Benchmarking treatment planning dose calculations using a Monte Carlo dose engine as a potential activity of a primary standard lab

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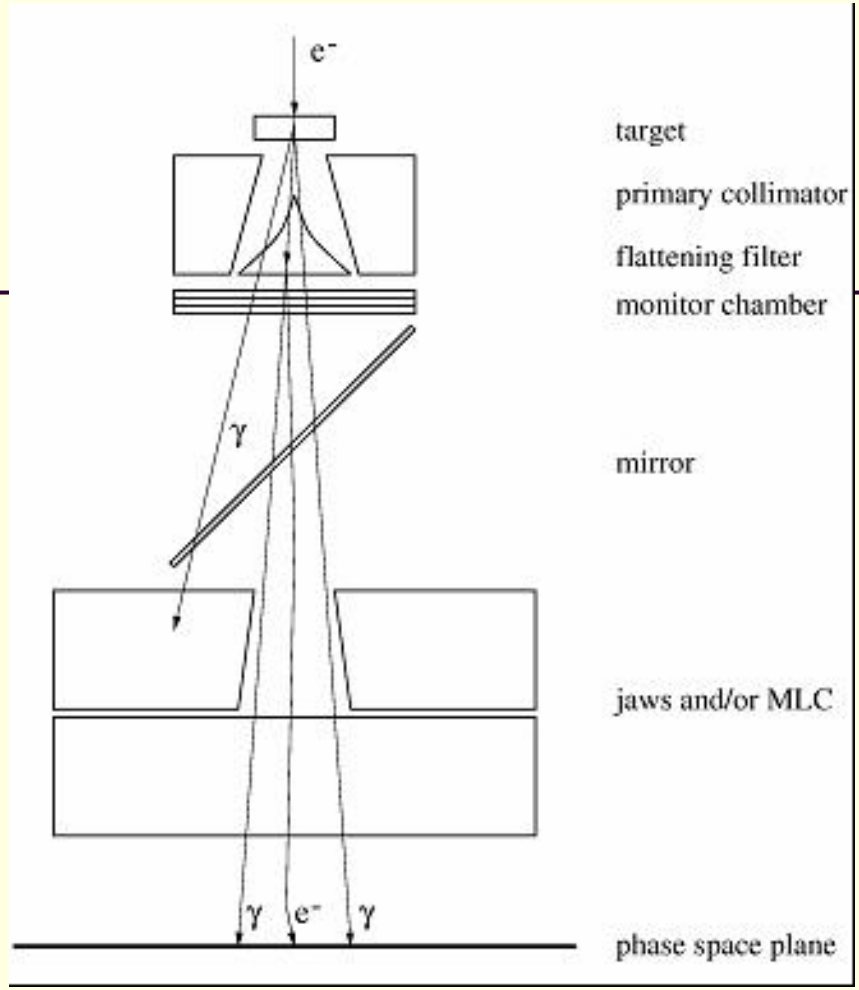
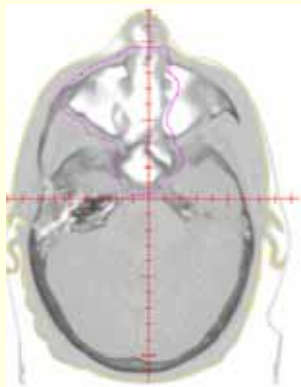
Monte Carlo treatment planning

- Linac head modelling
- Patient modelling: CT data – media/density conversion


e⁻
target
primary collimator
flattening filter
monitor chamber
γ
mirror
jaws and/or MLC
γ
e⁻
γ
phase space plane



General purpose Monte Carlo codes used for MCTP

- EGS4/EGSnrc (BEAMnrc/DOSXYZnrc)
- PENELOPE
- GEANT
- MCNP(X)

MCTP dose engines

- DOSXYZnrc/BEAMnrc engines (Leal et al, Spezi et al, Seco et al, Reynaert et al, …)
- MCDOSE, MCSIM (Ma et al)
- VMC, VMC++ (Kawrakow)
- XVMC (Fippel)
- Peregrine (Hartmann Siantar et al)
- DPM (Sempau et al)
- MCV (Siebers et al)
- …..

LSDG: MCDE

- Project started in 2001
- DOSXYZnrc → Component module for BEAMnrc (ctcreate included in patient CM)[1]
- Independent scoring grid (as in e.g. Peregrine)[2,3]
- Statistic stop (including OAR)[4]
- Dicom interface (CT, linac data, contouring info)
- Fortran 95 → dynamic memory allocation
- IMAT compatible[5]
- Inverse optimization compatible[6] (denoising[7])
- → Focussing on benchmarking (not on speed)

1 Reynaert et al, 2004, *Phys. Med. Biol.* **49** N235-N241; 2 De Smedt et al, 2004, *Phys. Med. Biol.* **49** 4623-4635; 3 De Smedt et al, 2005, *Phys. Med. Biol.* **50**, 4005-4019; 4 Vanderstraeten et al, 2007, Int J Rad Onc Biol Phys (in progress); 5 Olteanu et al 2006 (EWG-MCTP workshop); 6 De Smedt et al, 2007, JPCS (in progress); 7 De Smedt et al, 2006, *Med. Phys.* **33**, 1678-1687

Linac modelling

- 18 MV model: problem with energy of initial electrons: removal filters to limit number of tunable parameters: De Smedt et al, 2005, *Phys. Med. Biol*. **50** 5935-5951

- MLCE: Van de Walle et al, 2003, *Phys. Med. Biol*. **48 (3)**, 371-385

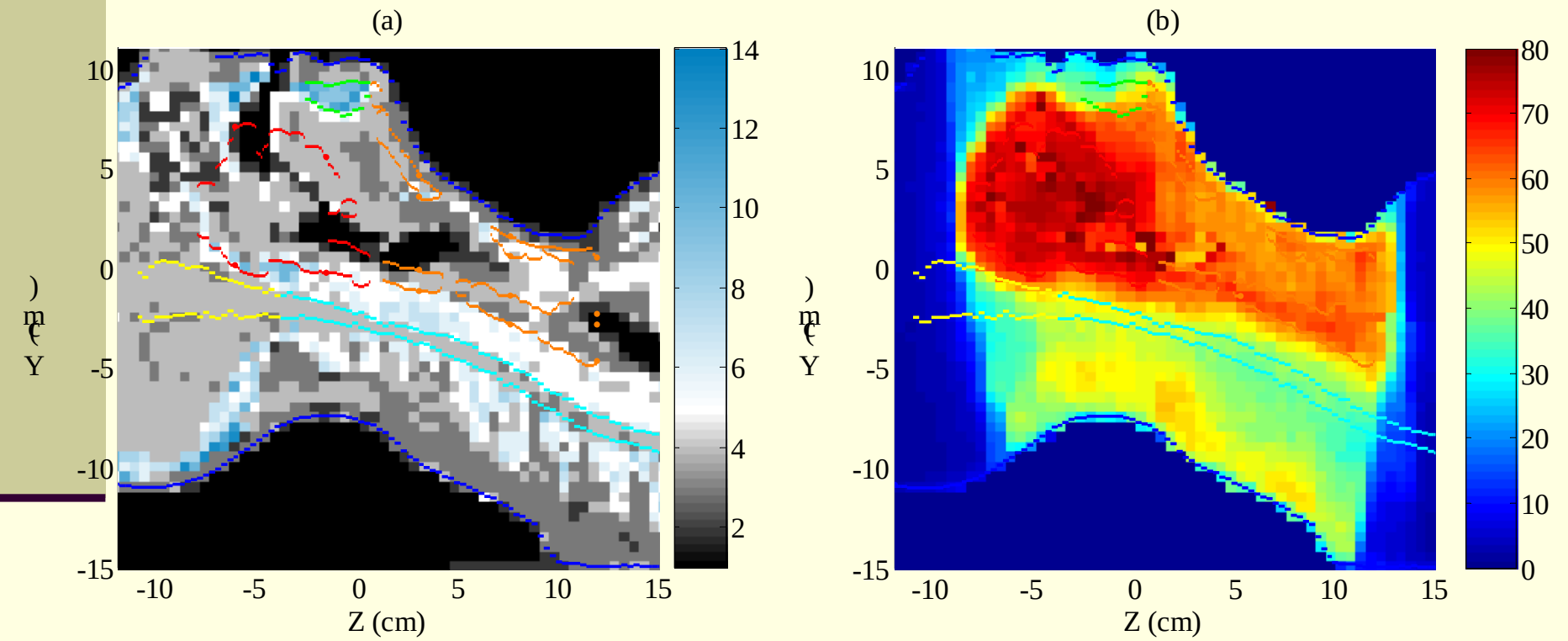
CT calibration

- EWG-MCTP project: Vanderstraeten et al, 2007, *Phys. Med. Biol*. **52**, 539-562
- Stoichiometric calibration method (Schneider et al 1996 *Phys Med Biol* **41** 111-124, Schneider et al 2000 *Phys Med Biol* **45** 459-478)
- RMI phantom calibrated in 7 centres in Europe
- Dosimetric evaluation individual scanner dependence

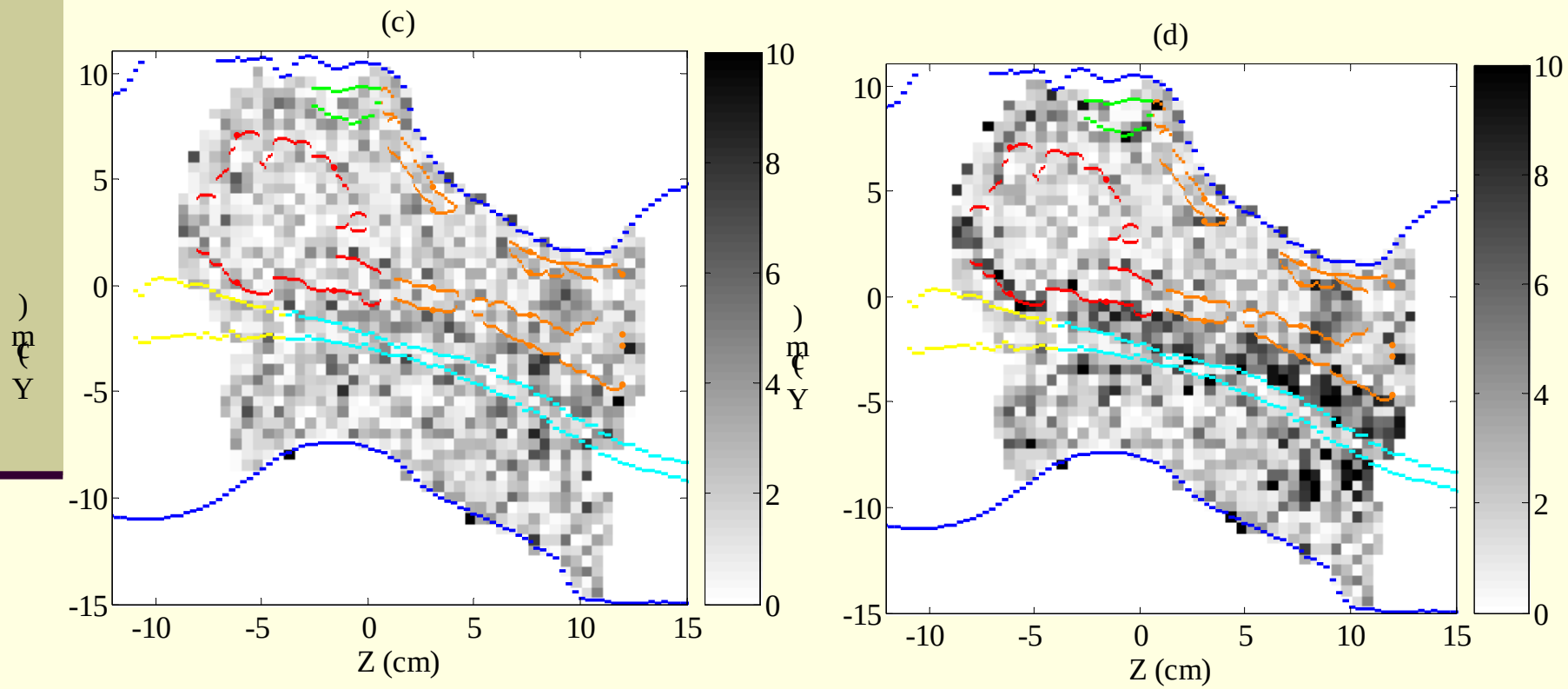
CT scanners

CT scanner	Location	K^{ph}/K^{KN}	K^{coh}/K^{KN}
Siemens Somatom Plus 4	Ghent University Hospital, Belgium	4.24×10^{-5} [a]	-1.77×10^{-3} [a]
Philips Gemini GXL PET/CT	Ghent University Hospital, Belgium	1.99×10^{-5}	9.26×10^{-4}
Siemens Somatom Sensation Open	University Hospital Tübingen, Germany	2.11×10^{-5}	3.70×10^{-4}
Siemens Somatom Sensation Open	Velindre Cancer Centre, Cardiff, UK	2.30×10^{-5}	3.49×10^{-5}
Siemens Somatom Sensation Cardiac 64	Clinica Quadrantes, Lisbon, Portugal	2.65×10^{-5}	-2.84×10^{-4}
Toshiba Xvision/EX	HUV Macarena, Seville, Spain	3.89×10^{-5}	-8.37×10^{-4}
GE HiSpeed QX/i	Royal Marsden Hospital, London, UK	2.78×10^{-5}	-3.98×10^{-4}
GE ProSpeed	Inselspital Radioonkologie, Bern, Switzerland	1.11×10^{-5}	4.79×10^{-3}

CT conversion

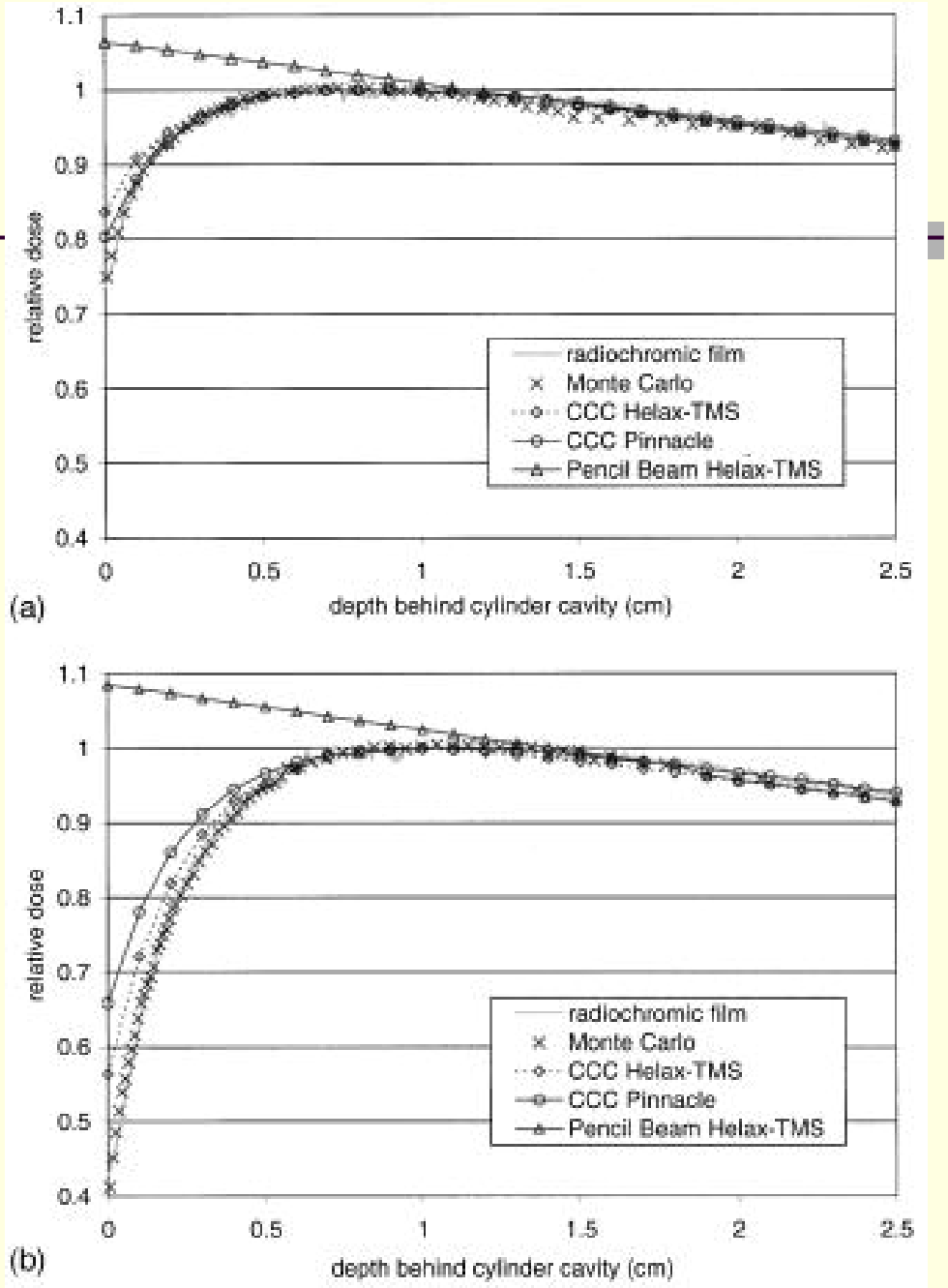


CT conversion (final)



QA: Phantom studies

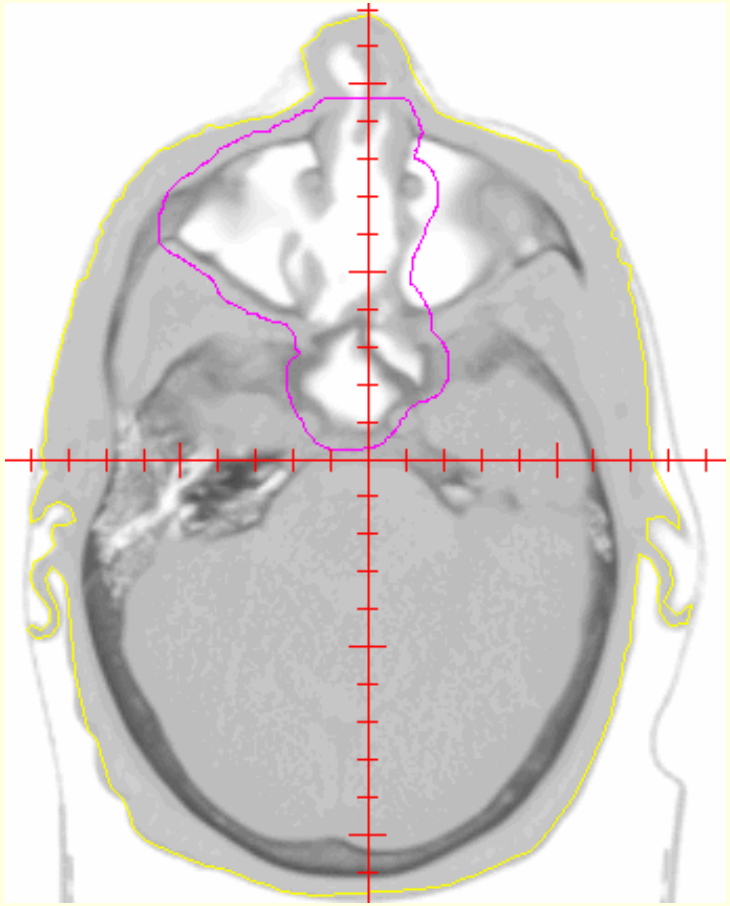
Why MC ?

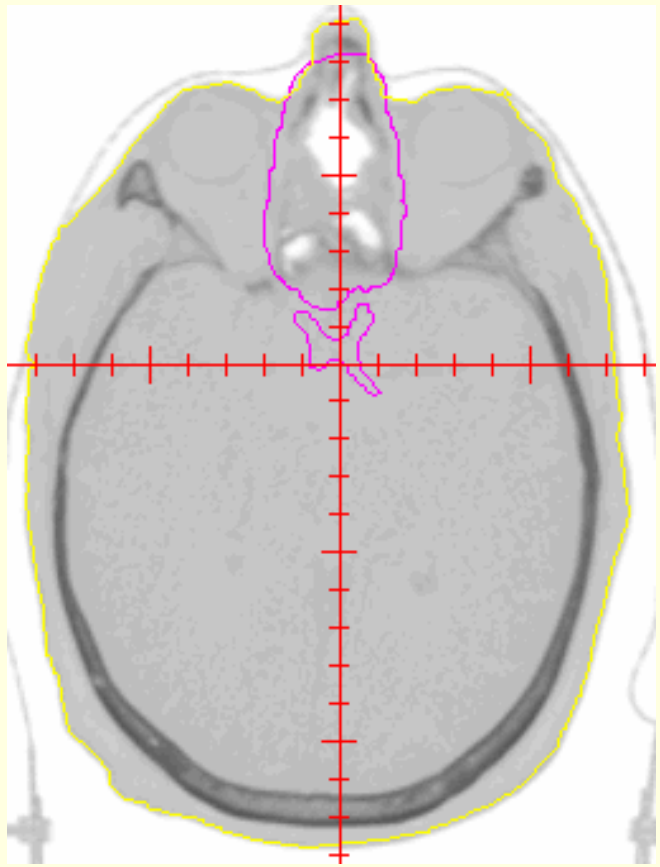


Martens et al, 2002, *Med. Phys*. **29,** 1528-1535

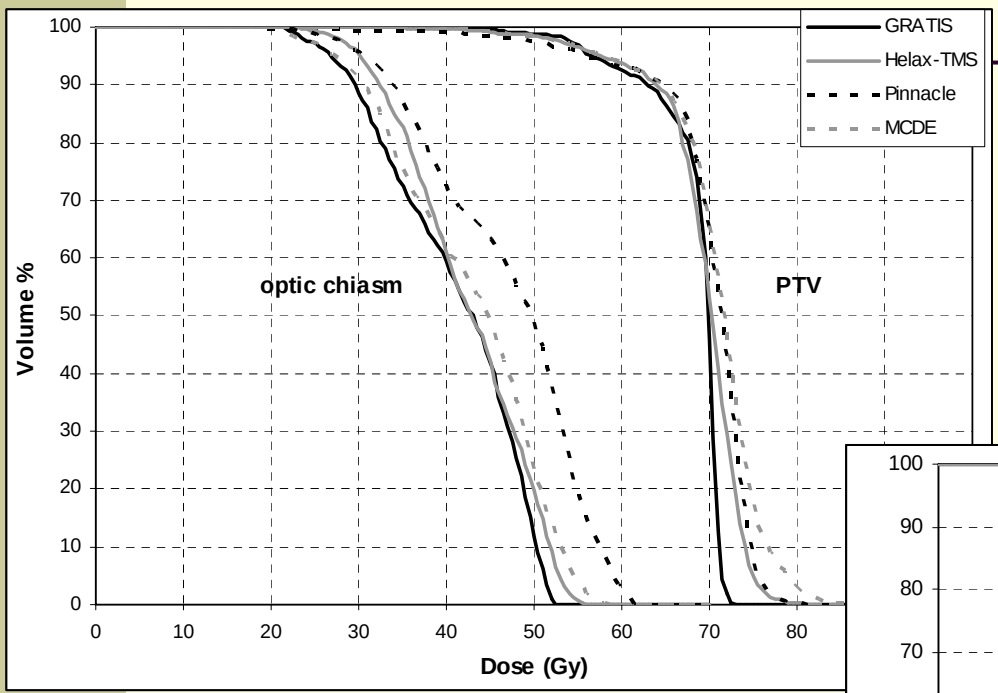
Patient studies:

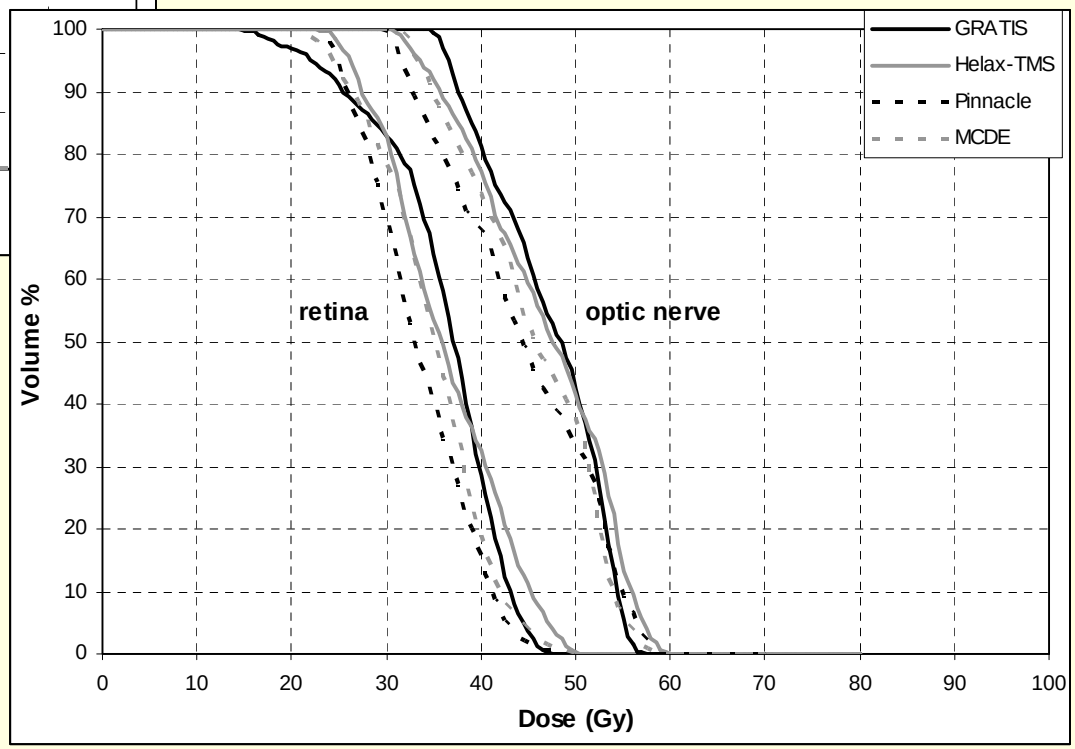
Ethmoid patients: GUH





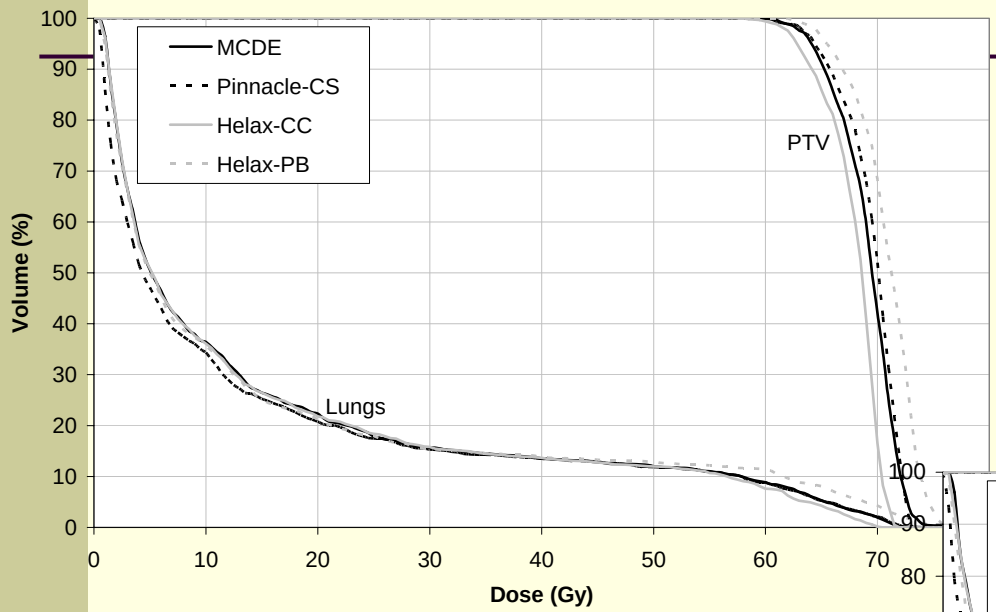
Ethmoid patients

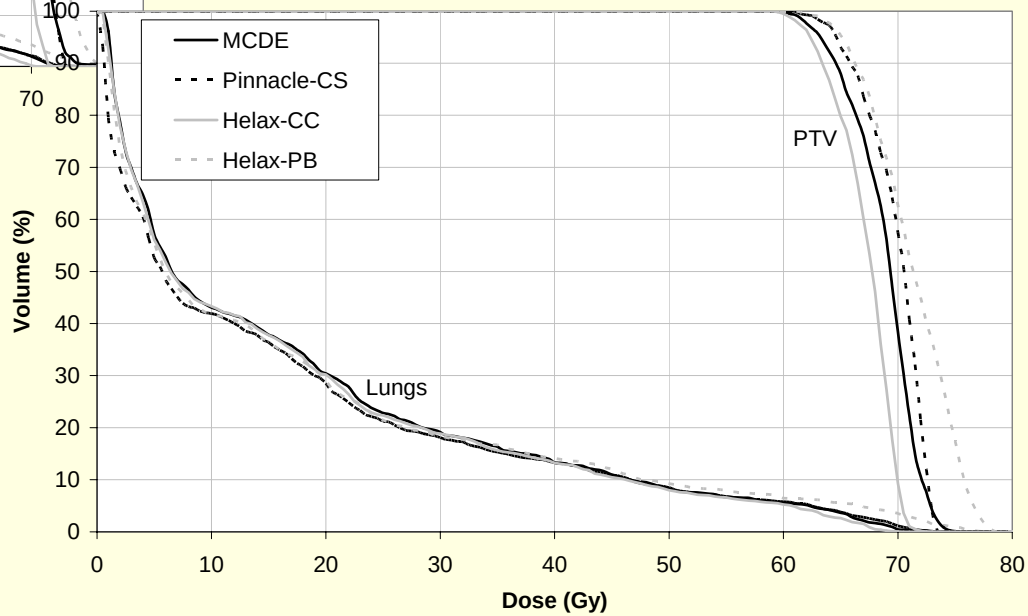




Paelinck et al 2006, Rad. Oncol. 81, 250-256

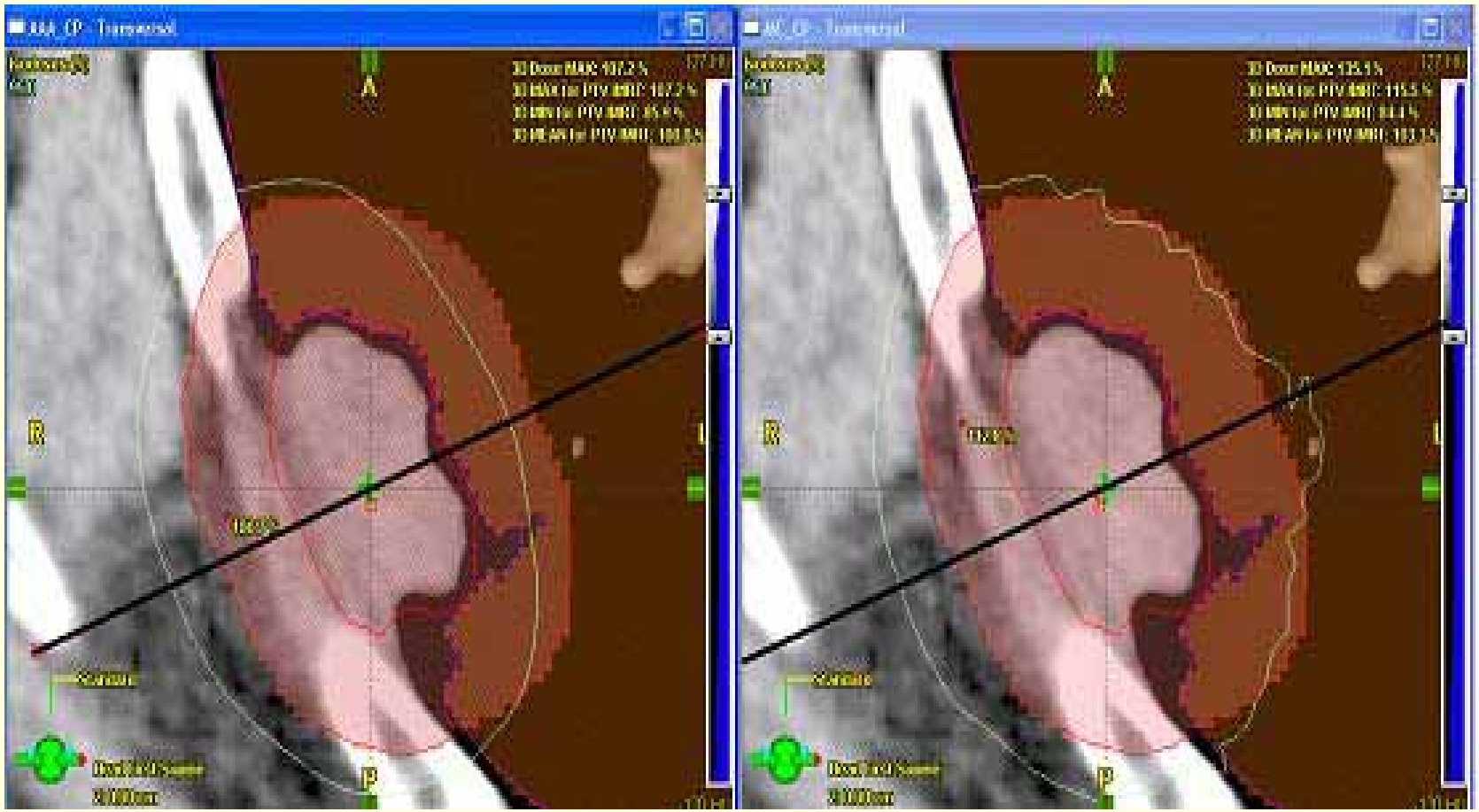
Lung patients GUH



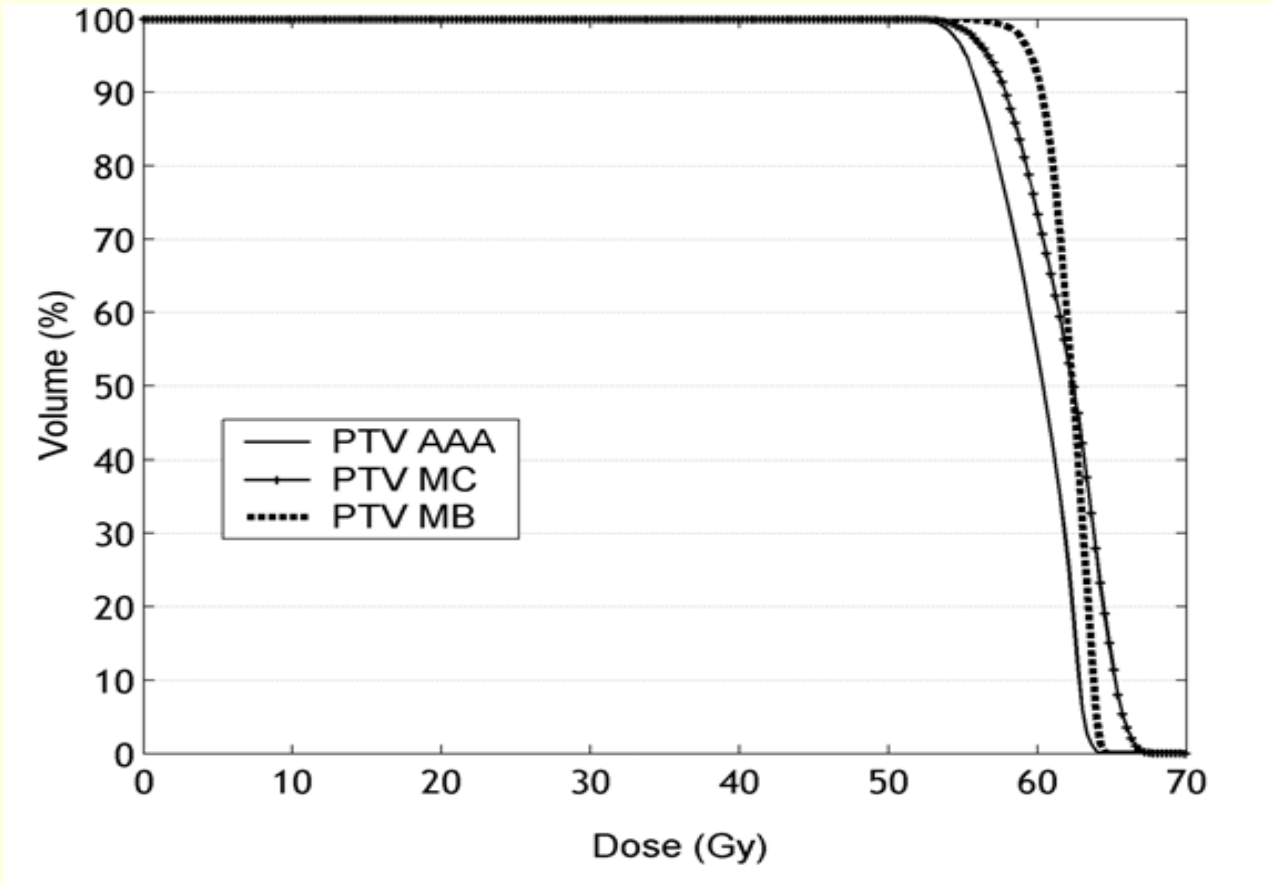


Vanderstraeten et al, 2006, *Med. Phys.* **33**, 3149-3158

Lung patients UCL

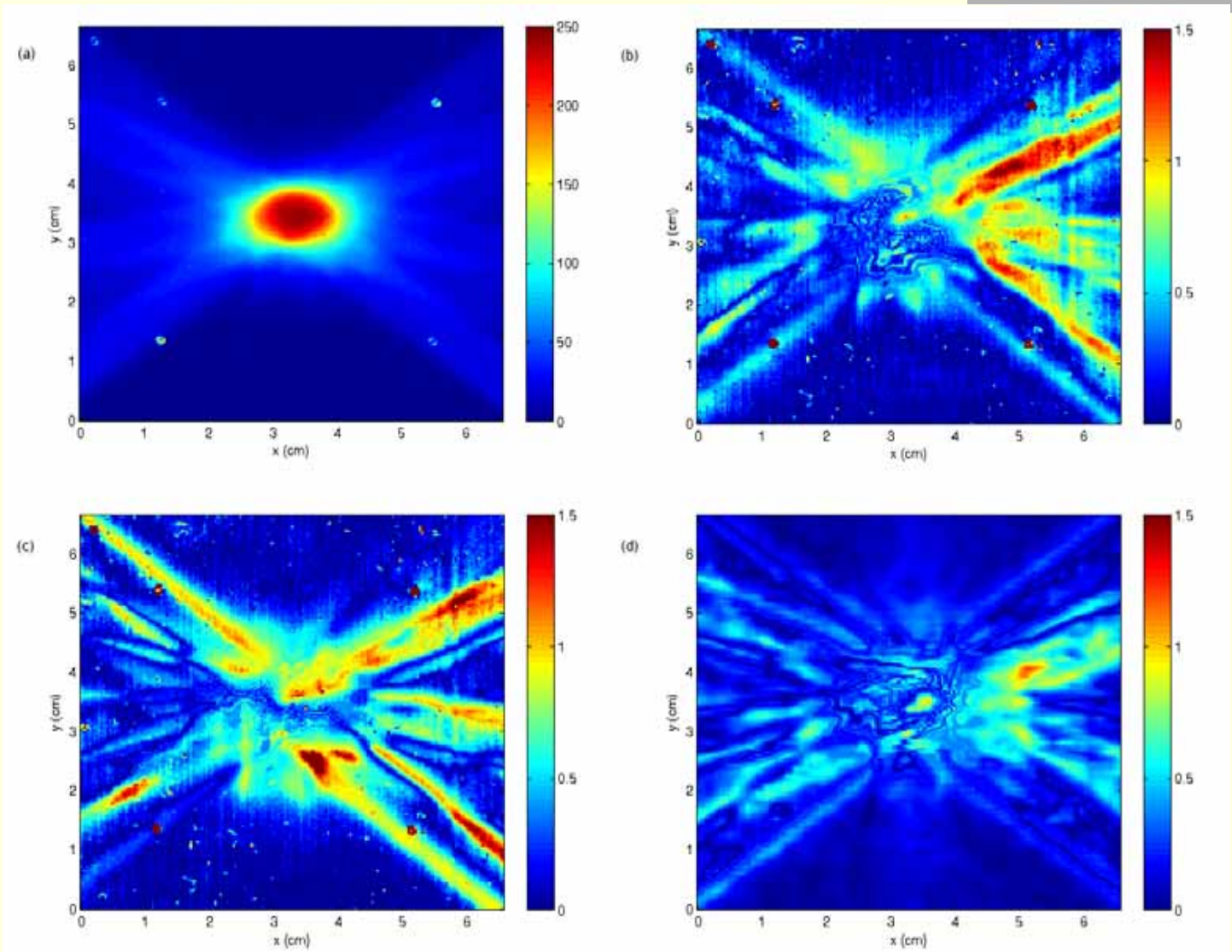


Lung patients UCL

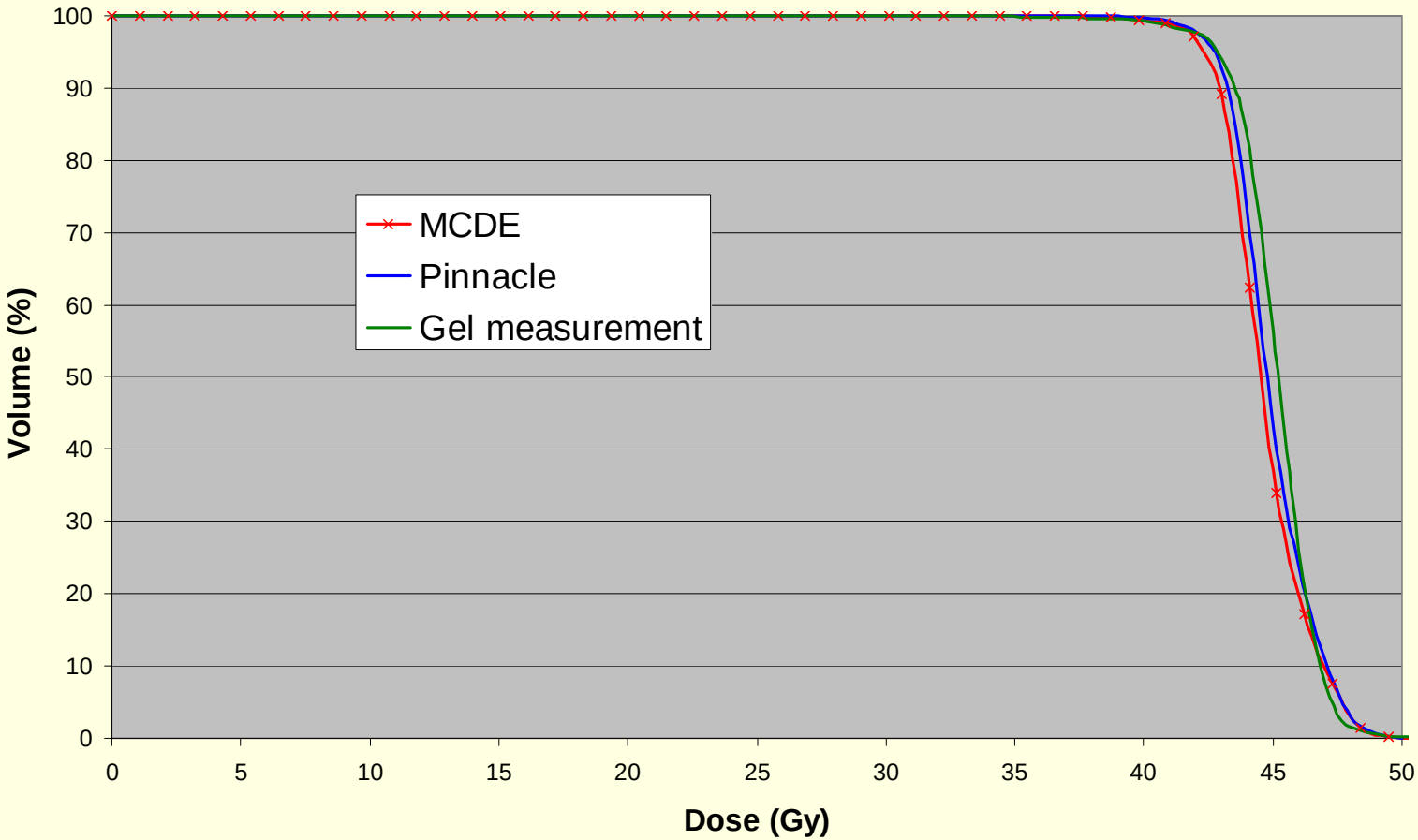


Sterpin et al, 2007, *Med. Phys.* In Press

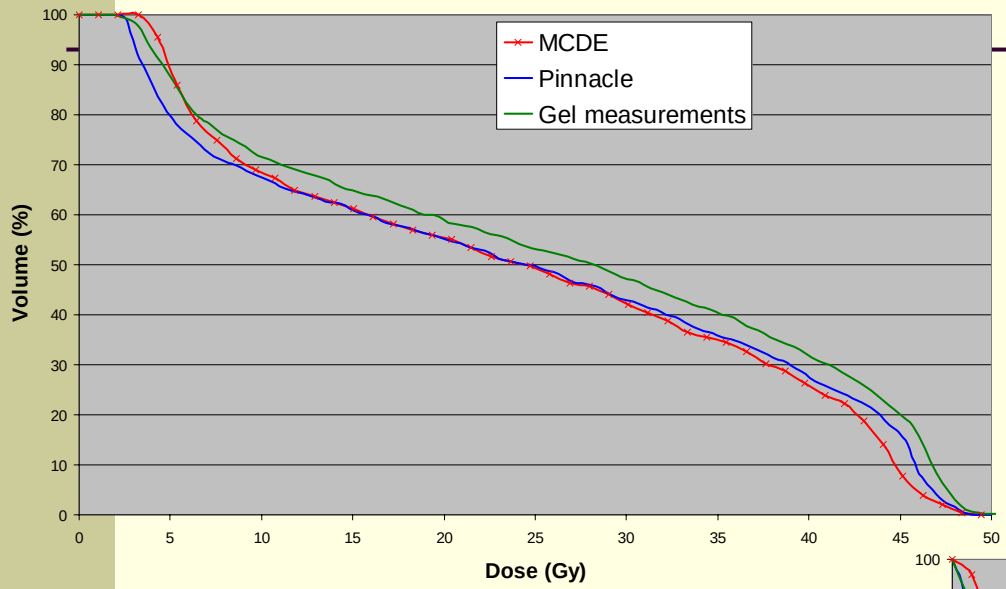
Stereotactic radiosurgery: radiochromic film dosimetry

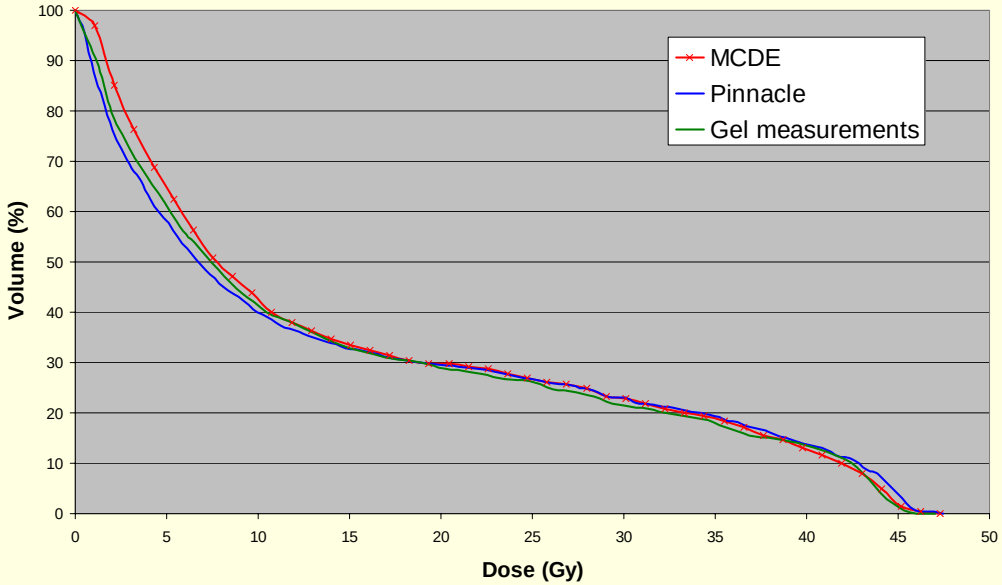


IMAT: Gel dosimetry (Y. De Deene et al)

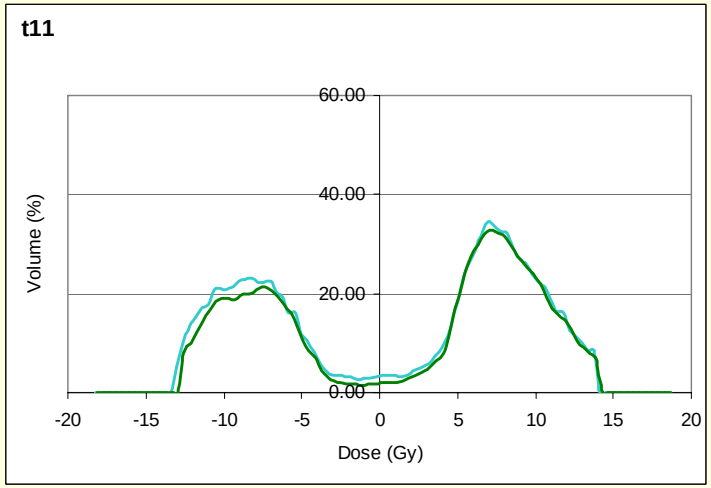


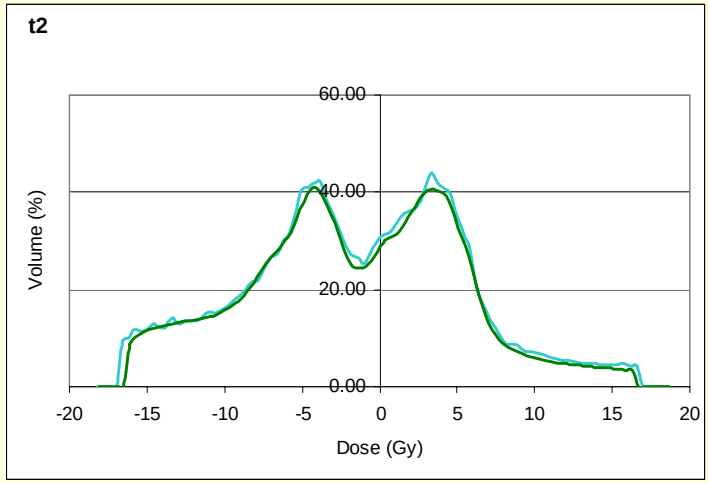
IMAT (bladder, small bowel)

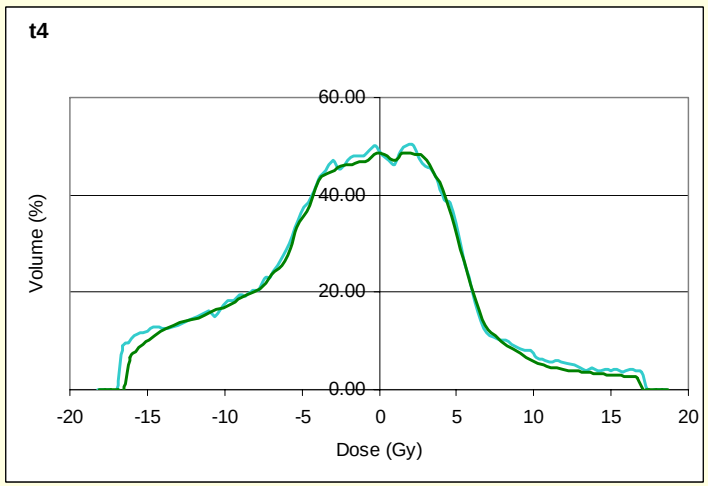


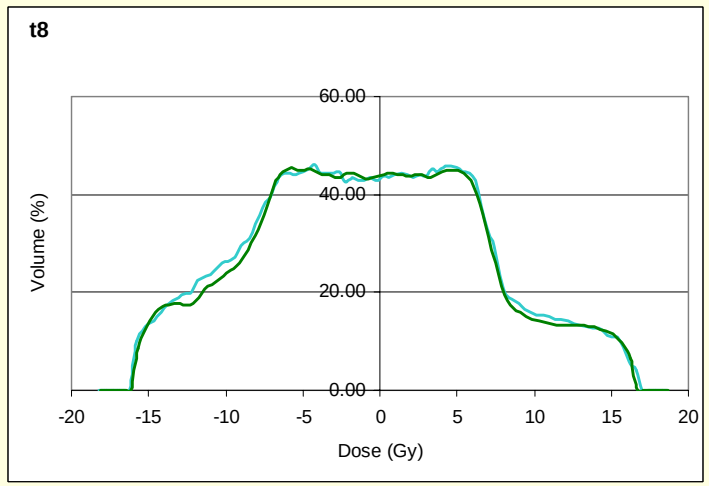


IMAT: dose profiles









Projects

- Introduce MCDE as a “standard” in LSDG for Belgium and the Netherlands (QA service)
- Euramet project proposal: 3D dosimetry for state of the art treatment modalities: ensuring traceability of MC dose engines

Experimental benchmarking techniques

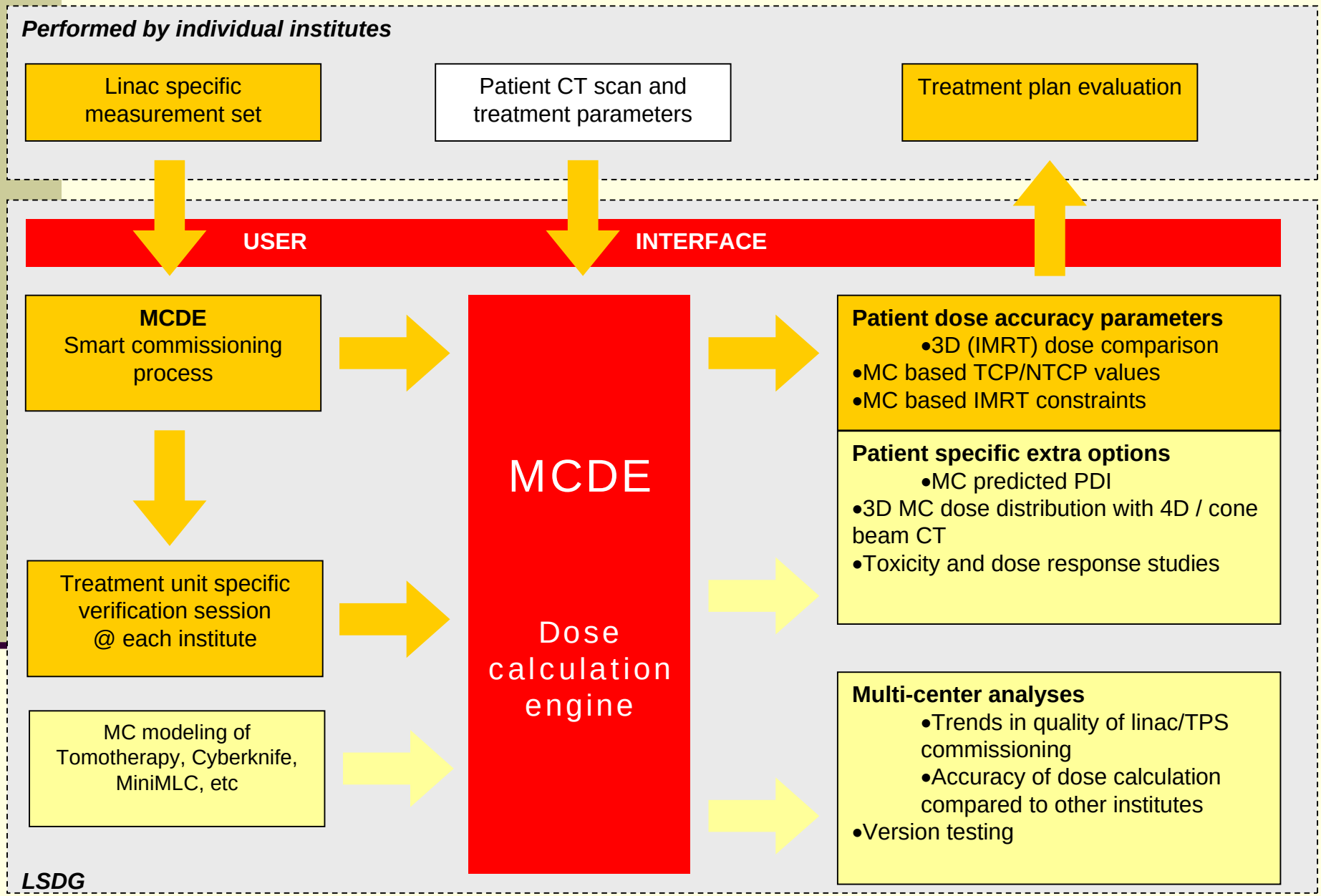
- MU checks in one point:
  - ion chambers: ESTRO Quasimodo project, FCCC (Ma et al)
  - alanine (e.g. NPL)
  - fricke (e.g. LNHB)
  - TLD
- 3D dosimetry: Gel dosimetry, film dosimetry: accuracy 3 % / 3 mm

But, What about ….

- Experimental techniques are not patient specific (phantom)
- Is accuracy good enough to decide on TP system ?
- For ion chamber point measurements, MC needed for correction factors
- Tissue equivalence

MC 3D dose verification

- Patient specific 3D dosimetry verification of treatment plan
- Accurate linac modelling (start from database)
- CT calibration
- Interfacing (collaboration TP vendors)
- Traceability !
- Network !
- Establishment large database: post treatment follow-up


Performed by individual institutes
Linac specific measurement set
Patient CT scan and treatment parameters
Treatment plan evaluation
USER INTERFACE
MCDE
Smart commissioning process
Treatment unit specific verification session @ each institute
MC modeling of Tomotherapy, Cyberknife, MiniMLC, etc
MCDE
Dose calculation engine
Patient dose accuracy parameters
•3D (IMRT) dose comparison
•MC based TCP/NTCP values
•MC based IMRT constraints
Patient specific extra options
•MC predicted PDI
•3D MC dose distribution with 4D / cone beam CT
•Toxicity and dose response studies
Multi-center analyses
•Trends in quality of linac/TPS commissioning
•Accuracy of dose calculation compared to other institutes
•Version testing
LSDG

In vivo ?

- EPID → MC based 3D dose reconstruction
- Cone beam CT data → input for MC dose engine

Summary

- Accurate/well tuned MC dose engines can be a powerfull tool for QA of radiotherapy treatment planning
- Not to replace measurements, but to complement them !
- Traceability/network necessary → standard labaratories

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- EWG-MCTP: M. Chin, M. Fippel, M. Fix, A. Leal, G. Lewis, G. Mora, J. Seco, J. Sempau, M. Soukup, E. Spezi

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