Applications of Geant4 in Proton Radiotherapy at the University of Texas M.D. Anderson Cancer Center

THE UNIVERSITY OF TEXAS MD ANDERSON CANCER CENTER

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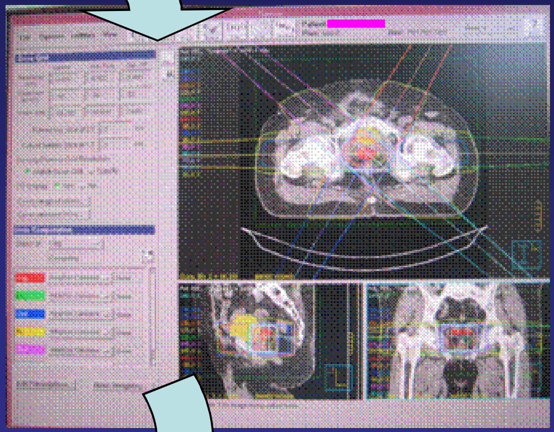
Uses of Monte Carlo

- Clinical Uses in Radiation Oncology
  - X-ray radiotherapy
  - Proton beam radiotherapy
- Research Activities
  - Proton radiotherapy
- Current “challenges” for Geant4

Clinical Workflow of Radiotherapy

CT images imported to
Treatment Planning System (TPS)

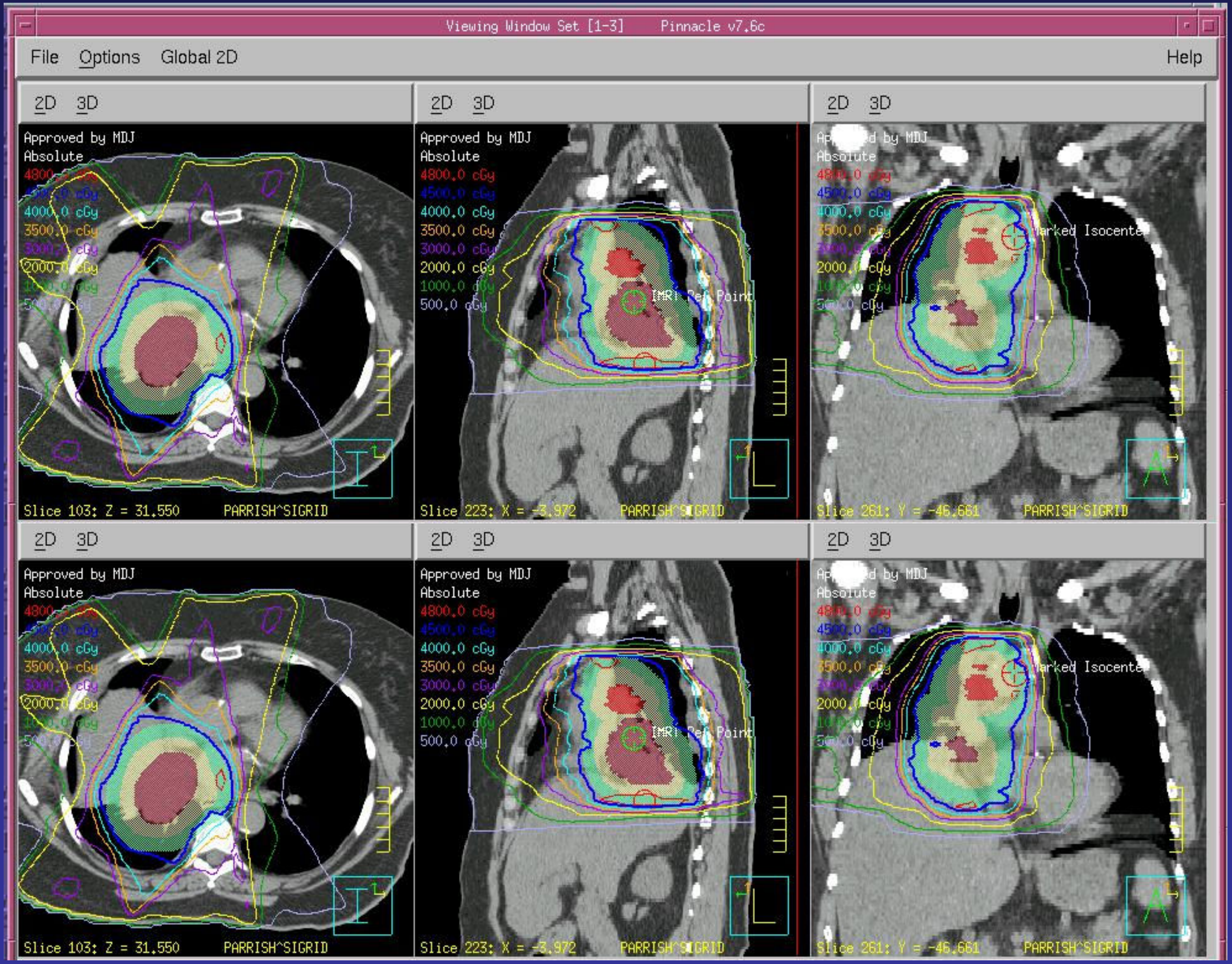
All parameters for dose delivery determined by TPS



All parameters sent
to proton delivery system
for patient treatment.

Applications of Monte Carlo in Radiotherapy

X-Ray Therapy

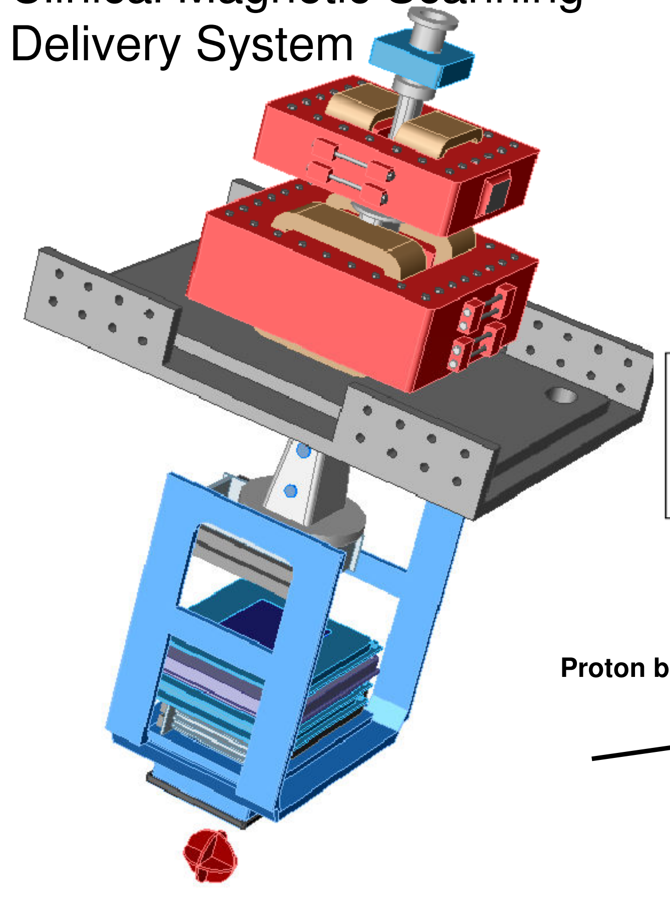


Treatment Planning System

Monte Carlo

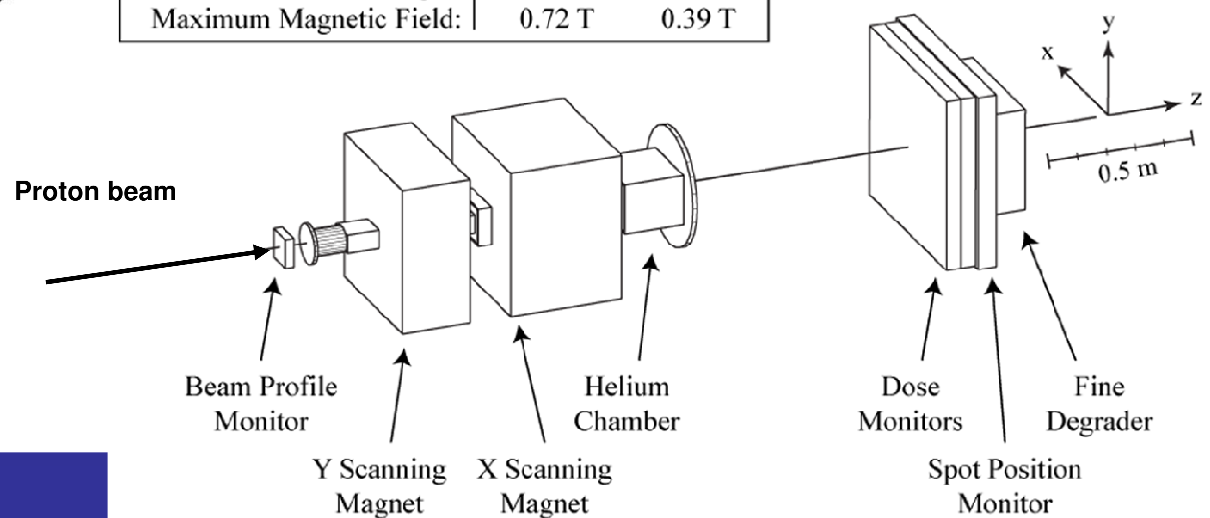
Applications of Monte Carlo in Proton Therapy

Clinical Magnetic Scanning Delivery System



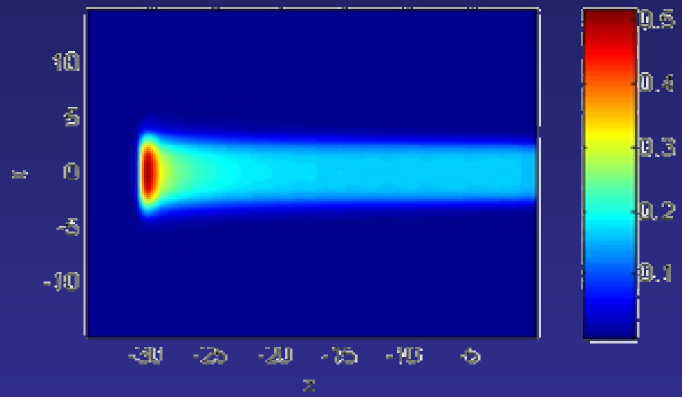
Use Monte Carlo to model treatment delivery equipment and calculate dose delivery (protons + secondary particles)

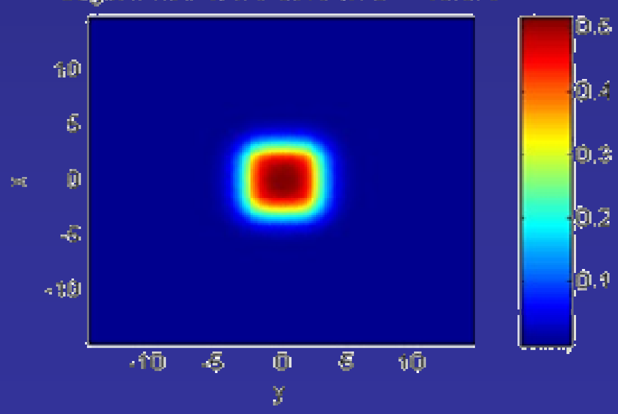
Scanning Magnet Specifics	Y Magnet	X Magnet
Distance to Isocenter:	263.85 cm	211.30 cm
Effective Pole Length:	23.3 cm	38.4 cm
Maximum Magnetic Field:	0.72 T	0.39 T



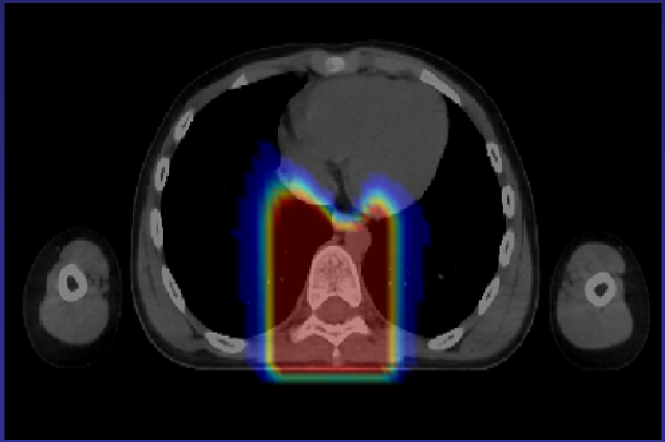
Applications of Monte Carlo in Radiotherapy

Simple Calculations of
Dose in water





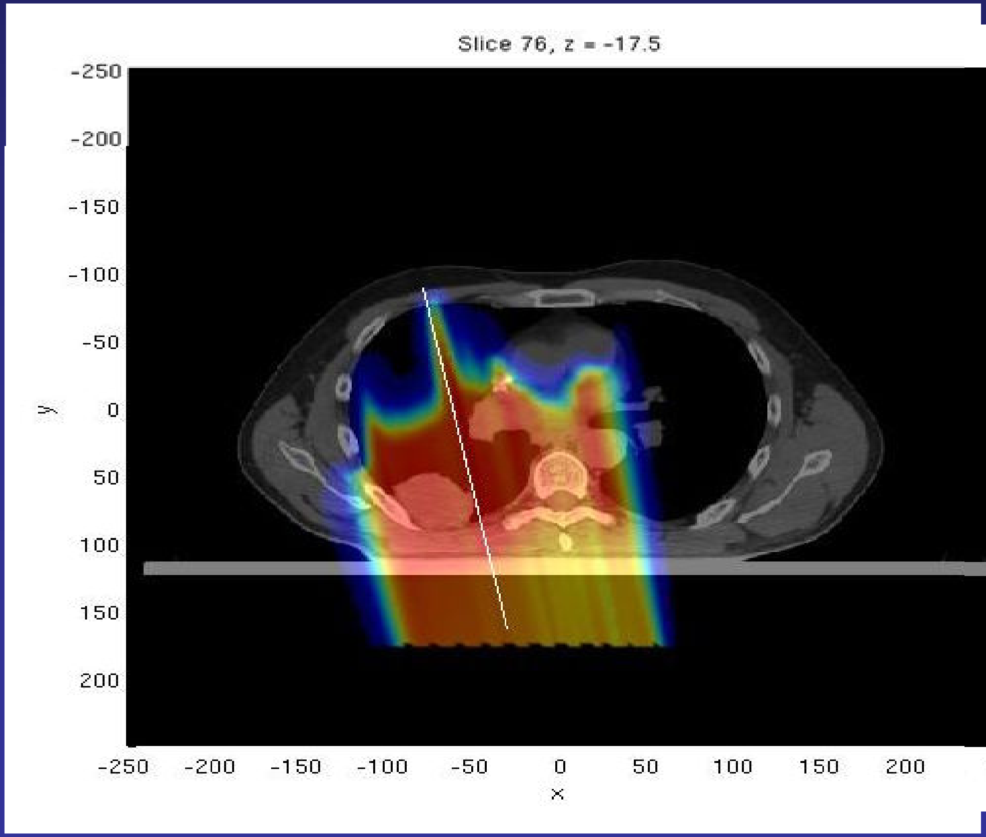
Clinical calculations of dose
in patient



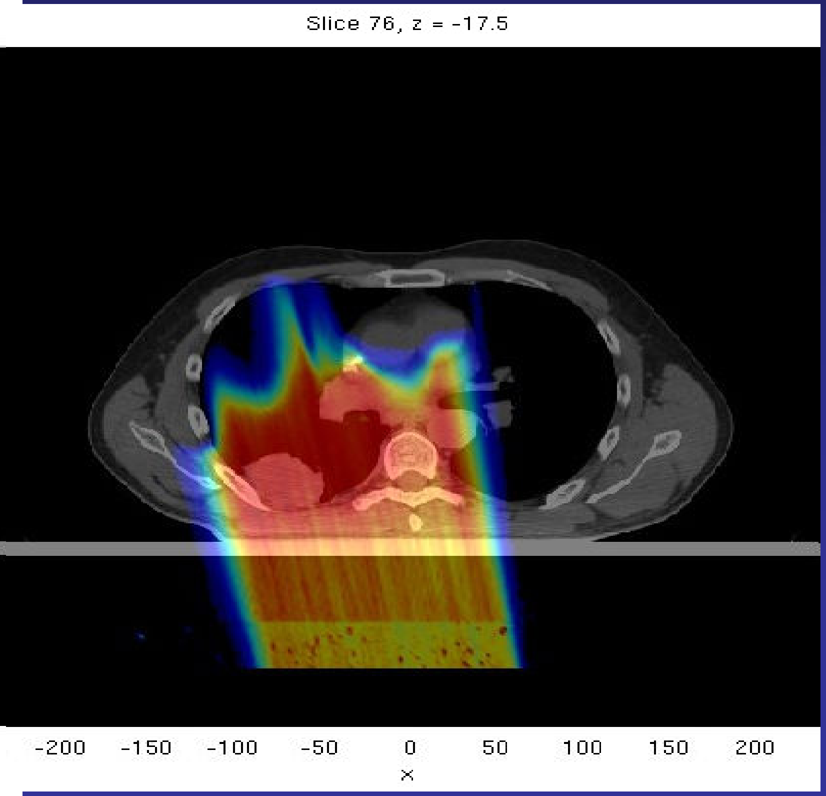
Clinical Uses: Proton therapy

- Use Monte Carlo (Geant4 and MCNPX) to verify proton dose distribution calculated using TPS

TPS



Monte Carlo



Clinical Uses: Proton therapy

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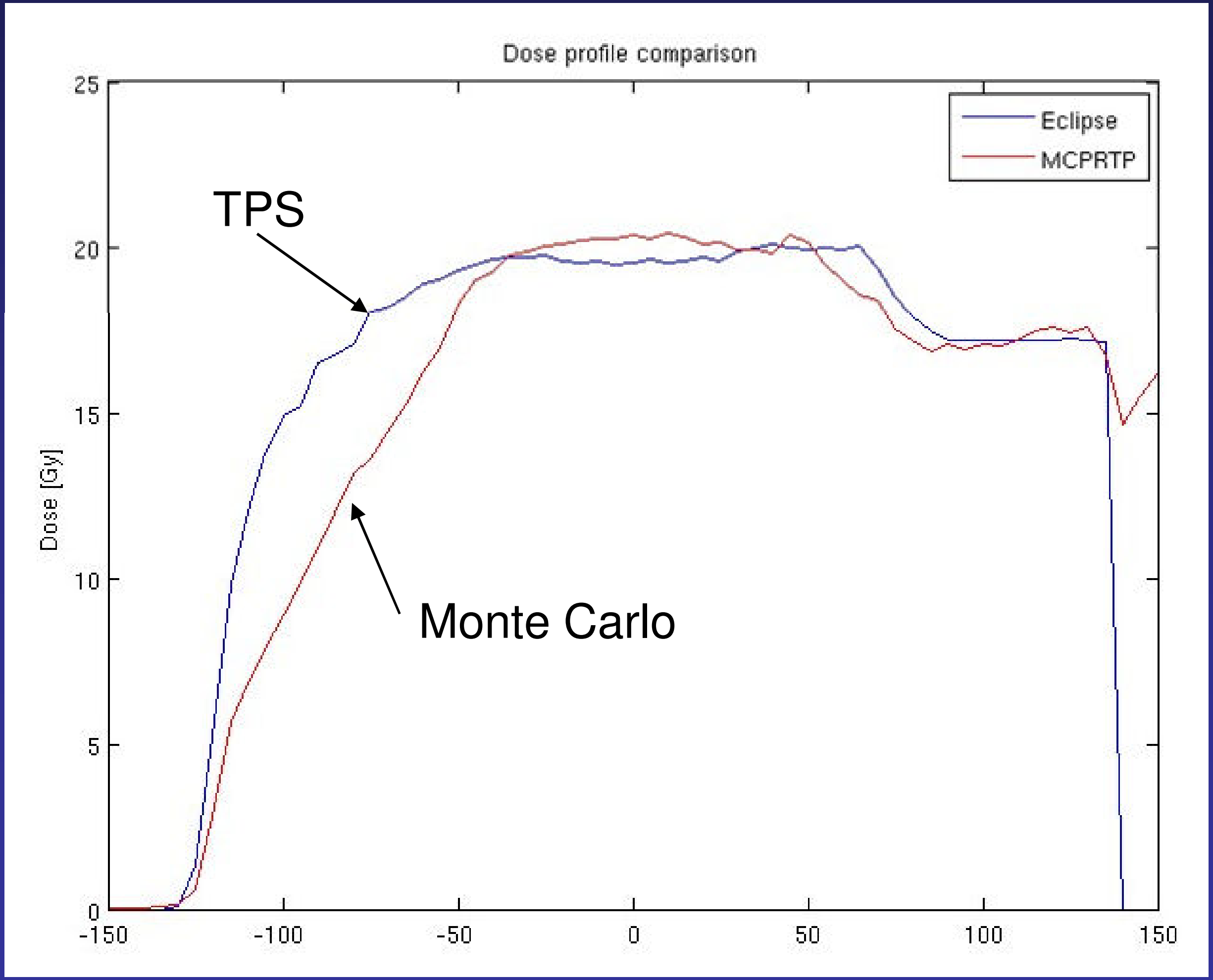
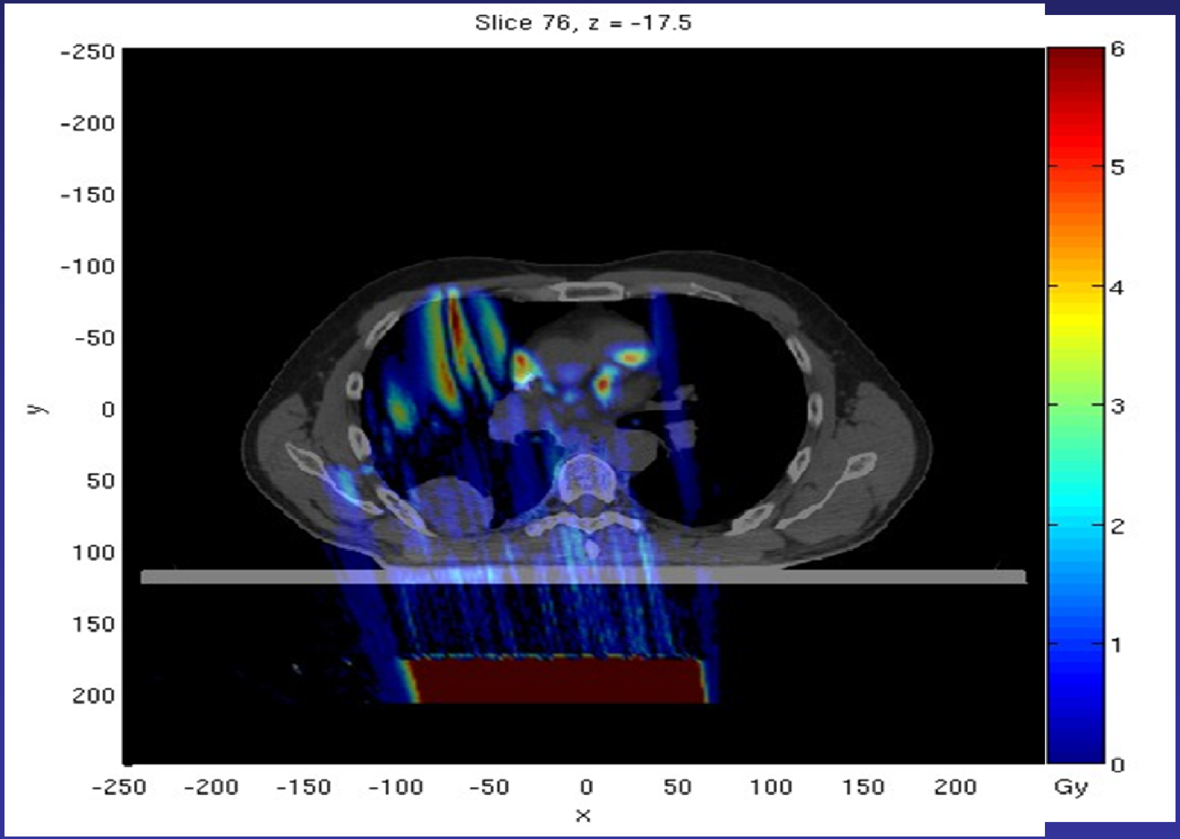


Clinical Uses: Proton therapy

- Use Monte Carlo (Geant4 and MCNPX) to verify proton dose distribution calculated using TPS

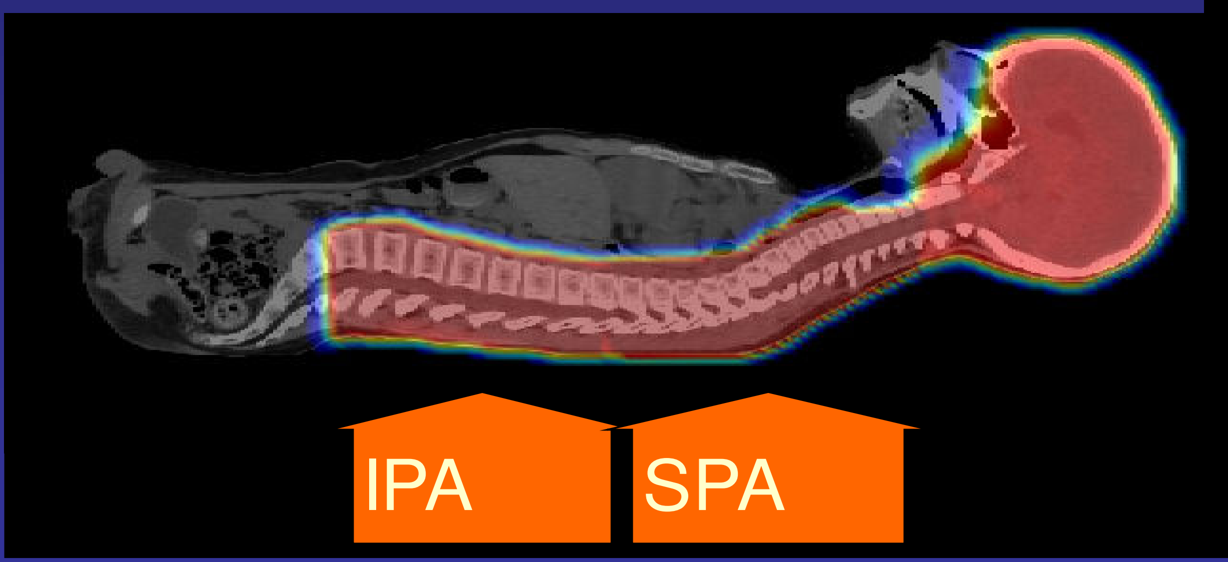
Dose difference = TPS – Monte Carlo

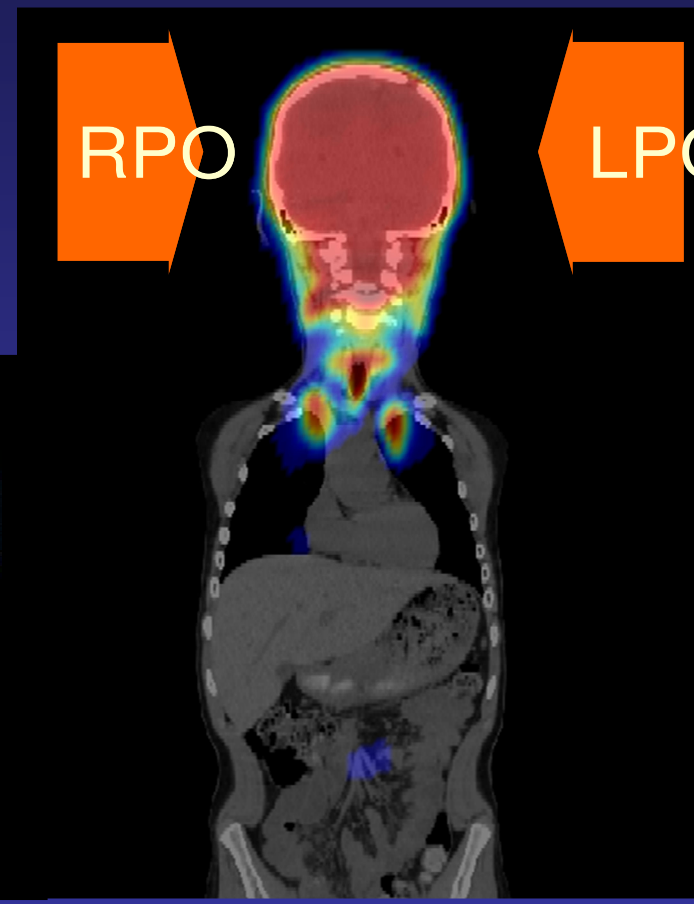


Clinical Uses: Proton Therapy

- Calculation of secondary neutron exposure for Pediatric treatments

- whole-body CT based calculation
- Four treatment fields



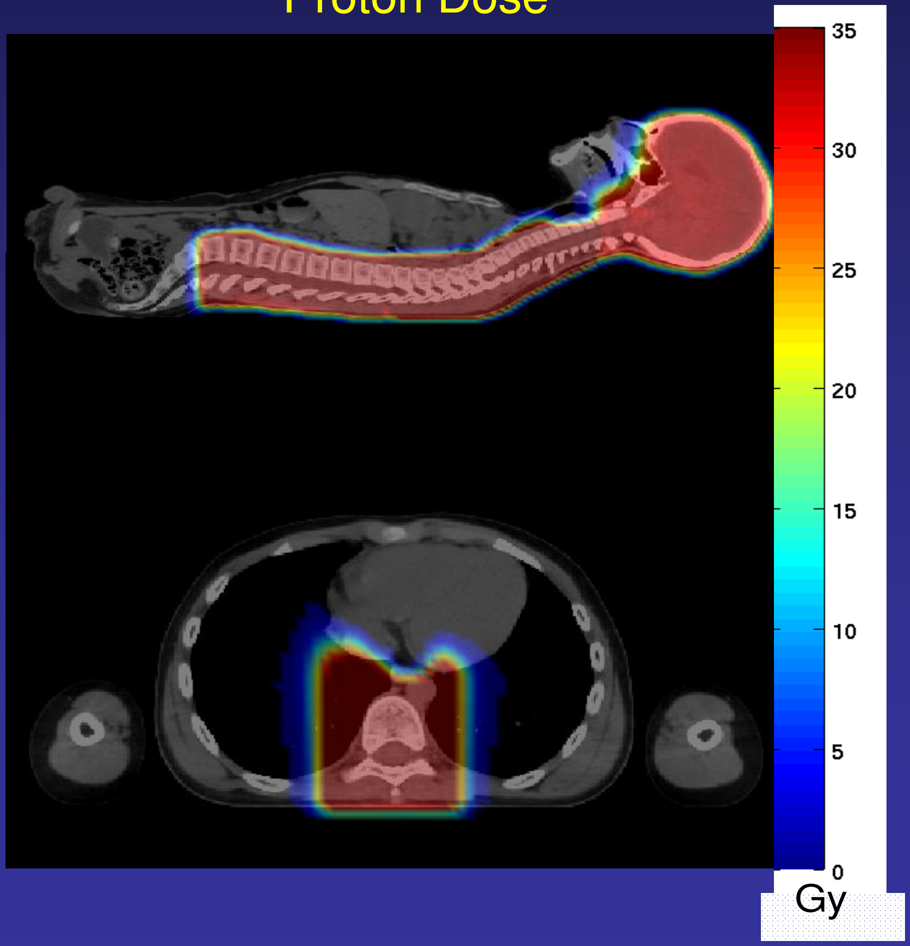


Taddei PJ et al. Phys Med Biol. 54(8):2259-75 (2009)

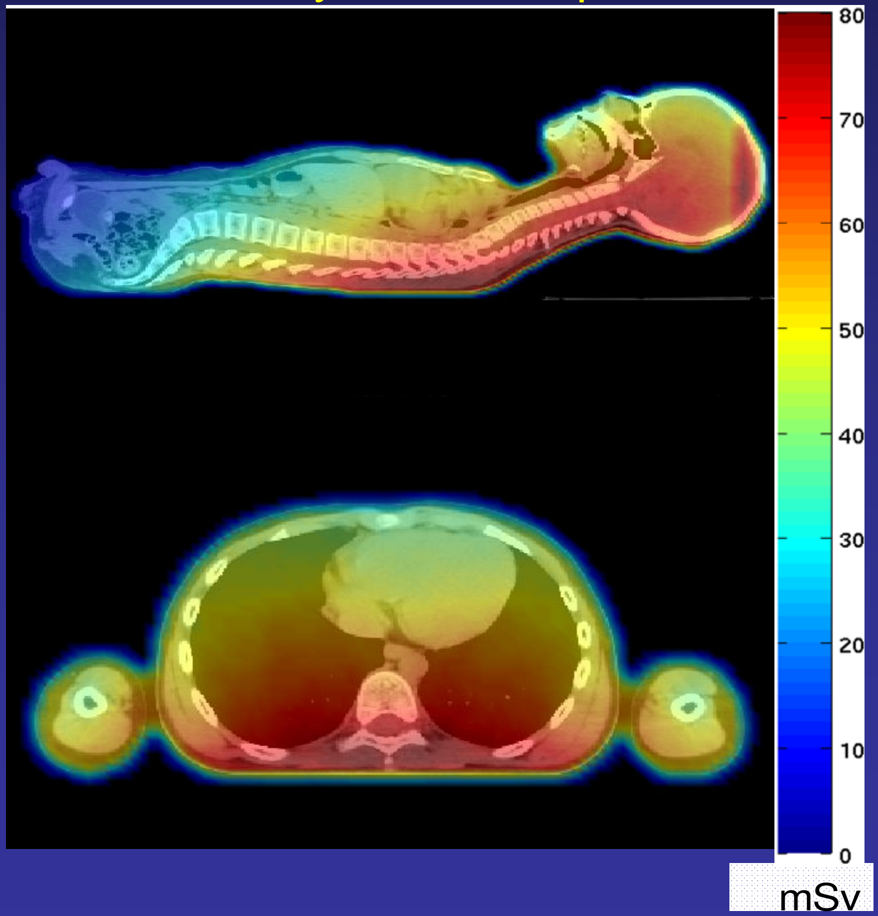
Clinical Uses: Proton therapy

- Calculation of secondary neutron exposure for Pediatric treatments

Proton Dose



Secondary neutron exposure

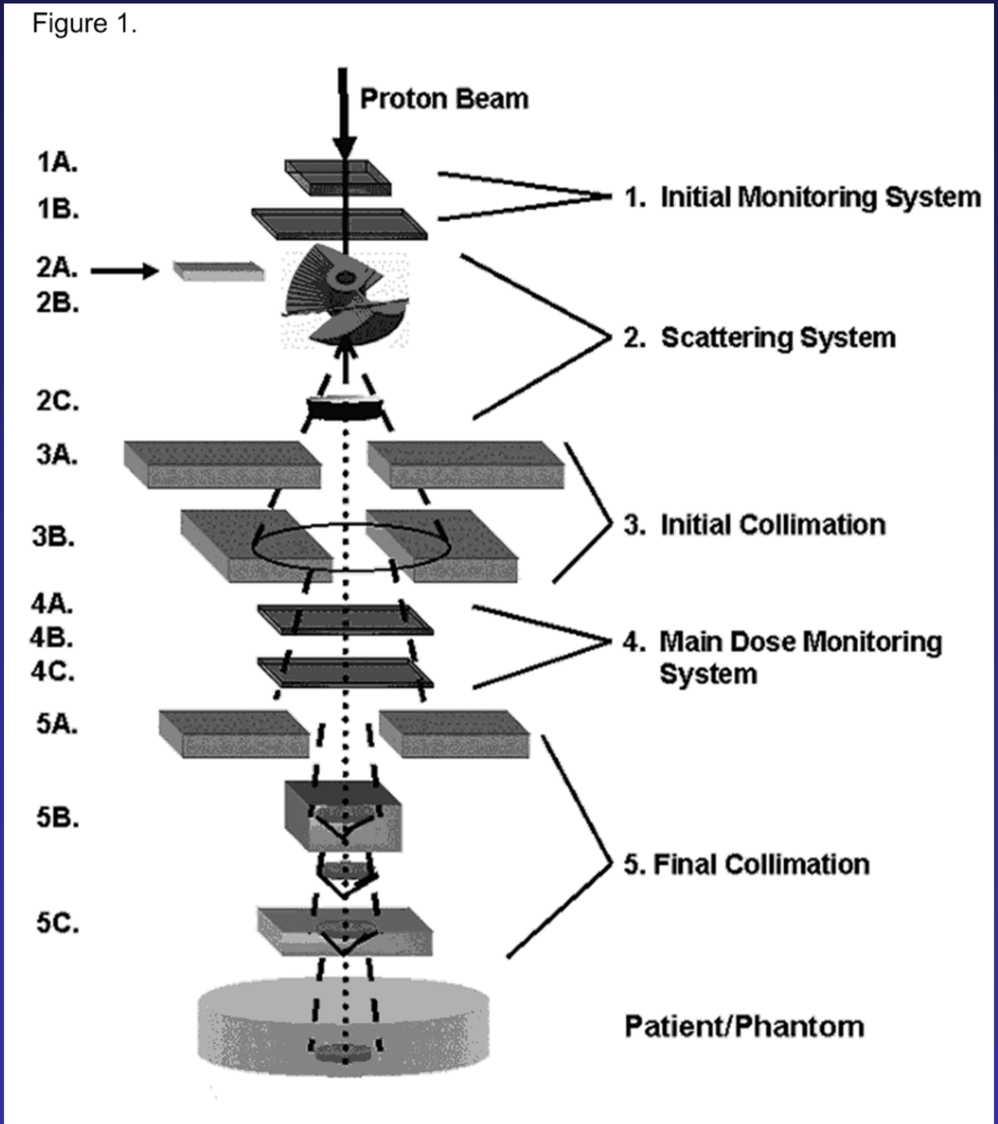


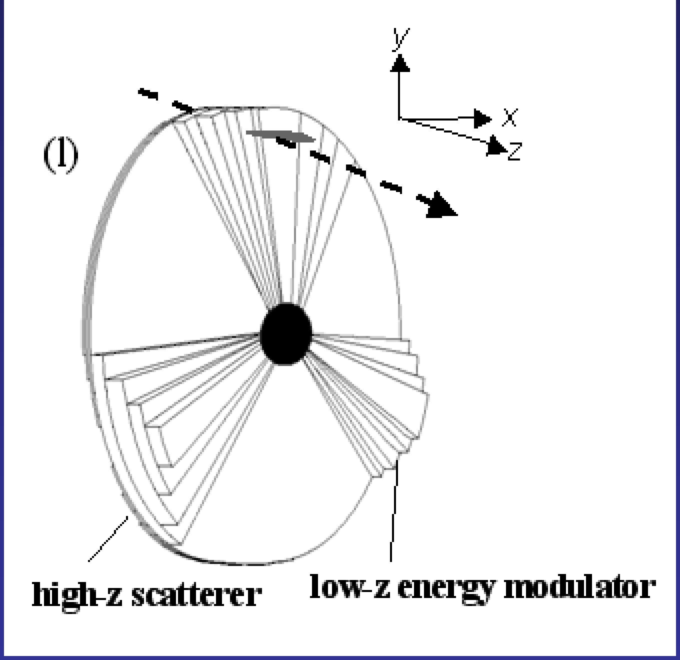
Research applications at MDA

- Treatment System Design
- Development of verification methods
- New techniques for beam delivery

Research: Treatment Nozzle Design

Improvements to existing treatment nozzles

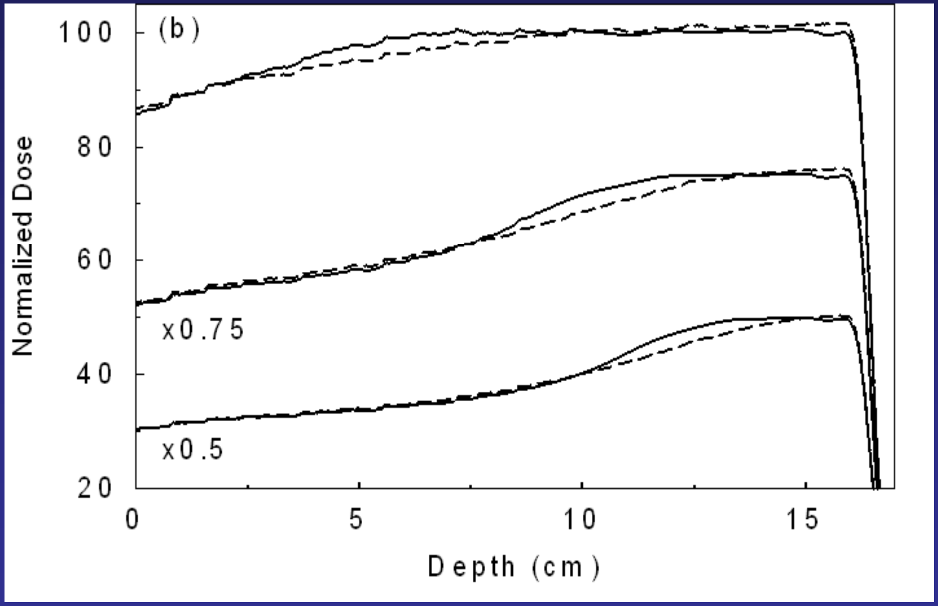


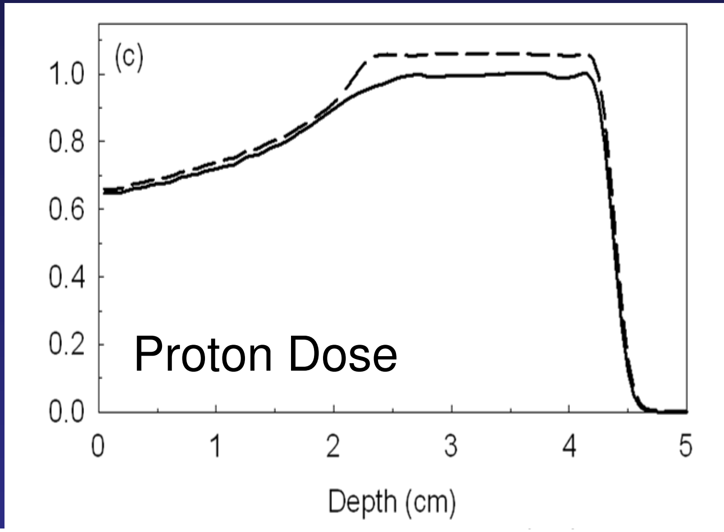


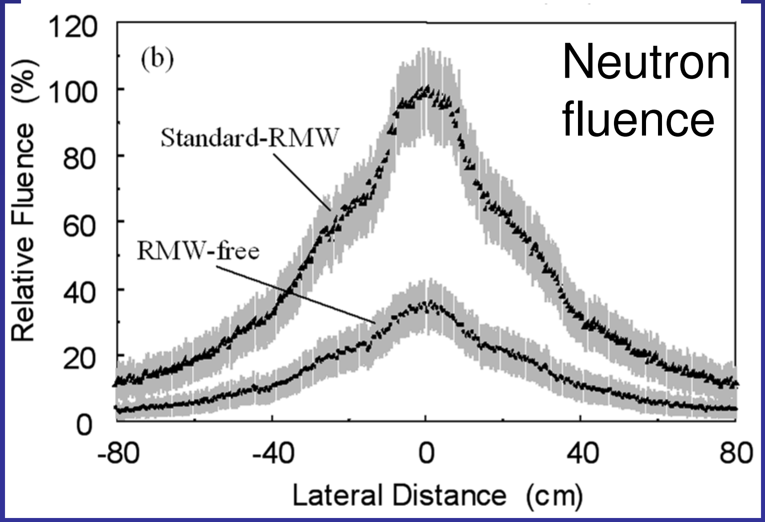
Research: Treatment Nozzle Design

If we Remove RMW?

If initial beam size changes?







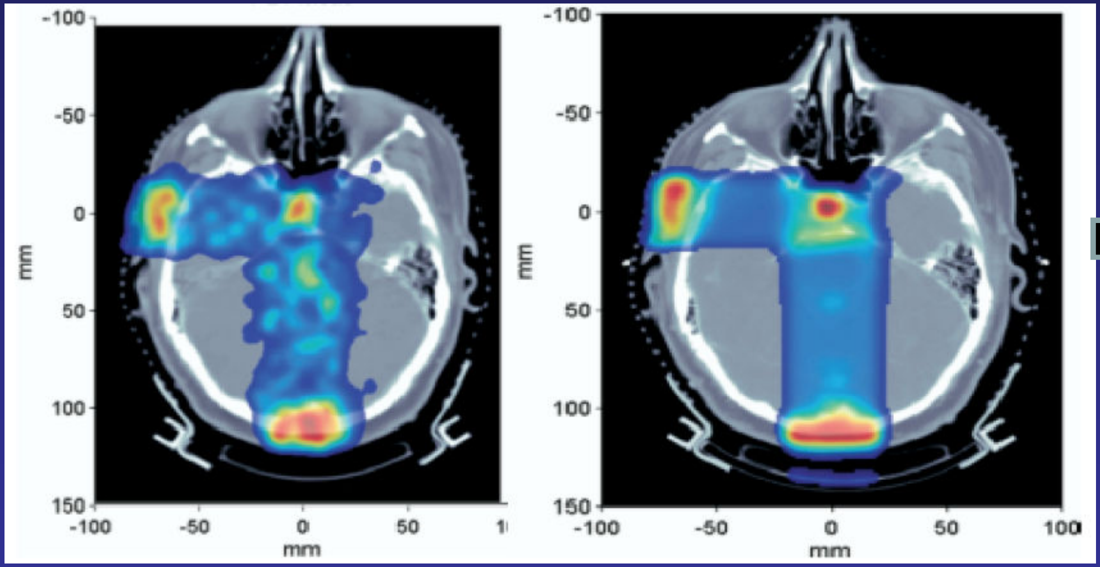
Research: New Imaging Techniques

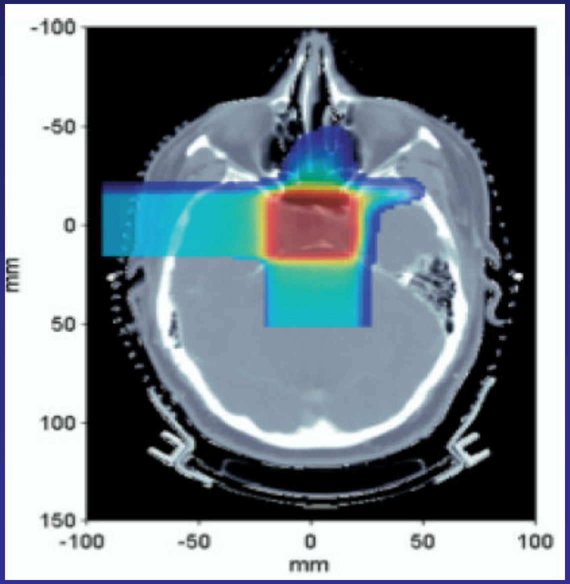
In-vivo Dose verification with Post treatment PET imaging

(1) Measure post treatment PET activation

(2) Monte Carlo calc of post treatment PET activation

(3) Estimate in vivo Dose distribution



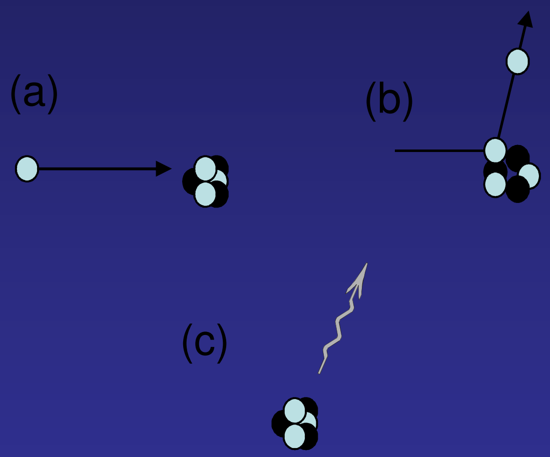


Parodi K *et al.* (2007) *Med. Phys.* 2007a;34:419-435.

Parodi K *et al.* (2007) *Int. J. Radiat. Oncol. Biol. Phys.* 68 920-934.

Research: New Imaging Techniques

In-vivo Dose verification with Prompt Gamma ray Imaging

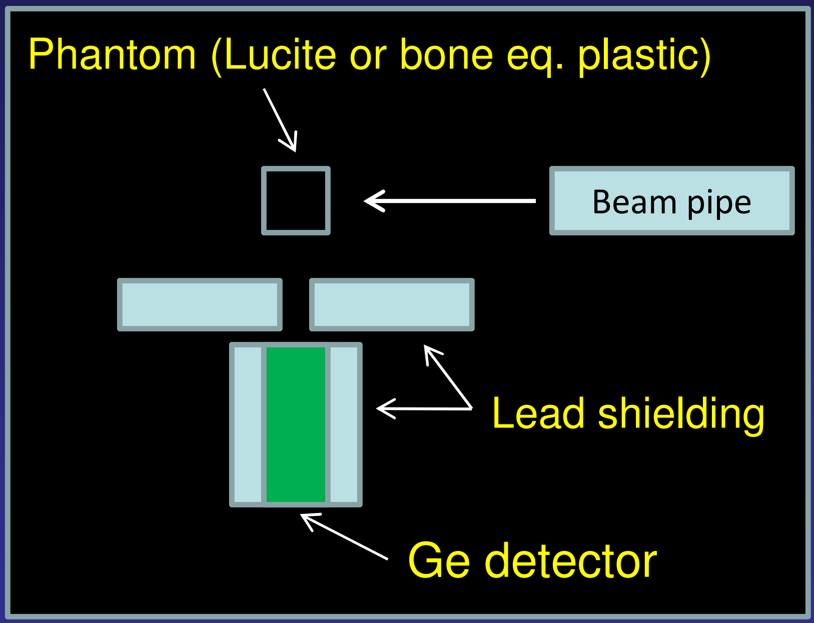


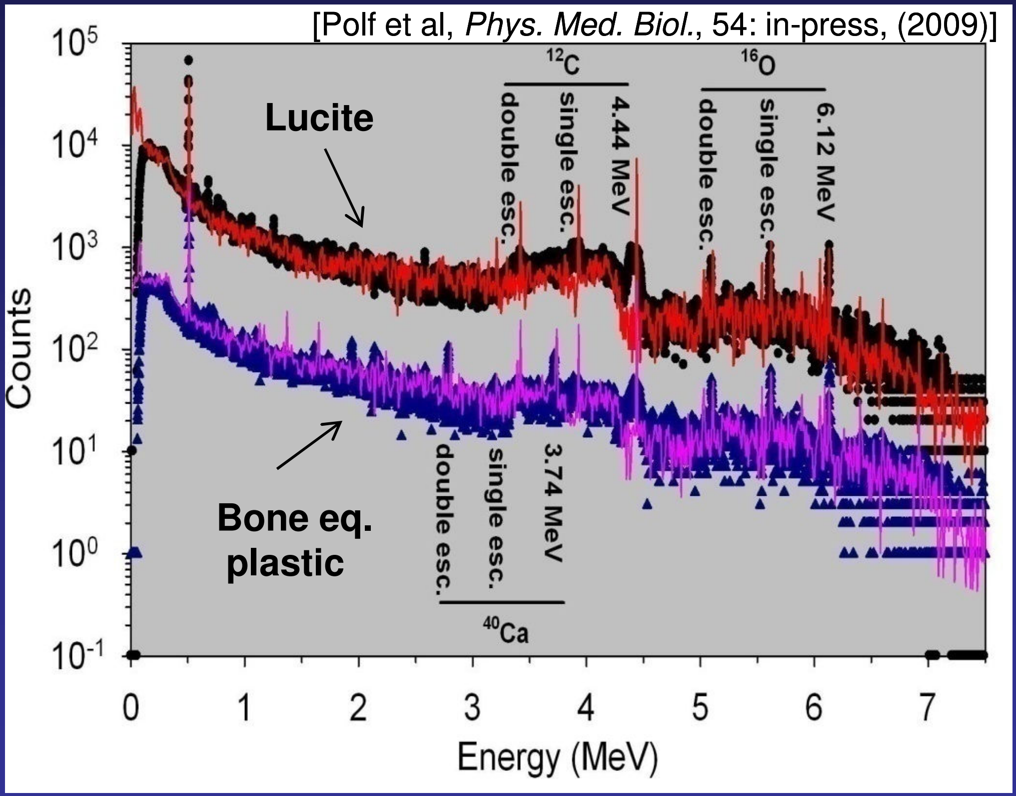
- Measure *Prompt* Gamma Ray Emission
  - Inelastic scattering [$A(p, p' \gamma)A$]
  - i.e. – “real-time” signal
  - each element emits characteristic gamma-rays with different energies
  - gamma rays only emitted where dose is deposited

Hypothesis: By properly measuring prompt gamma ray emission, we can images dose deposited and of elemental concentration and composition of irradiated tissues.

Research: New Imaging Techniques

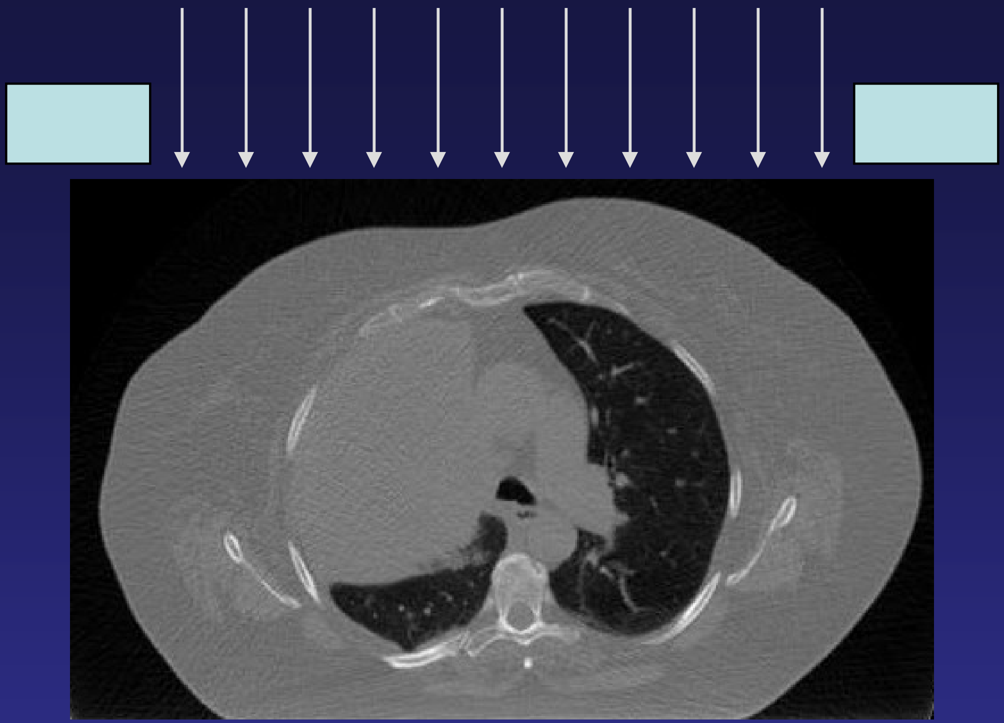
In-vivo Dose verification with Prompt Gamma ray Imaging

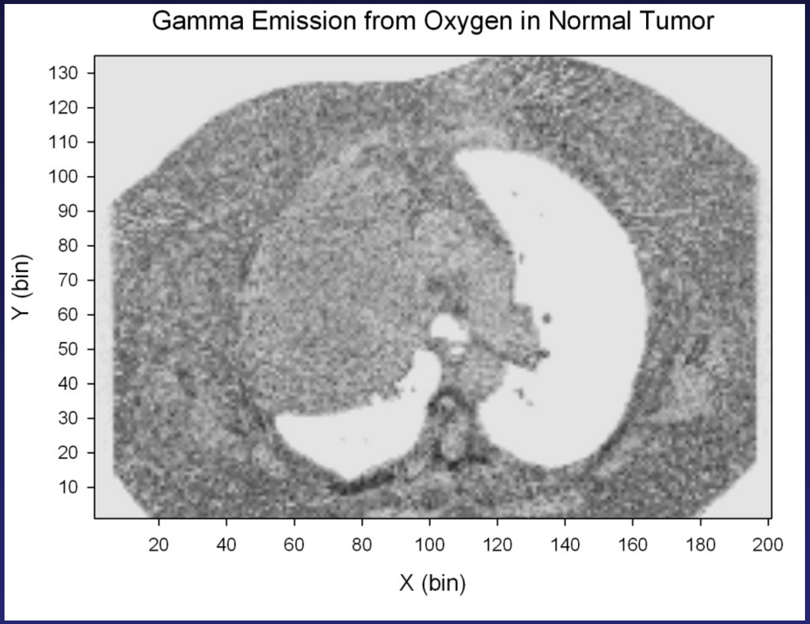


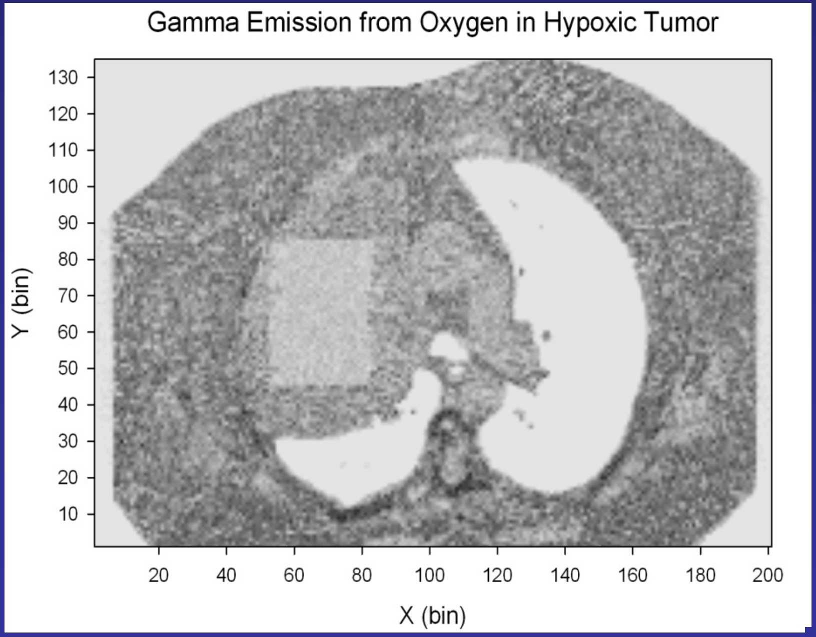


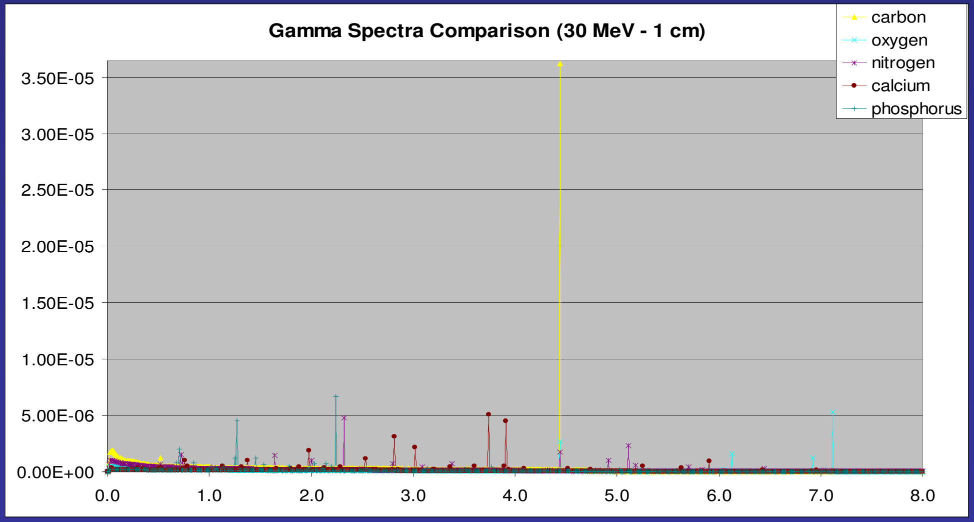
- Measurements (symbols)
- Geant4 Monte Carlo calculations (lines)
- tally energy dep. from Photo-electric, Compton, Pair Production in detector

Proton Beam




Gamma Emission from Oxygen in Normal Tumor
Y (bin)
X (bin)


Gamma Emission from Oxygen in Hypoxic Tumor
Y (bin)
X (bin)

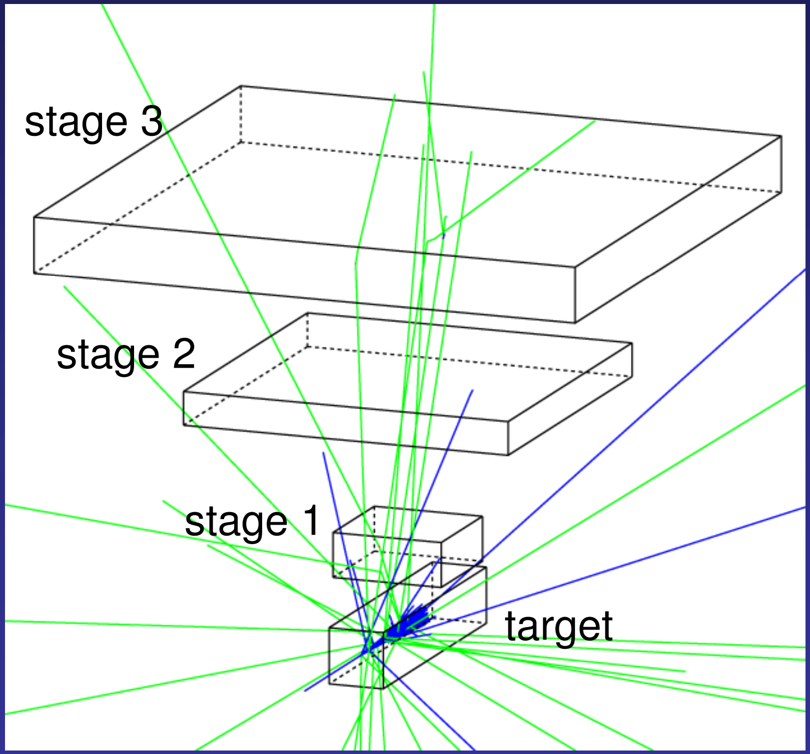

Gamma Spectra Comparison (30 MeV - 1 cm)
carbon
oxygen
nitrogen
calcium
phosphorus

Research: New Imaging Techniques

Prompt gamma imaging studies: Compton Camera Design

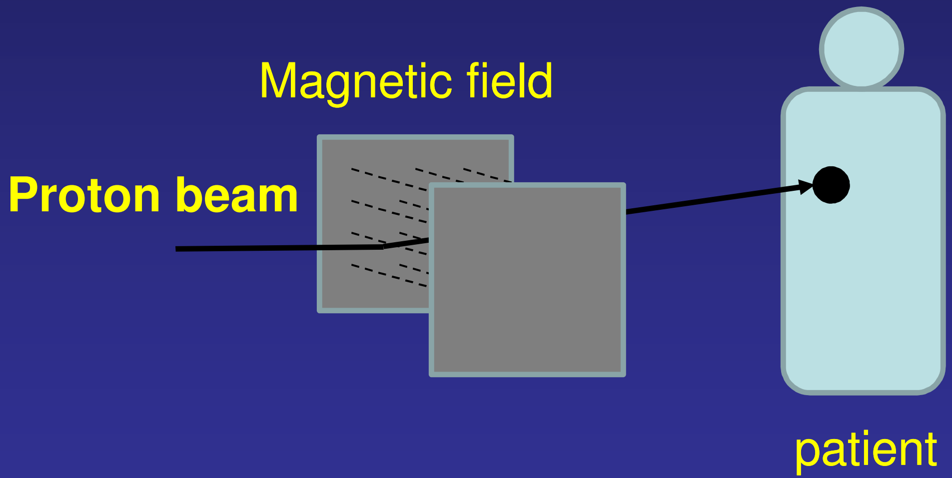
Design studies to optimize efficiency:

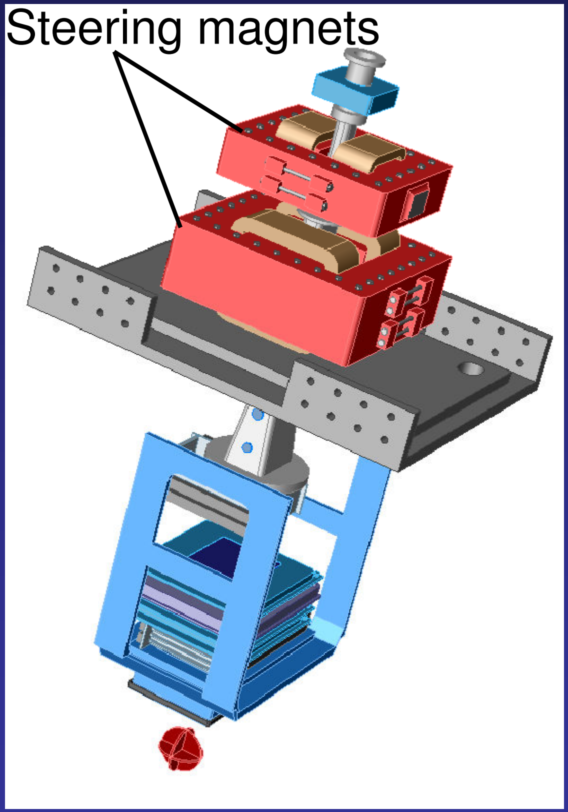
- triple scatters/proton
- Compton scattering
- detector material
- detector shape



Research: New Treatment Techniques

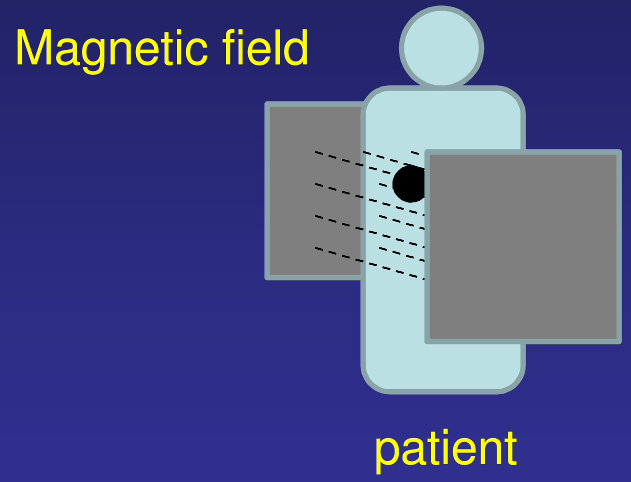
Feasibility studies of in-vivo magnetic steering

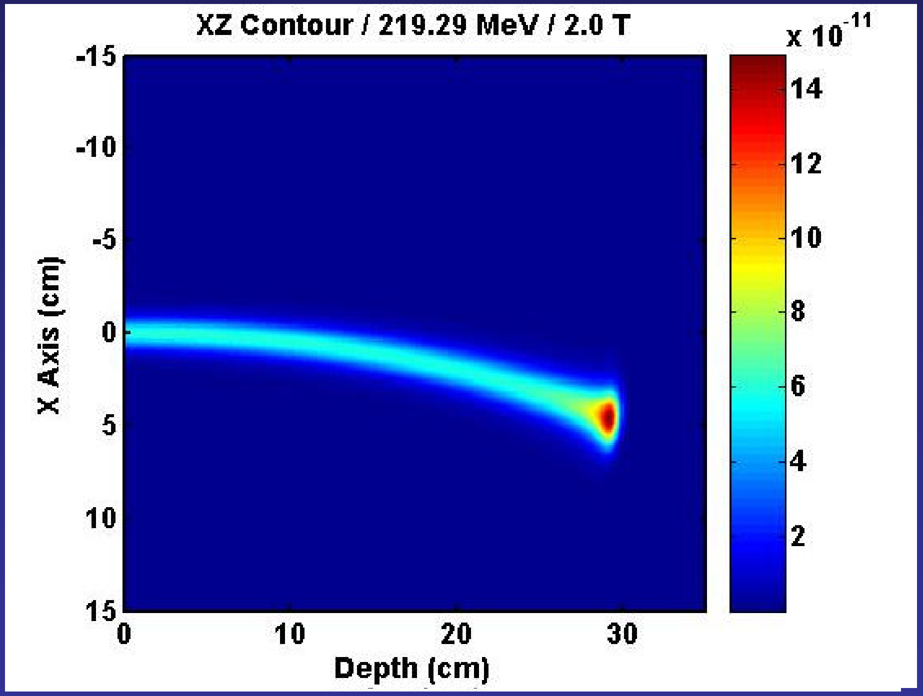




Research: New Treatment Techniques

Feasibility studies of in-vivo magnetic steering





Challenges and Limitations of Monte Carlo in Radiation Oncology

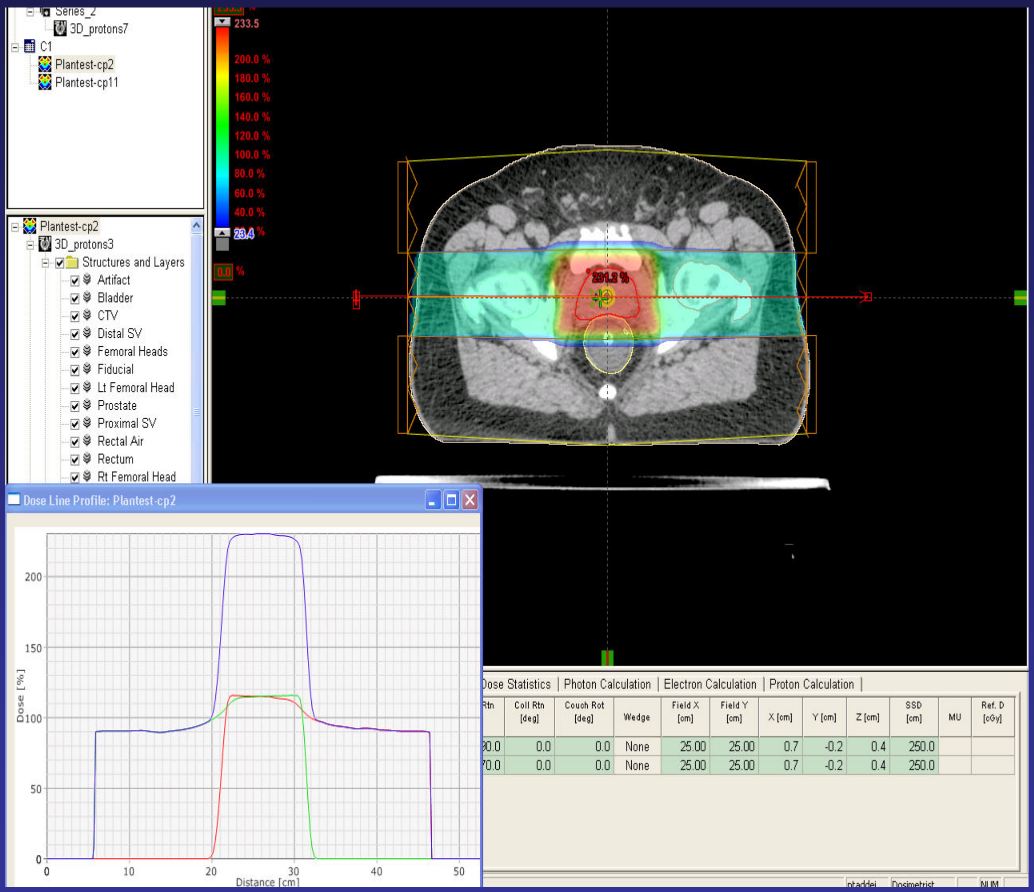
Clinical Issues

- Calculations in patient CT data

Research issues

- Disagreement with measured data
- modeling of nuclear processes

Challenges and Limitations: Clinical Issues



Clinical TPS:

- calculate patient dose < 1 min
- uses Analytical calculation algorithms

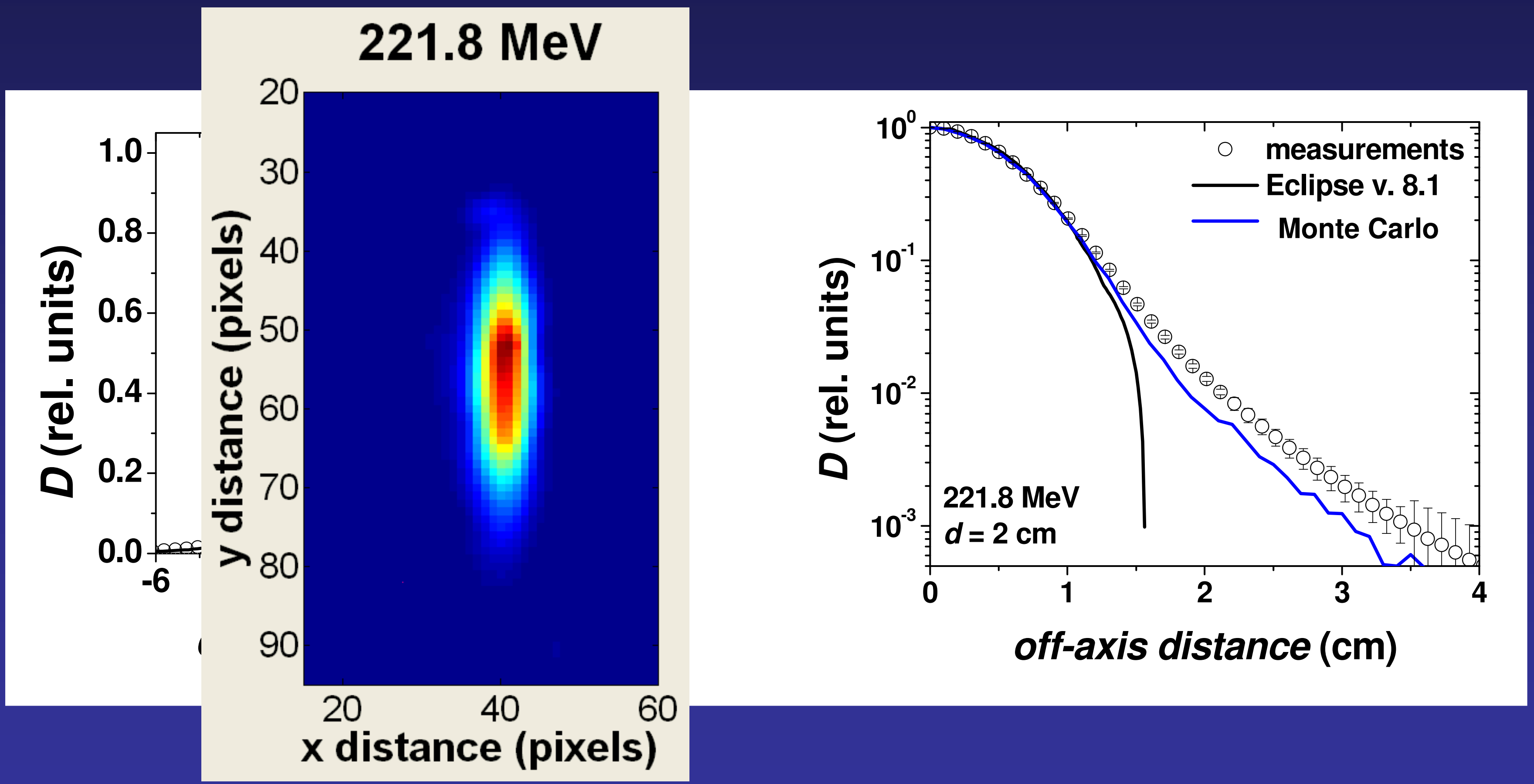
Why not Monte Carlo?

-MC calcs too slow in CT data

- greater than 5 hrs to calculate a full patient treatment plan!!

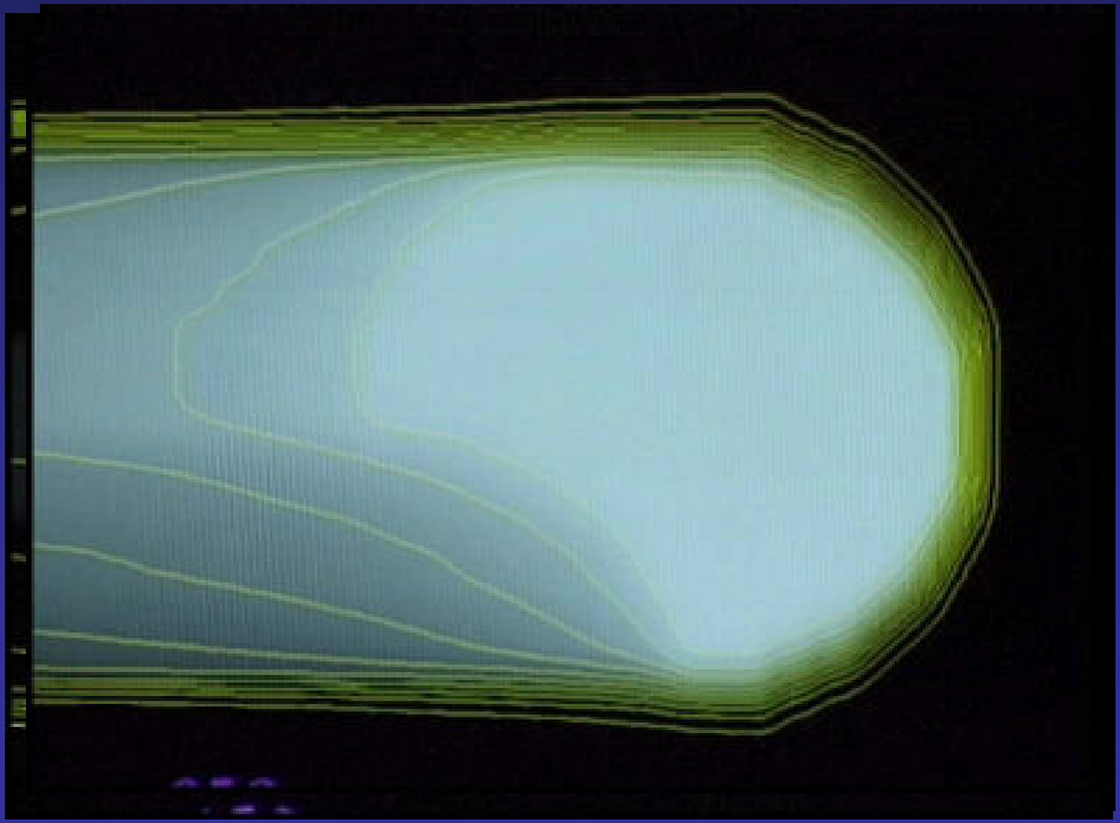
Challenges and Limitations: Clinical Issues

Magnetic Beam Scanning: Dose calculation accuracy



Challenges and Limitations: Clinical Issues

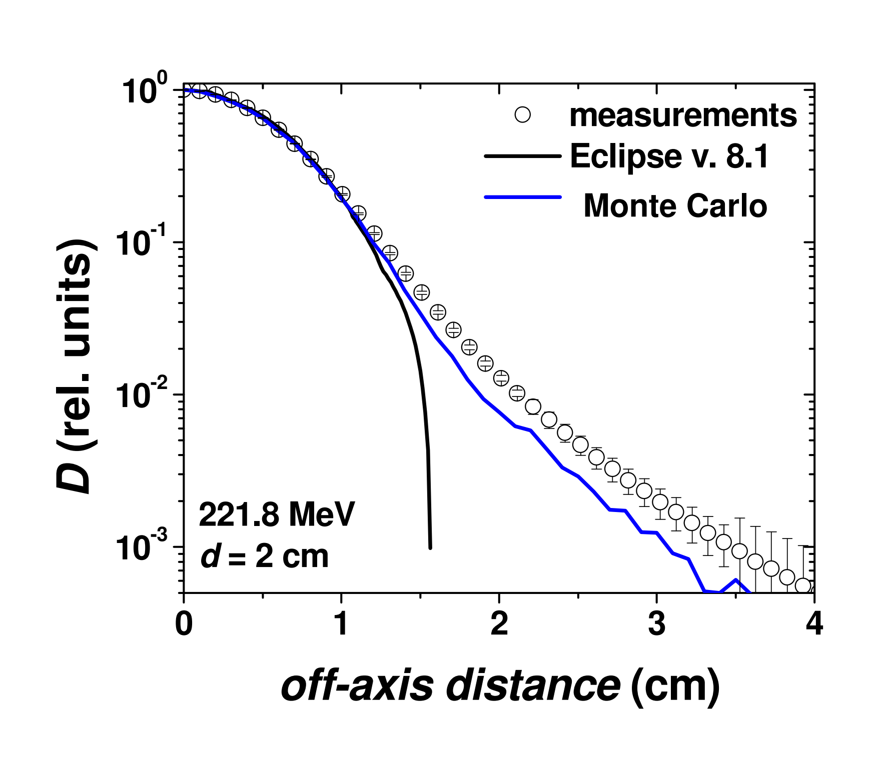
Magnetic Beam Scanning: Dose calculation accuracy



A full set, with a homogenous dose conformed distally *and* proximally

Pedroni, PSI

Challenges and Limitations: Clinical Issues

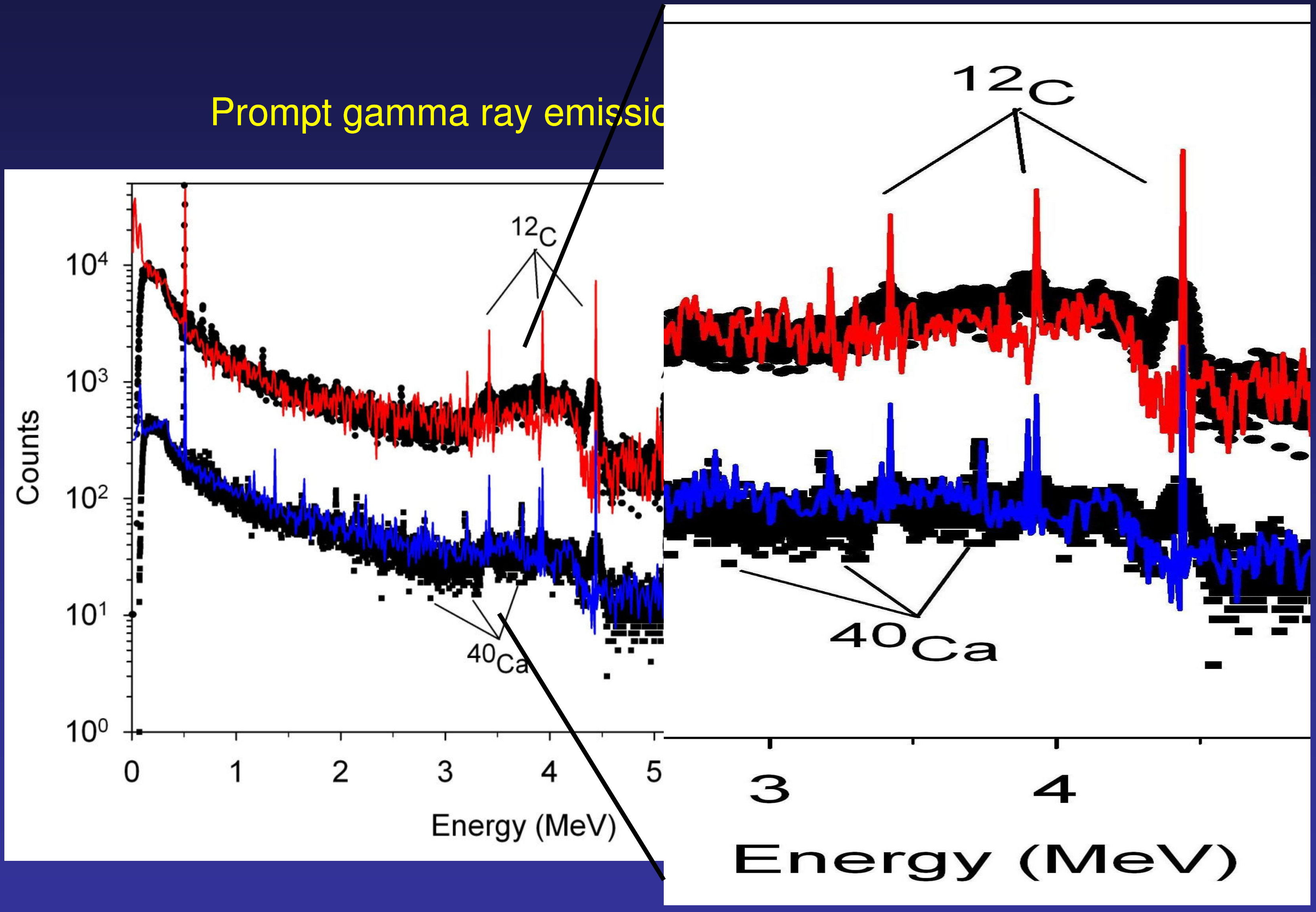


1 spot:
Difference < 0.1 percent

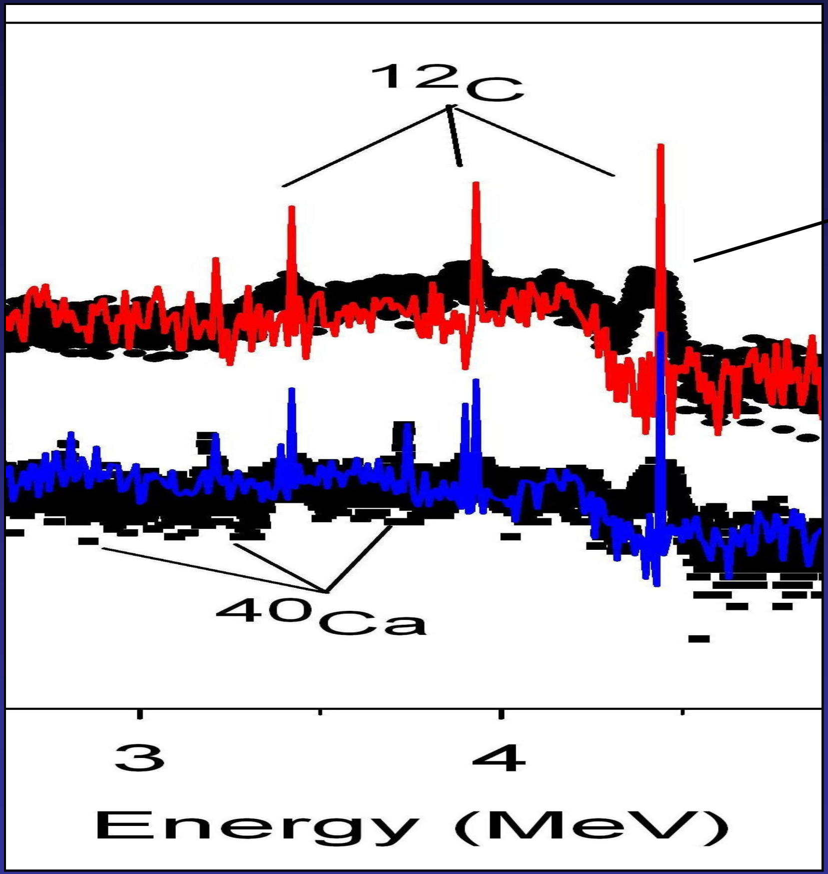
10,000 spots:
Difference > 5 percent

Challenges and Limitations: Clinical Issues

Prompt gamma ray emissio



Challenges and Limitations: Clinical Issues



Nuclear Doppler Broadening Of the 4.44 Mev ^{12}C peak.

- Excellent modeling of Doppler Broadening for low energy x-rays

- However, no modeling for Nuclear Broadening

Conclusions on Monte Carl in Proton Therapy

- Geant4 is integral part in Clinical activities
  - treatment planning and verification
- Integral in research activities
  - equipment design
  - new treatment techniques
- Still some challenges
  - calculations in CT datasets
  - proton-nuclear interaction models?

Thank You!

Questions?