Tracking emissions during proton radiotherapy

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HEP Seminar 13 Feb 2015

First things first

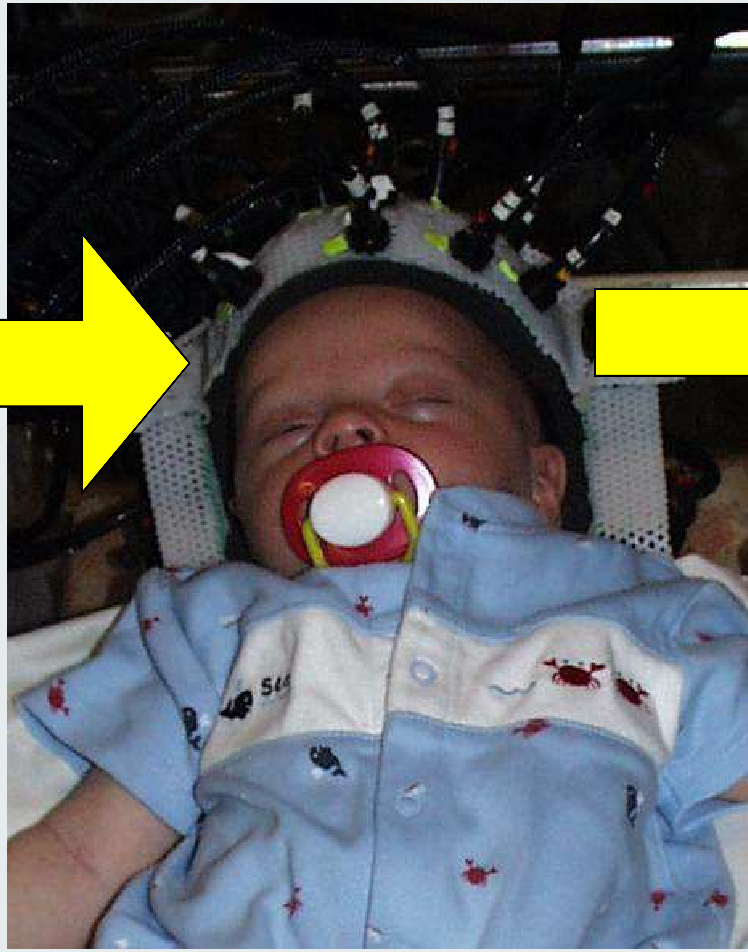
A long history…

' If a candle was held behind his head, or the sun happened to be behind it, the cranium appeared semi-transparent and this was more or less evident until he attained his fourteenth year'

Richard Bright, Guy's Hospital, on a patient with hydrocephalus, 1831.

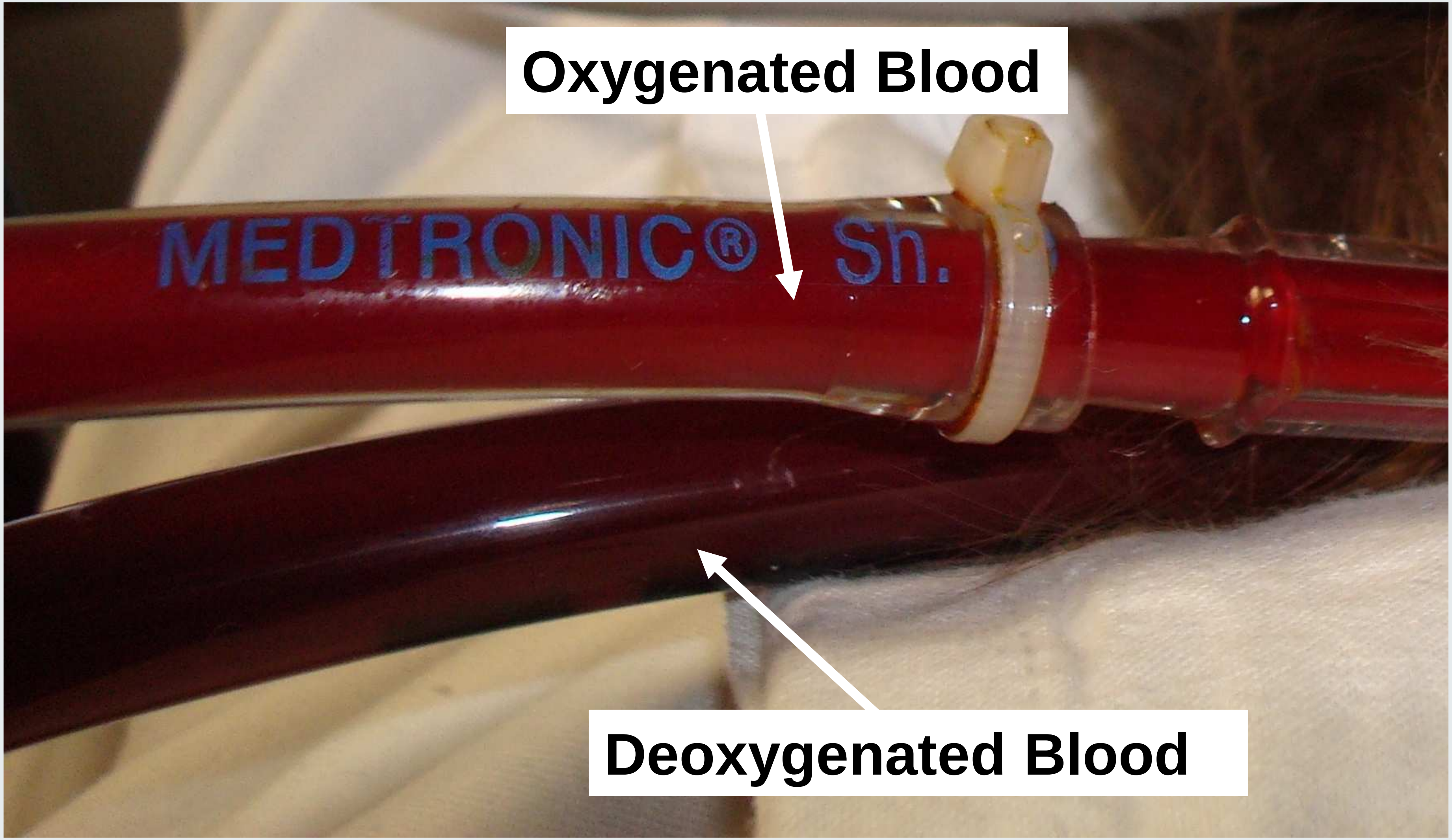
High attenuation

$500\ W\ m^{-2}$

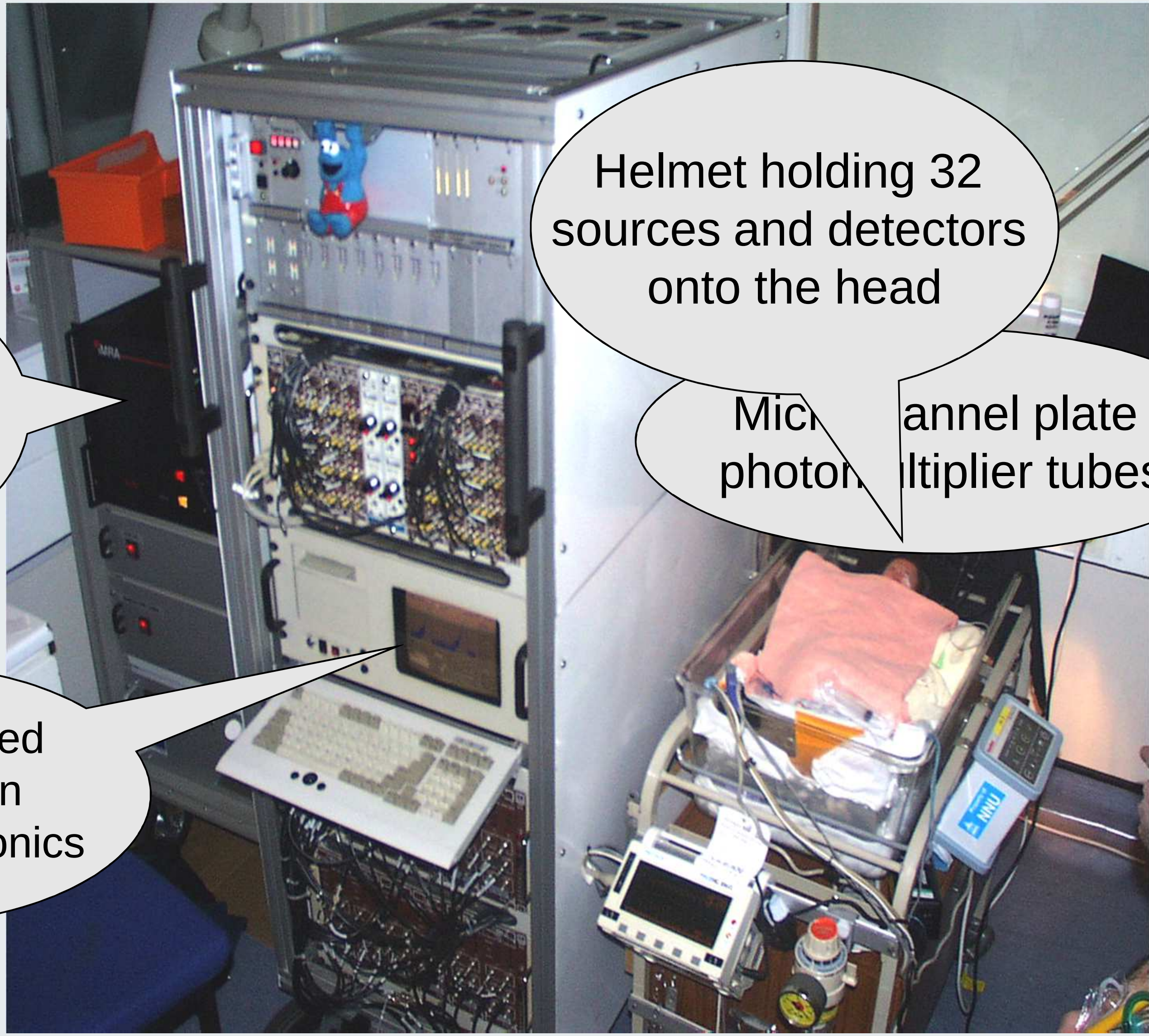


$10^{-14}\ W\ m^{-2}$

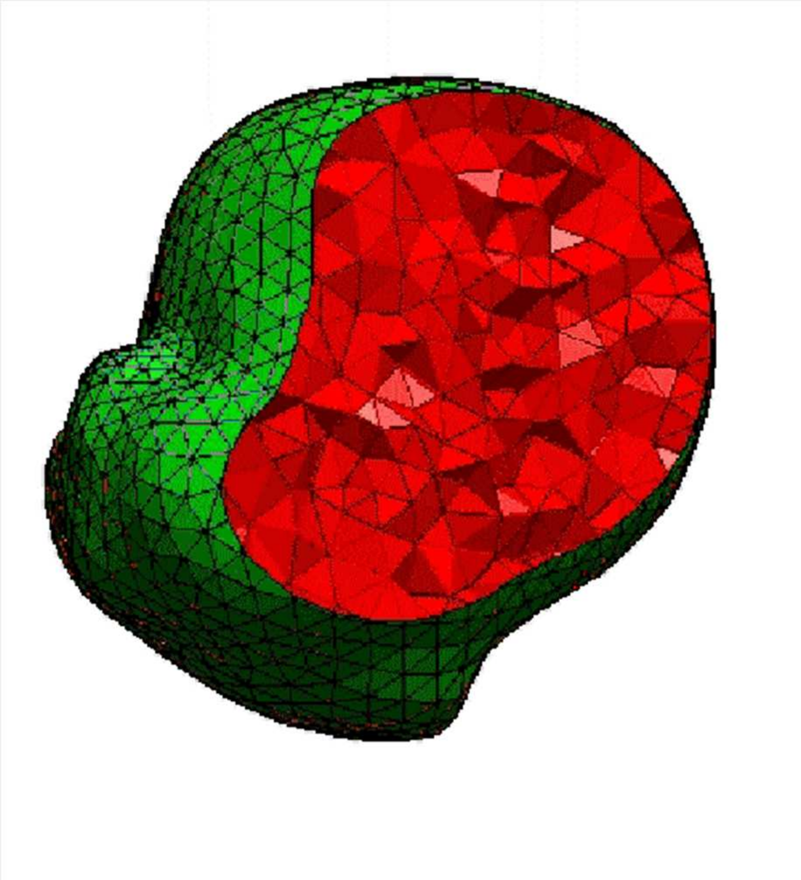
Optical absorption depends on haemodynamics

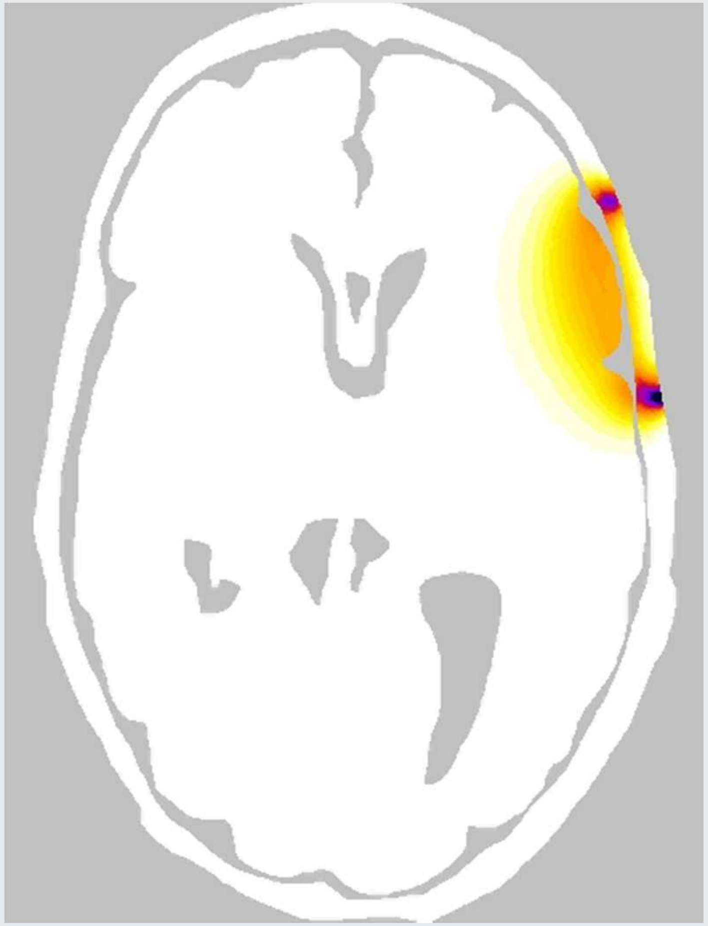


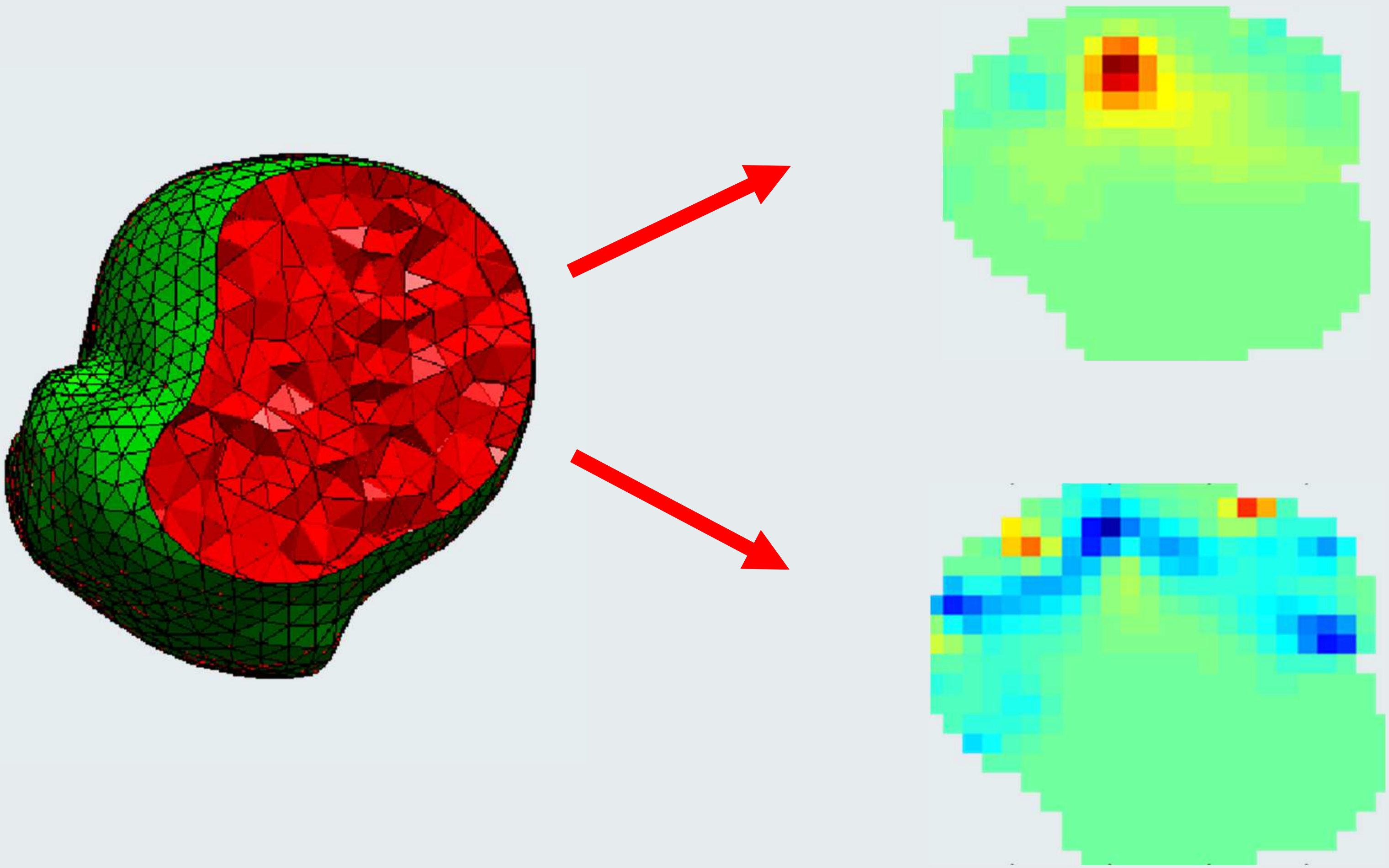
Optical tomography

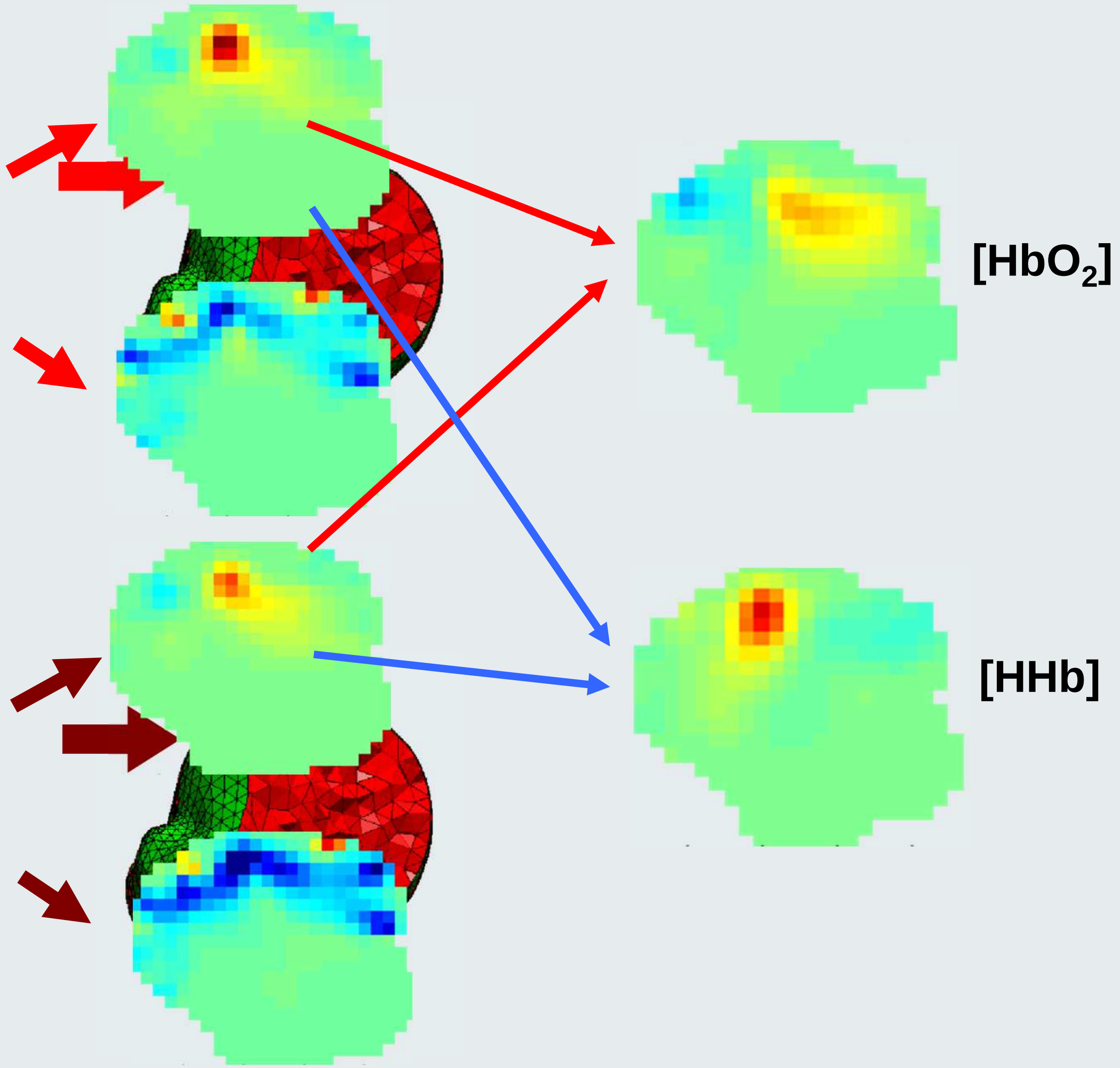


Forward model



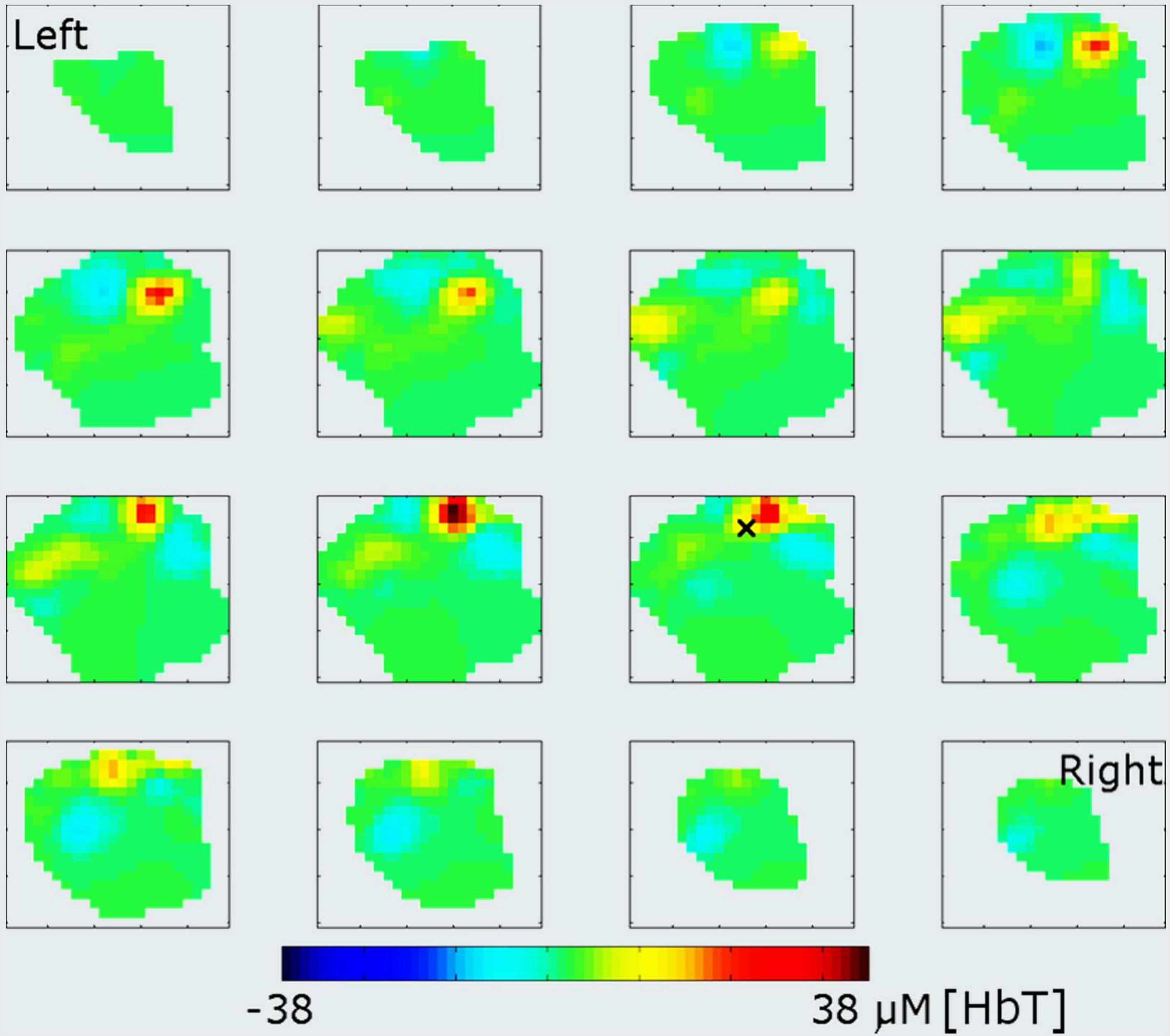





[HbO2]
[HHb]


MOLTEX
MOLTEX
MOLTEX

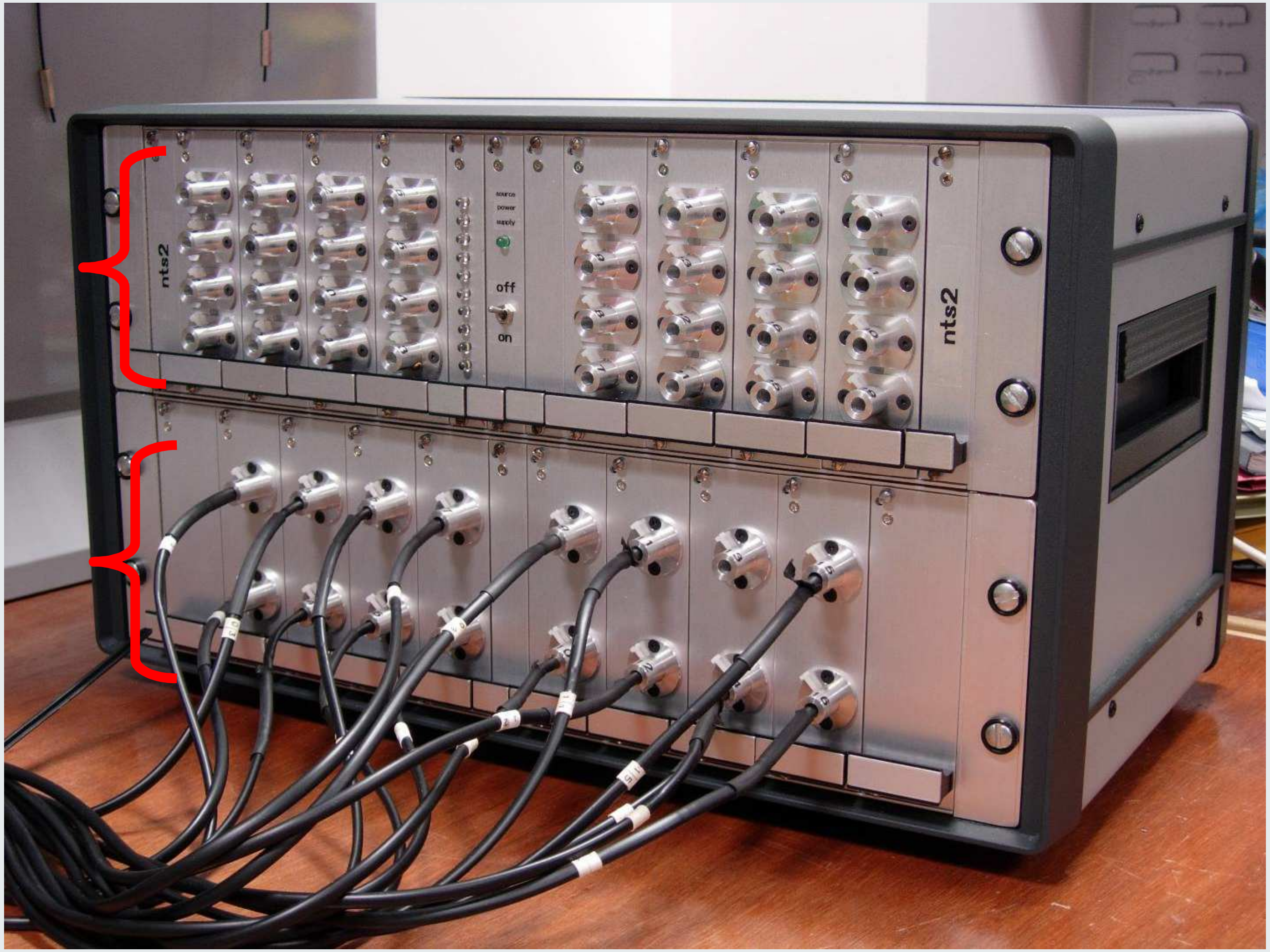
Motor evoked responses


Left
Right
-38
38 μM [HbT]

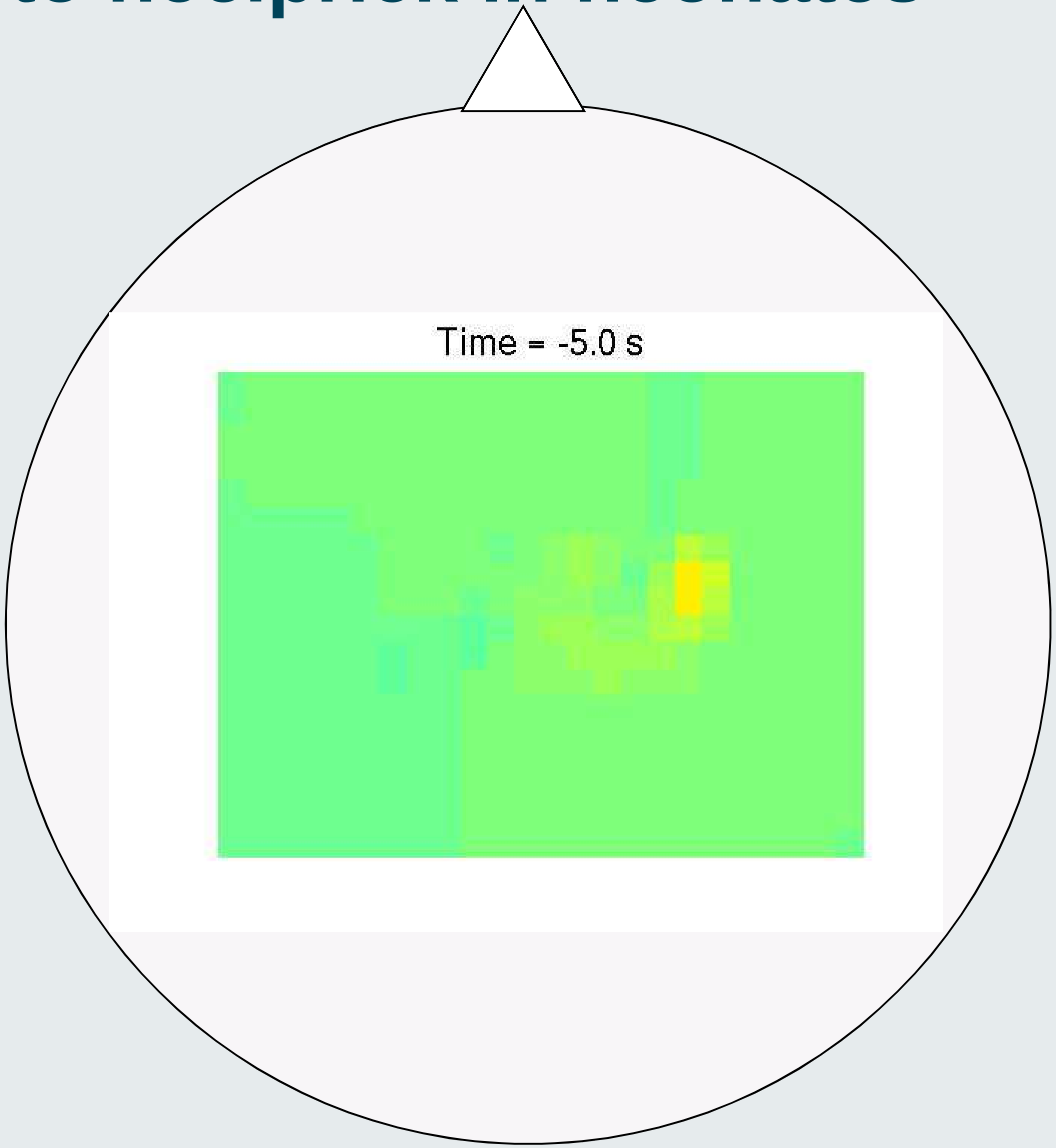
UCL optical topography system

32 laser diodes
- 16 at 775 nm
- 16 at 850 nm

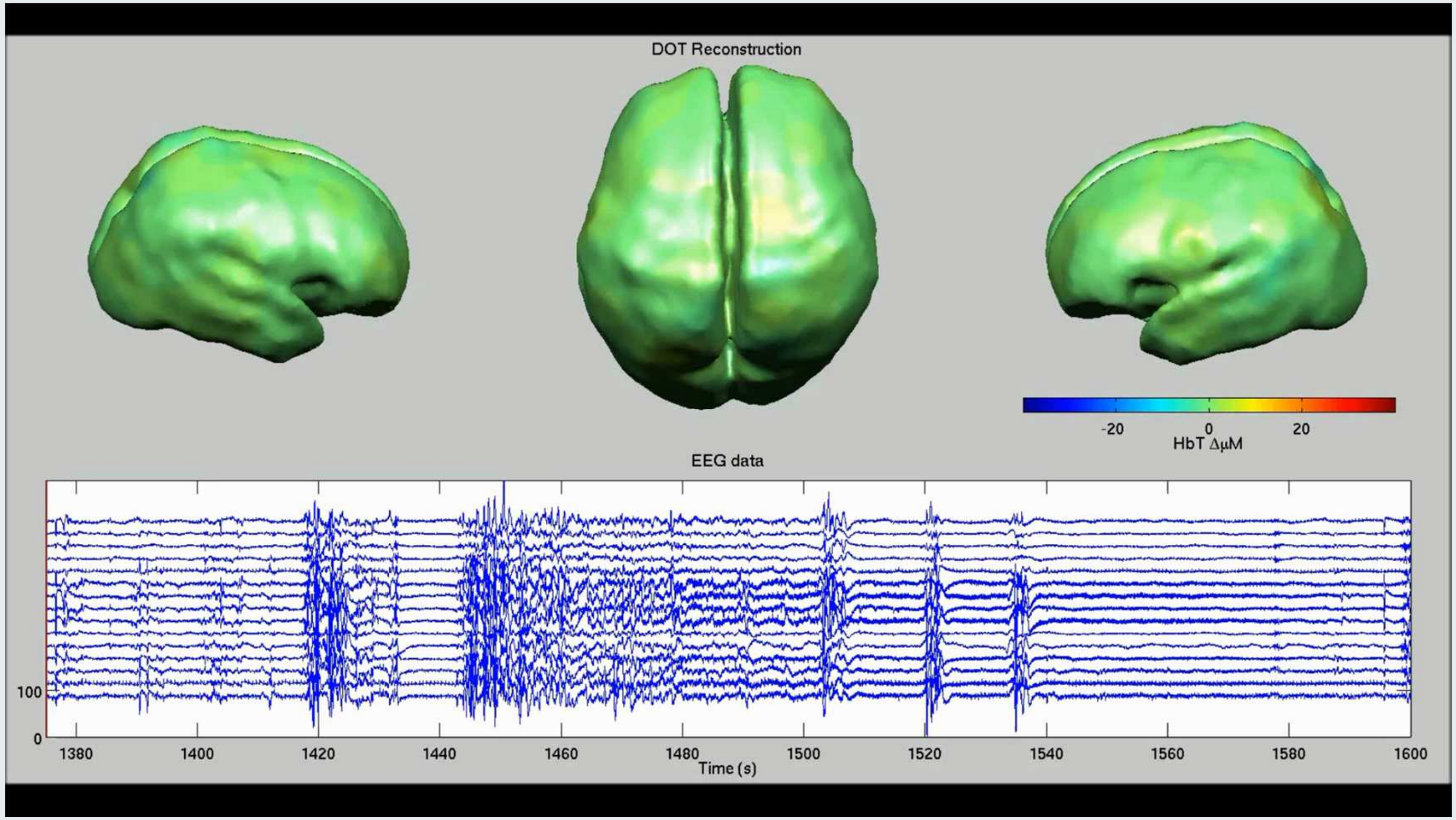
16 detectors



Cortical response to heelprick in neonates



Cortical haemodynamics during neonatal seizures



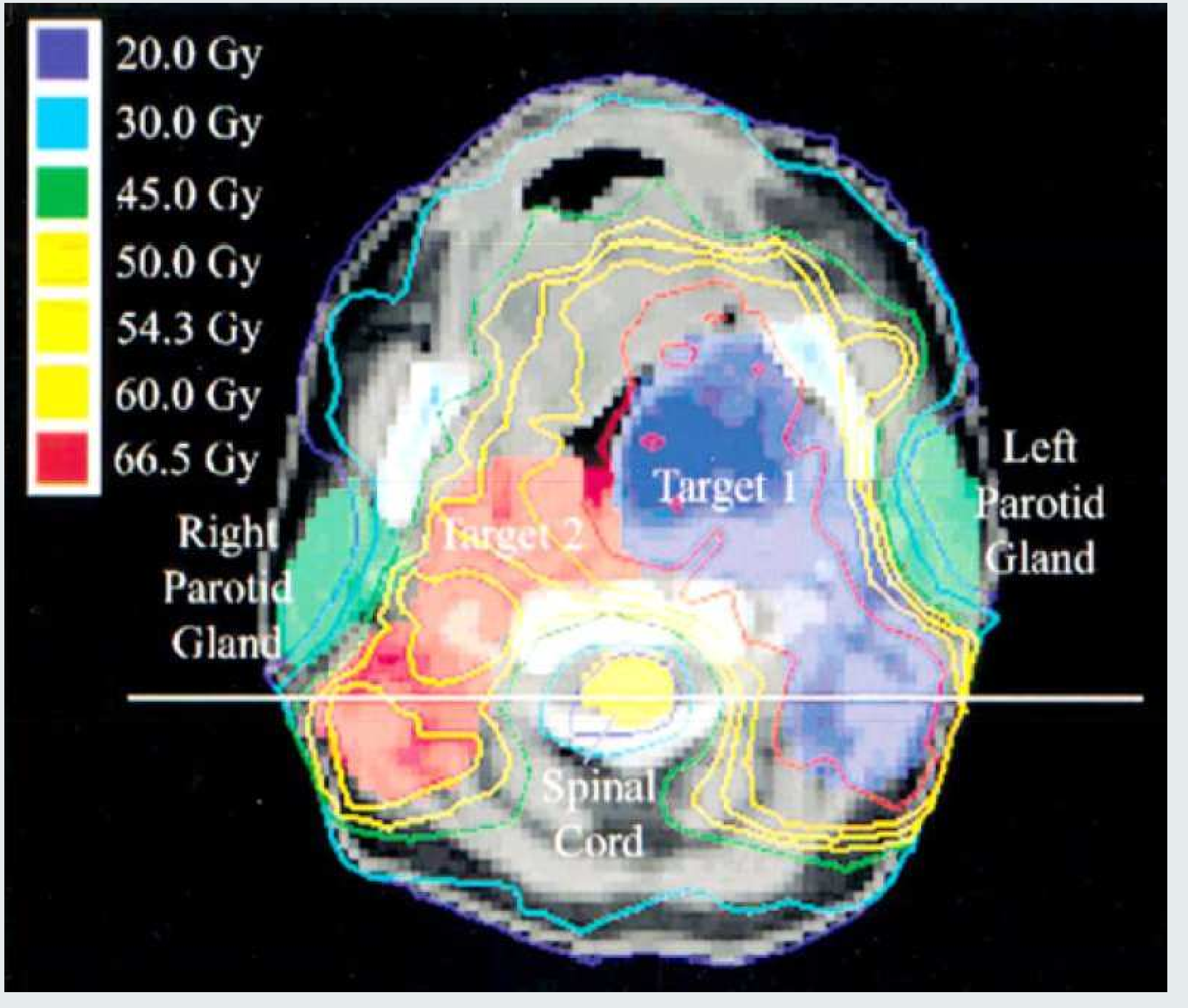
Singh at al Neuroimage Clin. 2014 5:256-65.

Current research

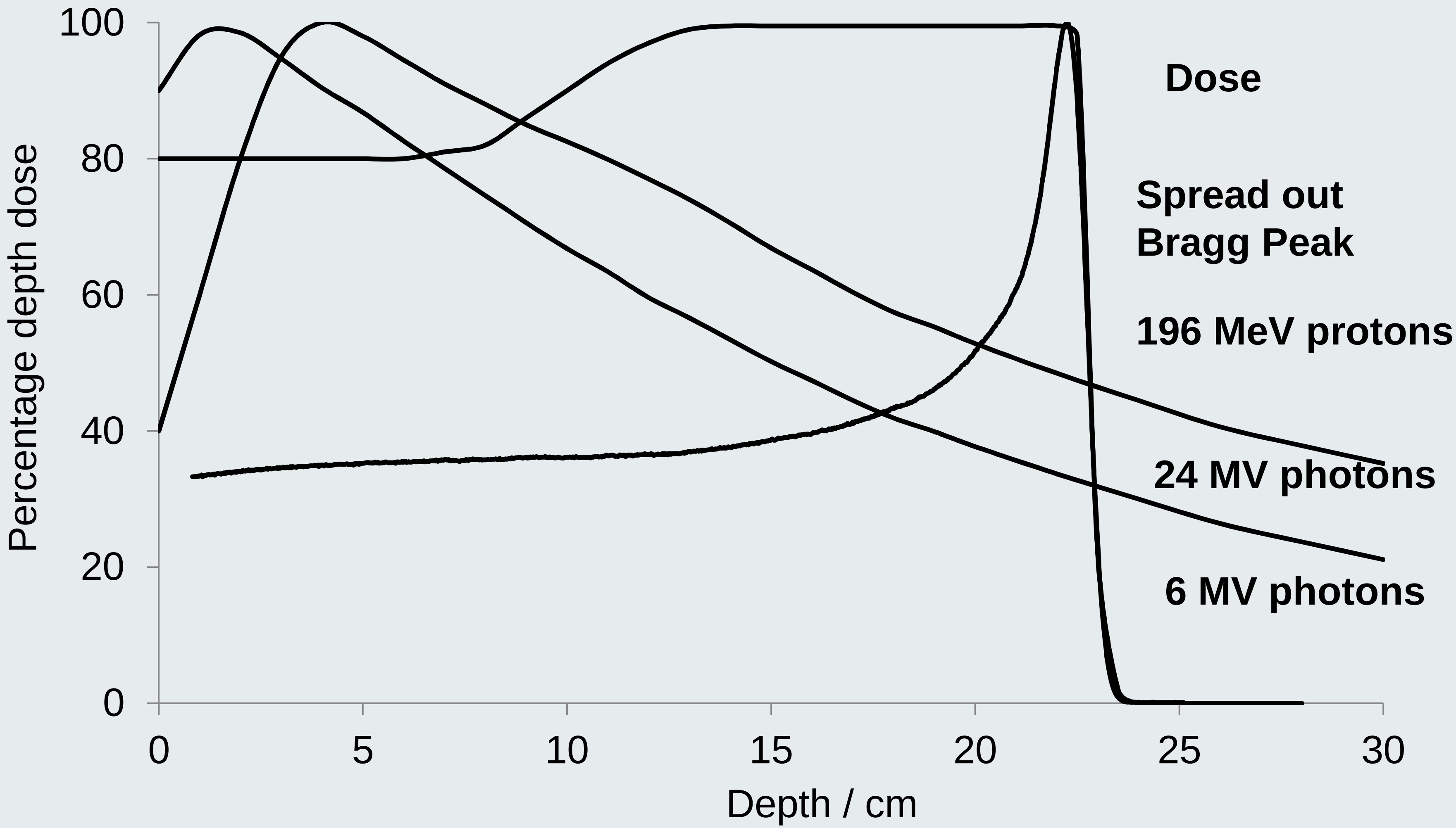
- Neonatal epilepsy with Addenbrookes
- Psychology research with various collaborators
  - Autism
  - Language development
  - Effects of malnutrition on brain development
  - Adult intensive care
- Modular, wireless, wearable, portable system

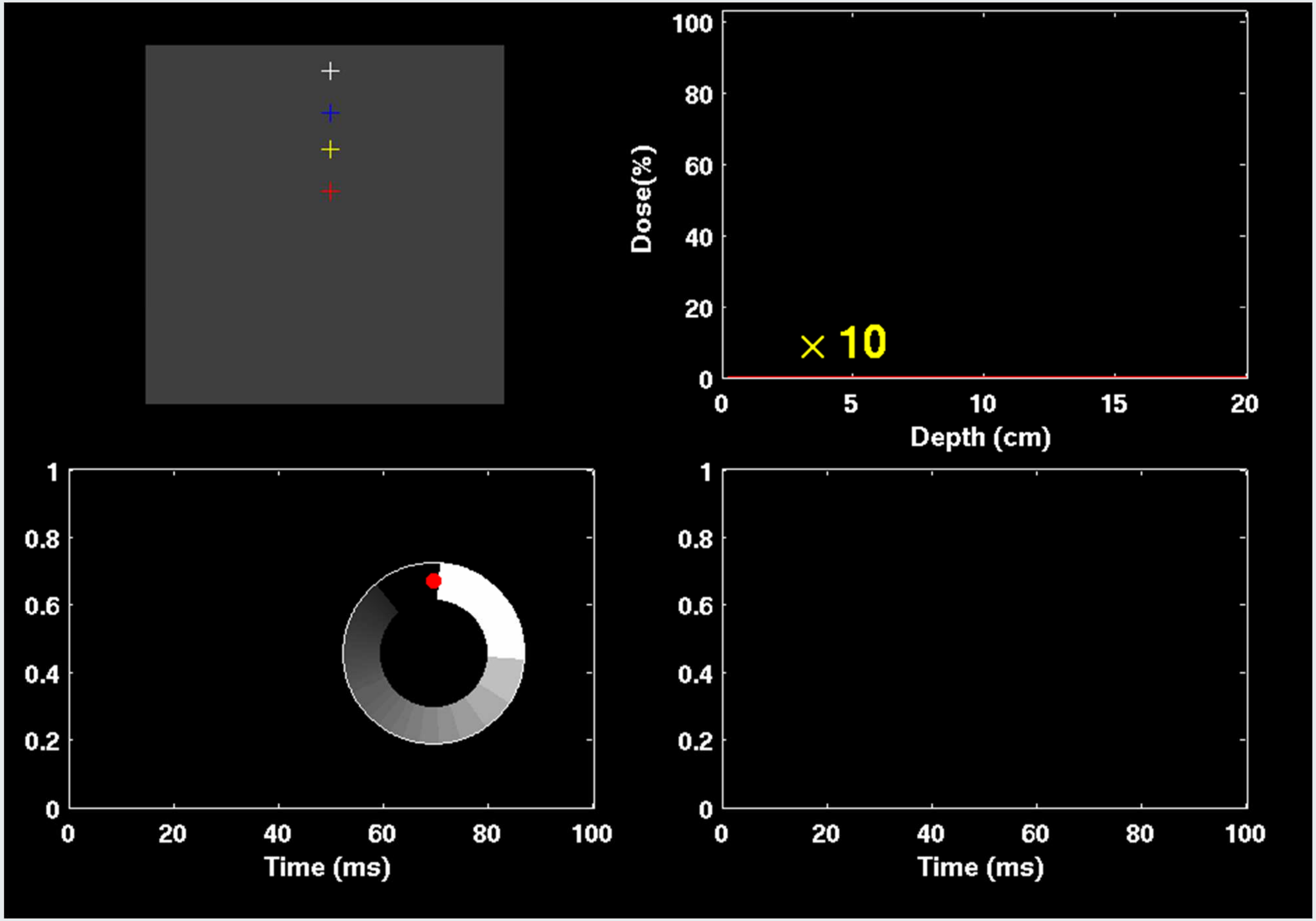
Proton therapy

Intensity modulated radiotherapy



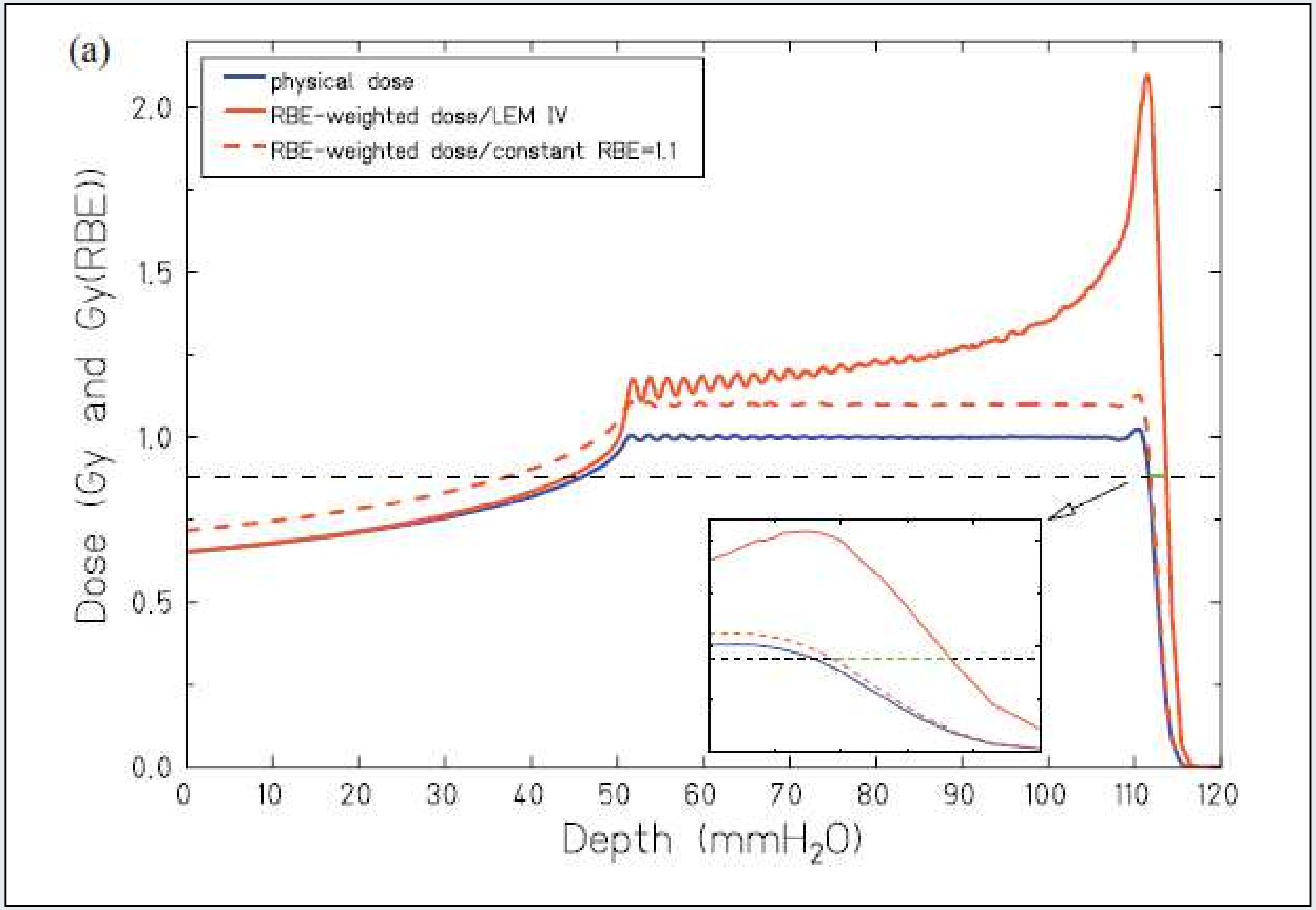
Depth dose curves





Animation produced by Hassan Bentefour

Relative biological effectiveness changes with energy



Grun et al (2013) Med. Phys. 40 (11), 111716-1

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26 September 2014 Last updated at 19:10

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Ashya King: NHS to fund Prague proton beam therapy

Ashya King is undergoing treatment at the Proton Therapy Centre (PTC) in Prague

The NHS has agreed to fund the care of brain tumour patient Ashya King who is undergoing proton beam treatment at a Czech clinic.

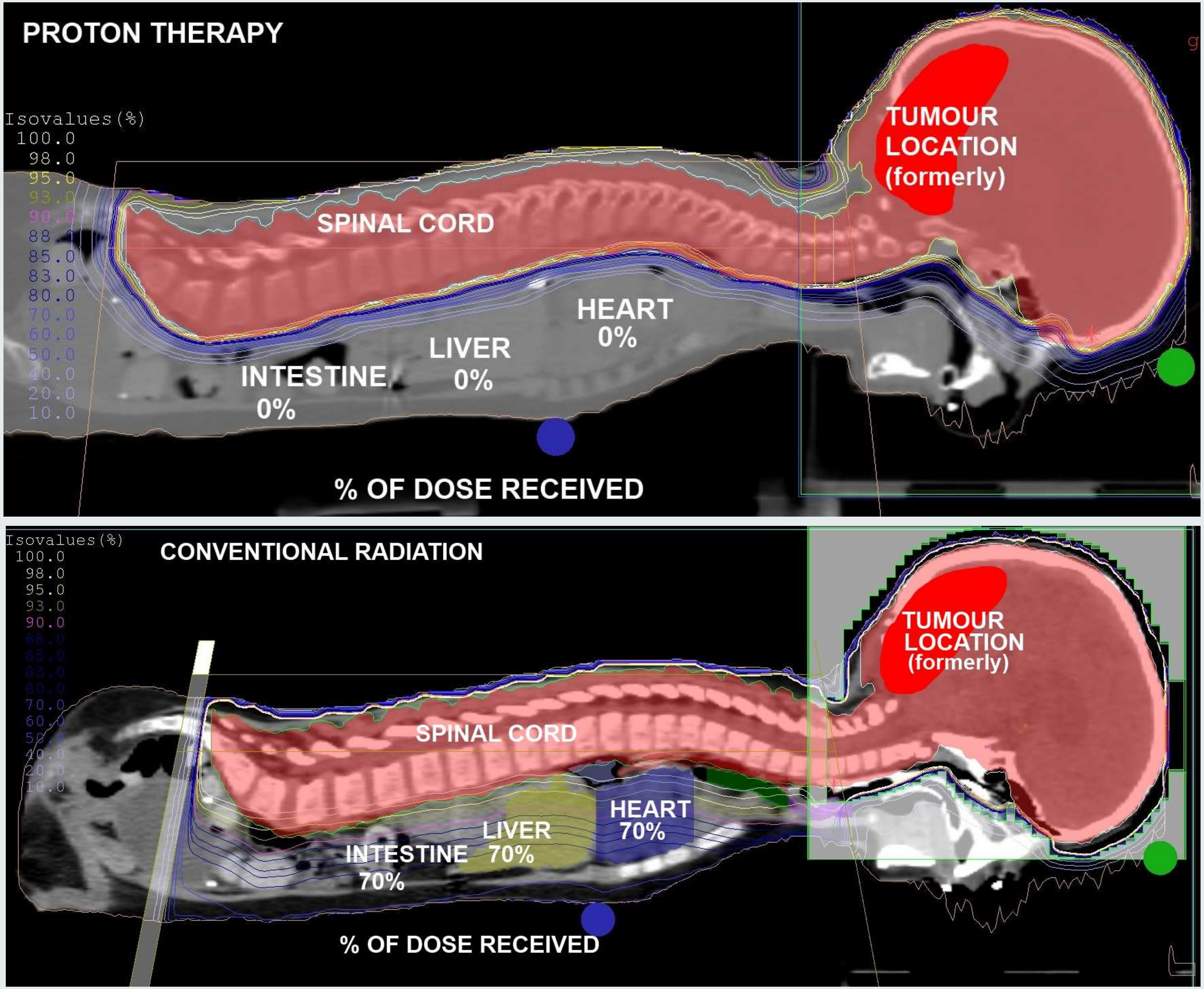
The five-year-old has been receiving post-operative radiotherapy at the Proton Therapy Centre (PTC) in Prague since 15 September.

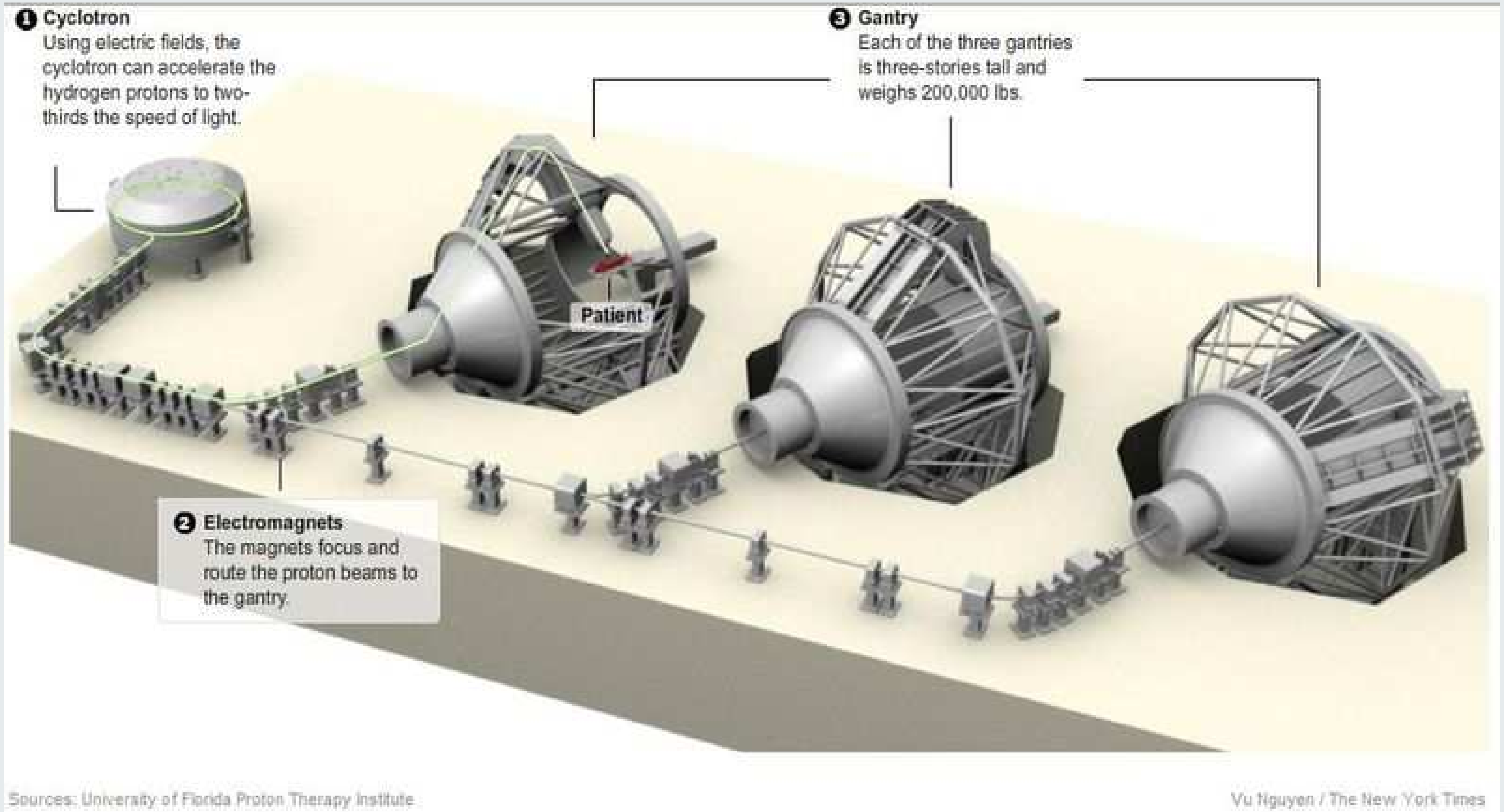
In a statement, NHS England said it was "clearly best" he continued to be treated "uninterrupted".

His 30-session treatment is due to last six weeks.

Related Stories

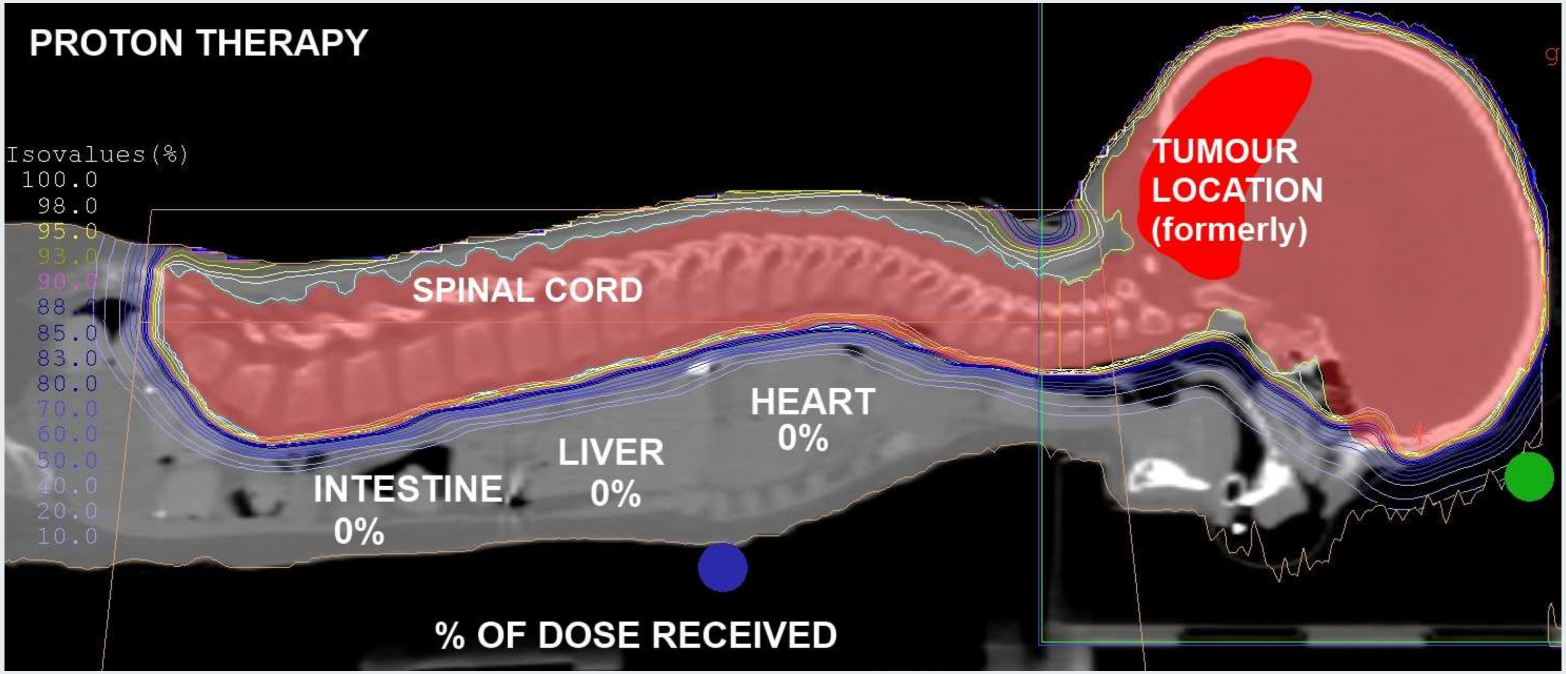
- Ashya proton beam sessions begin
- Ashya hospital staff 'receive abuse'
- Ashya undergoes Prague clinic scans


PROTON THERAPY
Isovalues (%)
100.0
98.0
95.0
93.0
90.0
88
85.0
83.0
80.0
70.0
60.0
50.0
40.0
20.0
10.0
TUMOUR LOCATION (formerly)
SPINAL CORD
HEART 0%
LIVER 0%
INTESTINE 0%
% OF DOSE RECEIVED
CONVENTIONAL RADIATION
Isovalues (%)
100.0
98.0
95.0
93.0
90.0
TUMOUR LOCATION (formerly)
SPINAL CORD
HEART 70%
LIVER 70%
INTESTINE 70%
% OF DOSE RECEIVED

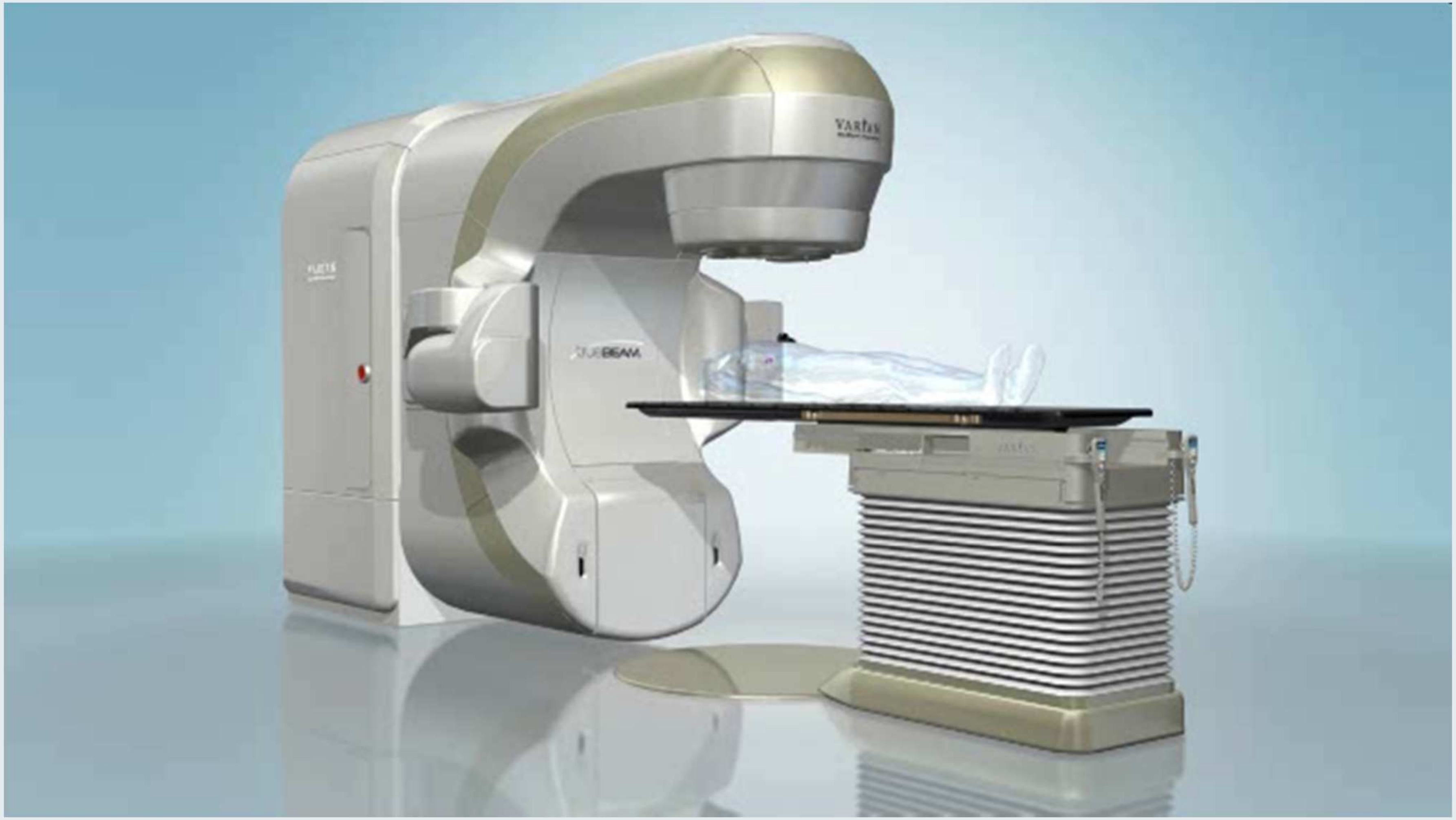

1 Cyclotron
Using electric fields, the cyclotron can accelerate the hydrogen protons to two-thirds the speed of light.
3 Gantry
Each of the three gantries is three-stories tall and weighs 200,000 lbs.
Patient
2 Electromagnets
The magnets focus and route the proton beams to the gantry.
Sources: University of Florida Proton Therapy Institute
Vu Nguyen / The New York Times

The challenge

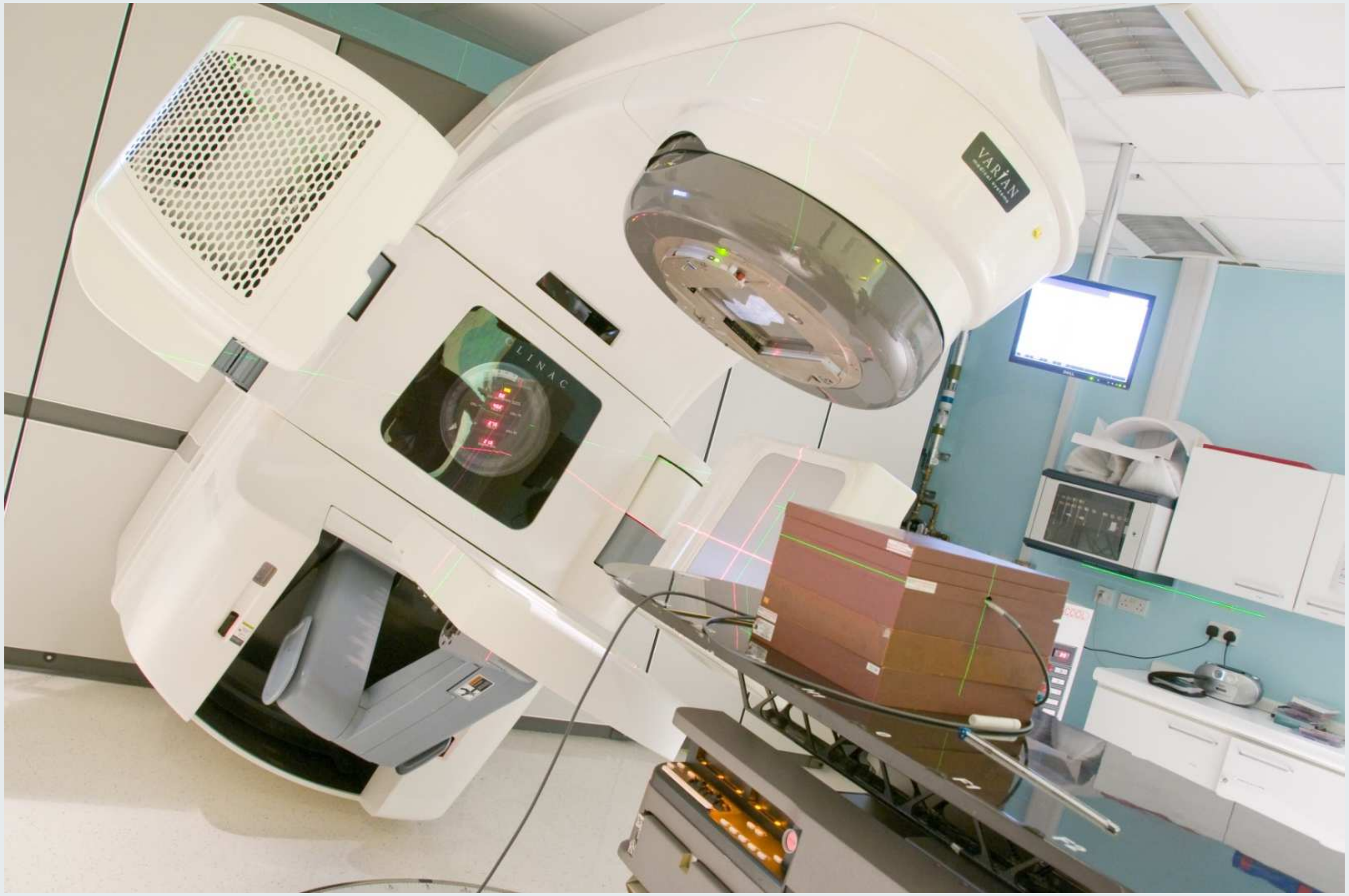
Proton therapy requires knowledge of dose distribution relative to tumour and other organs.



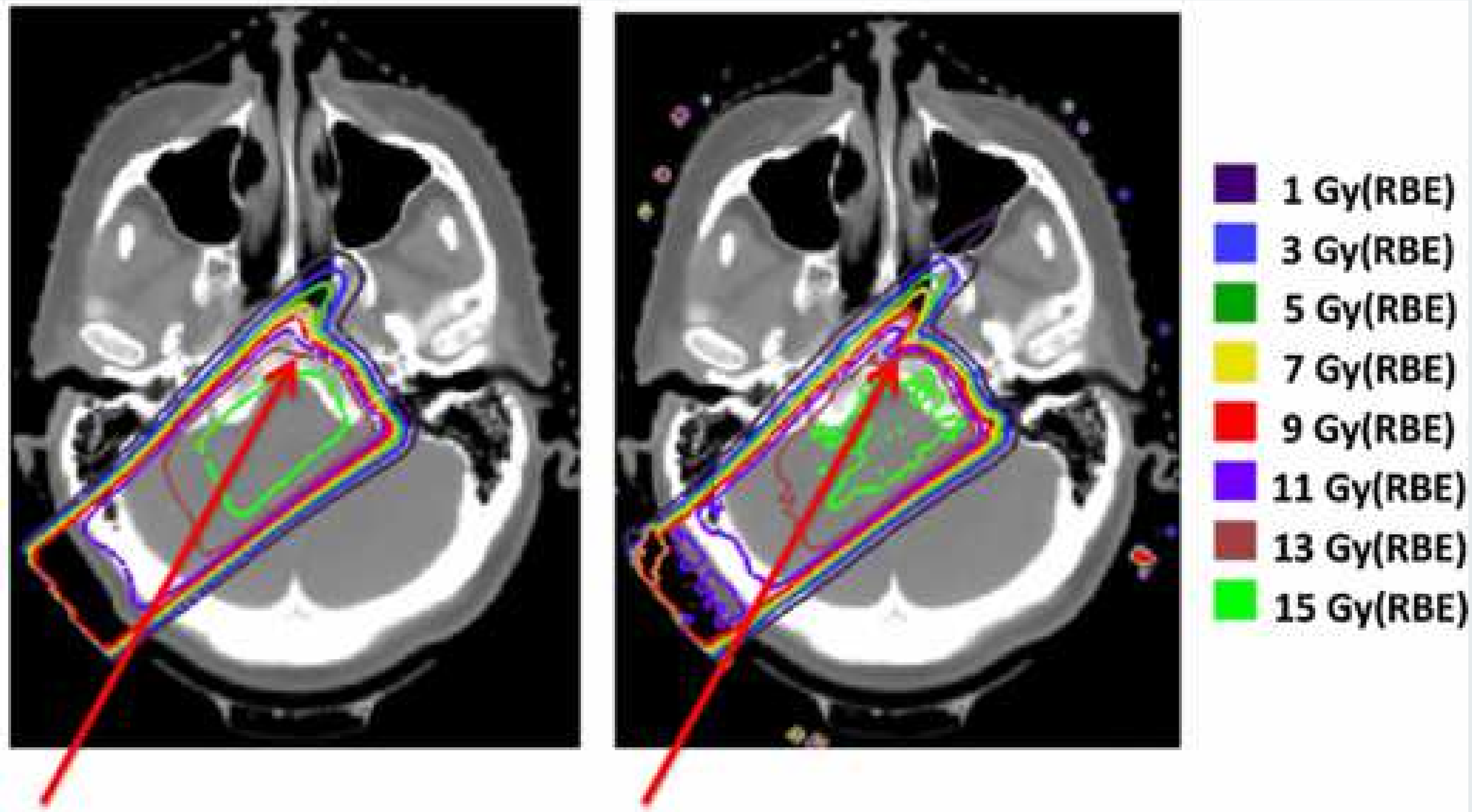
Latest techniques use multiple, rapidly changing beams of photons or protons to conform to tumour



Current standard QA gives accurate point dosimetry



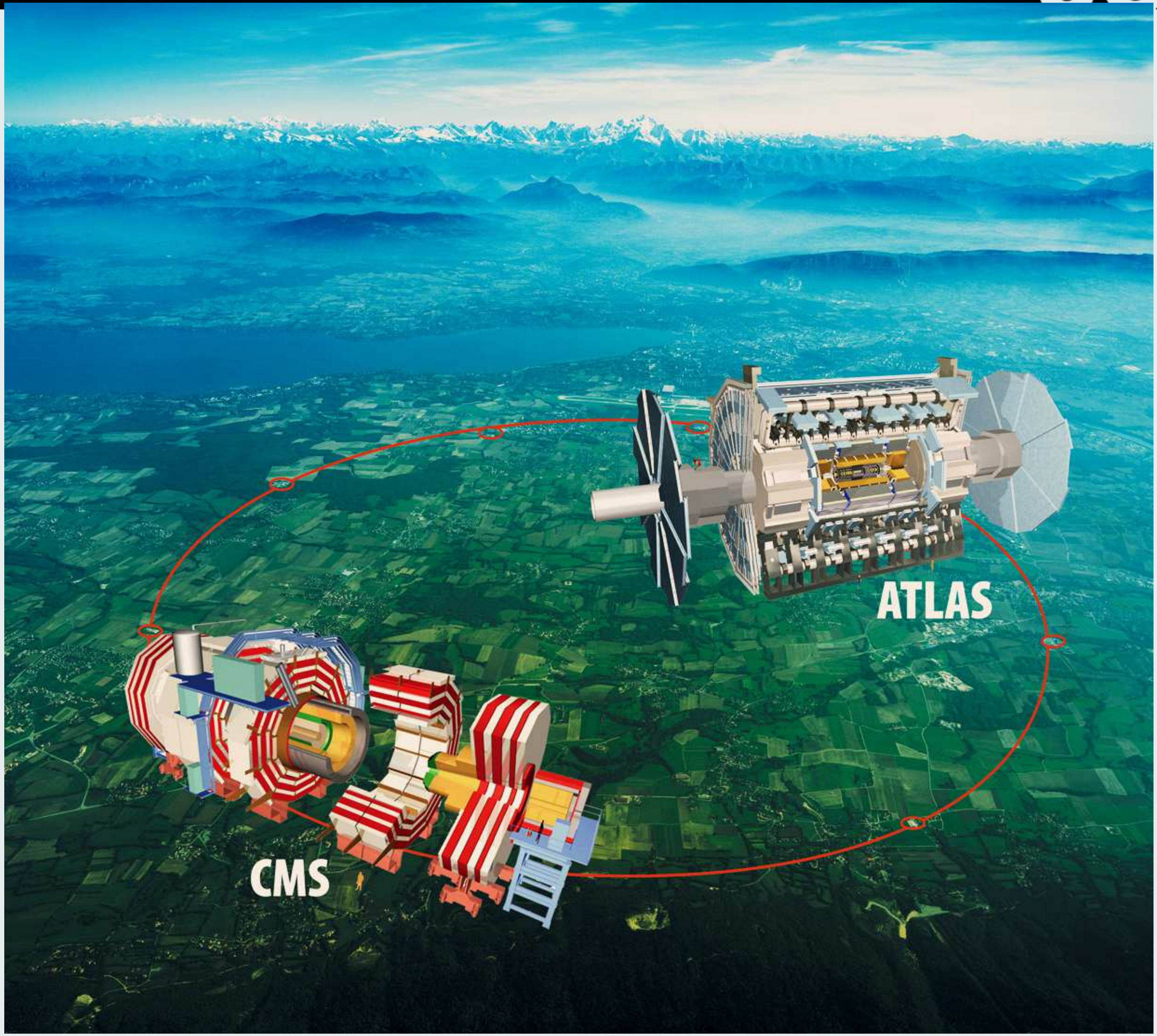
Imaging is necessary but not sufficient



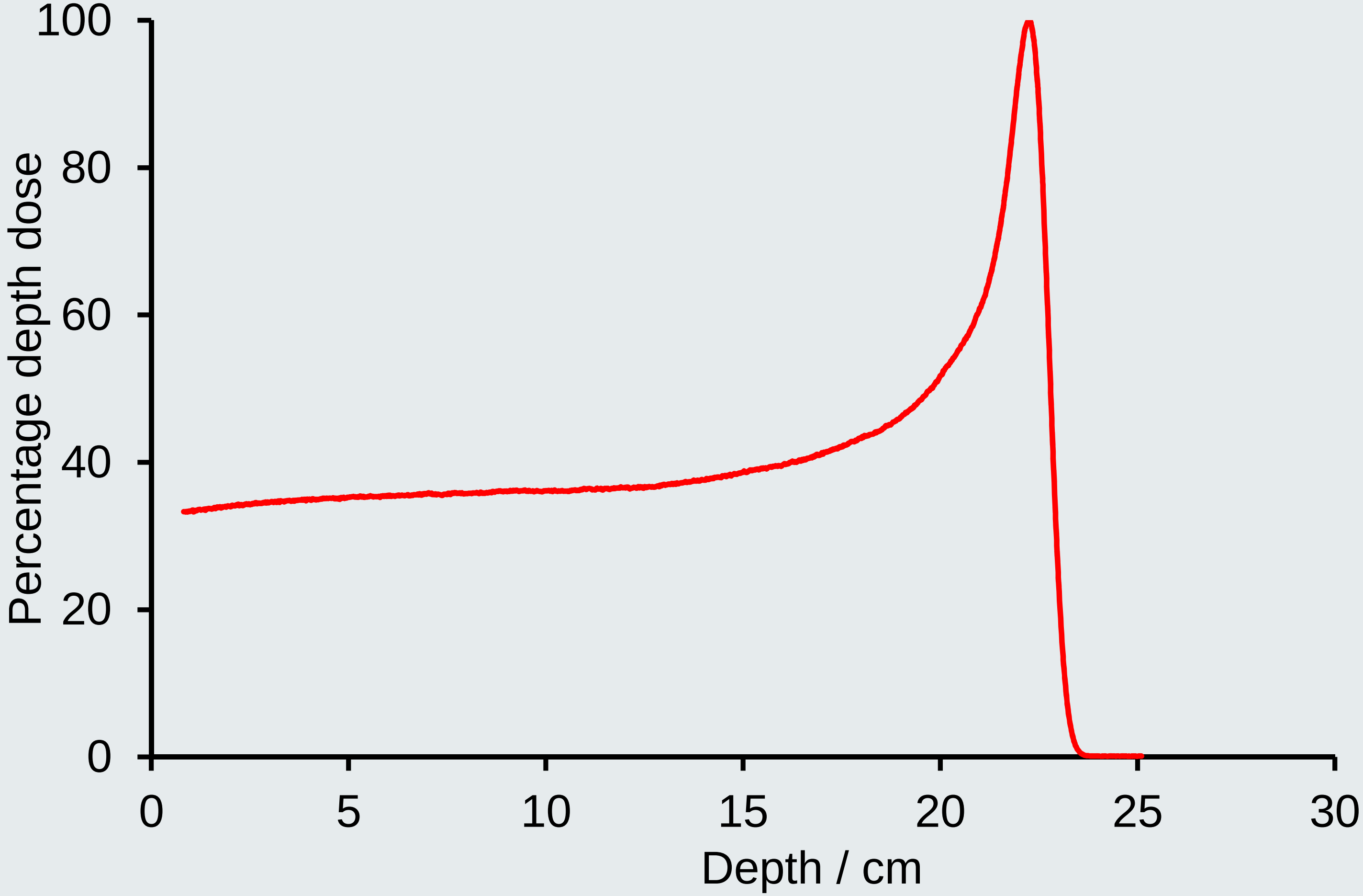
The question:

Can we monitor emissions from a proton beam to provide 3D time-varying dosimetry?

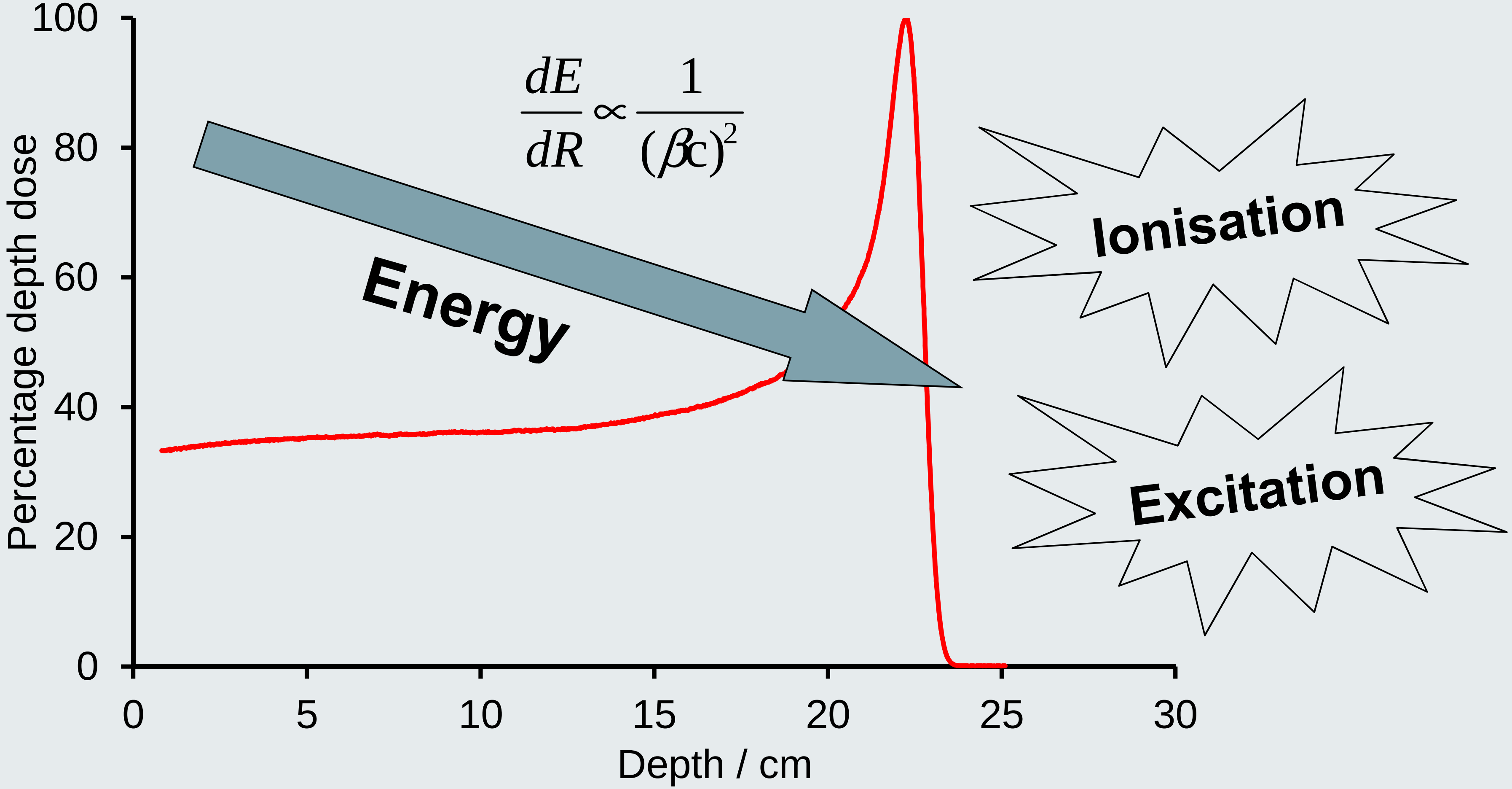
Can we monitor emissions from a proton beam to provide 3D time-varying *in vivo* dosimetry?


ATLAS
CMS

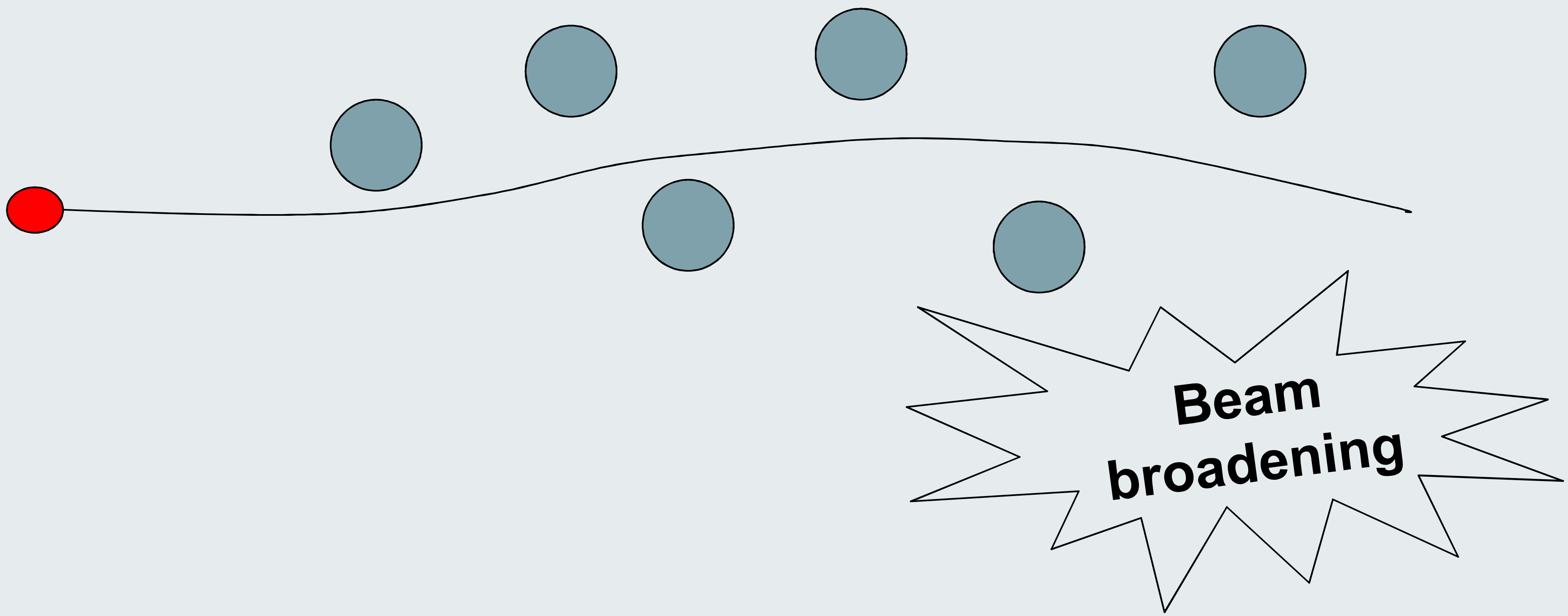
Interactions of protons with tissue (=water)



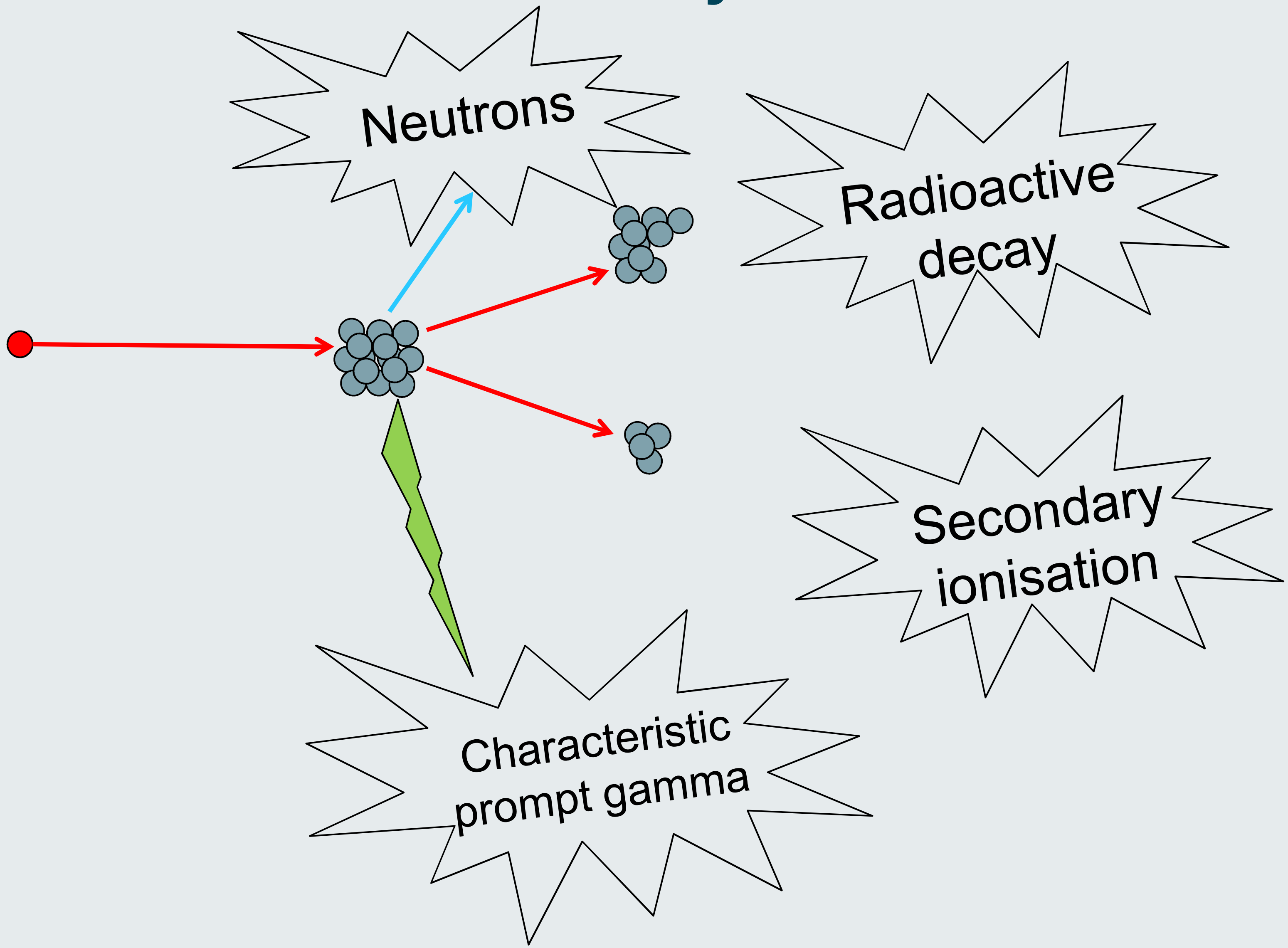
Protons lose energy to orbital electrons



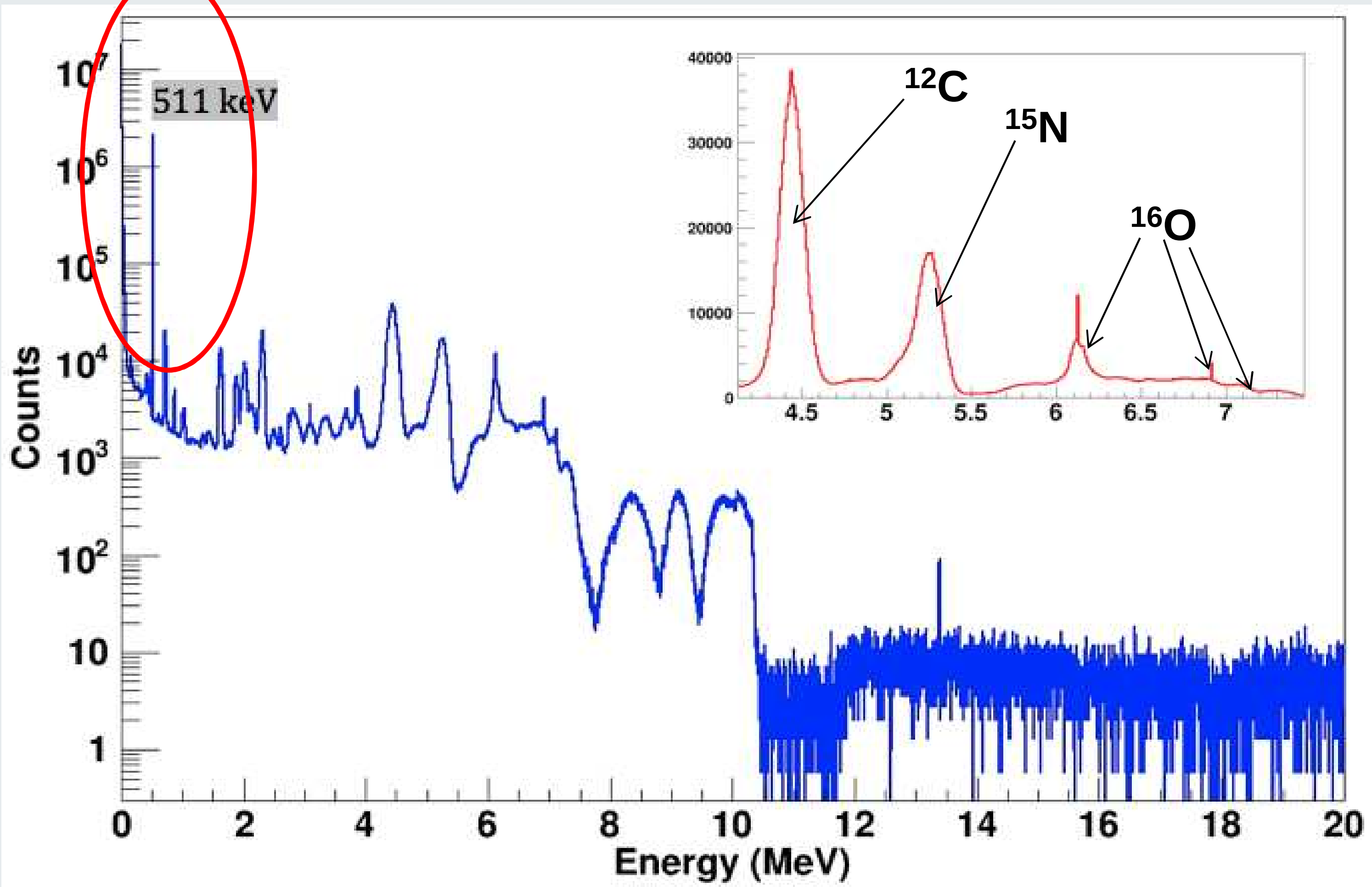
Protons scatter off nuclei elastically



Protons interact inelastically with nuclei



Prompt gamma emission from excited nuclei



Helo et al Phys. Med. Biol. **59** (2014) 7107–7123

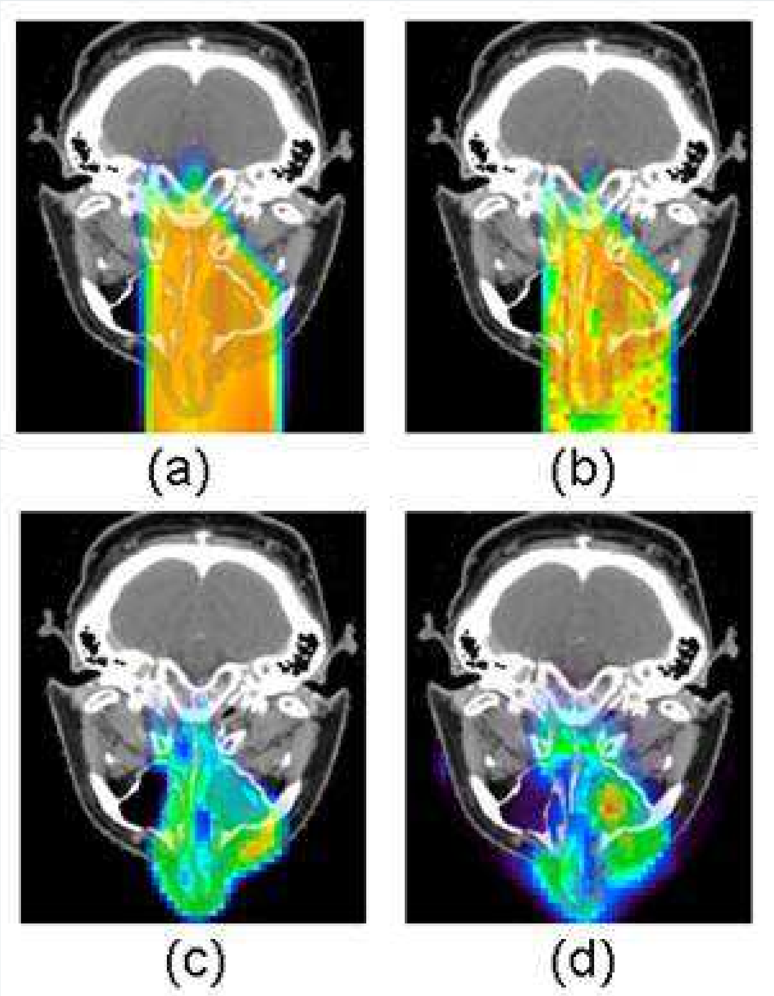
Prompt gamma emission from excited nuclei

Advantages

- Real time verification
- No additional dose
- Range accuracy ~1 mm

- Disadvantages
  - Low signal from small, fast-moving beams
  - Emissions stop 2-3 mm from Bragg peak
  - Background noise from other emissions

Positron emission tomography



Offline PET

(a) Treatment planning dose distribution;
(b) Monte Carlo simulated dose distribution;
(c) Monte Carlo simulated PET distribution;
(d) PET measurement.

Zhu and Fakhri Theranostics 2013; 3(10):731-740.

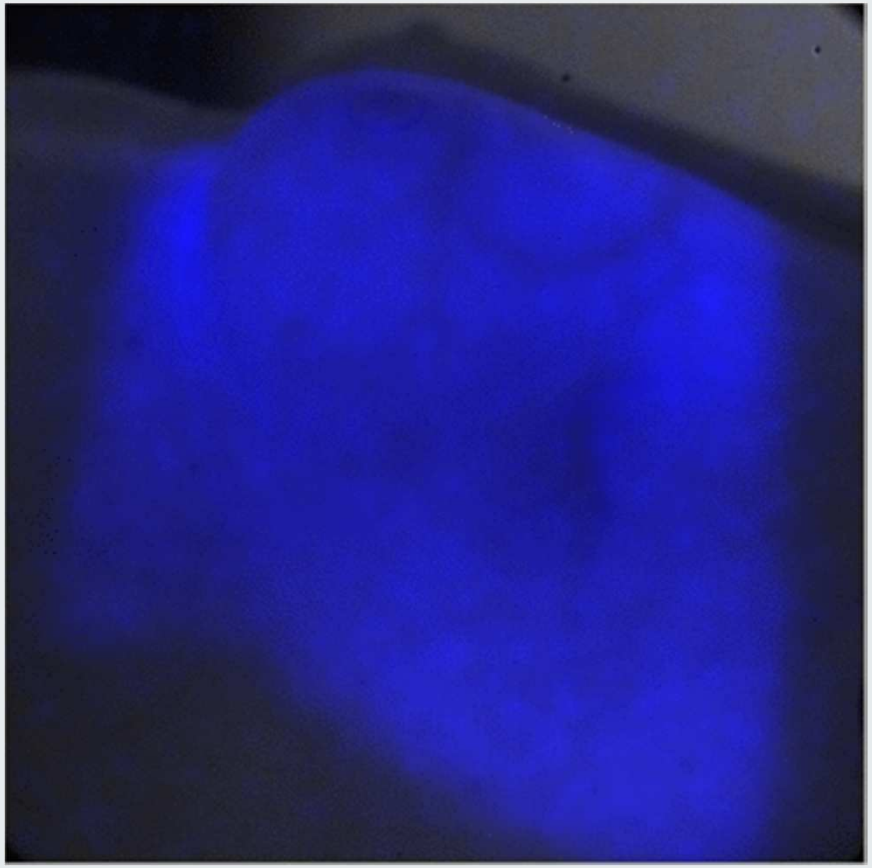
Positron emission tomography

Advantages

- Practical with existing equipment (online or offline)
- Range to 1-2 mm accuracy in some regions

- Disadvantages
  - Biological washout
  - Short half lives
  - Depends on elemental composition of tissue
  - Energy threshold for activation means no signal from Bragg peak

Cherenkov imaging



Brian Pogue and team at Dartmouth
http://cancer.dartmouth.edu/focus/Cherenkov_effect_Radiation_Oncology.html

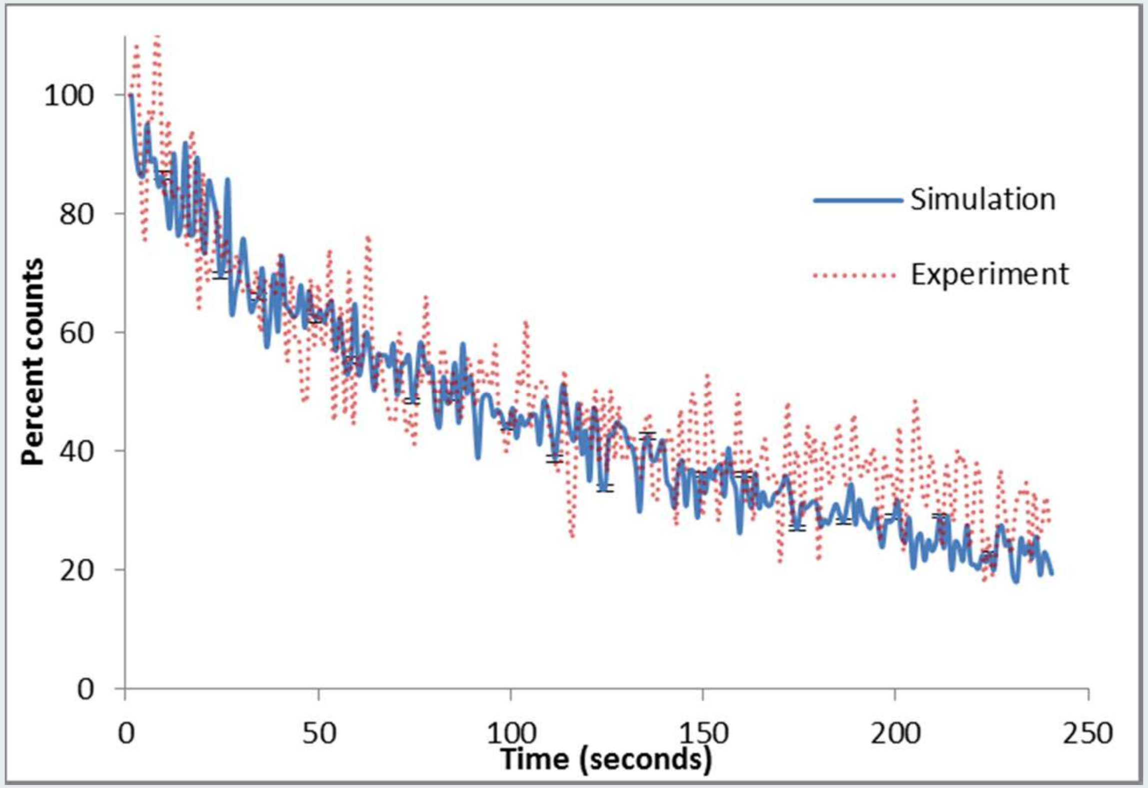
Cherenkov imaging

Fast component.

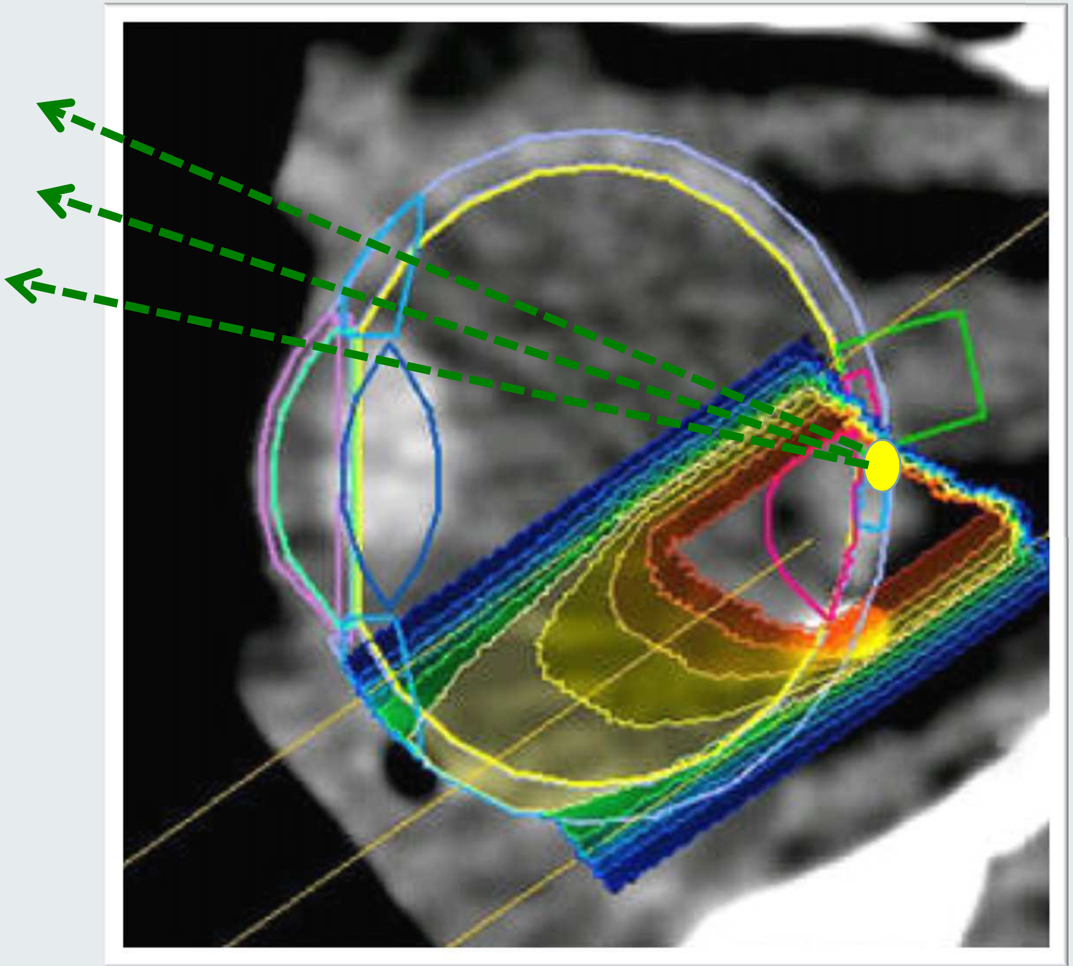
From ionisations caused by prompt gamma (and neutrons)

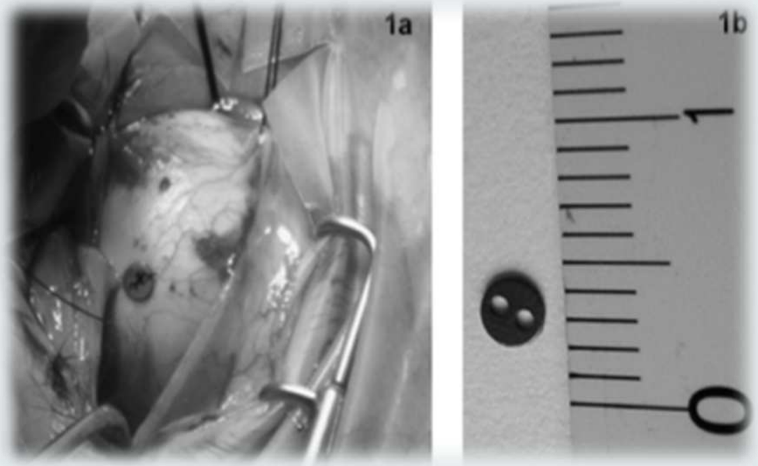
Slow component.

From positrons

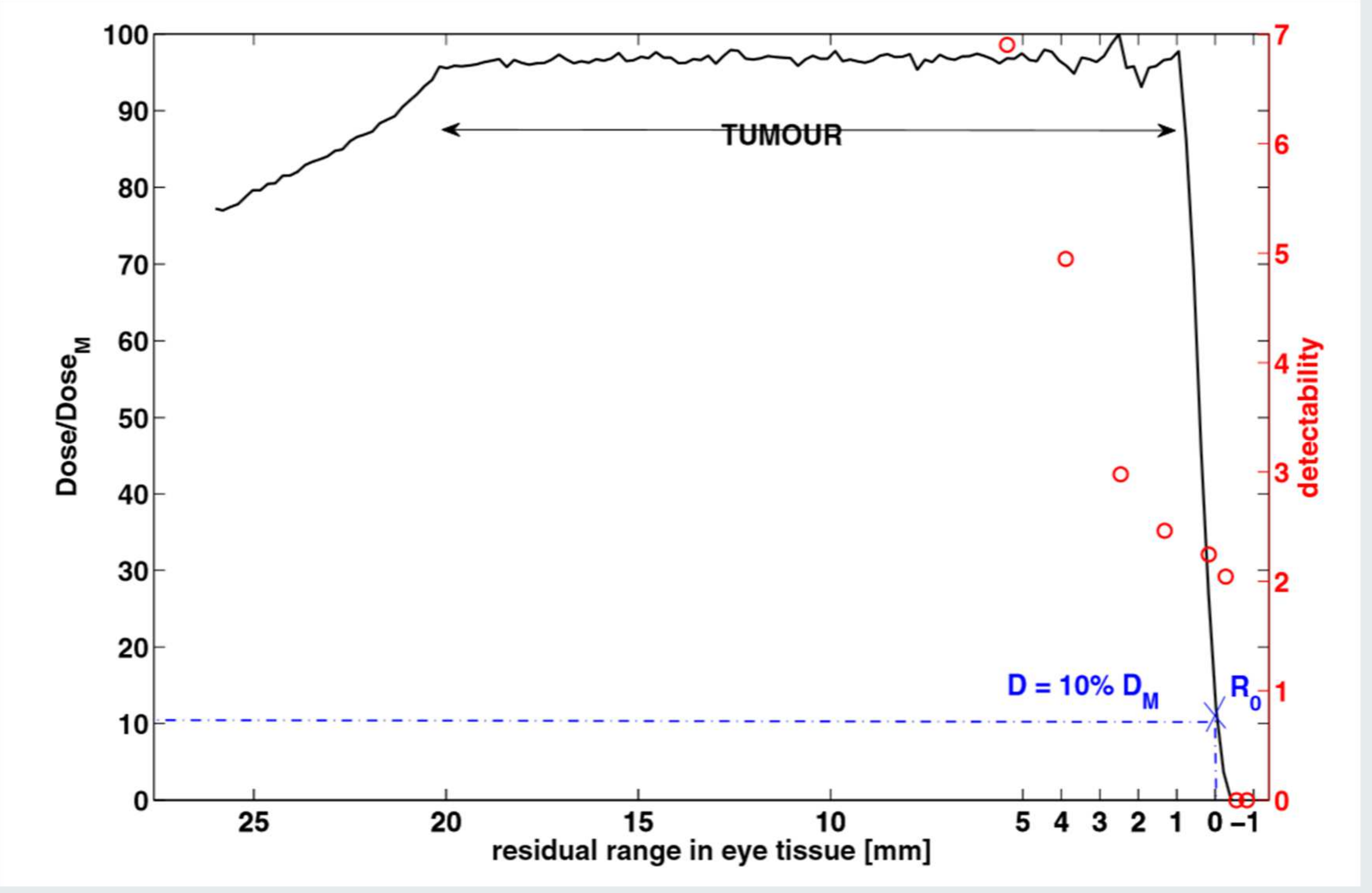


Particle Induced X-ray Emission





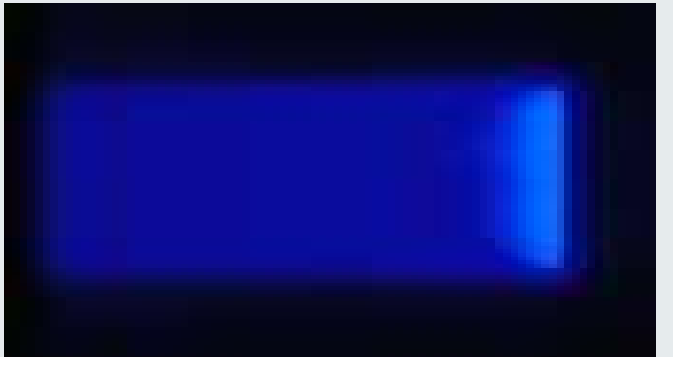
Particle Induced X-ray Emission

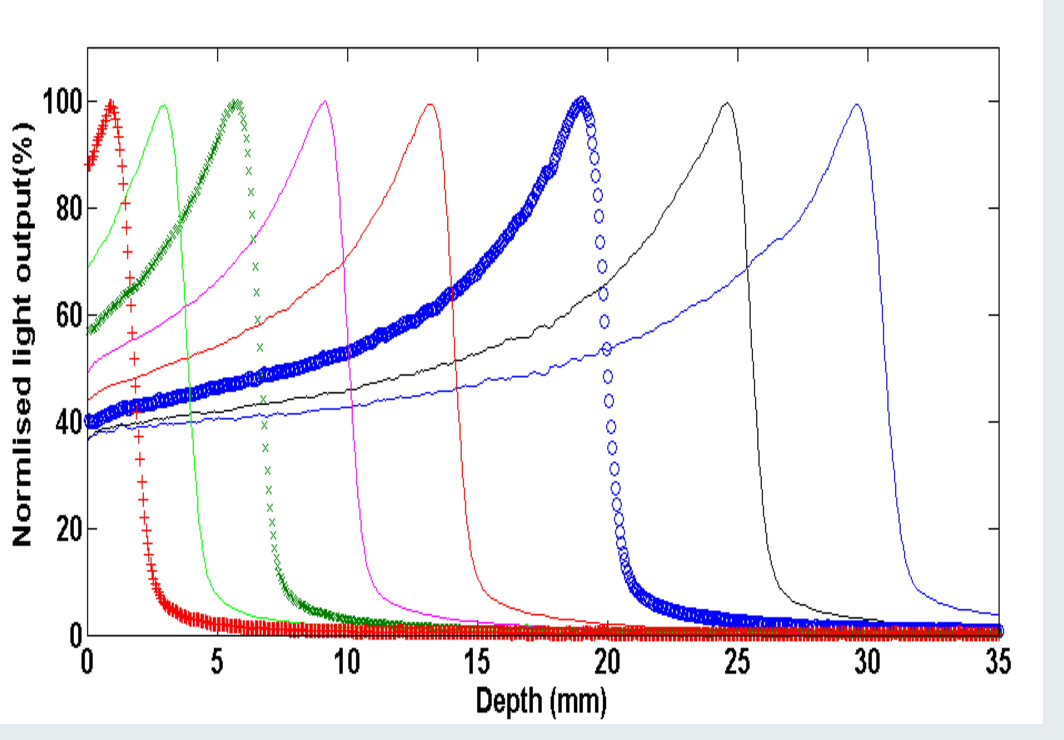


La Rosa et al (2014) Phys Med Biol 59(11) p2623

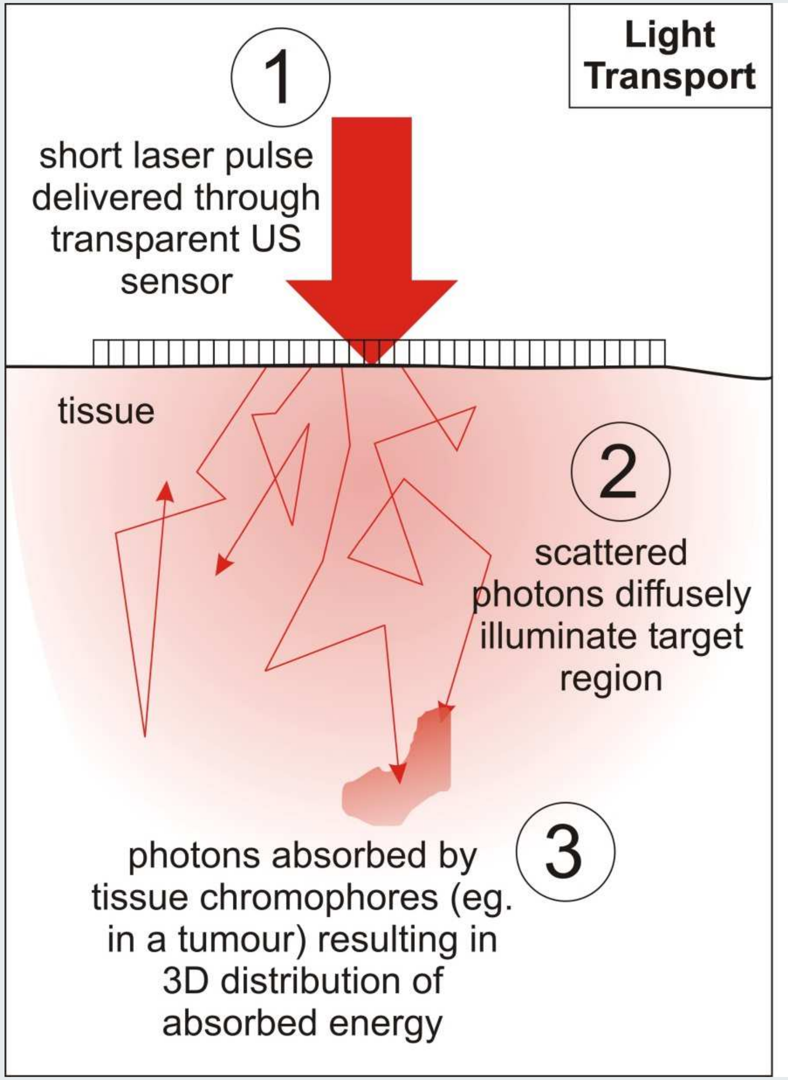
Scintillation

Scintillation

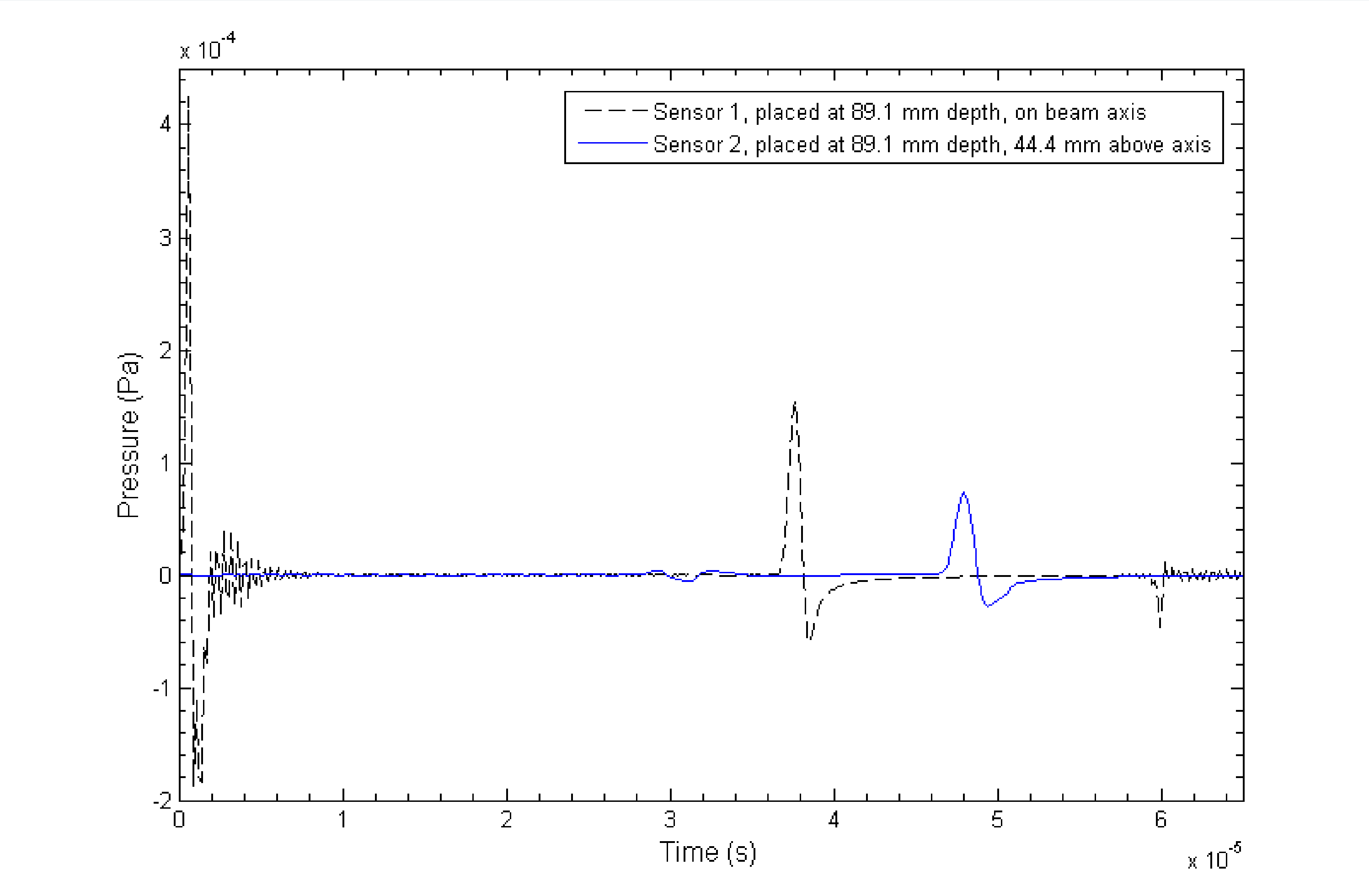




Protoacoustics

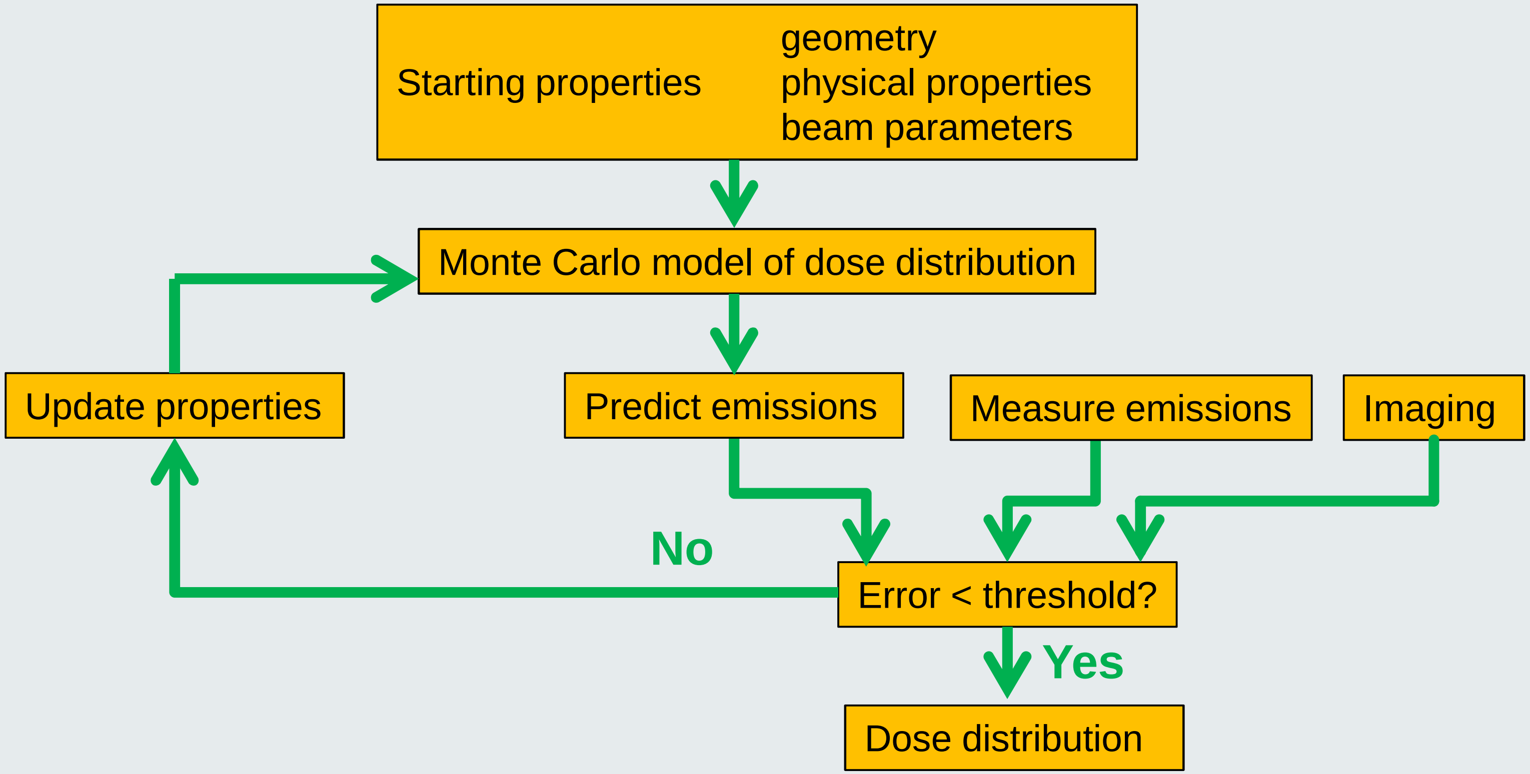


Protoacoustics

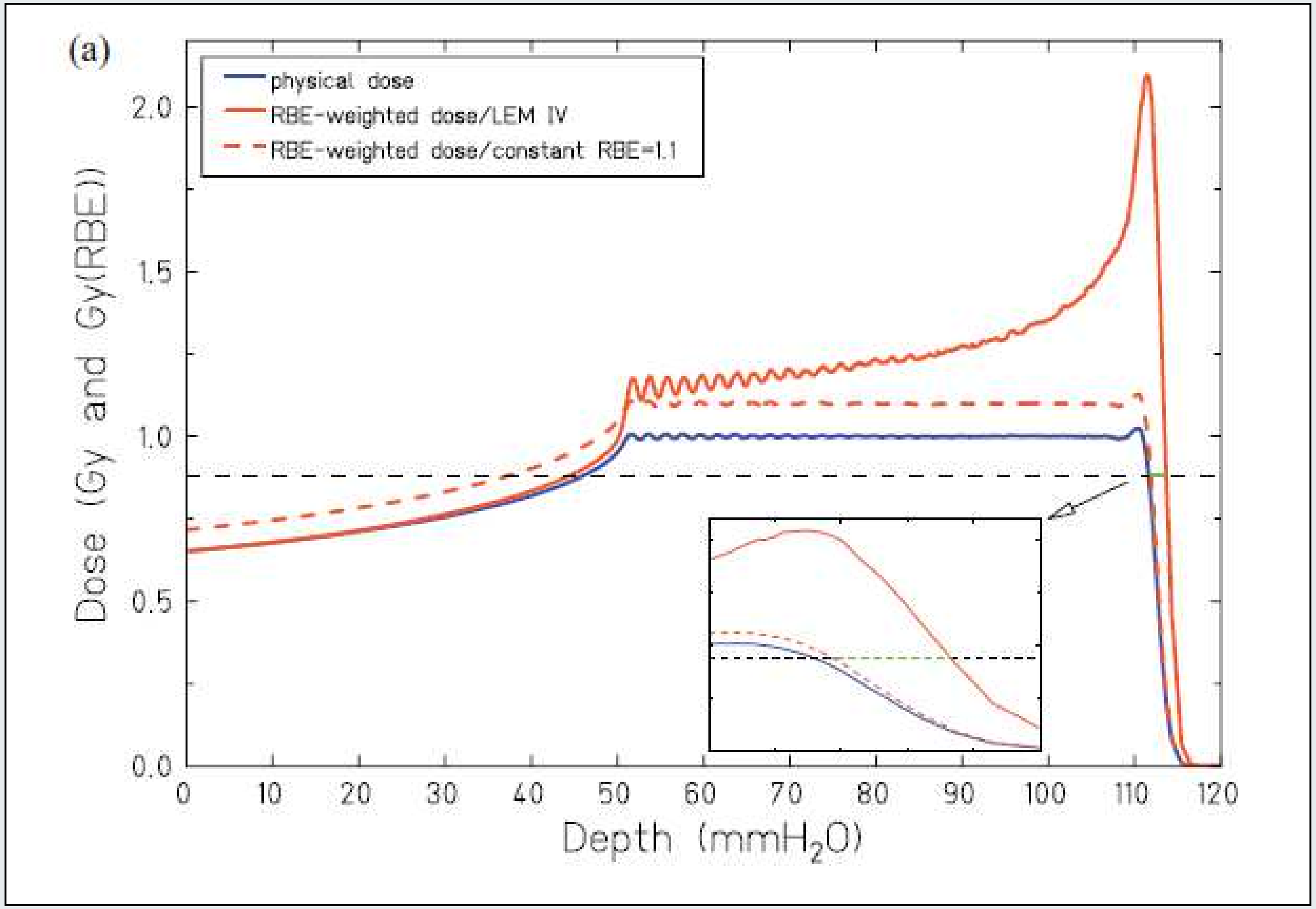


BUT range is determined by low energy protons

Informing a model of proton interactions from measurements



It’s worse than that.



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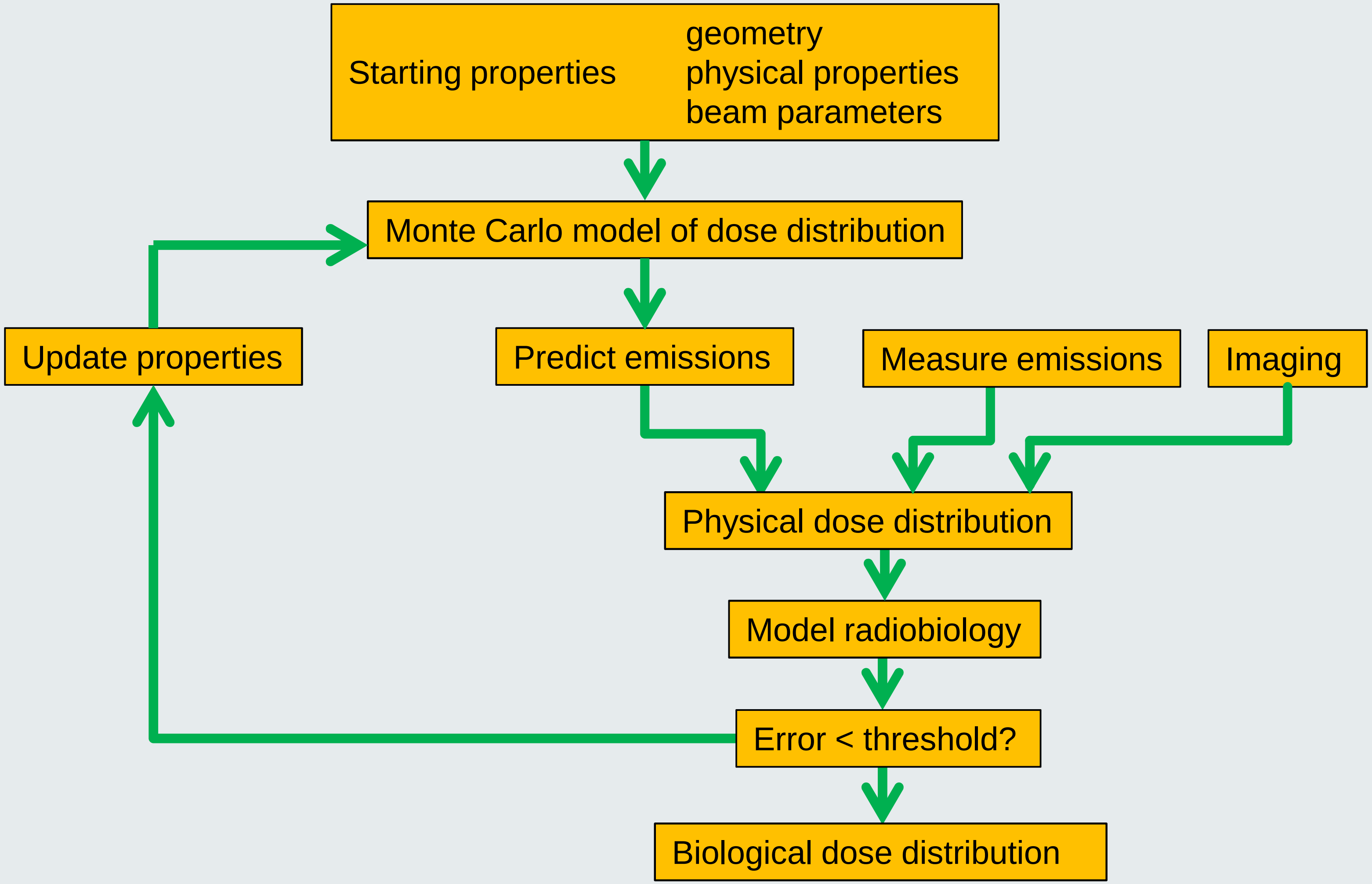
Informing a model of proton interactions from measurements



"Sure he was great, but don't forget that Ginger Rogers did everything Fred Astaire did, ... backwards and in high heels."

Acknowledgements

Mansour Almurayshid
Simon Arridge
Topun Austin
Rob Cooper
Laura Dempsey
Paul Doolan
Derek D’Souza
Nick Everdell
Jem Hebden
Yusuf Helo
Simon Jolly
Andrzej Kacperek
Vanessa La Rosa
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