) \cdot \Gamma(\mathbf{r})$$

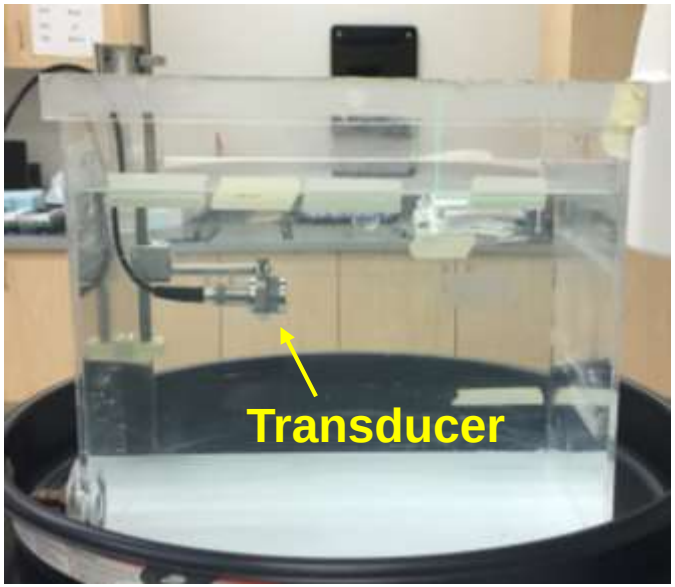
Project objective

- Previous work has demonstrated feasibility of using XACT as a dosimetry tool through simulations
- Experimental work has been limited to irradiation of metal blocks
- Present work aims to demonstrate ability of XACT to act as a relative dosimetry technique in water

Experimental set-up

Beam's eye view

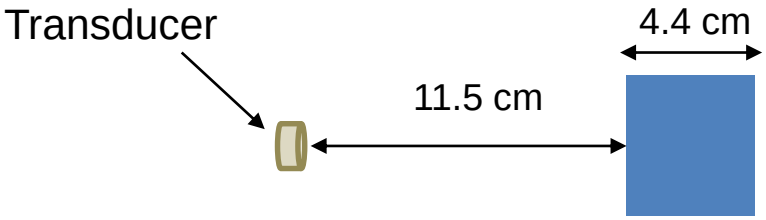


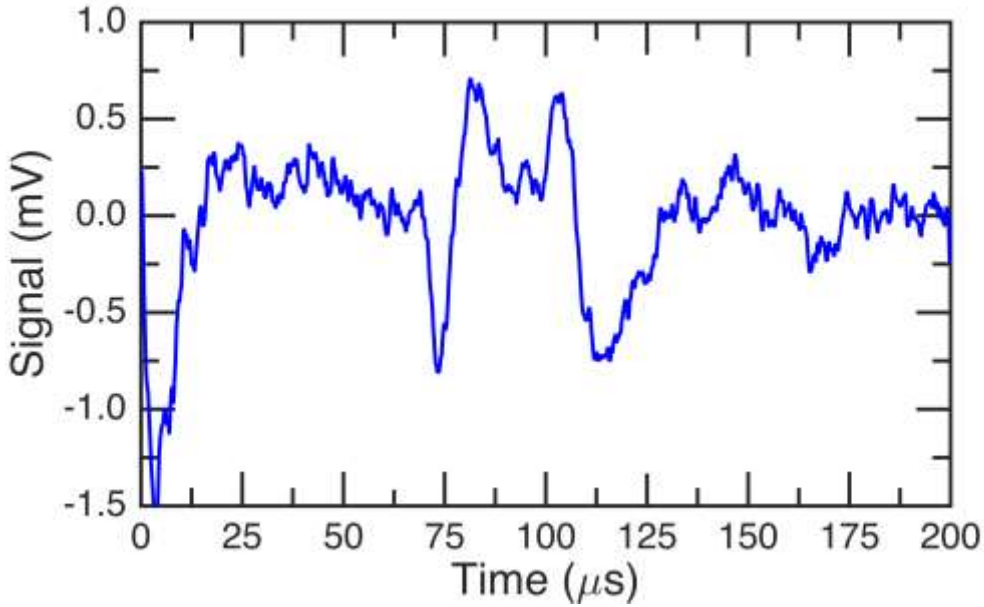


Radiation parameters

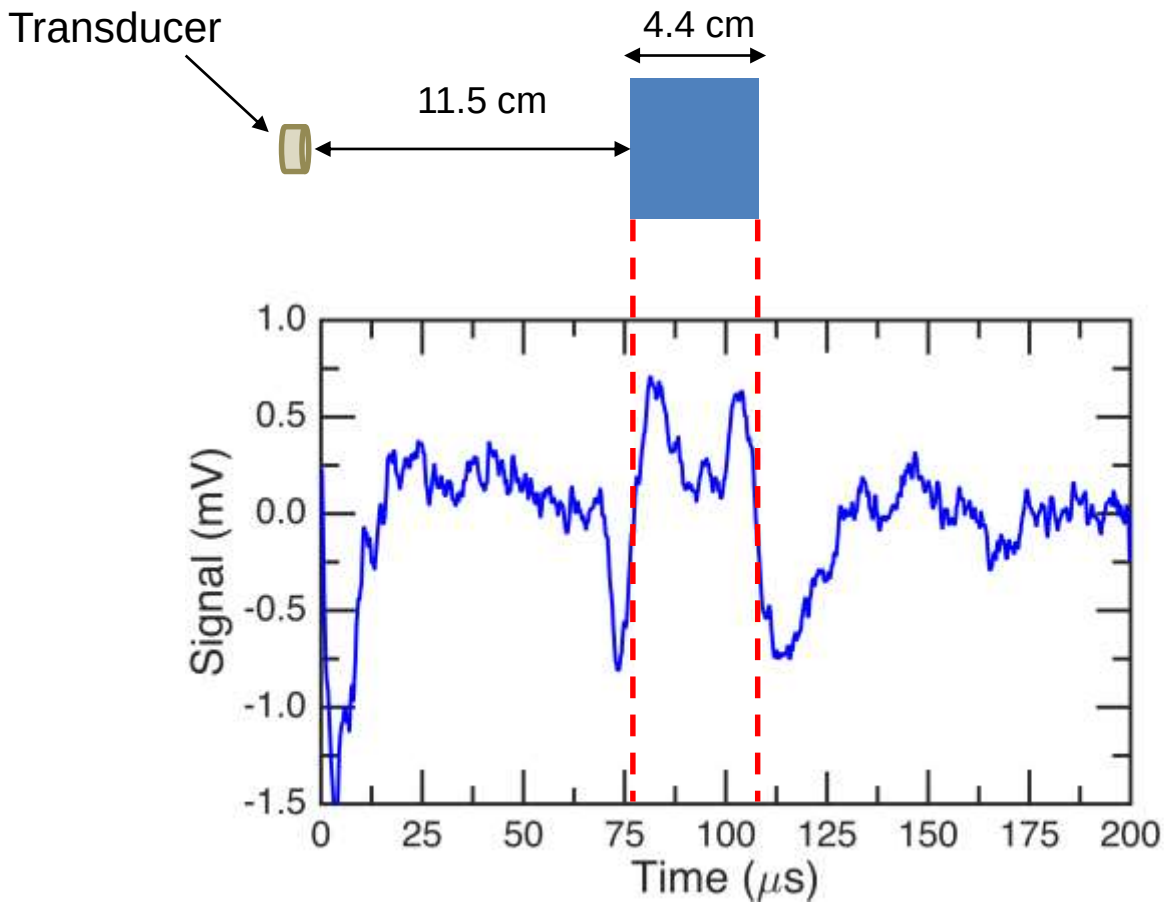
- 10 MV flattening filter free photon beam produced by clinical radiotherapy linac (Varian TrueBeam)
- At 10 cm depth (imaging plane):
  - Dose per pulse = 0.77 mGy
  - Temperature increase per pulse = 185 nK
- Pulse repetition frequency = 180 Hz
- Pulse length = 4 μs

Typical transducer signal



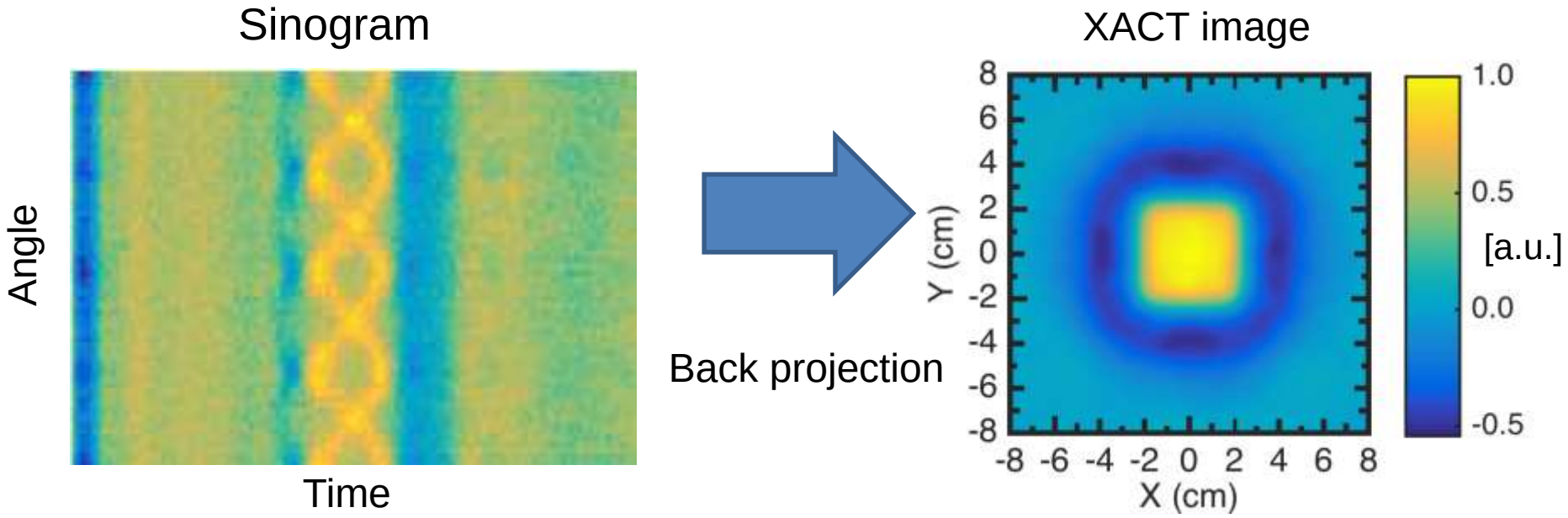


Typical transducer signal



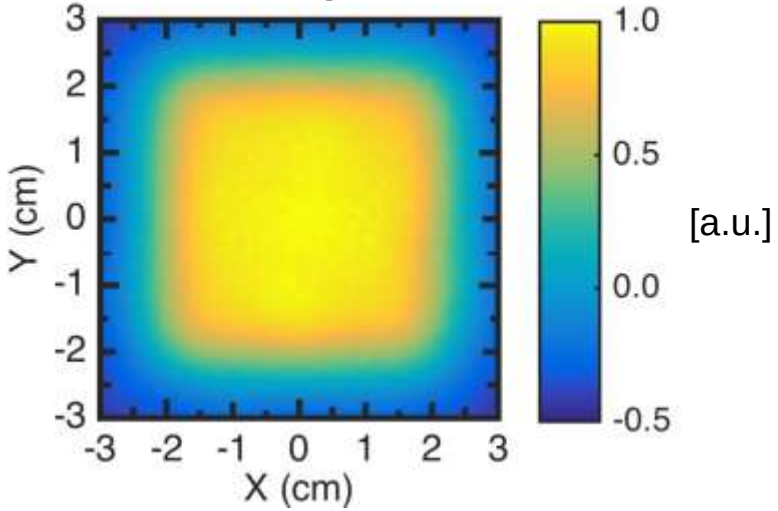
Imaging parameters

- Signals acquired at 60 angles
- Image reconstructed from sinogram using back projection algorithm
- XACT images are relative dose images

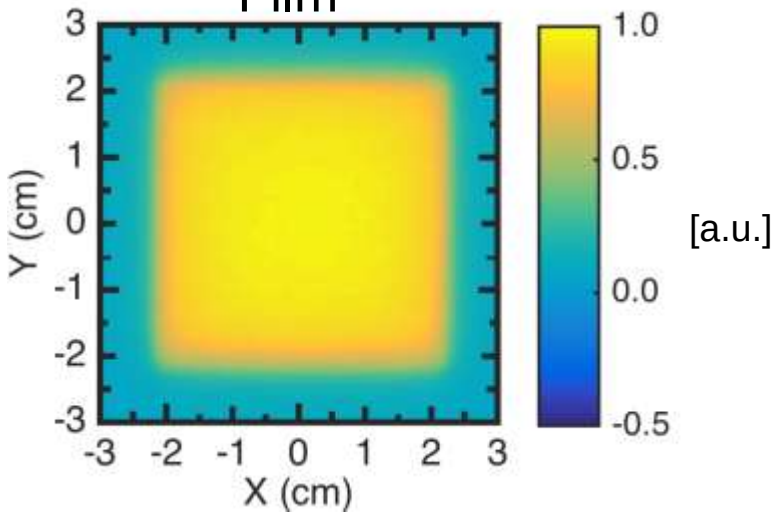


Simple field: Dose comparison

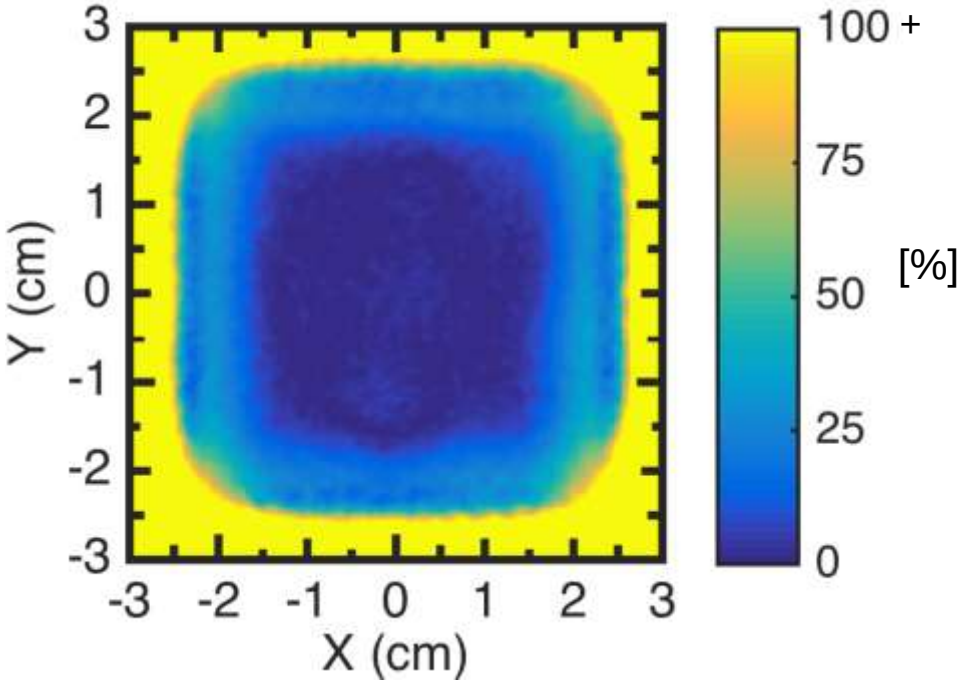
XACT



Film



Percent difference map



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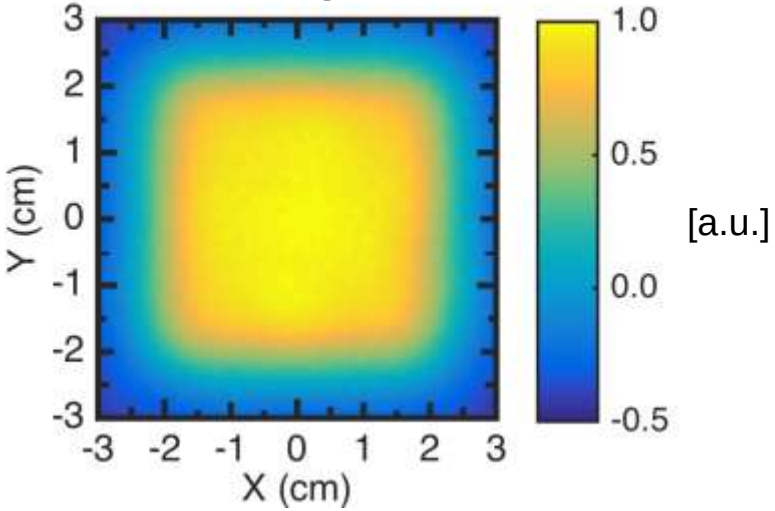
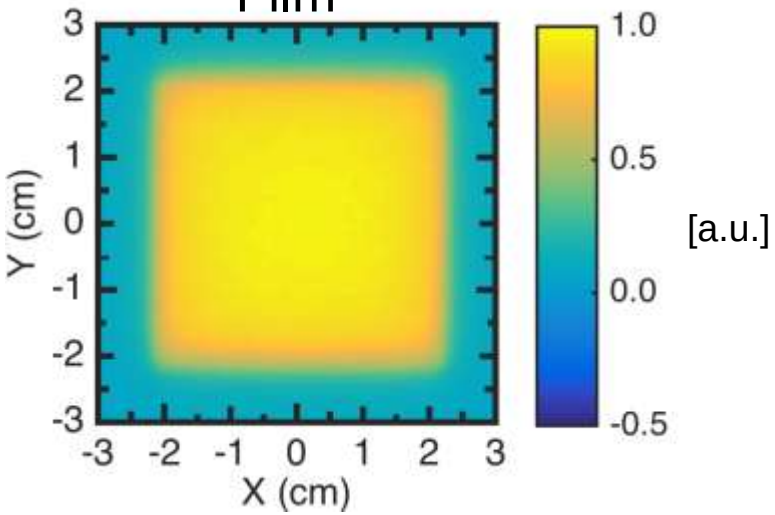


Film



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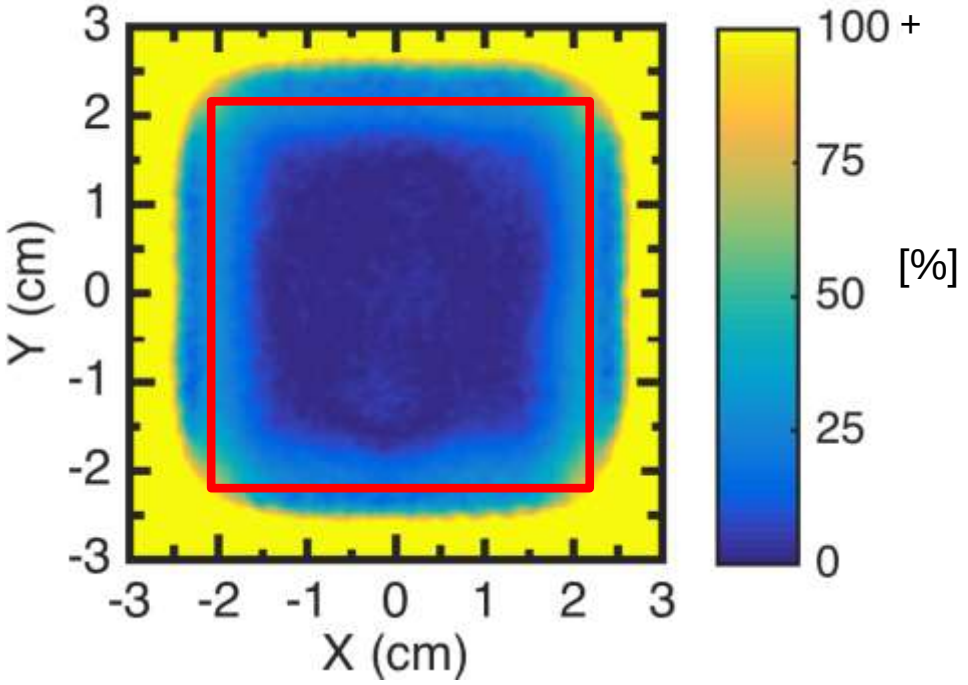
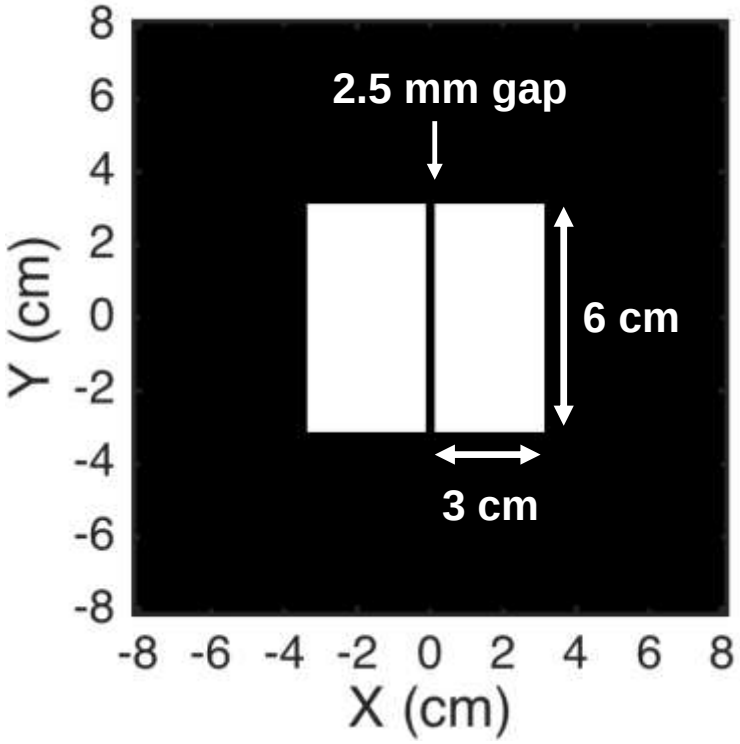


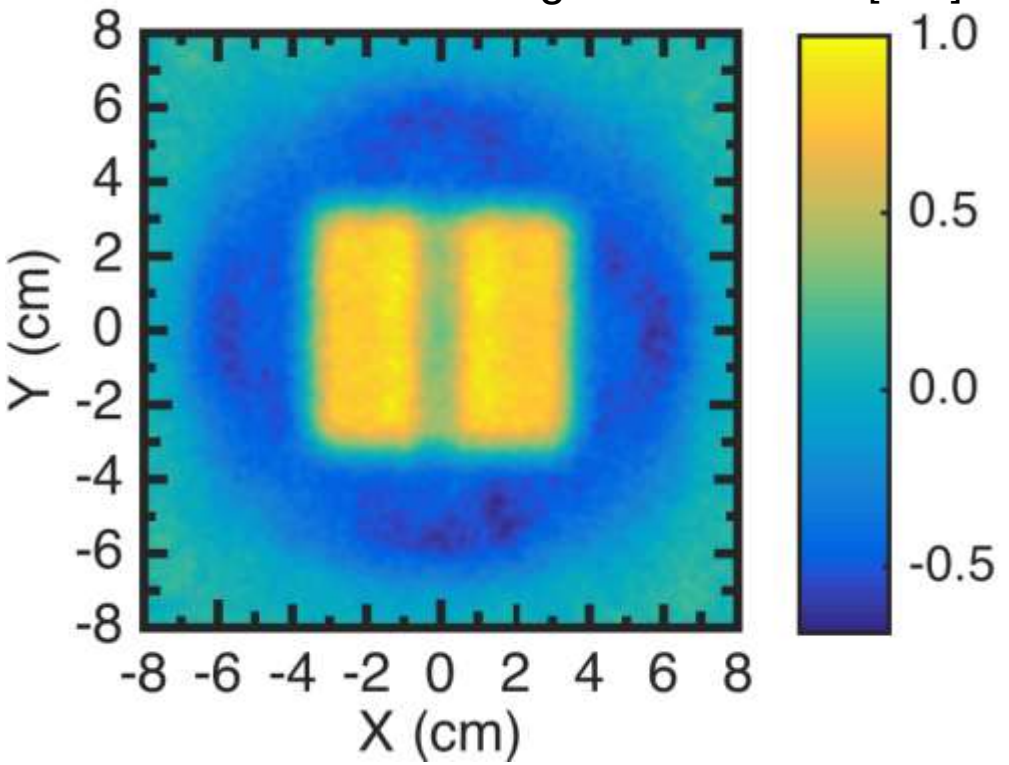
Root mean square error = 12.2%

Resolution test: XACT image

Field diagram

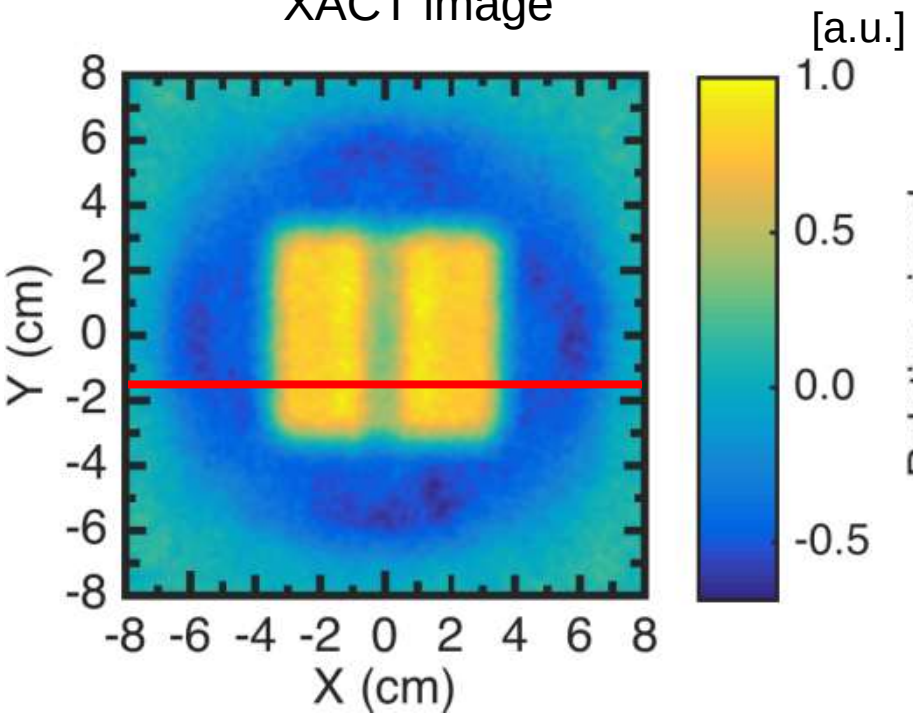


XACT image

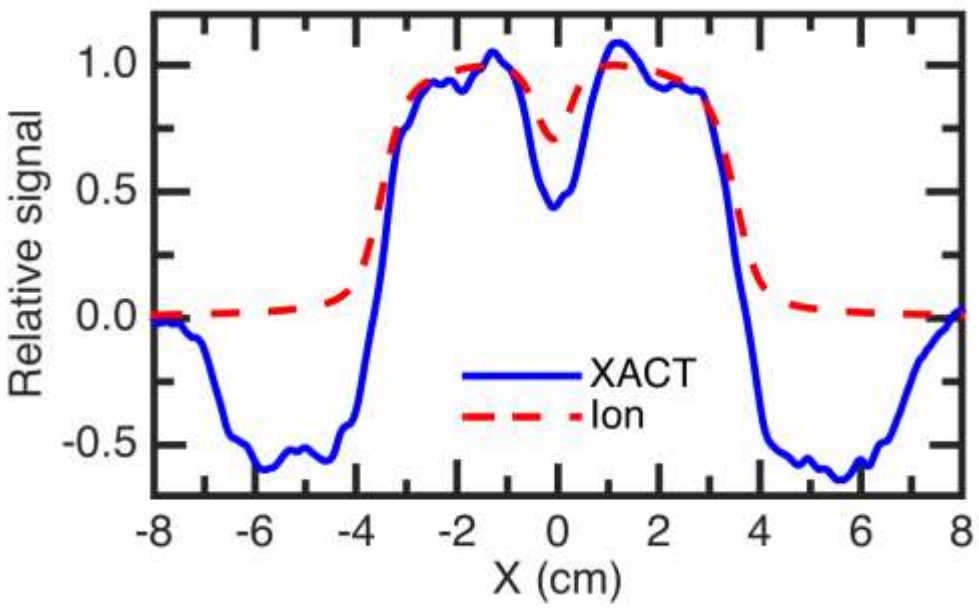


Resolution test: Dose comparison

XACT image

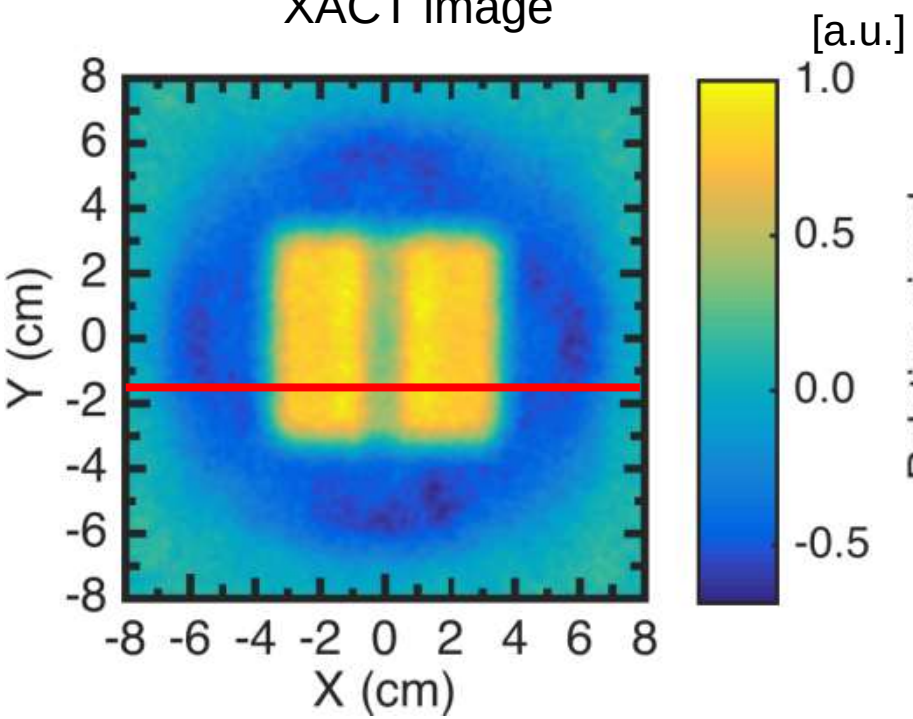


Extracted profiles

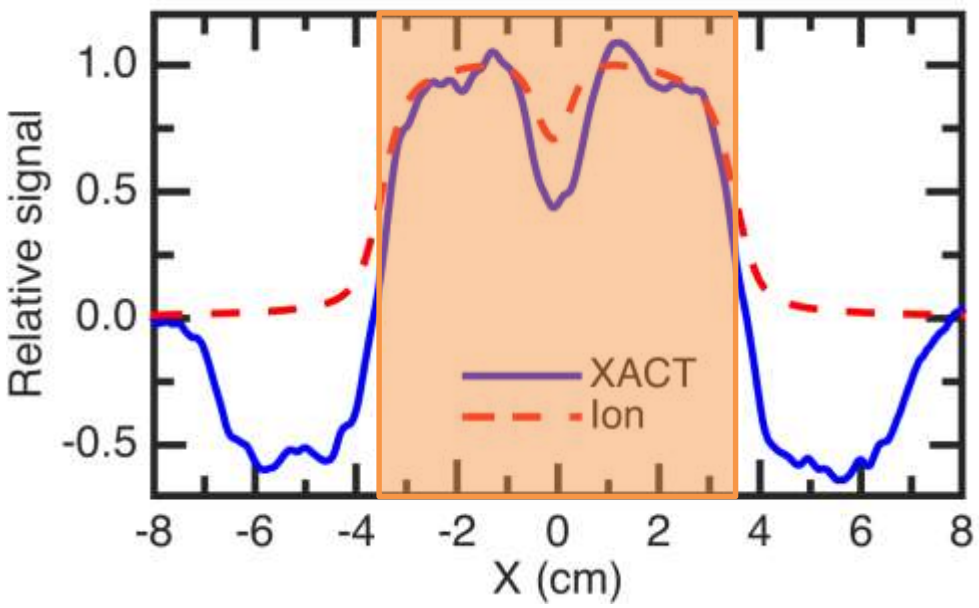


MLC field: Dose comparison

XACT image



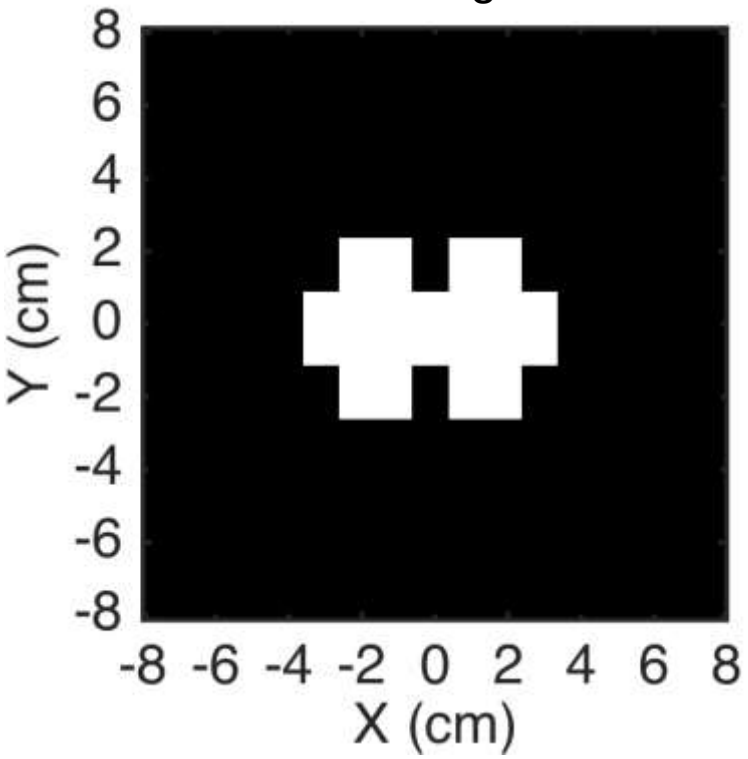
Extracted profiles



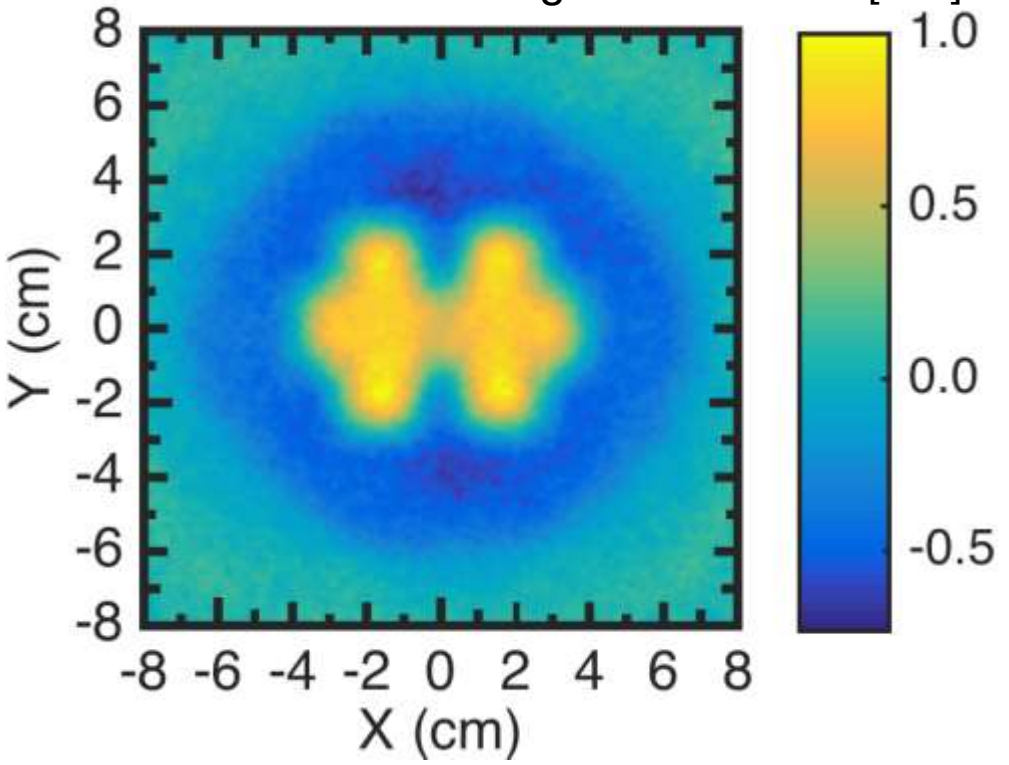
Root mean square error = 13%

Complex field: XACT image

Field diagram

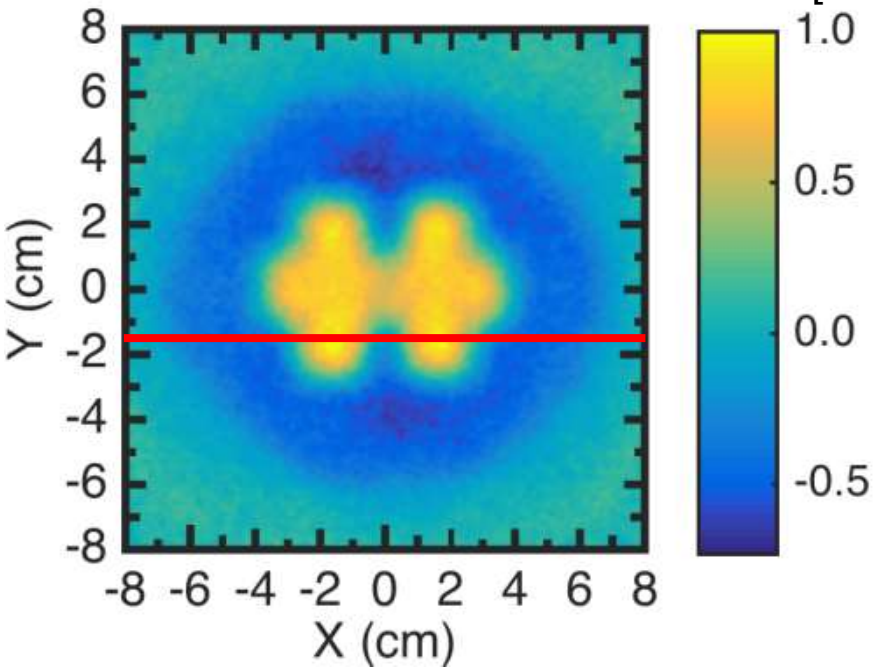


XACT image



Complex field: Dose comparison

XACT image



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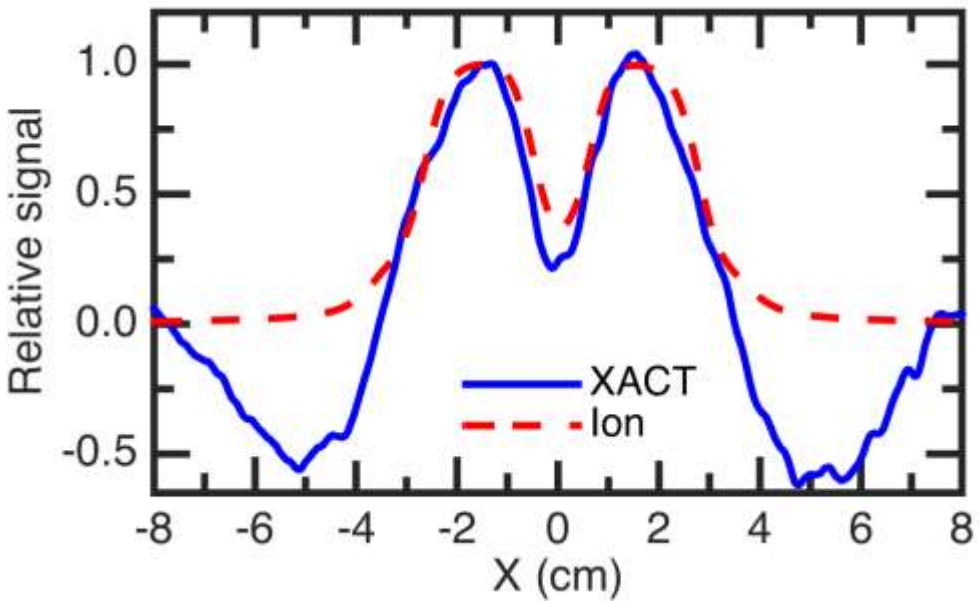

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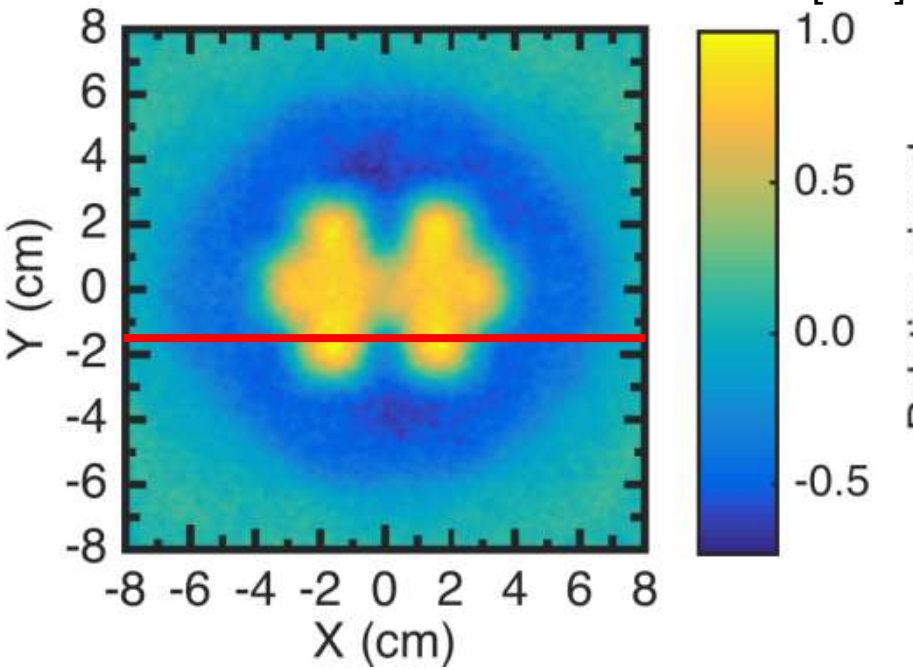

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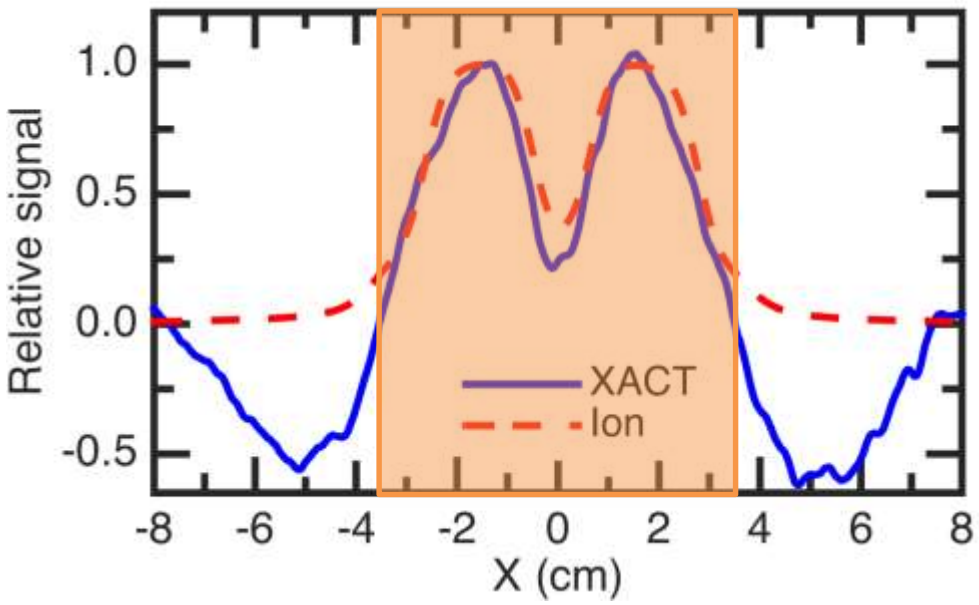

Root mean square error = 10.9%

Outlook: XACT as a dosimeter

- Motivation for XACT dosimetry:
  - Real-time
  - Volumetric
  - No beam perturbation
  - Energy independent
  - Potential to combine with ultrasound imaging

- Future potential applications:
  - 3D dose mapping
  - Small field dosimetry
  - *In vivo* dosimetry
  - Absolute dosimetry

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NSERC CRSNG

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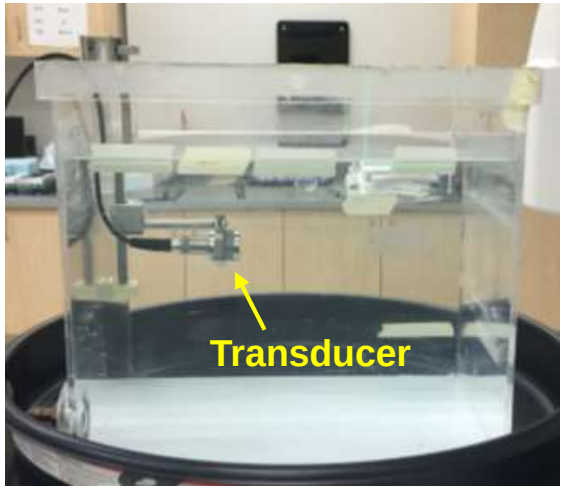
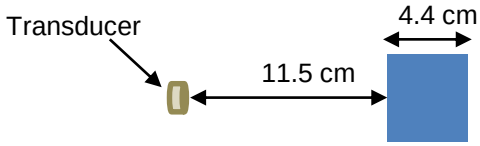
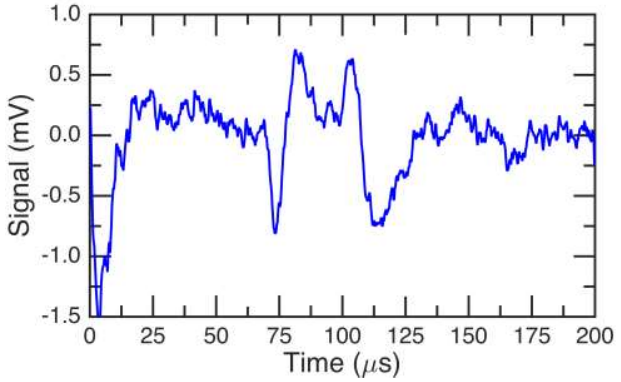
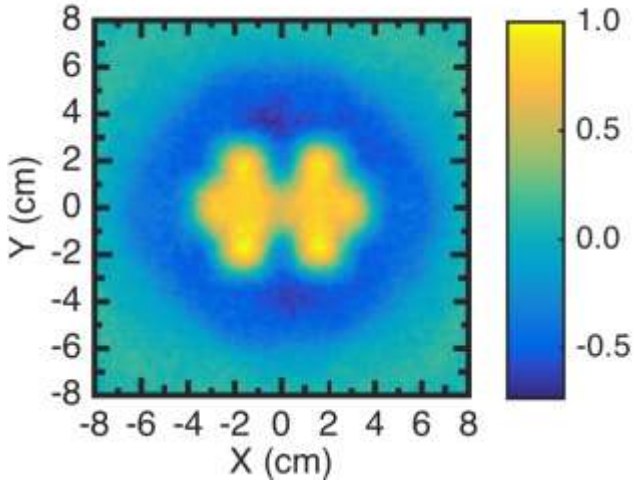
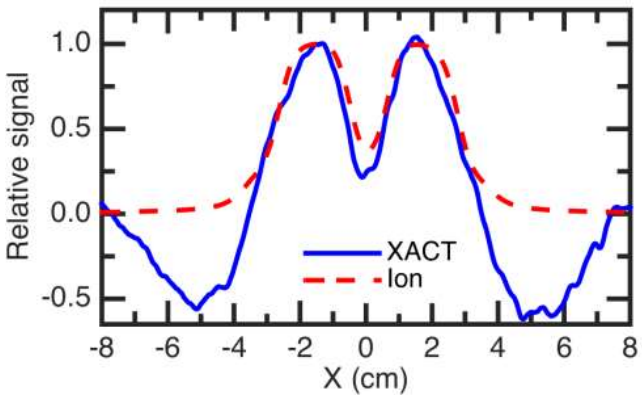
Thank you!


Transducer


Transducer
4.4 cm
11.5 cm


Signal (mV)
Time (μs)


Y (cm)
X (cm)


Relative signal
XACT
Ion
X (cm)