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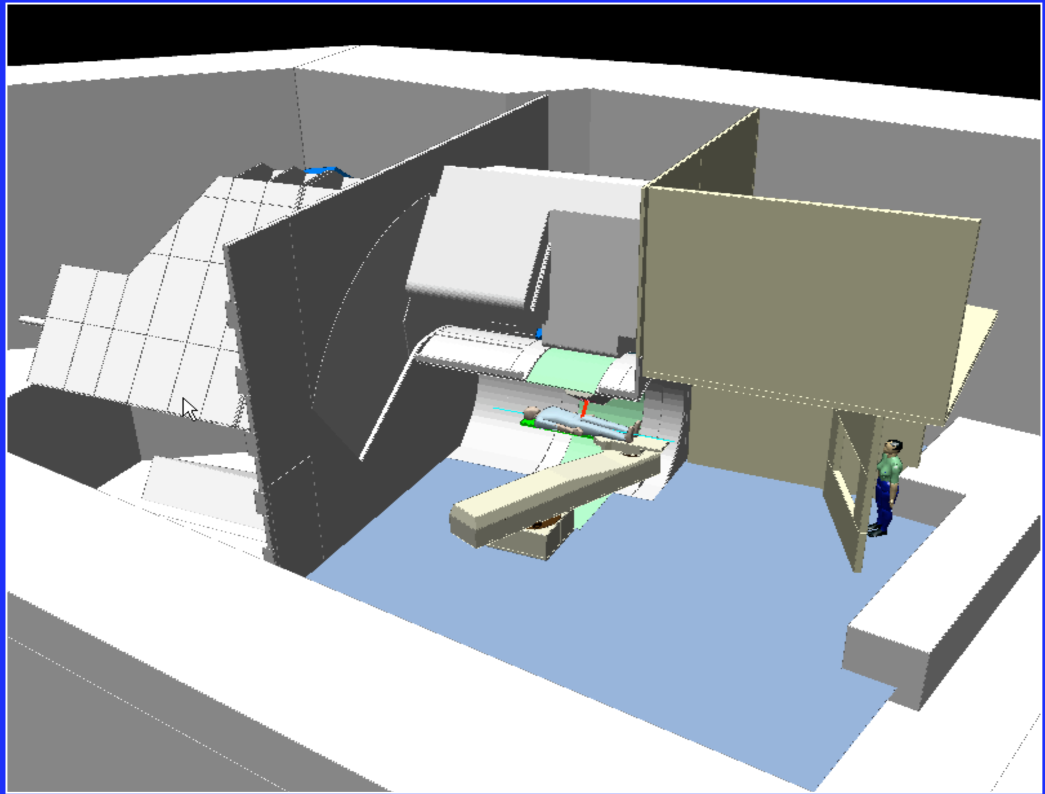
State-of-the-art proton therapy: The physicist's perspective



Tony Lomax, Centre for Proton Radiotherapy,
Paul Scherrer Institute, Switzerland

Overview of presentation

1. State-of-the-art proton delivery
2. Current challenges
3. New directions in proton therapy
4. Summary

Current delivery technology

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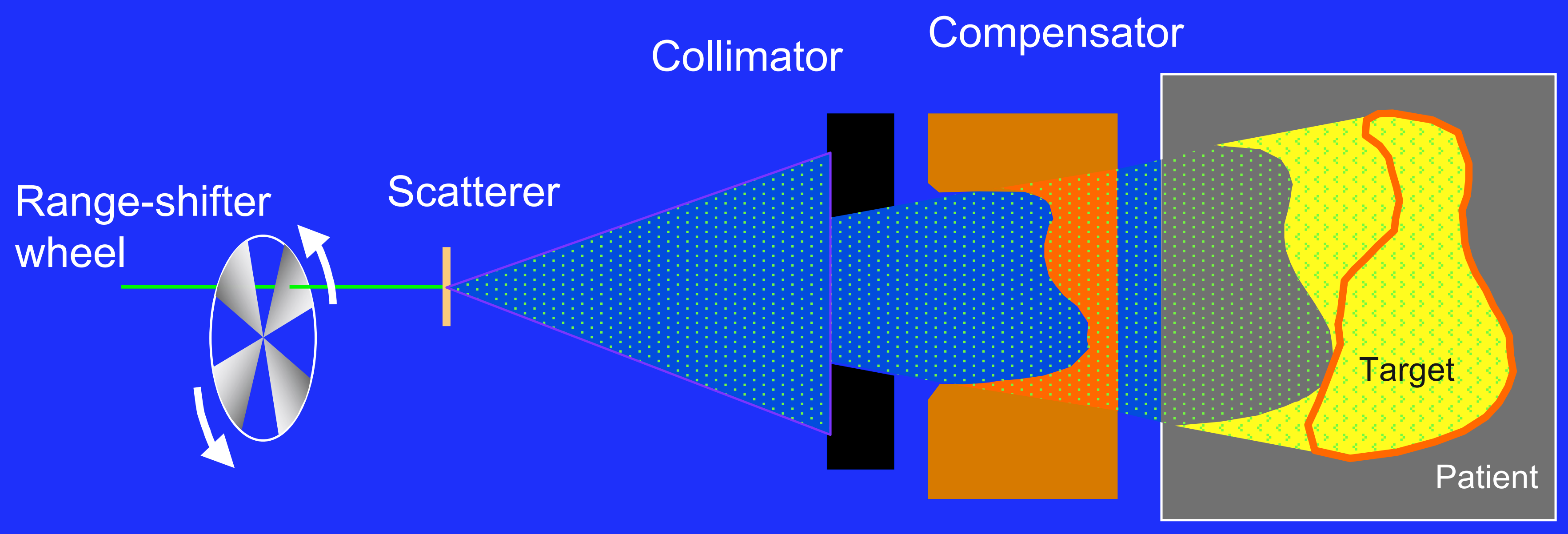
Passive scattering



Current delivery technology

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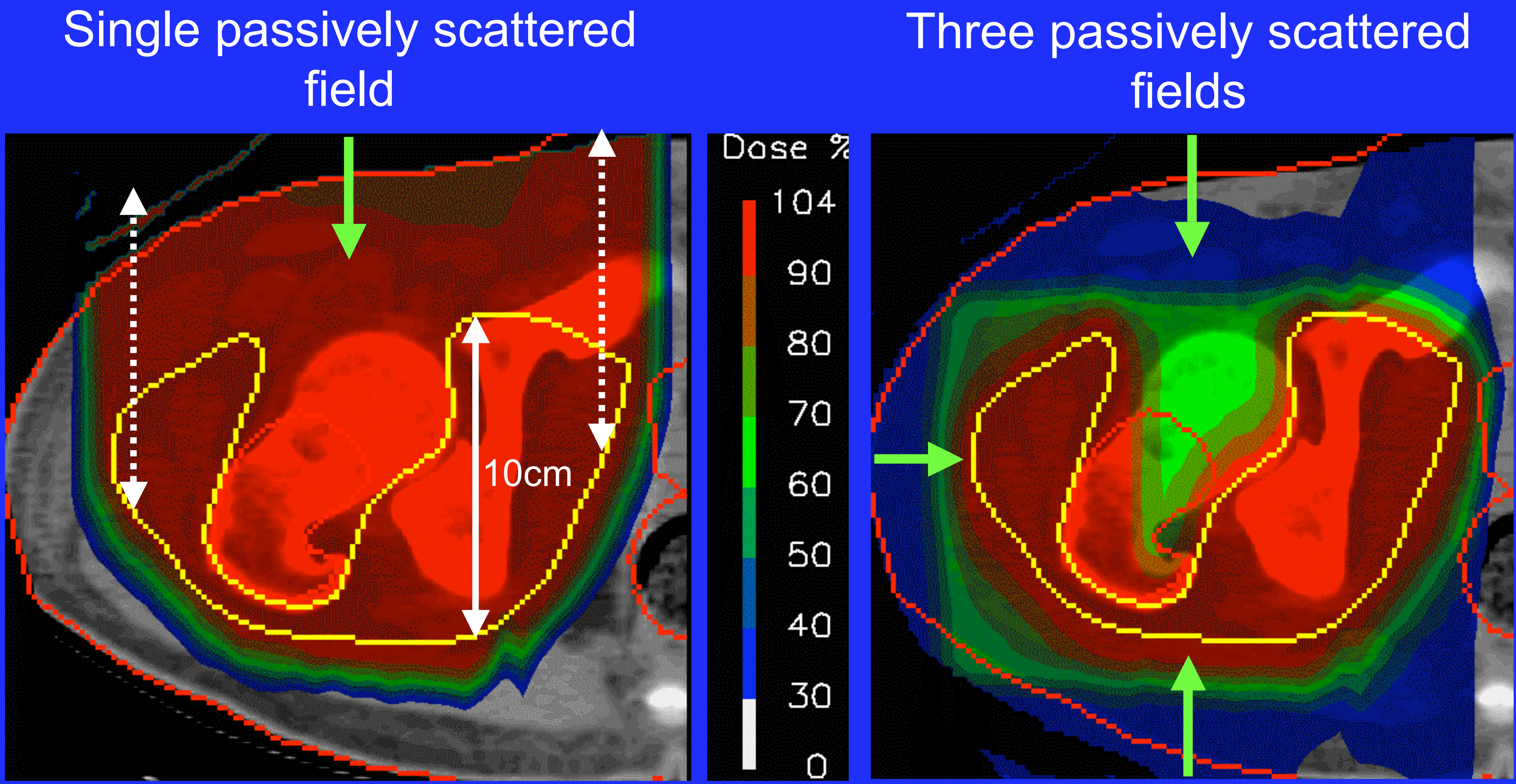
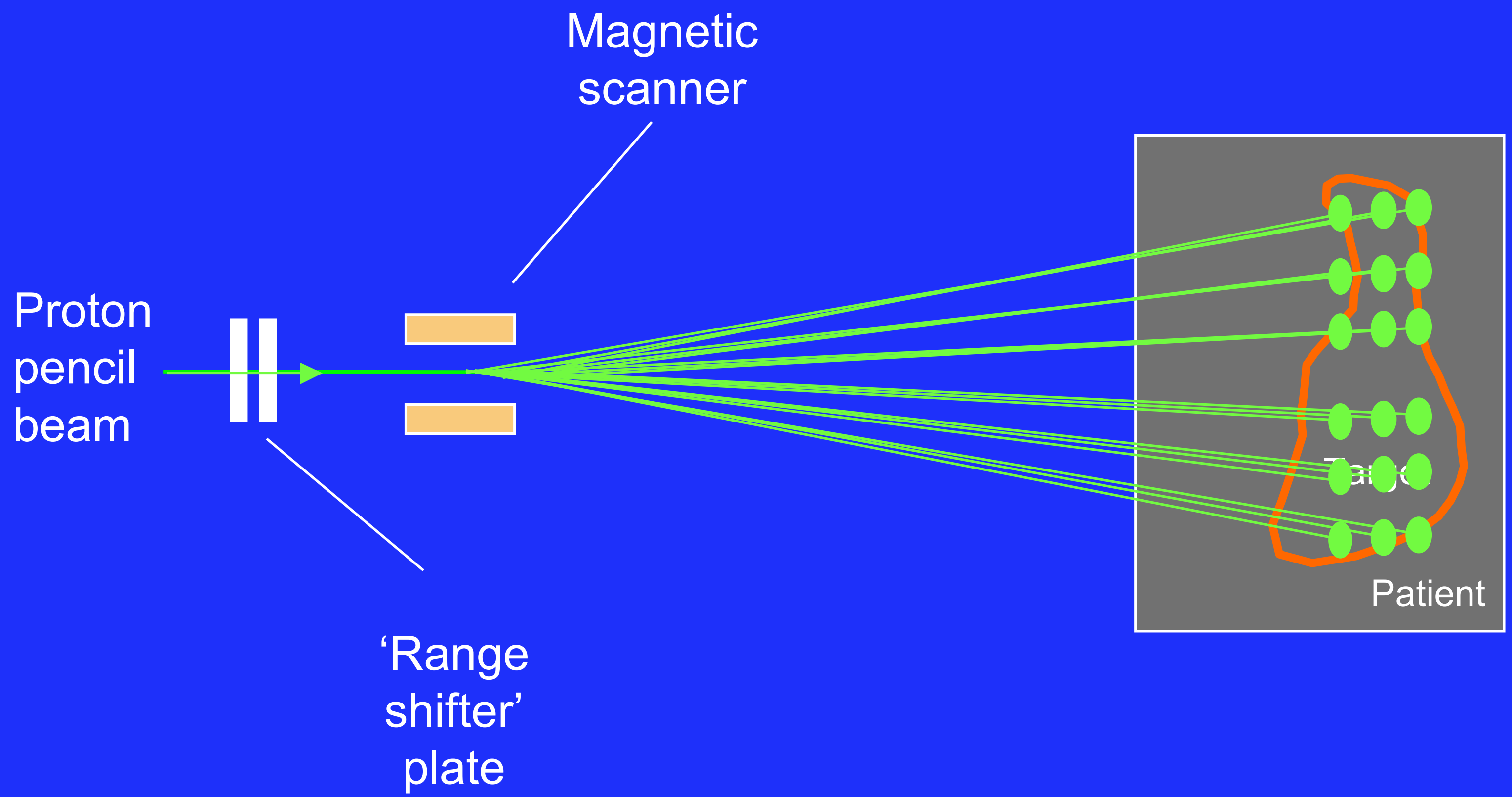


Fixed extent SOBP leads to poor sparing of normal tissue proximal to target

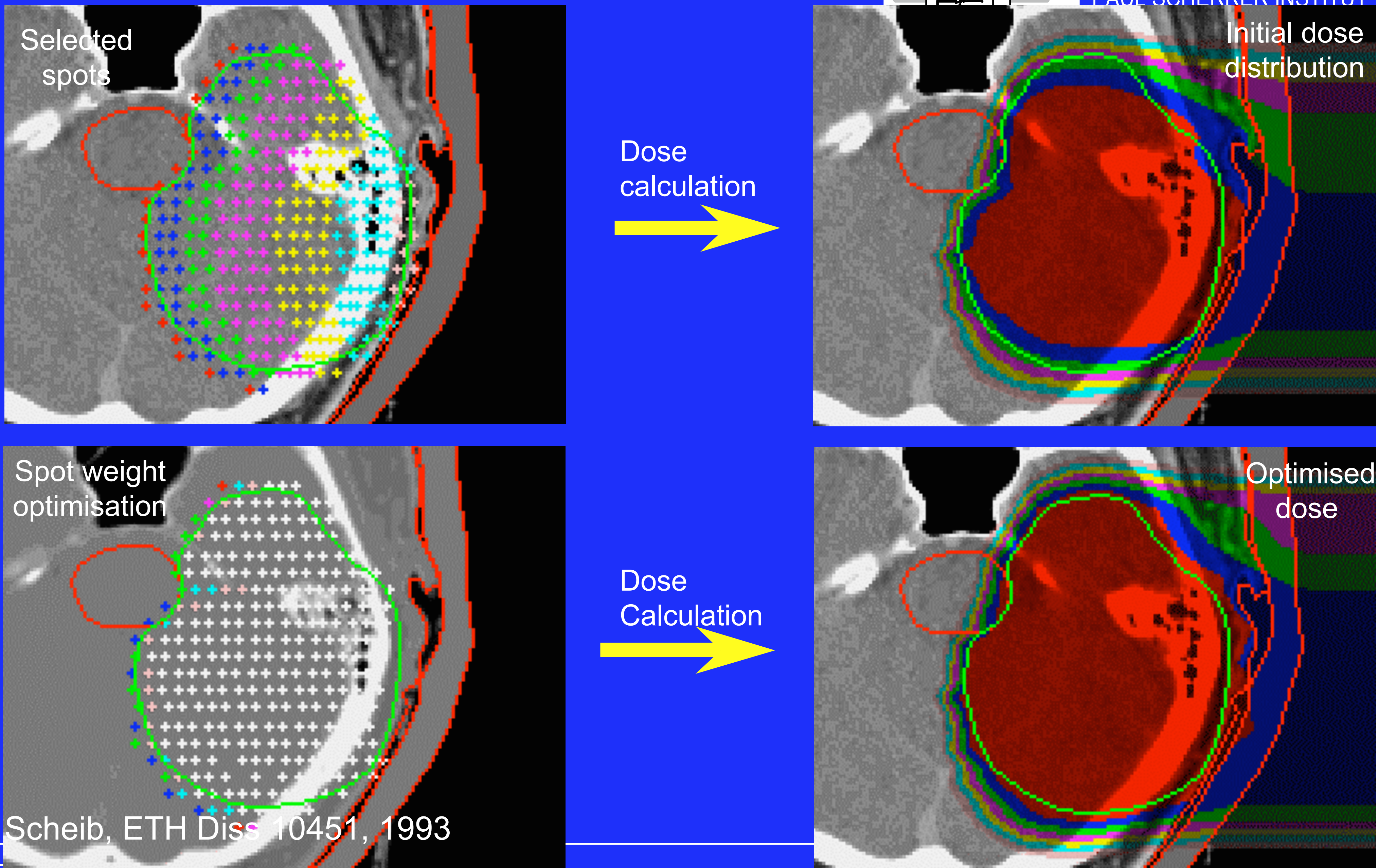
Conformation of dose can be improved through the use of multiple fields

Spot scanning

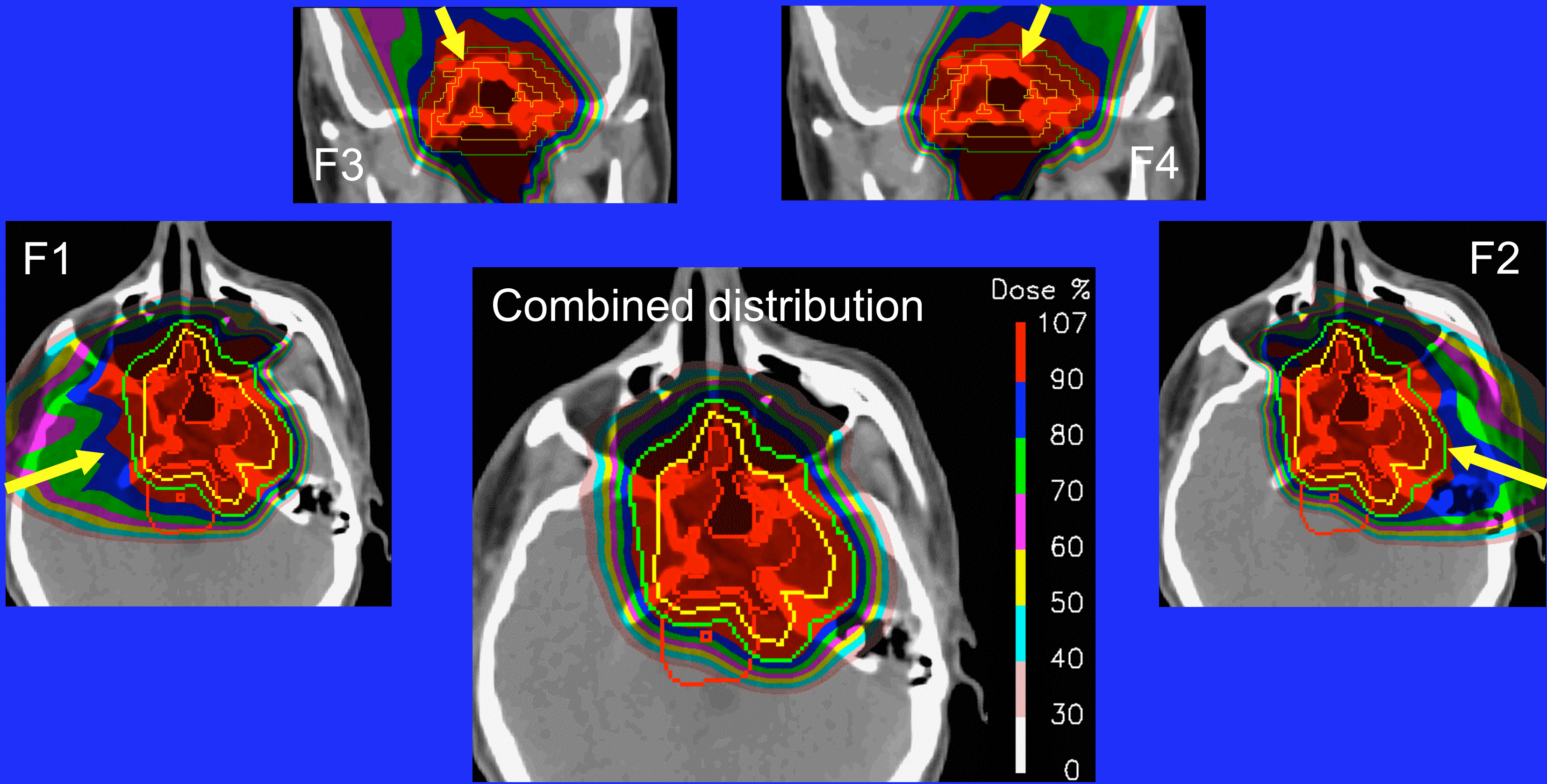


Pedroni et al, *Med Phys*. 22:37-53, 1995

Current delivery technology

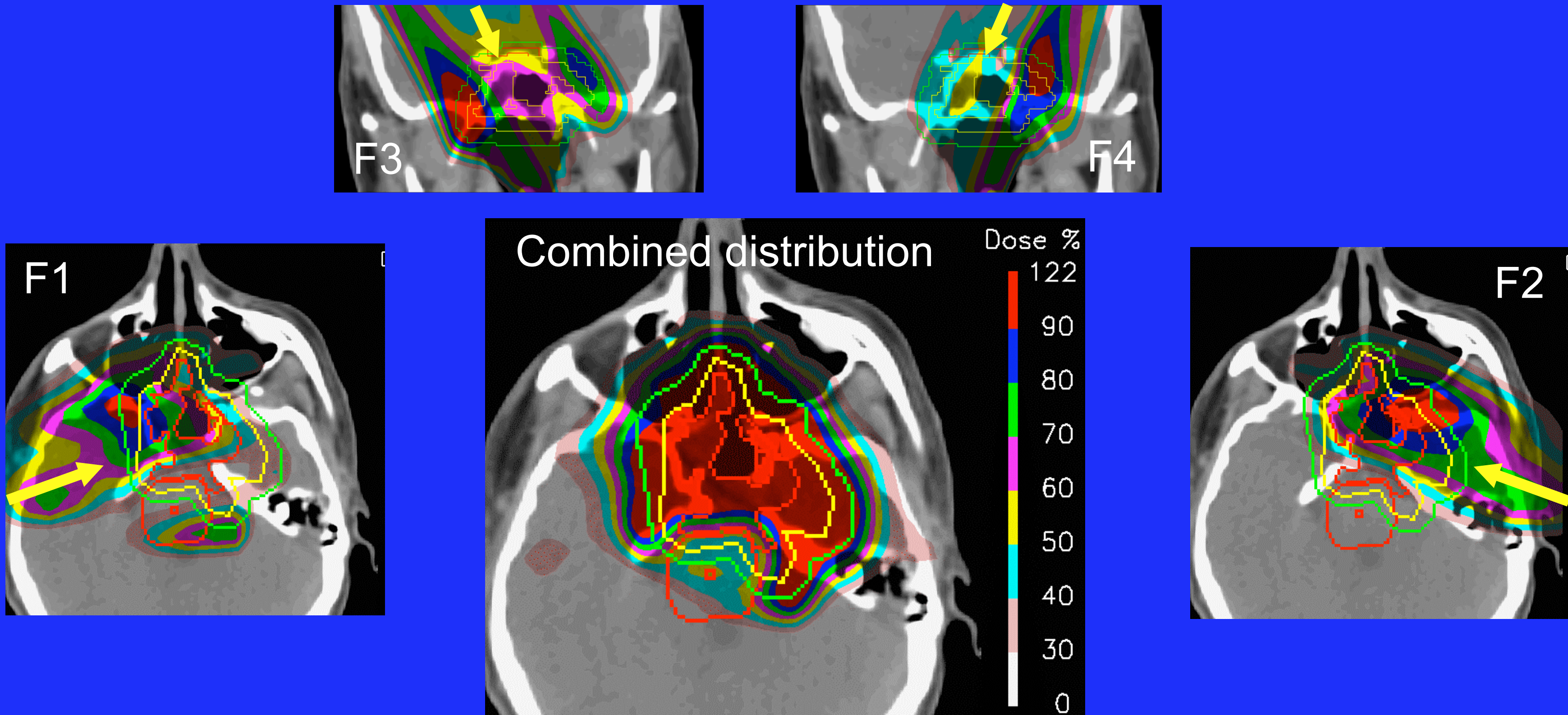


A SFUD (single field, uniform dose) plan consists of the addition of one or more individually optimised fields.



Note, each individual field is homogenous across the target volume

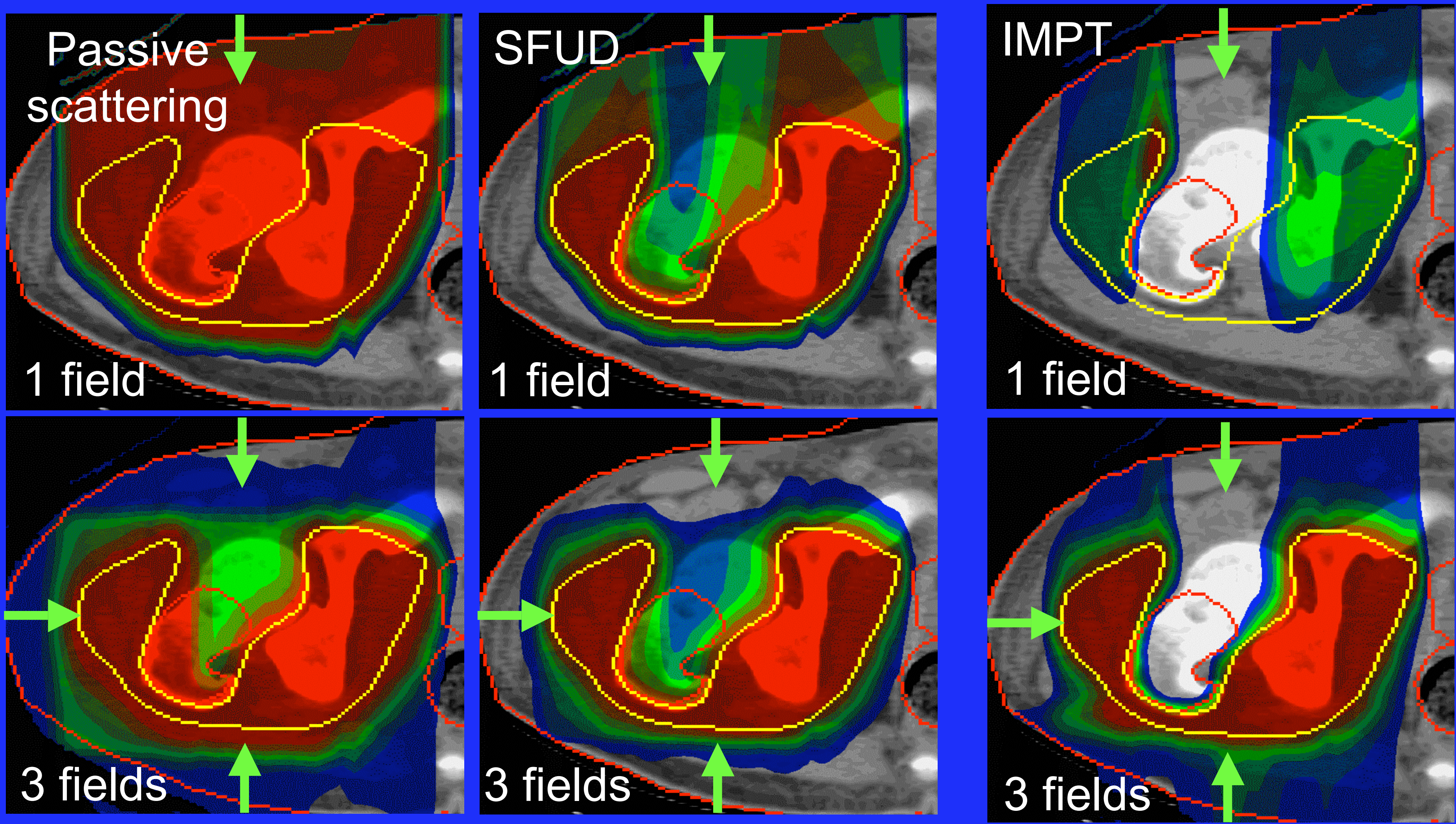
Intensity Modulated Proton Therapy: The simultaneous optimisation of all Bragg peaks from all incident beams. E.g..



Lomax, *Phys. Med. Biol*. 44:185-205, 1999

Current delivery technology

The three ‘orders’ of proton therapy compared



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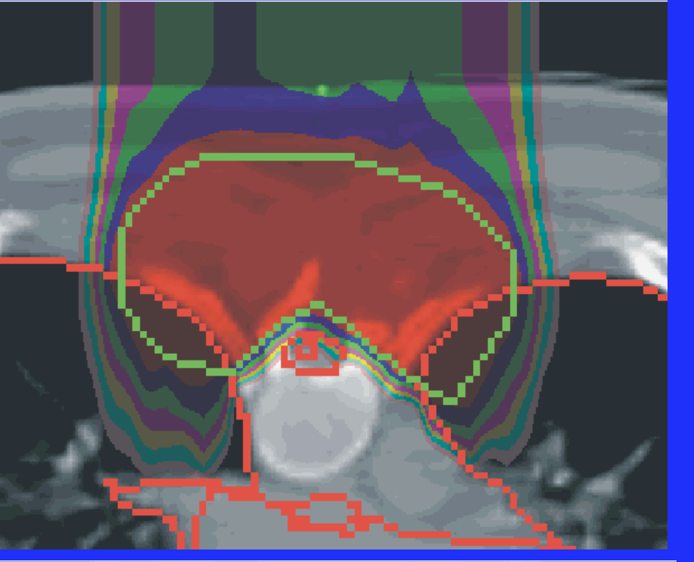
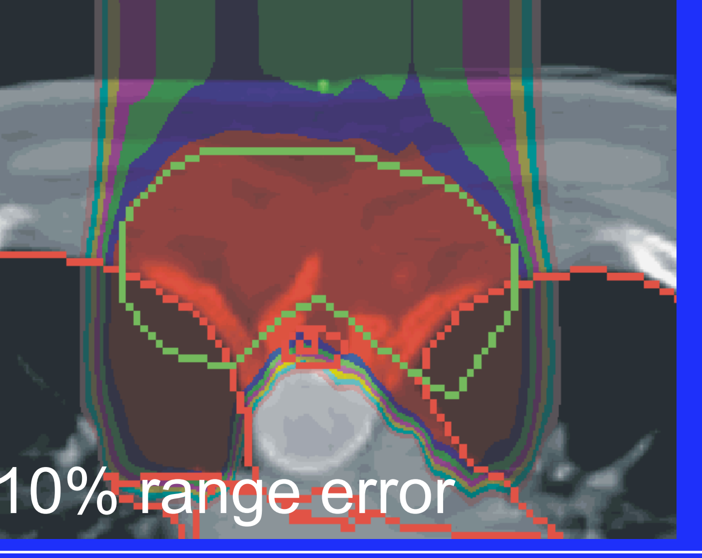
Range uncertainty

The advantage of protons is that they stop.



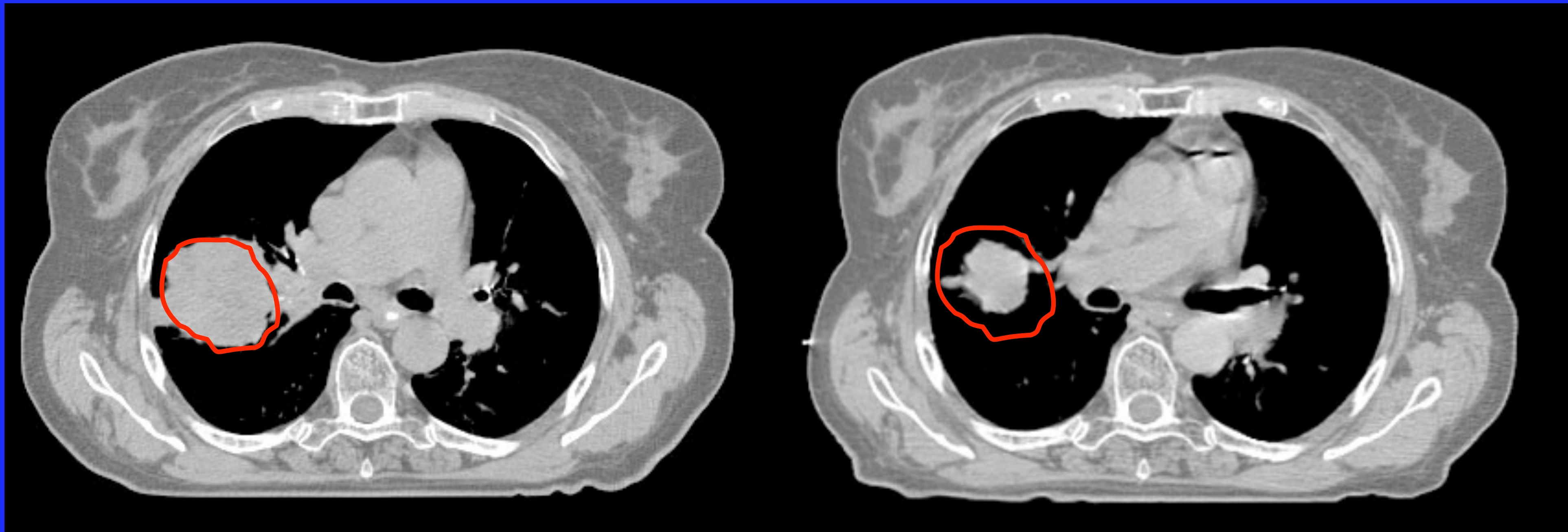
The disadvantage of protons is that we don't always know where…



Tumour shrinkage

Initial Planning CT
GTV 115 cc

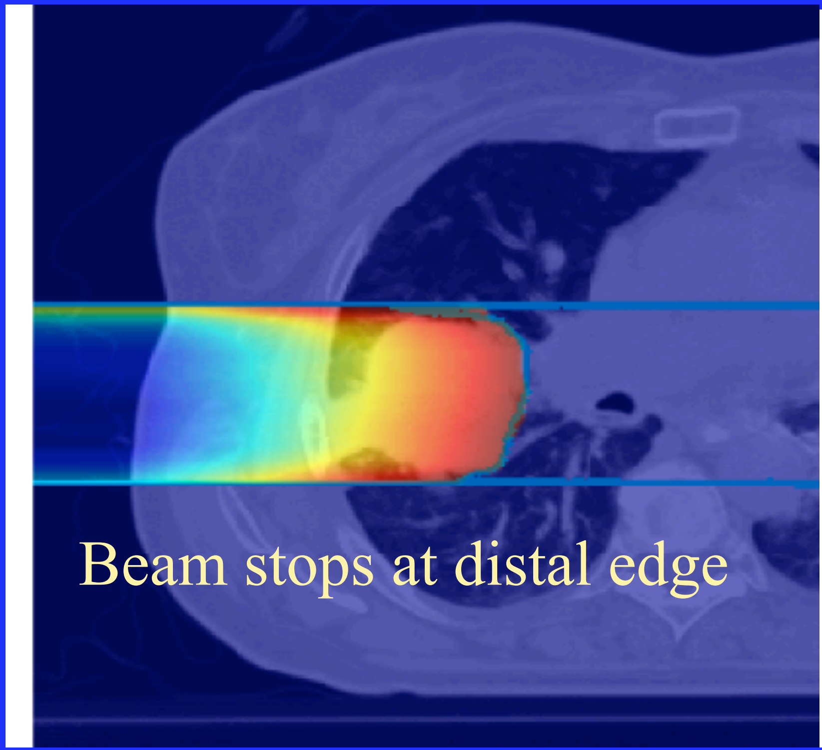
5 weeks later
GTV 39 cc



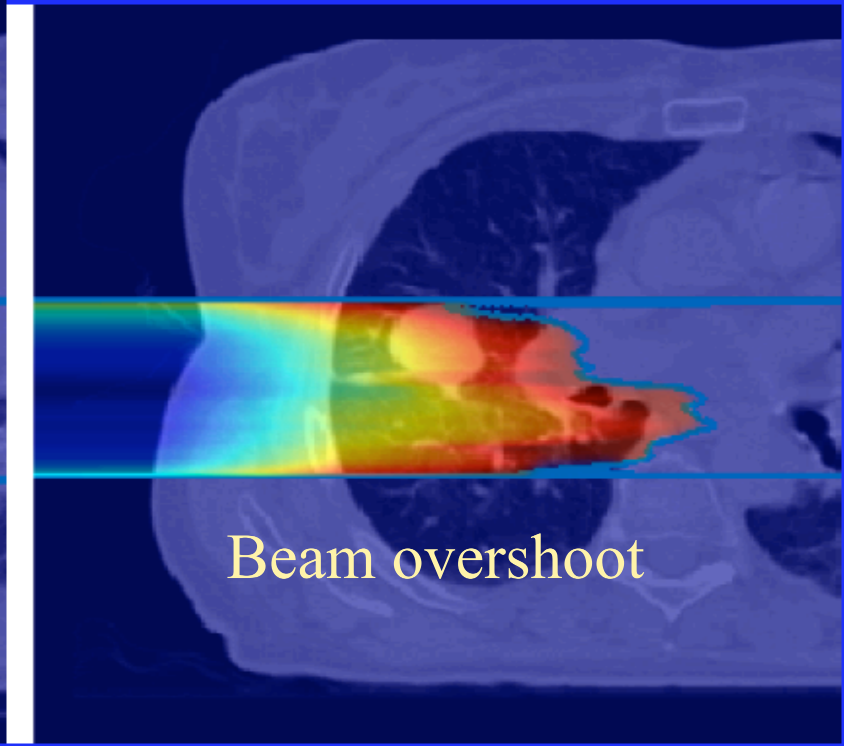
S. Mori, G. Chen, MGH, Boston

Tumour shrinkage

Planning CT



CT after 5 weeks



S. Mori, G. Chen, MGH, Boston

Current challenges: range uncertainty

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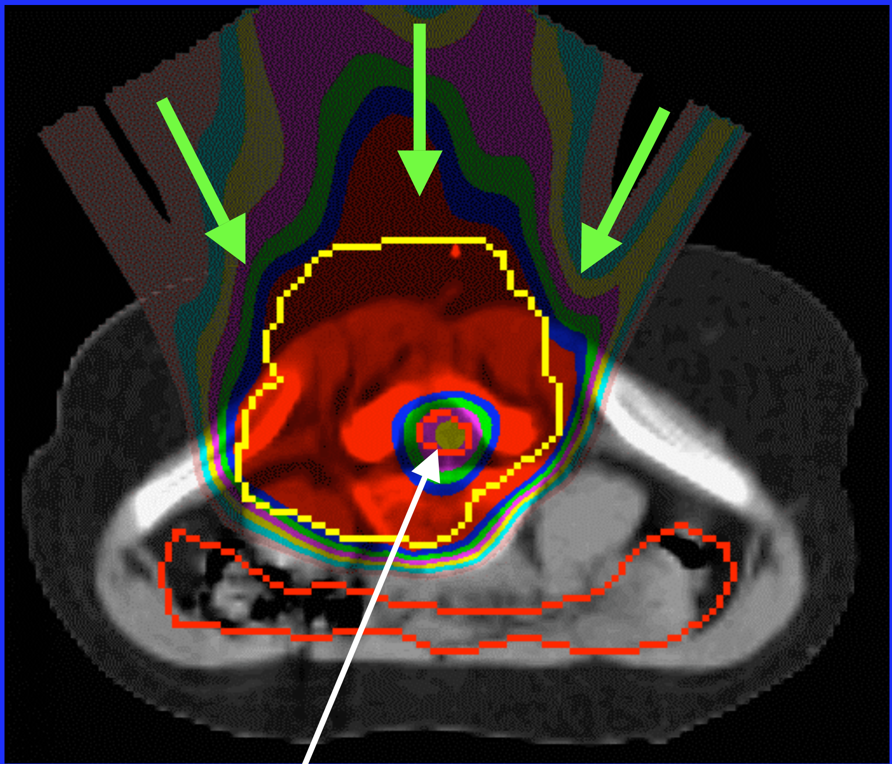
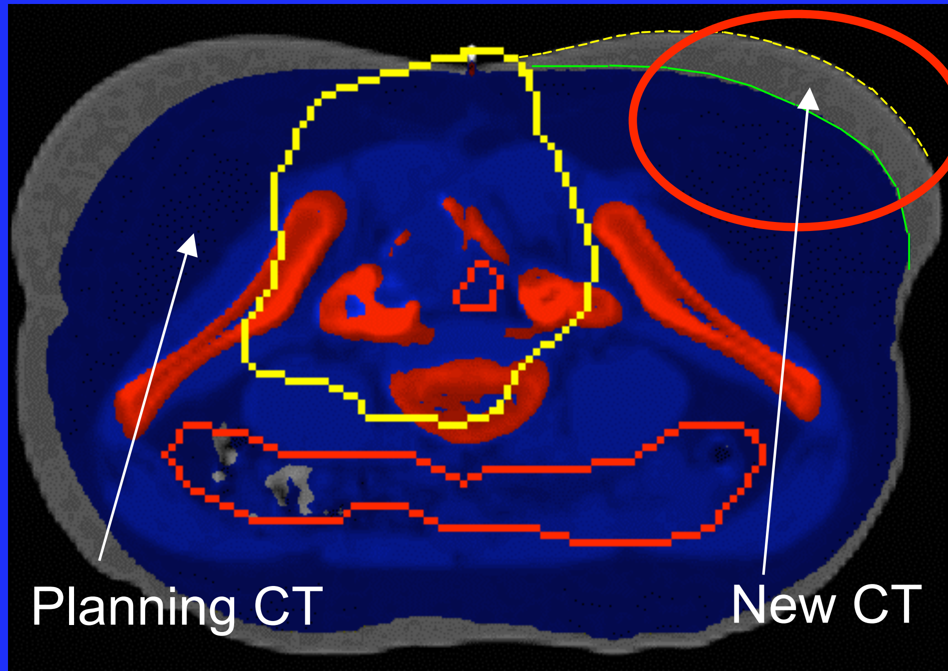
Patient weight changes

3 field IMPT plan to an 8 year old boy



Note, sparing of spinal cord in middle of PTV

During treatment, 1.5kg weight gain was observed



Max range differences:
SC 0.8cm
CTV 1.5cm

Francesca Albertini and Alessandra Bolsi (PSI)

Current challenges: range uncertainty

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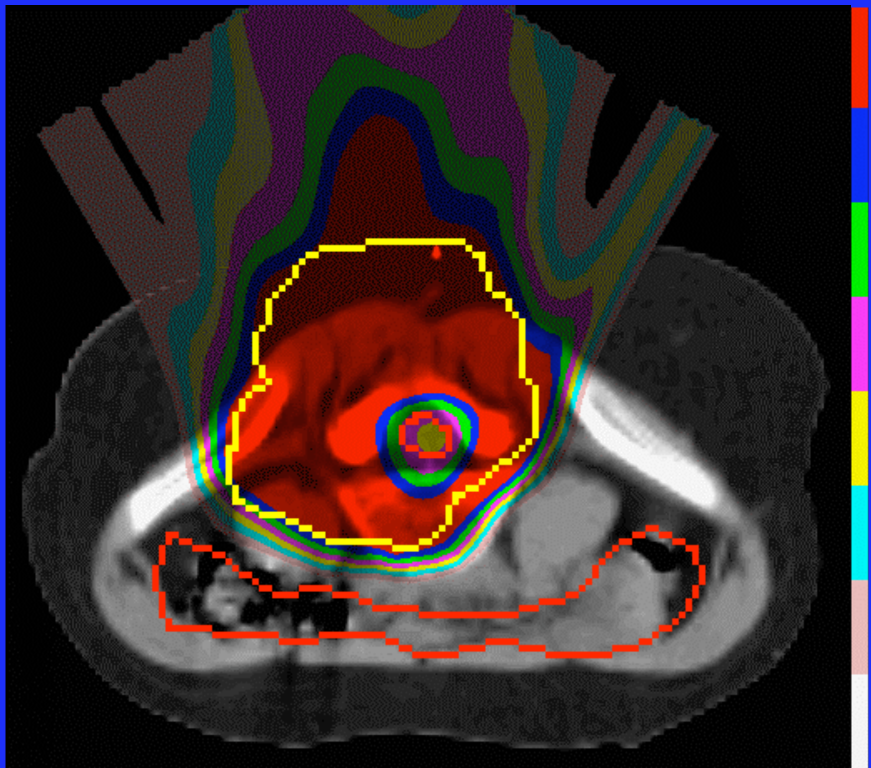
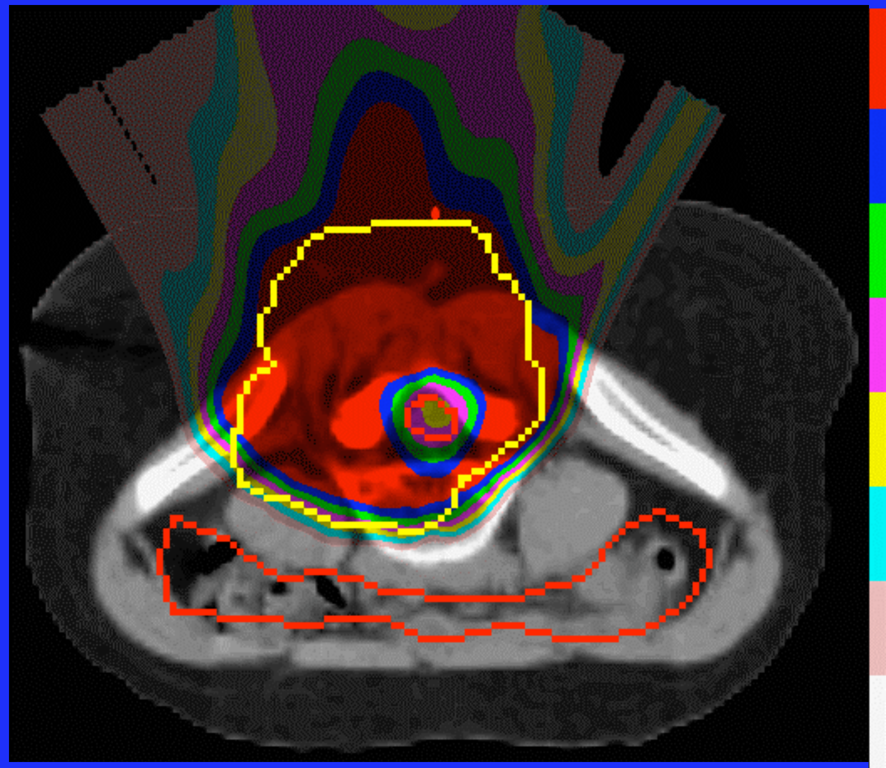
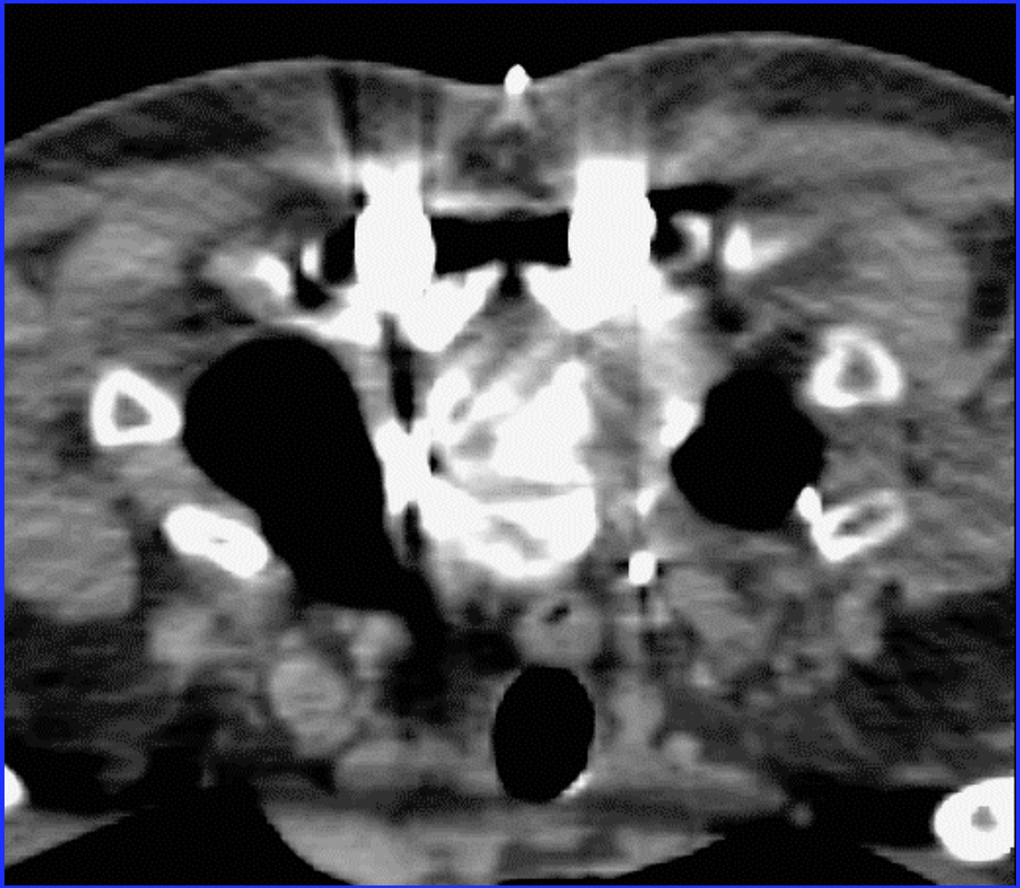
Nominal plan	Recalculation on new CT
	

CTV	Mean	V90
Nominal	96.5%	78%
New	95.0%	74%

Spinal cord	Mean	Max
Nominal	30.0%	74%
New	28.5%	76%

CT artefacts

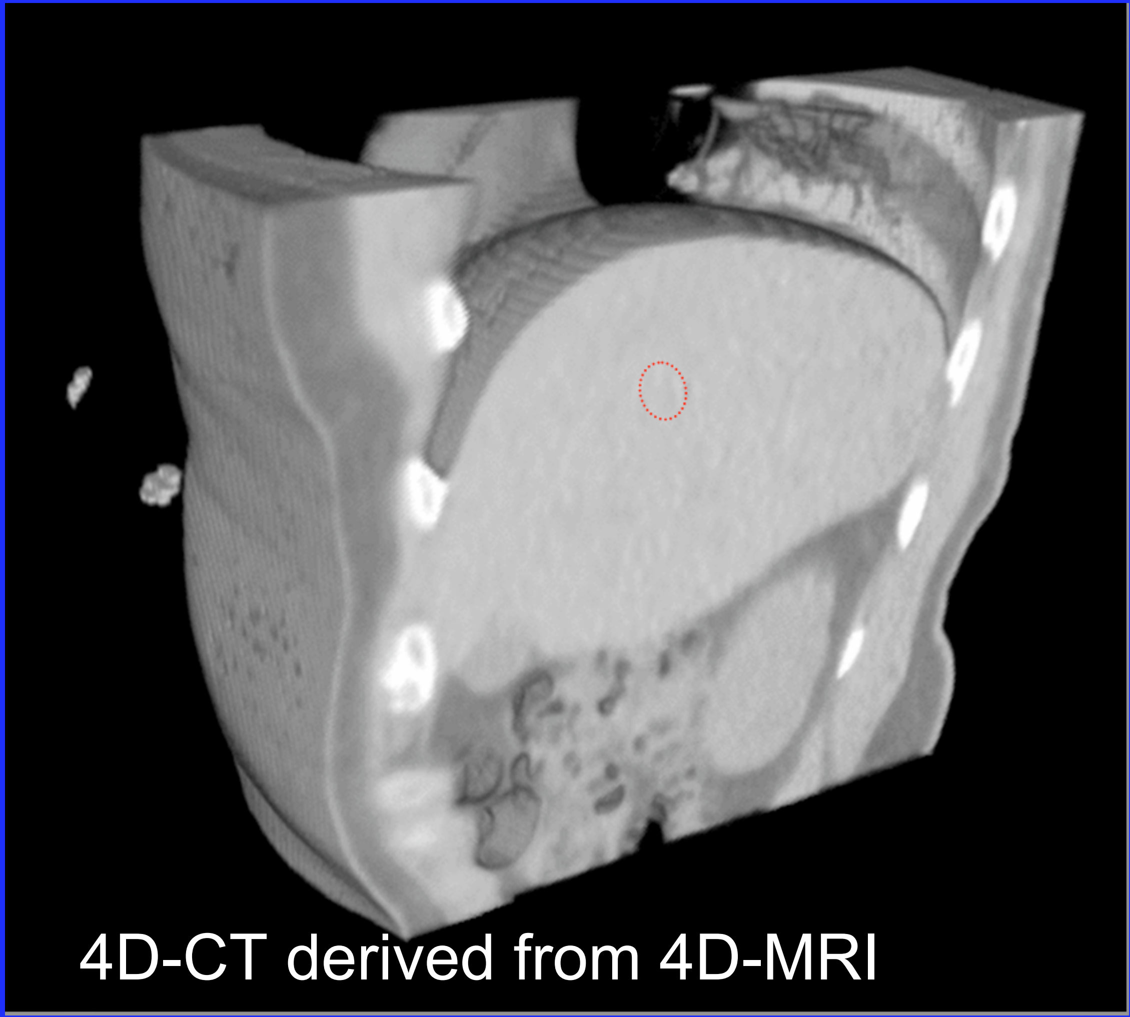


Many patients referred for RT post-operatively and with metal (titanium) stabilisation

How accurately can we calculate proton ranges in such CT data sets?

Organ motion

What is the effect of organ motion on proton therapy?

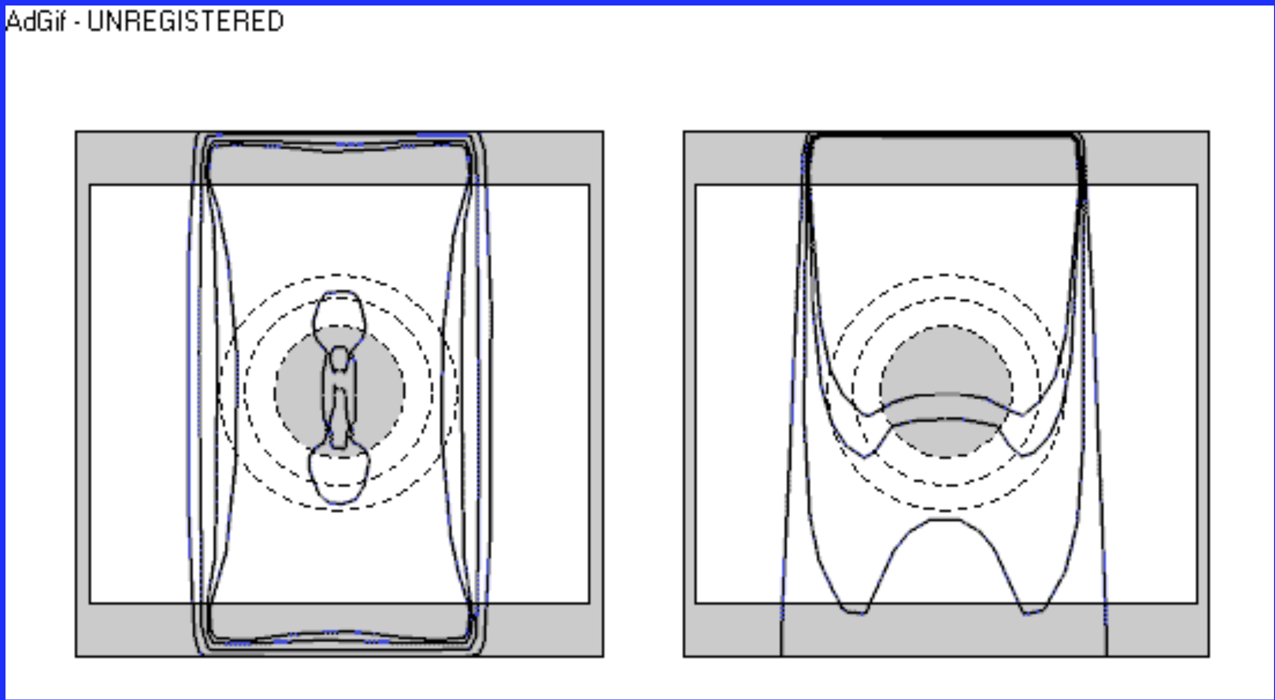


Martin von Siebenthal, Phillipe Cattin, Gabor Szekely, Tony Lomax, ETH, Zurich and PSI, Villigen

Organ motion and passive scattering

Parallel opposed photons

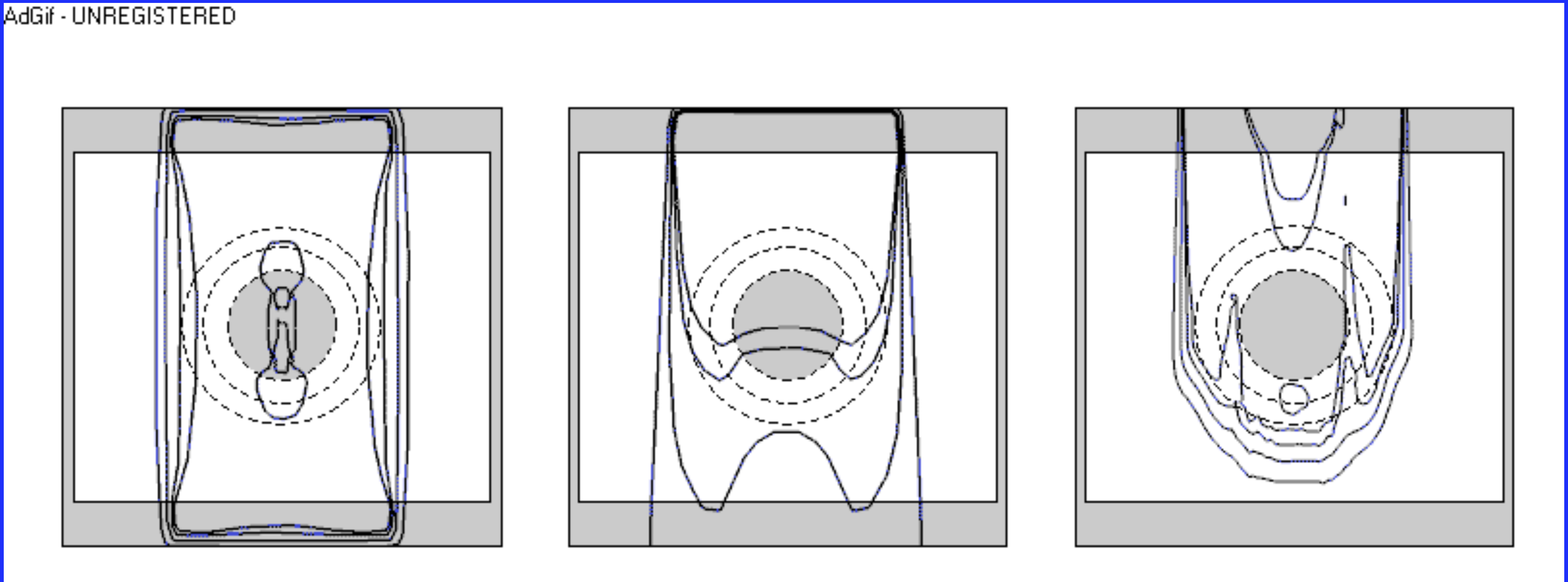
Single field photons



Images courtesy of Thomas Bortfeld, MGH, Boston

Organ motion and passive scattering

Parallel opposed photons	Single field photons	Single field protons



Images courtesy of Thomas Bortfeld, MGH, Boston

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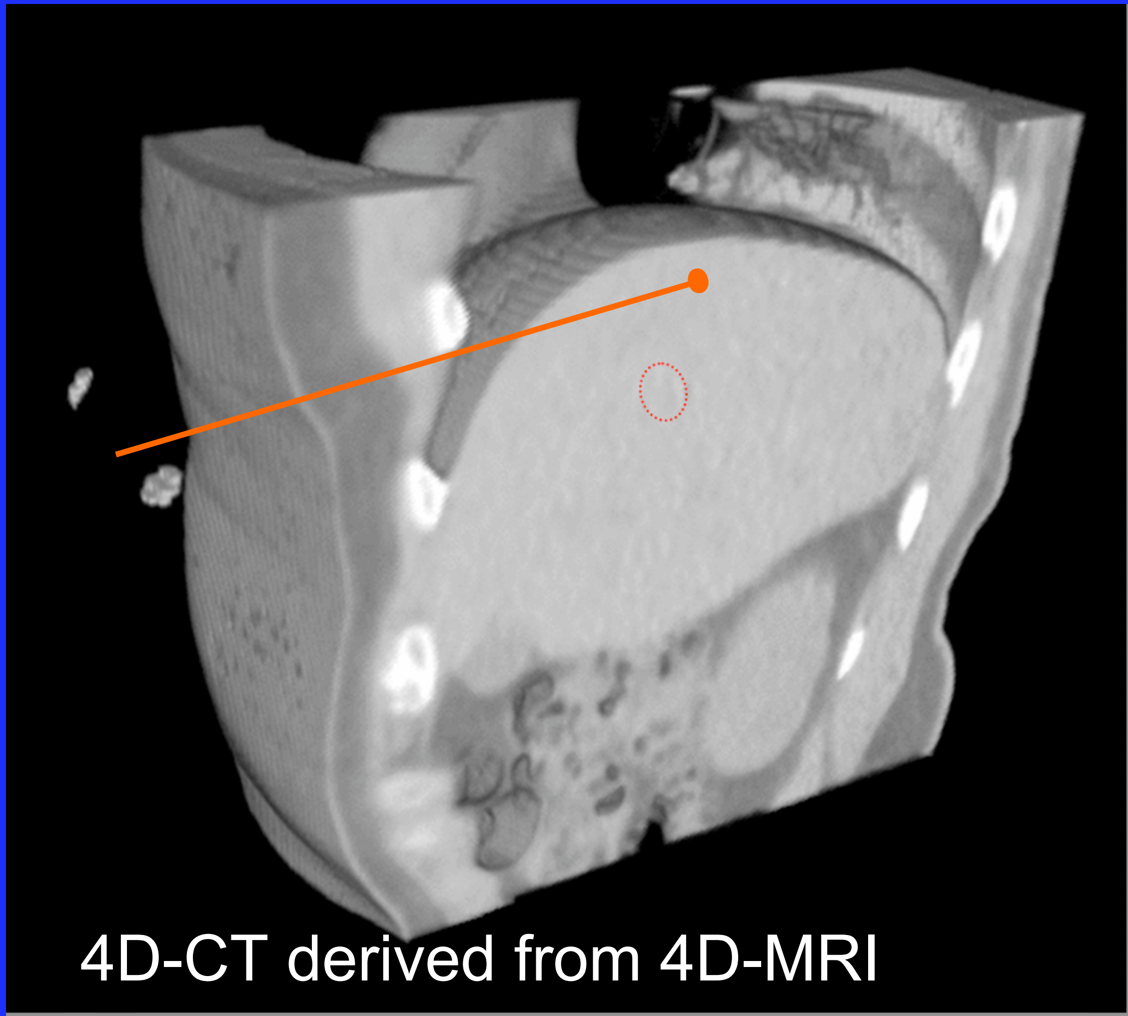
Organ motion and scanning

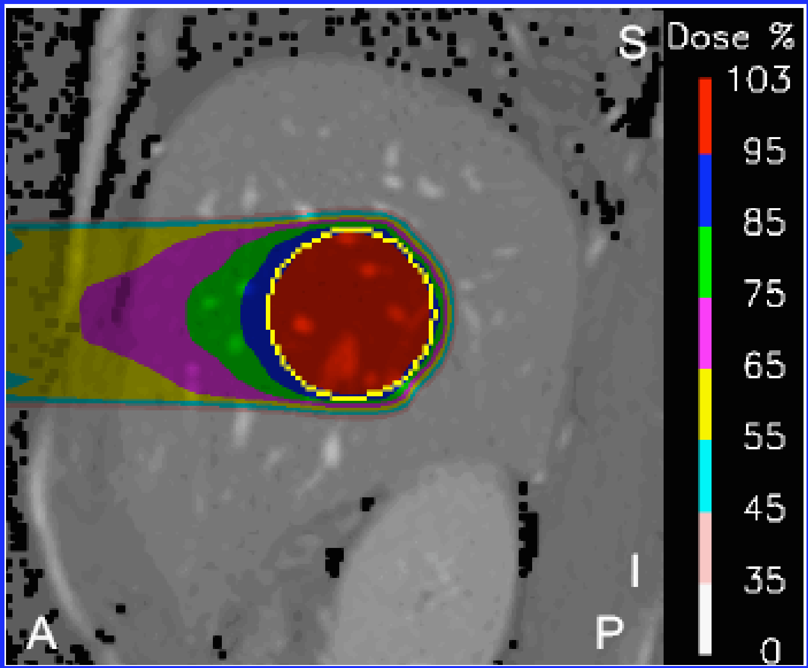
A scanned beam in a moving patient.



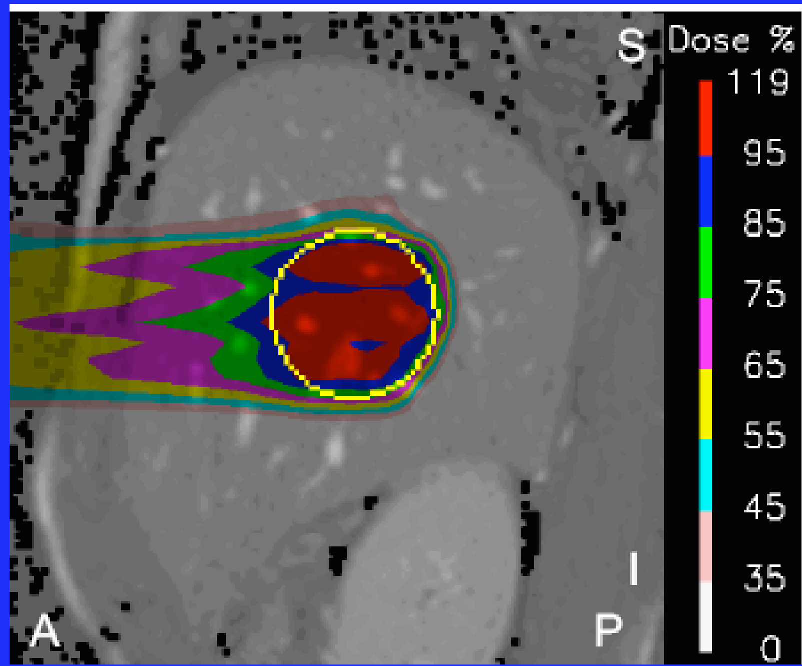
Martin von Siebenthal, Phillipe Cattin, Gabor Szekely, Tony Lomax, ETH, Zurich and PSI, Villigen

Organ motion and the 'interplay' effect

Nominal (static) dose



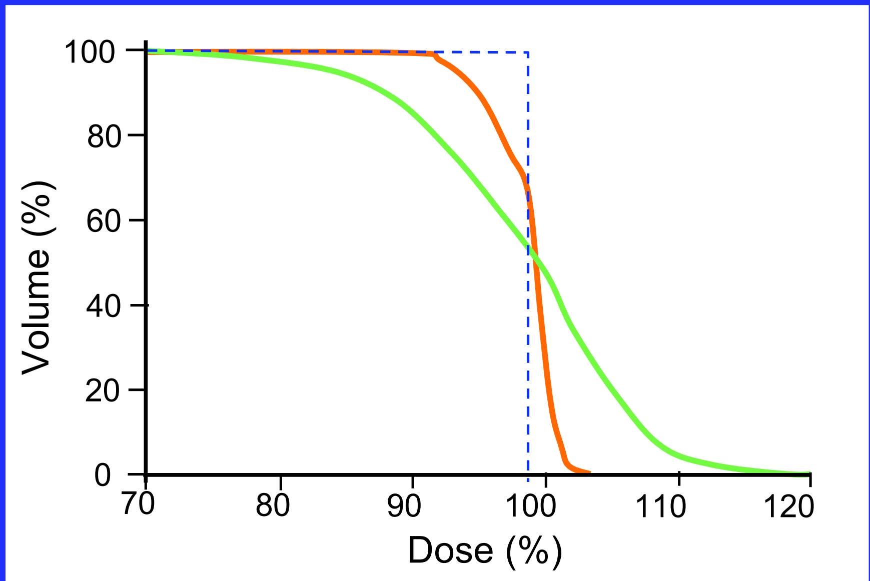
Calculated with 'real' motion from 4D-MRI of volunteer



Organ motion and the 'interplay' effect

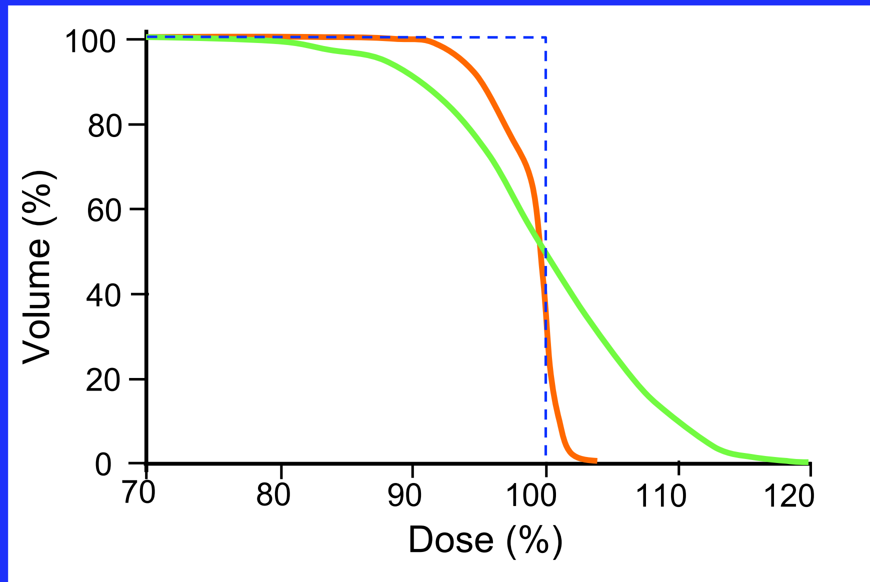
Motion patient 1

Amplitude ~ 11mm



Motion patient 2

Amplitude ~ 8mm



Scanning is particularly sensitive to organ motion

Overview of presentation

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New directions in proton therapy

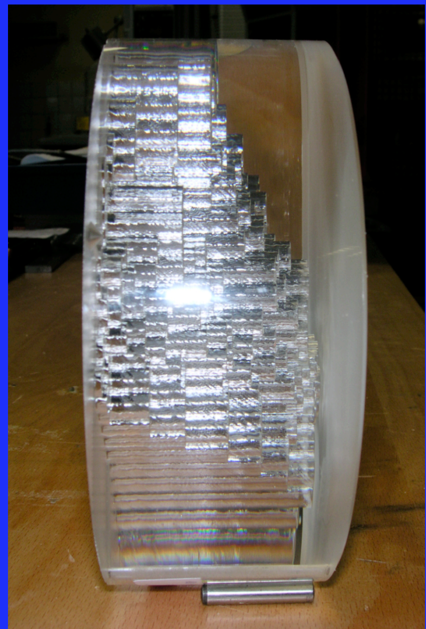
1. Possible improvements to passive scattering

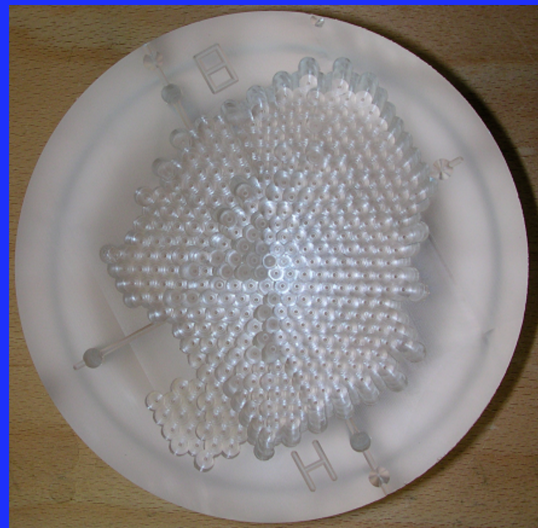
2. Dealing with range uncertainties

3. Organ motion and scanning

Field specific hardware for passive scattering

Collimator





Compensator

Can these be automated?

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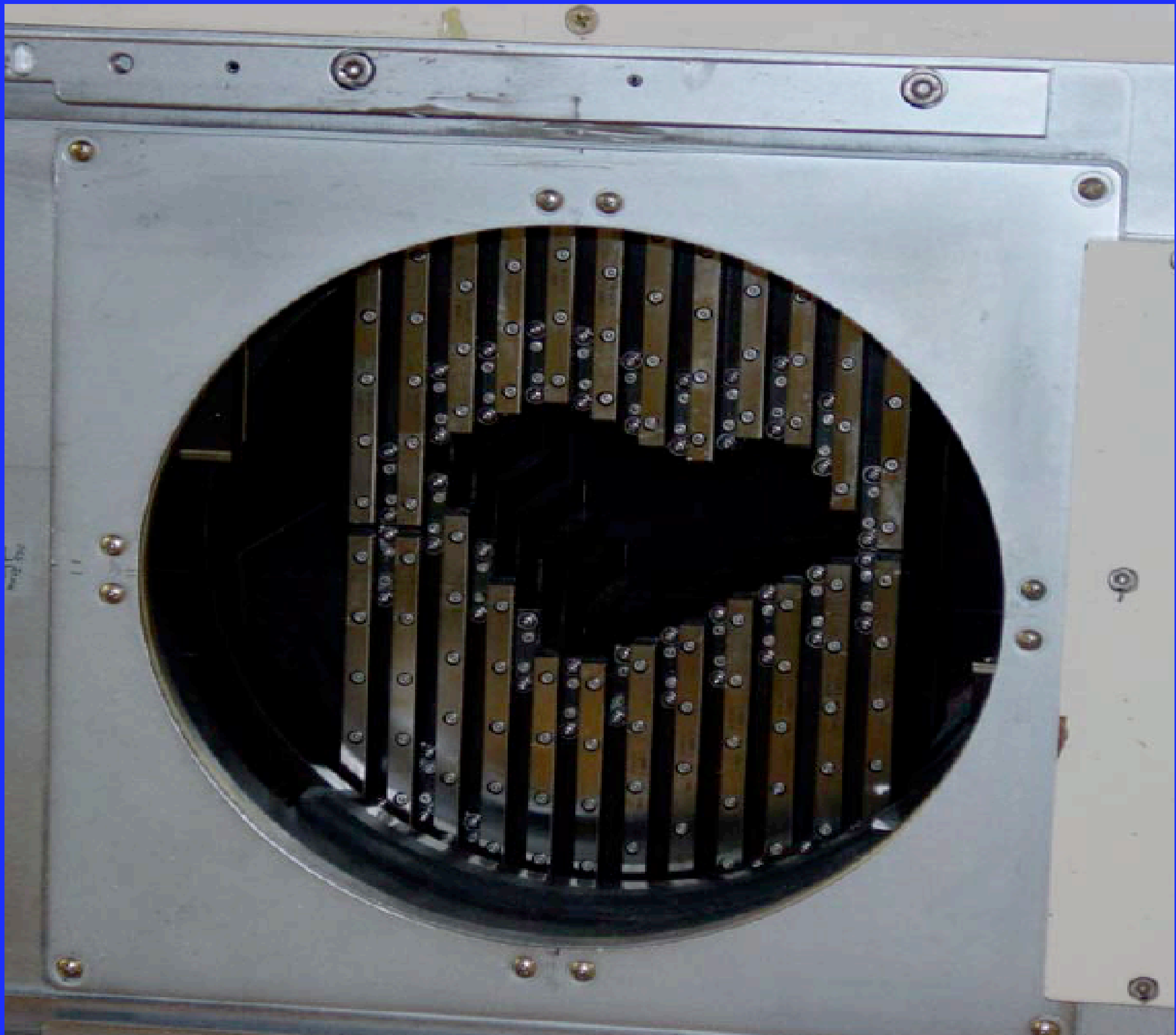
Proton Multi-leaf collimators



Particle MLC from Chiba (Japan)

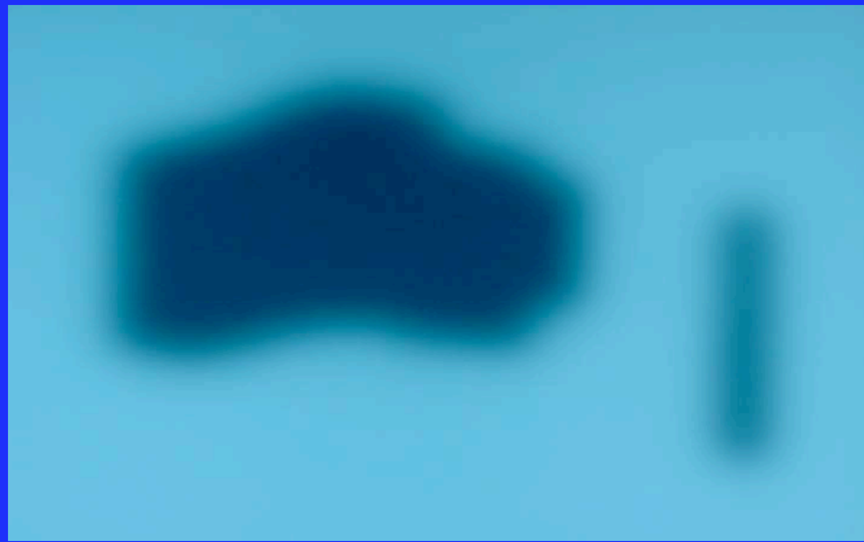
- Saves changing collimators every field
- Can be used to 'simulate' scanning
- Could be used to deliver IMPT?

Proton Multi-leaf collimators

Film dosimetry performed at Loma Linda using MLC and passively scattered proton beam

Shape at surface

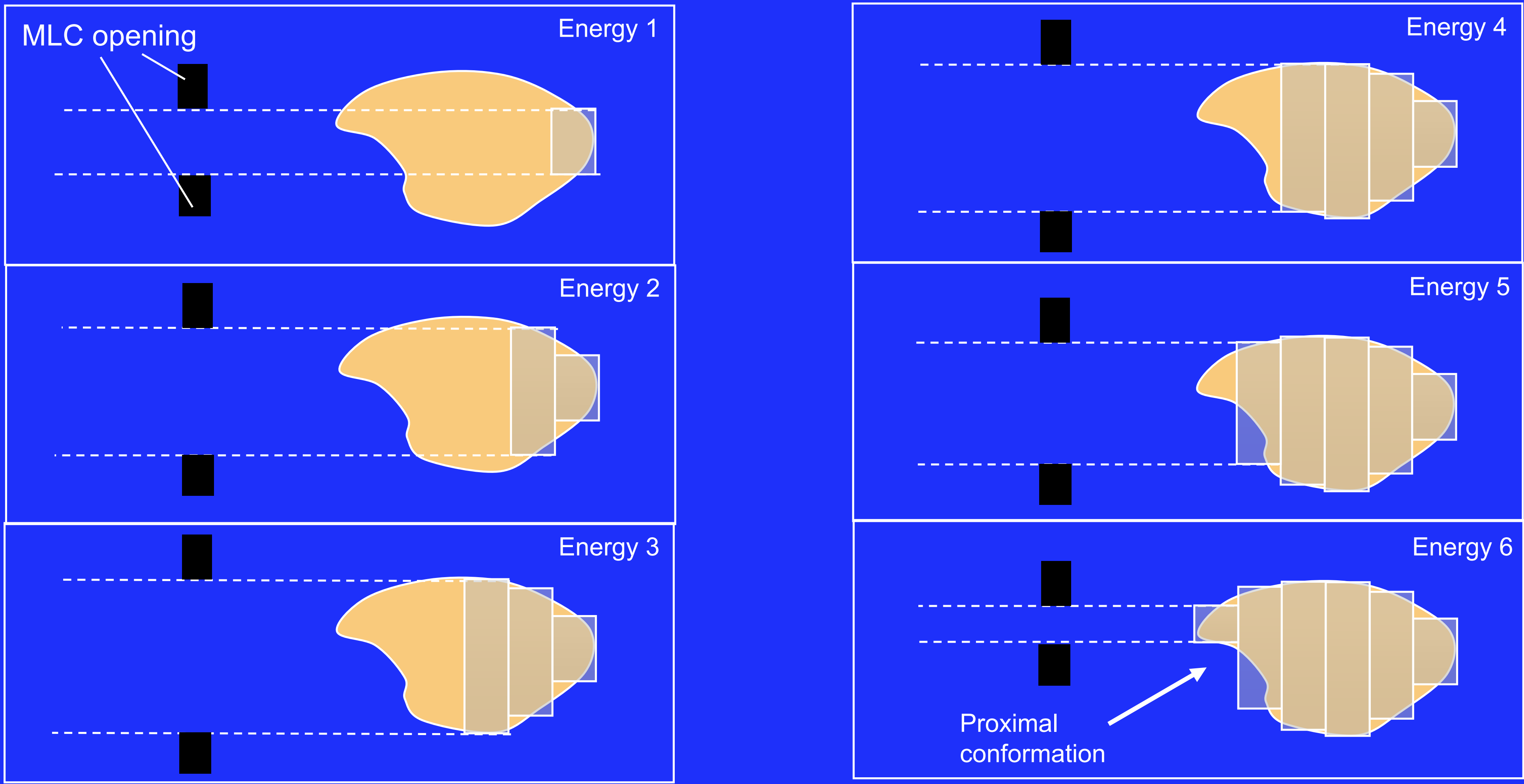
Shape after 29cm water



Mike Moyers, LLUMC

Proton Multi-leaf collimators

Simulated scanning using dynamic MLC's



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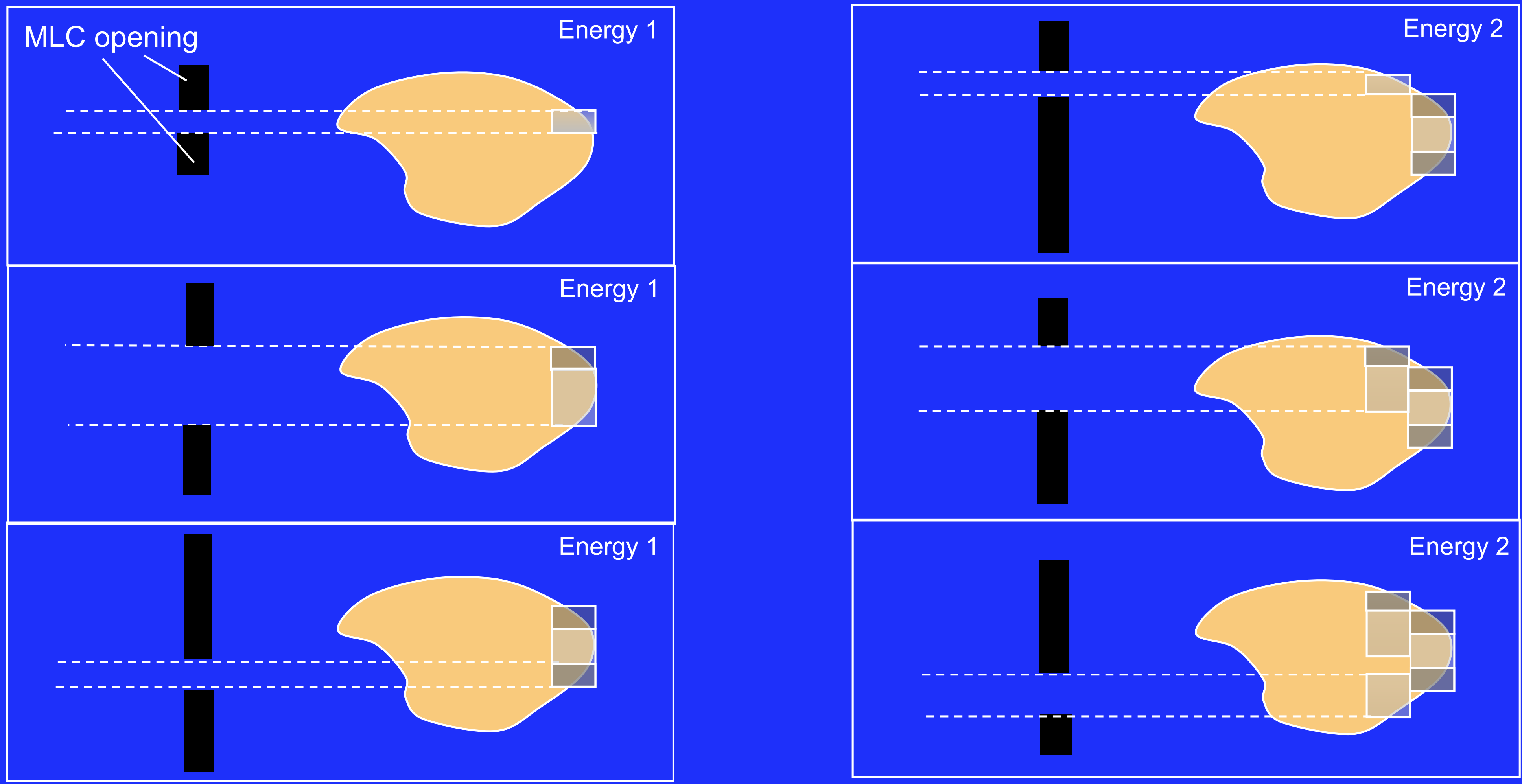
Proton Multi-leaf collimators

IMPT using dynamic MLC’s?



New directions in proton therapy

1. Possible improvements to passive scattering
2. Dealing with range uncertainties
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Dealing with range uncertainties

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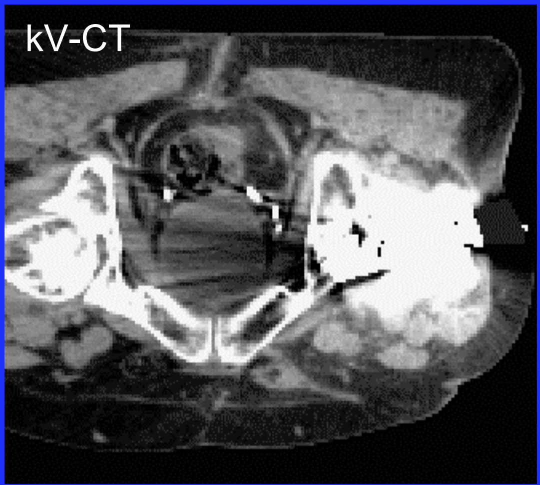
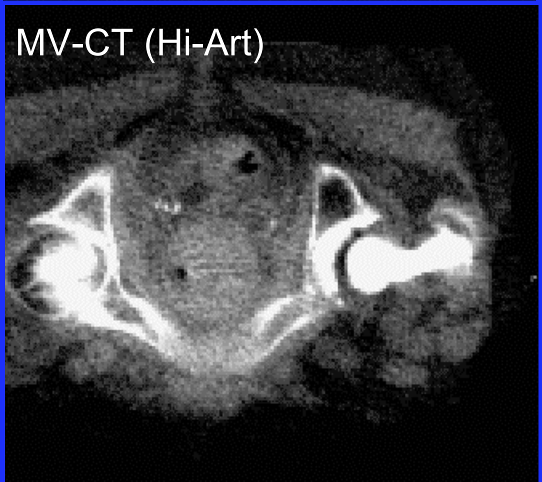
Imaging for range

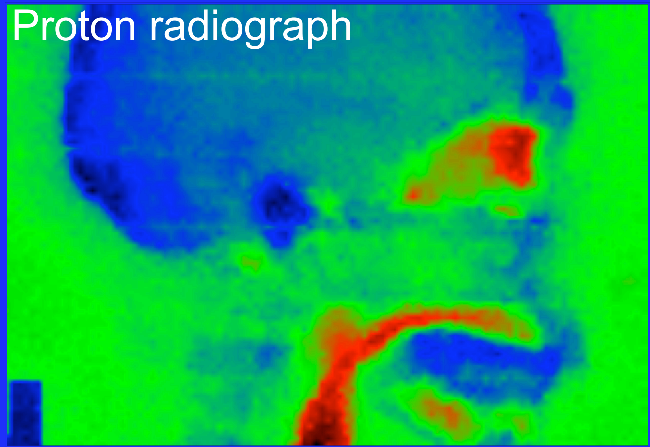
MV-CT

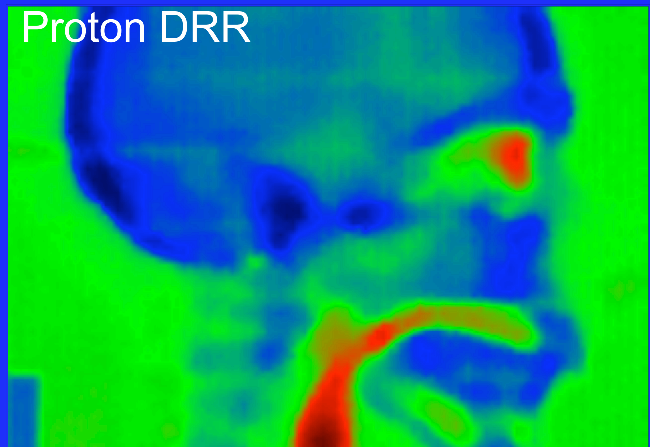




Ospedale San Rafaele, Milan
Francesca Albertini, PSI

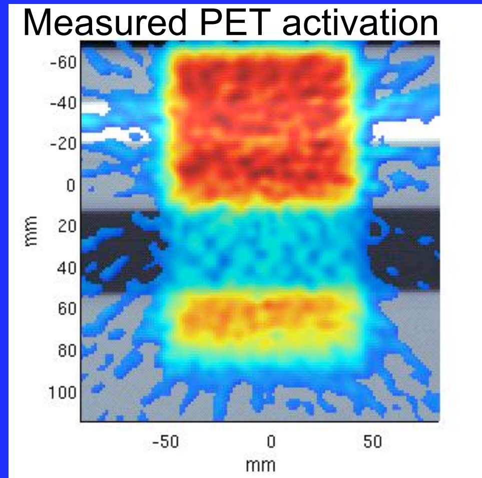
Proton radiography

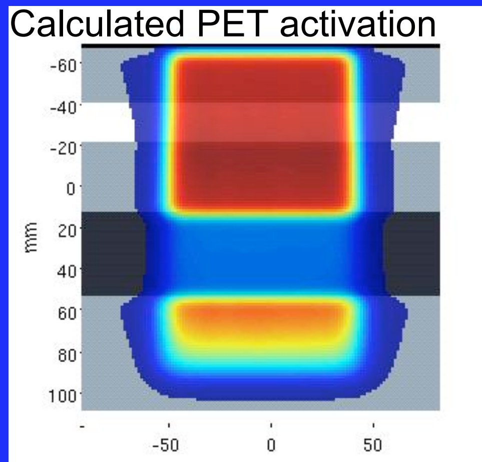




Uwe Schneider, Zurich
Alexander Tourovsky, PSI

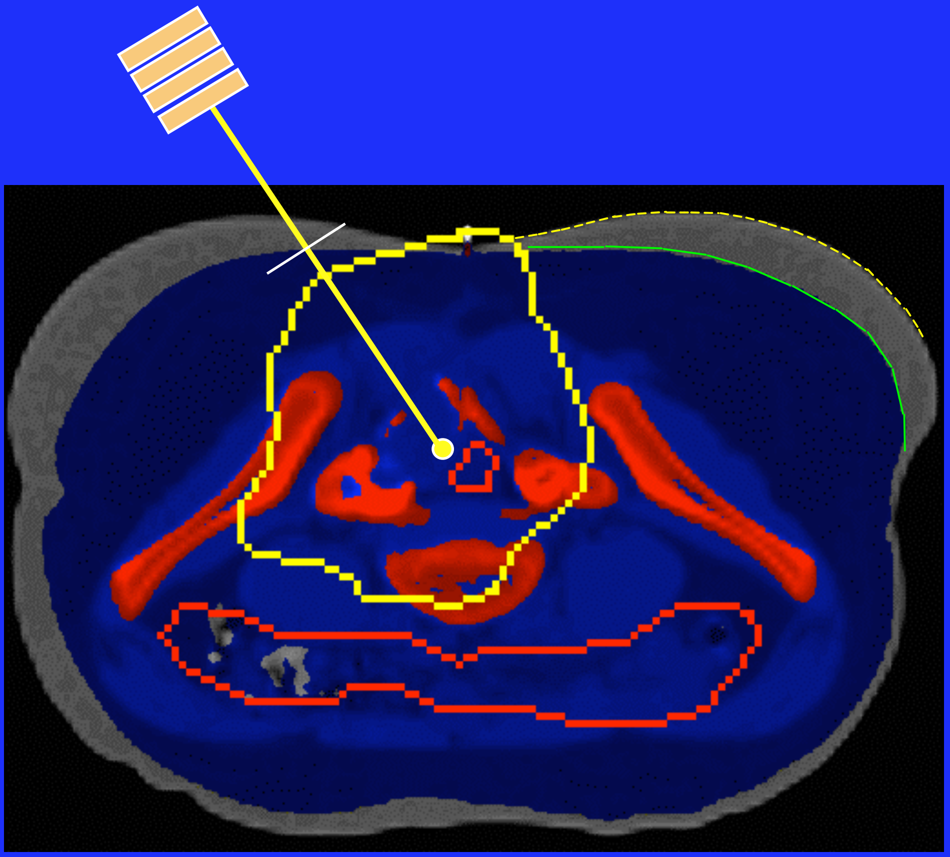
Activation PET





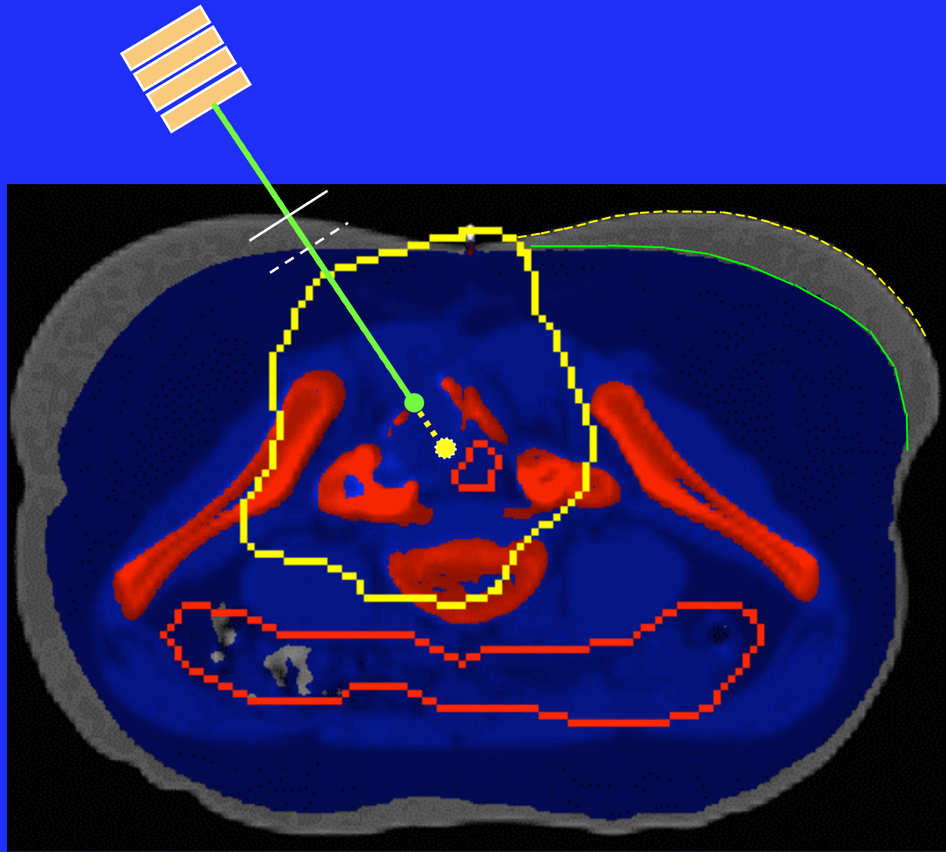
Katia Parodi, Thomas Bortfeld
MGH, Boston

Range adapted proton therapy



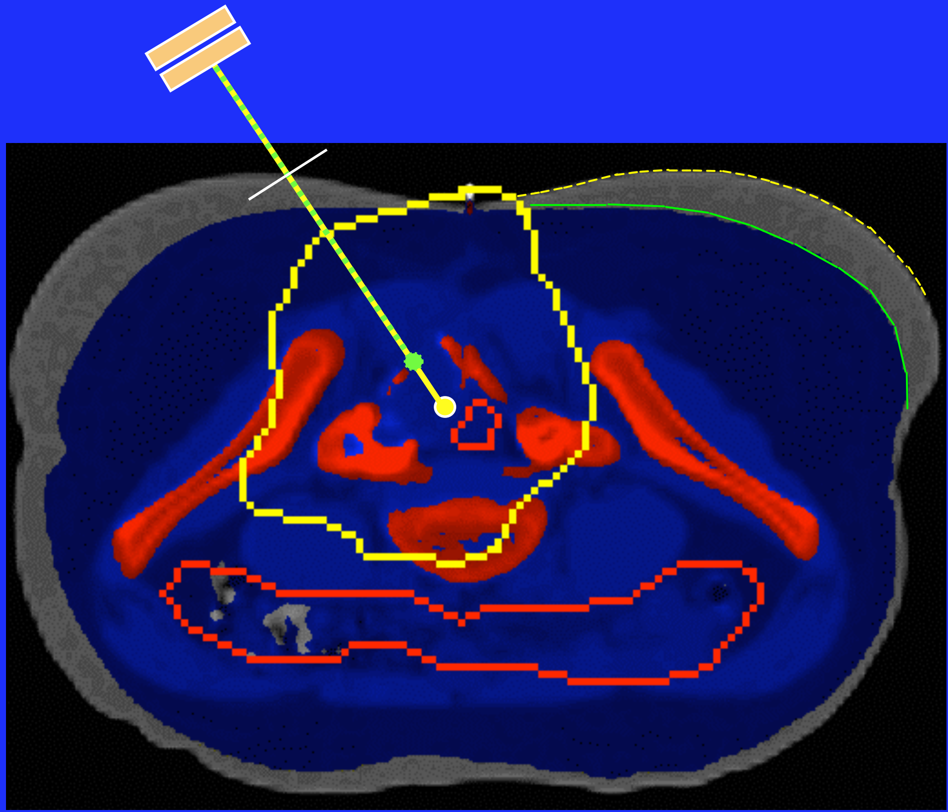
Alessandra Bolsi, PSI

Range adapted proton therapy



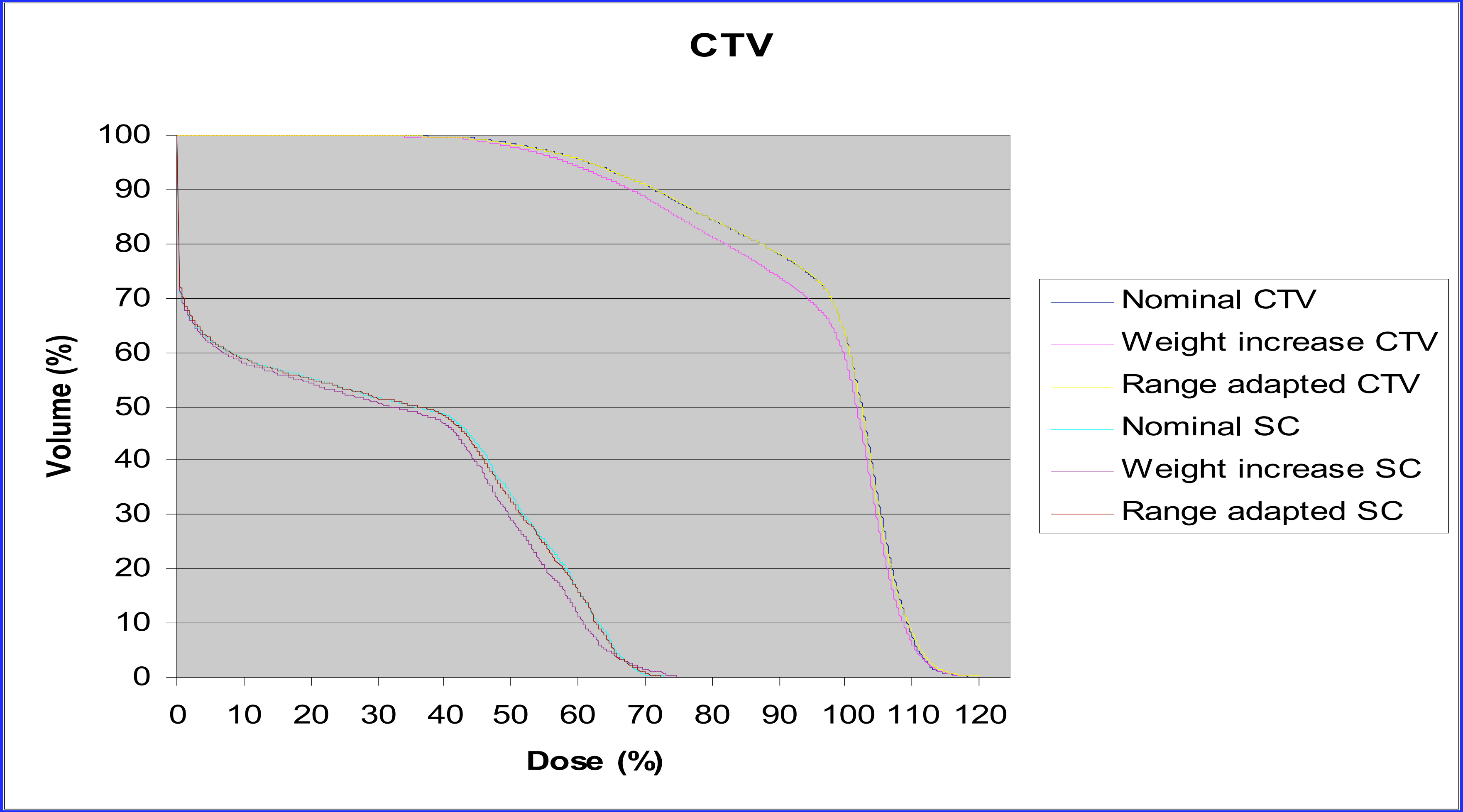
Alessandra Bolsi, PSI

Range adapted proton therapy



Alessandra Bolsi, PSI

Range adapted proton therapy



Alessandra Bolsi, PSI

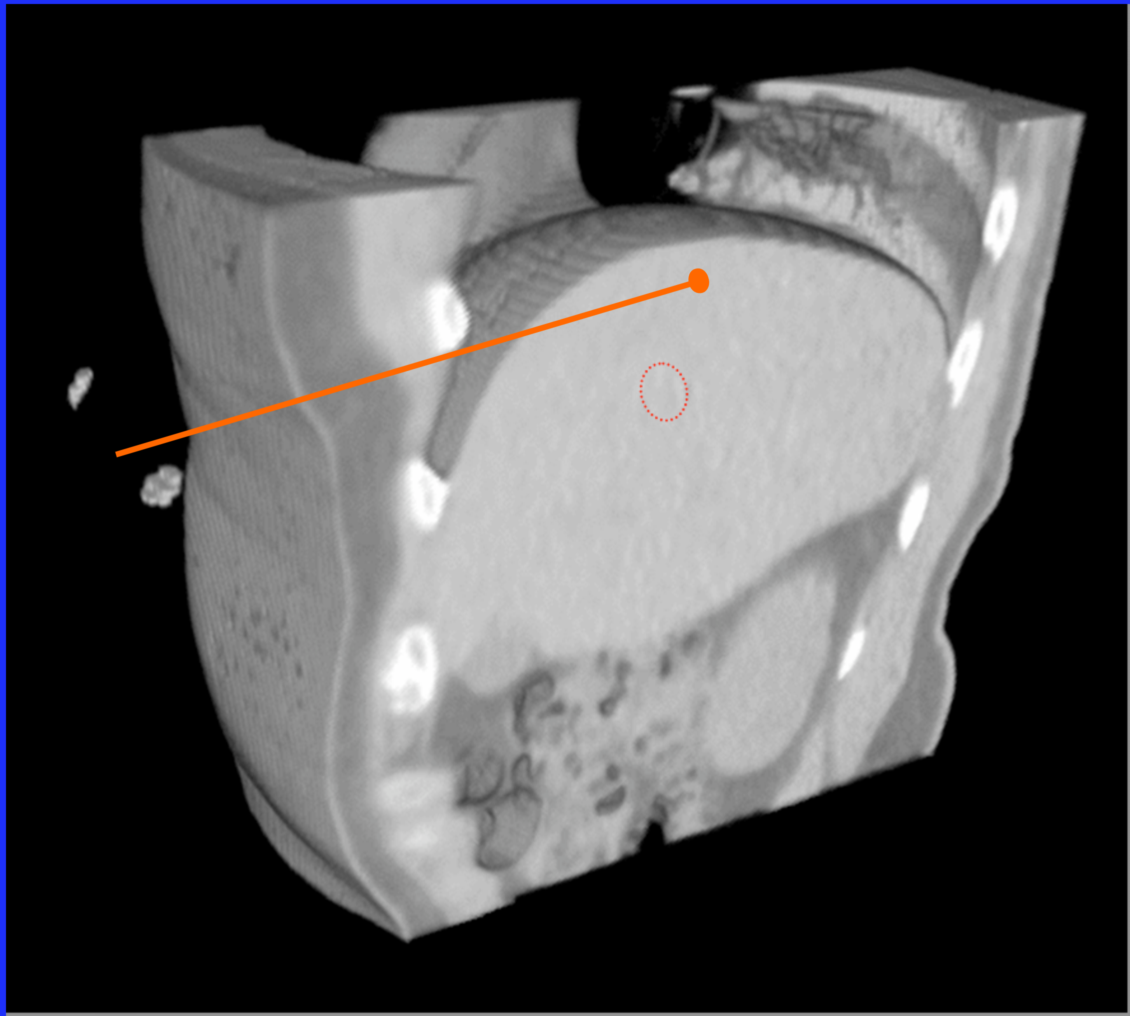
New directions in proton therapy

1. Possible improvements to passive scattering
2. Dealing with range uncertainties
3. Organ motion and scanning

Organ motion and scanning

Rescanning

Repaint scanned beam many times such that statistics dictate coverage and homogeneity of dose in target (c.f. fractionation)



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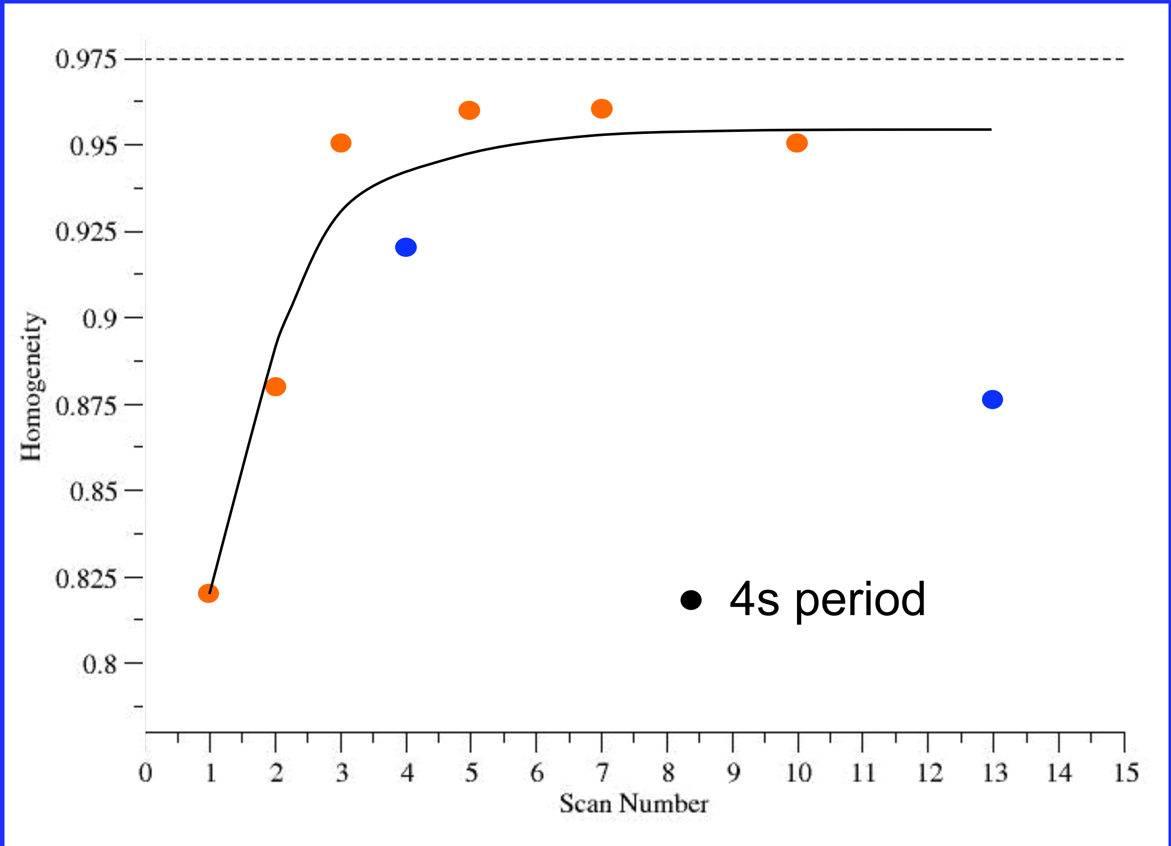
Rescanning

Re-scanning in presence of Cos^4 motion with 1cm amplitude



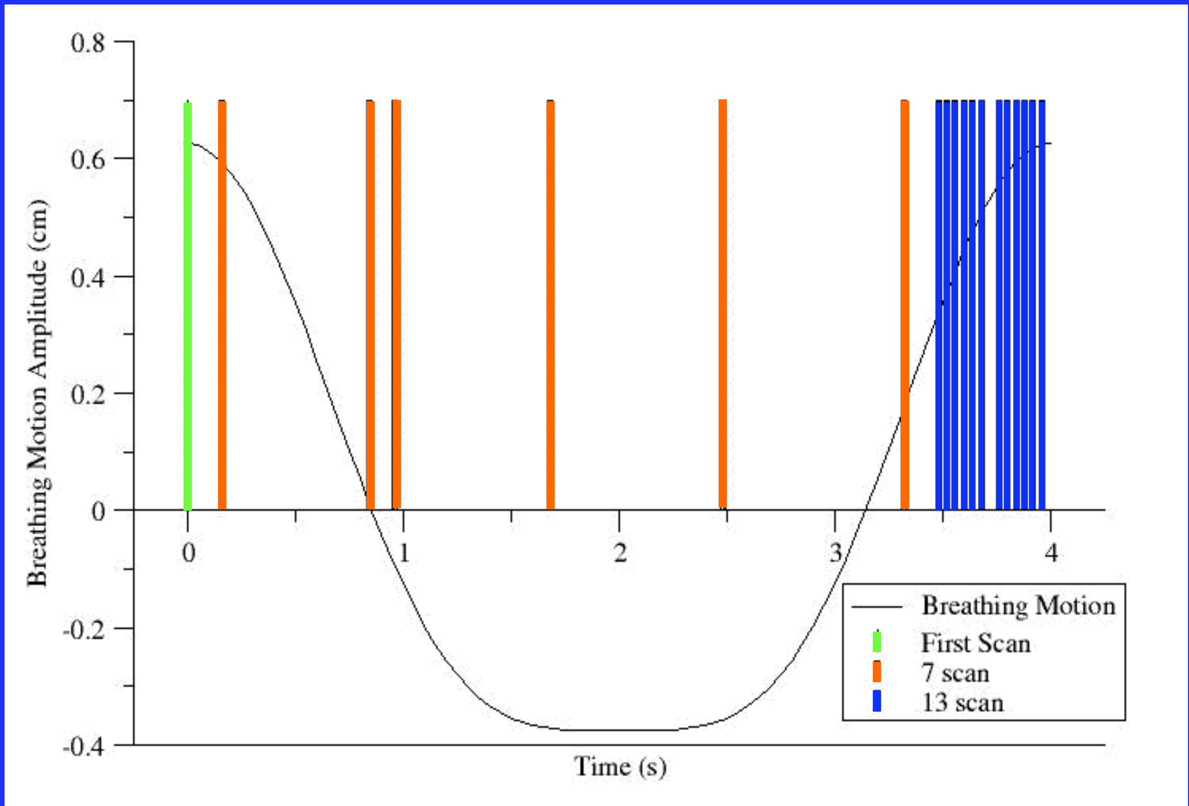
- Cylindrical target volume
- Re-scanned different times to same total dose
- Scan times calculated for realistic beam intensities and dead times between spots
- Analysis carried out for different periods of motion

Not always improving homogeneity with number of re-scans!

Marco Schwarz, Sylvan Zenklusen ATREP and PSI

Rescanning

The 'synchronicity' effect



- Very preliminary results
- A 'real' effect for perfectly regular breathing?
- Could well be less of an issue when breathing is more irregular
- For regular breathing, could be avoided by selecting the re-scanning period to avoid effect or varying period scan-to-scan
- Probably not a big issue in reality

See presentation from Silvan Zenklusen, Saturday

Organ motion and scanning

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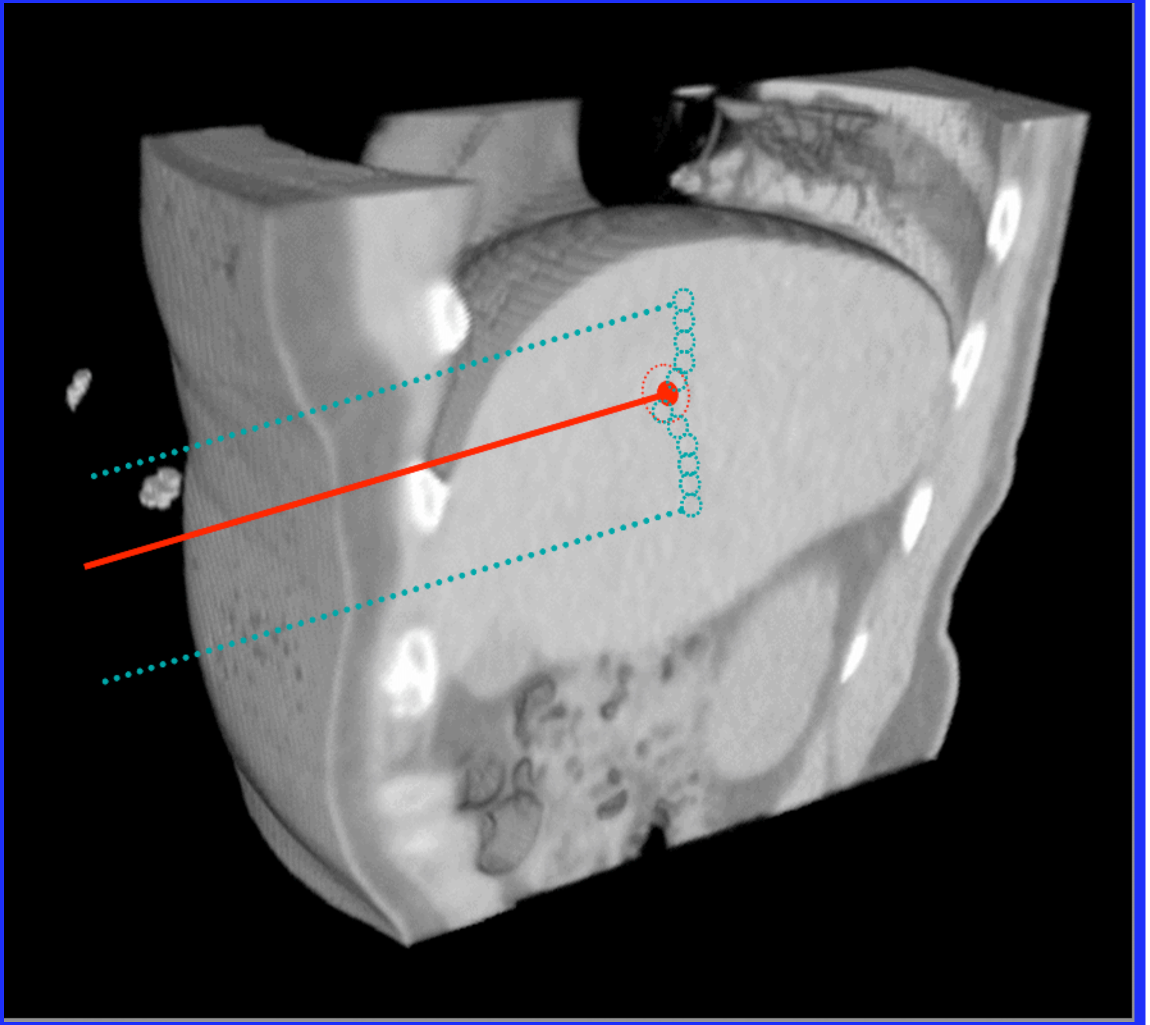
Tracking

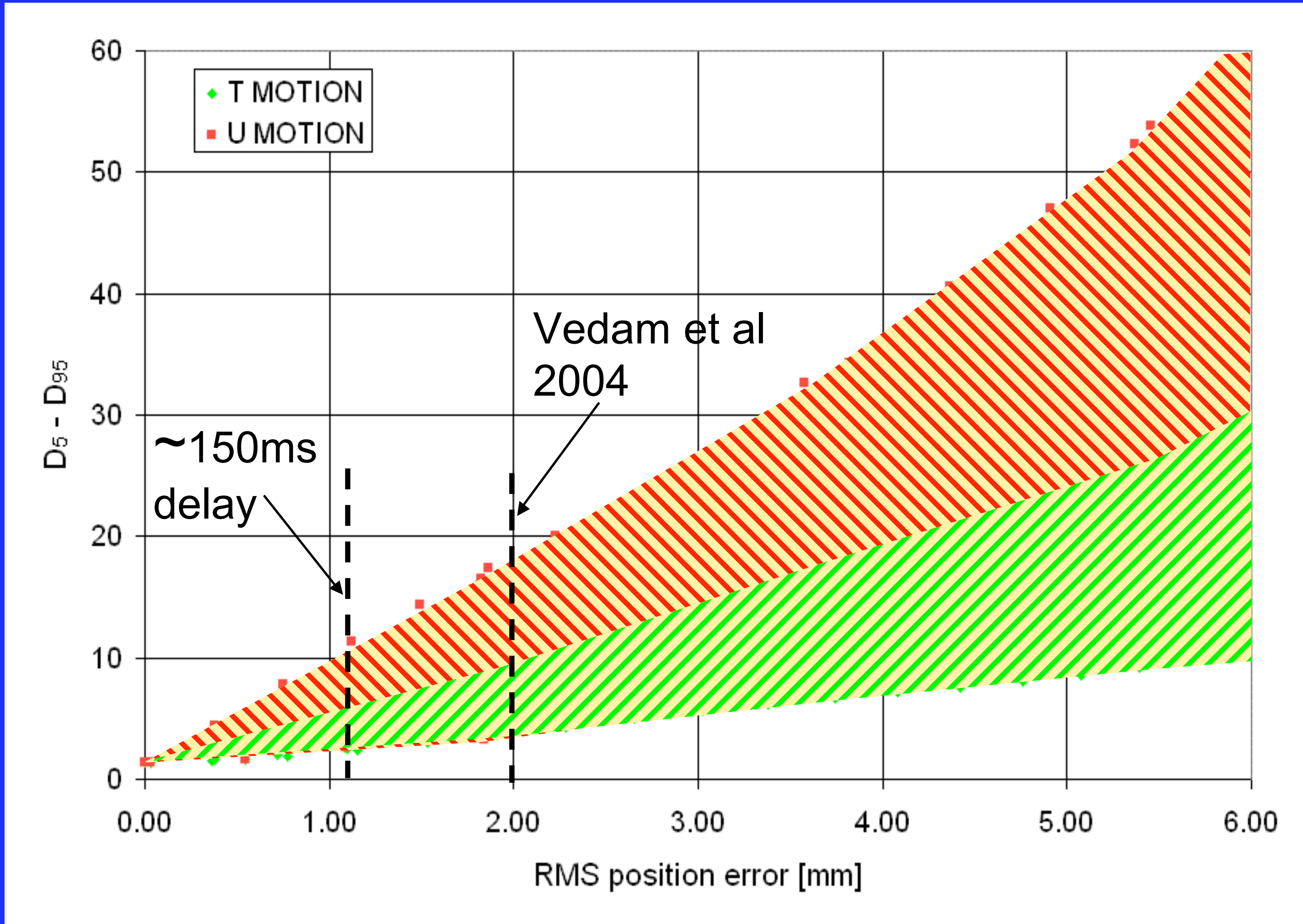
Track motion of tumour using scanning system based on some anatomical/physiological signal



Tumour Tracking

Plot of dose homogeneity as function of RMS position error due to motion and 'imperfect' tracking

Cos^4 motion with varying detection delays and tracking accuracies

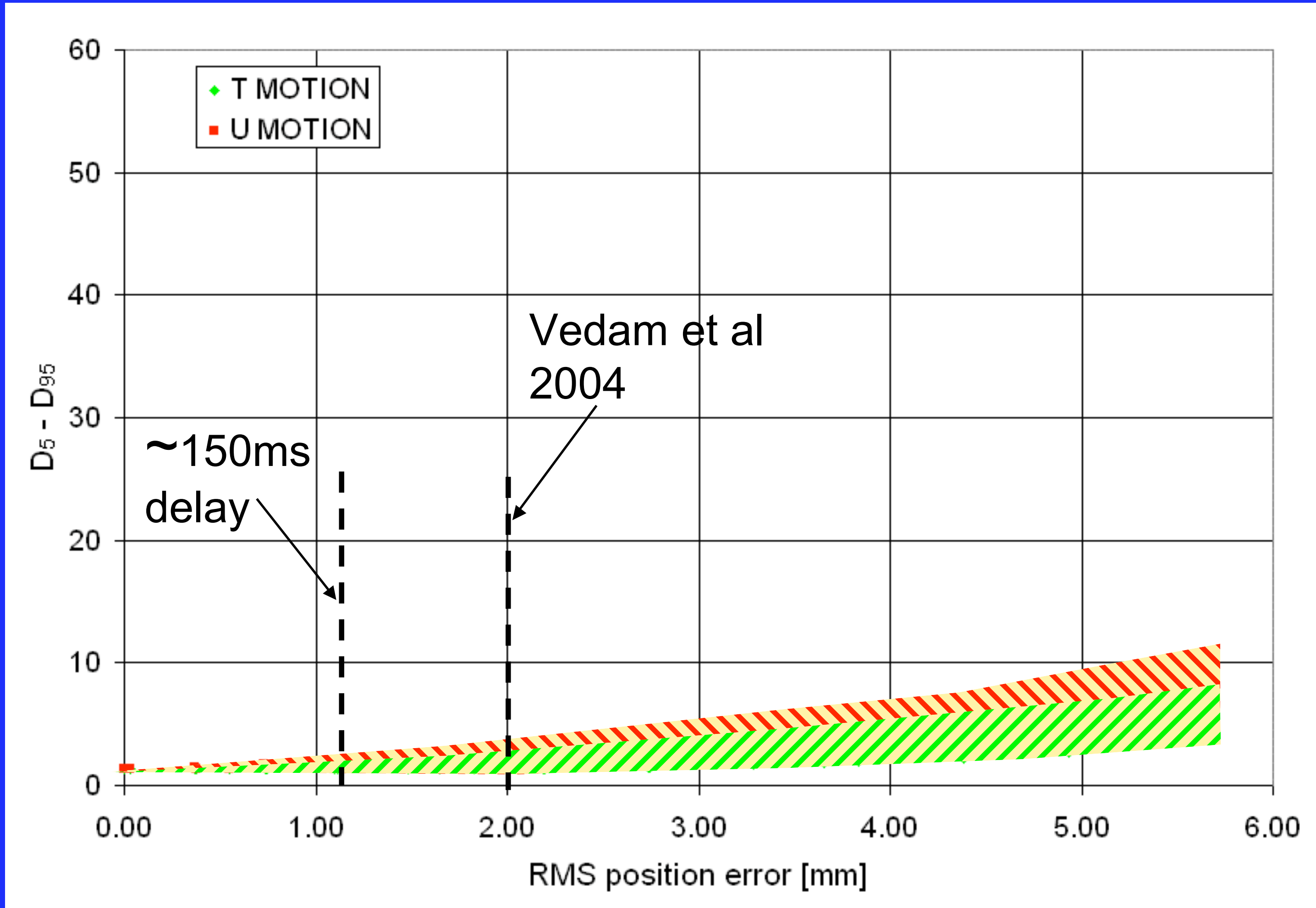


Steven van de Water, PSI/TUDelft

Tumour Tracking

Re-tracking – tracking the tumour repeatedly within one fraction

E.g. 4 times



Steven van de Water, PSI/TUDelft

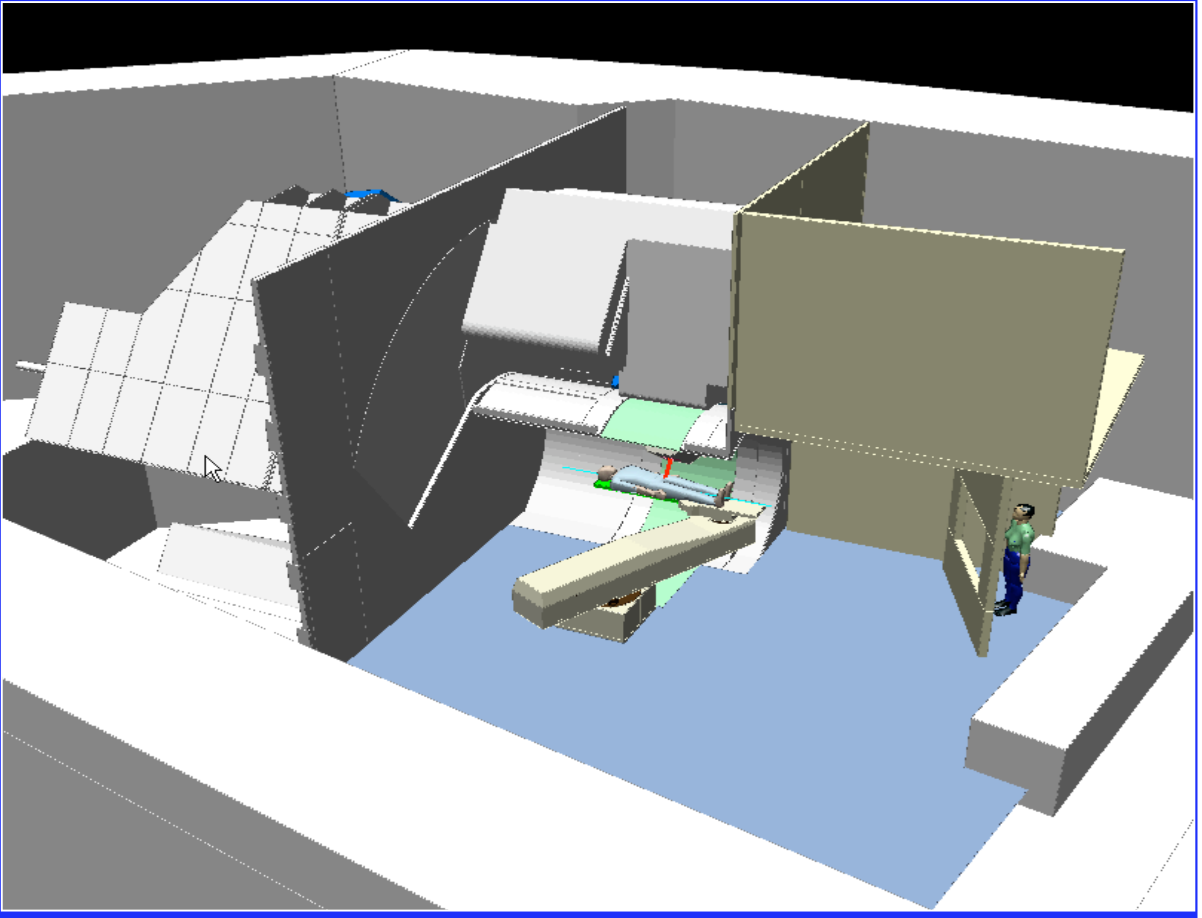
PSI Gantry 2

Main features:

- Fast upstream energy variation (~150ms for 5mm range step)
- Double magnetic scanning
- Capable of delivering 2Gy/litre in 6s!
- ‘Simulated parallel scanning’ – passive scattering with a scanning gantry
- First patients – summer 2009

The PSI Gantry 2

How it looks now…



… and how it will look by the end of 2008

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FIRST BEAM THROUGH THE NEW GANTRY 2 OF PSI

E. Pedroni - Paul Scherrer Institute - 17:22, 9. May 2008

...another milestone for the PSI therapy project
(A. Lomax, M. Jermann, E. Pedroni,
C. Bula, D. Meer, M. Schippers and T. Böhringer)

... the reason for the happiness

Summary

- Although passive scattering is still the preferred choice for proton therapy, scanning and IMPT will become more widespread in the next years (c.f. MD Anderson)
- To what extent can scattering be improved through the use of automated field hardware (MLC's etc)?
- Range uncertainty and organ motion (particularly for scanning) remain the main challenges to proton therapy and much interesting and exciting work is still to be done in organ management, range imaging and adaptive proton therapy
- The field is ripe for new input, ideas and innovations…