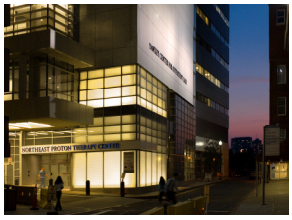
Accuracy of Proton Dose Computation Algorithms and Need for Improvements

Monte Carlo



H. Paganetti PhD
Associate Professor of Radiation Oncology, Harvard Medical School
Director of Physics Research, Massachusetts General Hospital, Department of Radiation Oncology

Monte Carlo *Introduction*

Why Monte Carlo ?

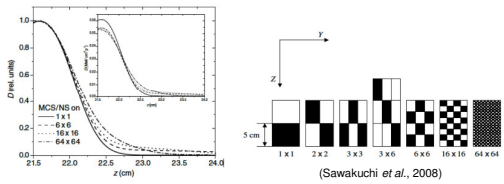
- Monte Carlo dose calculation should be more accurate compared to analytical dose calculation, in particular in complex geometries
- Differences between Monte Carlo and analytical algorithms can be more clinically significant in proton therapy compared to photon therapy due to higher dose gradients and the end of range of proton beams
- Monte Carlo can be used to predict quantities other than dose (fluence, LET, …) for research

Monte Carlo *Introduction*

Source of range uncertainty in the patient	Range uncertainty
Independent of dose calculation:	
Measurement uncertainty in water for commissioning	± 0.3 mm
Compensator design	± 0.2 mm
Beam reproducibility	± 0.2 mm
Patient setup	± 0.7 mm
Dose calculation:	
Biology (always positive)	+ 0.8 %
CT imaging and calibration	± 0.5 %
CT conversion to tissue (excluding I-values)	± 0.5 %
CT grid size	± 0.3 %
Mean excitation energies (I-values) in tissue	± 1.5 %
Range degradation; complex inhomogeneities	- 0.7 %
Range degradation; local lateral inhomogeneities *	± 2.5 %

H. Paganetti: Range uncertainties in proton beam therapy and the impact of Monte Carlo simulations
Phys. Med. Biol. 57: R99-R117 (2012)

Monte Carlo *Introduction*

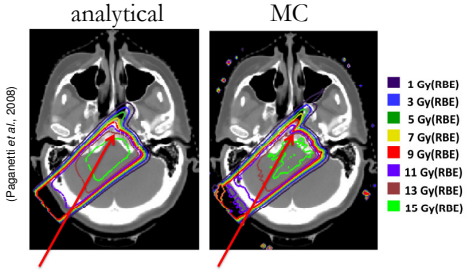


(Sawakuchi *et al.*, 2008)

range uncertainty for analytical dose calc. ~ -0.7%

Monte Carlo *Introduction*

analytical MC



range uncertainty for analytical dose calc. ~ ±2.5%

Monte Carlo *Introduction*

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Total (excluding *)	2.7% + 1.2 mm
Total	4.6% + 1.2 mm

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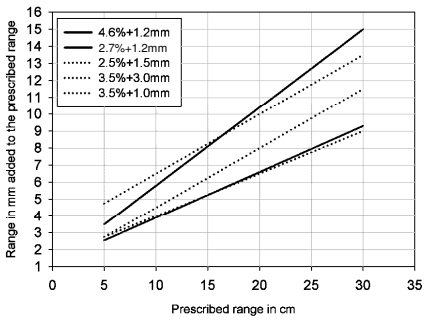
Monte Carlo *Introduction*

Applied range uncertainty margins for non-moving targets



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Monte Carlo *Introduction*

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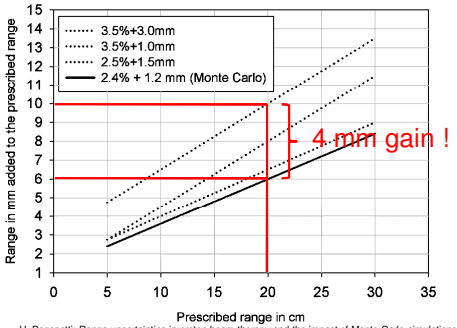
Monte Carlo *Introduction*

Applied range uncertainty margins for non-moving targets



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Monte Carlo *Introduction*

Conclusion:

1. Monte Carlo for routine dose calculation is desirable (not only because of range uncertainties)

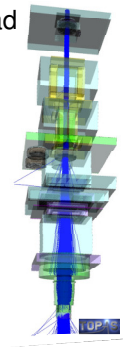
2. We need to make Monte Carlo dose calculation
- **Easy to Use**
- **Accurate (validated)**
- **Standardized**
- **Fast**

Monte Carlo *Introduction*

Treatment Head

Generic

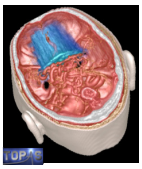
Specific



Patient

Generic

Specific

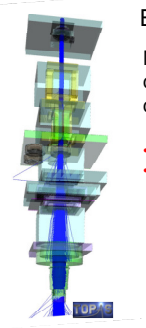


Monte Carlo *Treatment head simulation*

Passive scattering

Most important components for dose calculation:

- Double scattering system (scattering foils and contoured scatterer)
- Modulator wheel or ridge filter
- patient specific aperture
- patient specific compensator

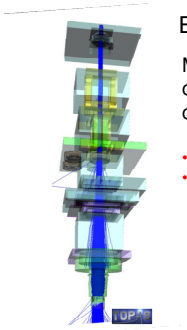


Beam scanning

Most important components for dose calculation:

- Scanning magnets
- (Degrader)

Monte Carlo *Treatment head simulation*



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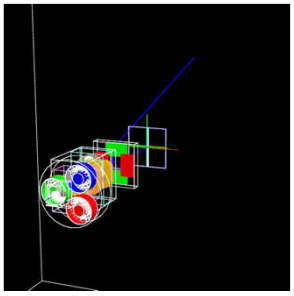
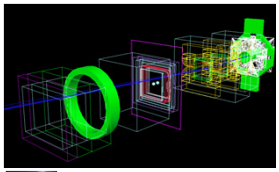
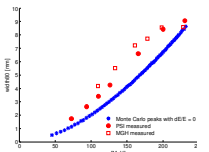
Monte Carlo *Treatment head simulation*

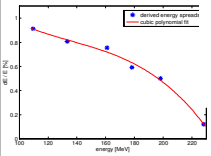


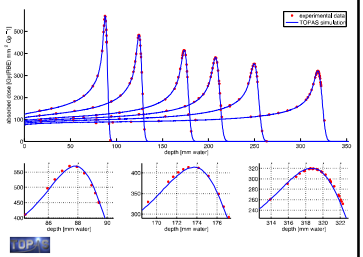


Monte Carlo *Treatment head simulation*

Beam model







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Monte Carlo *Treatment head simulation*

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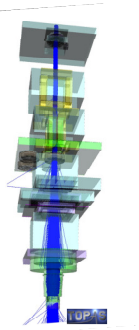
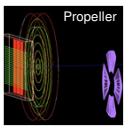
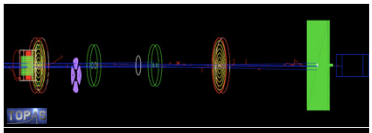


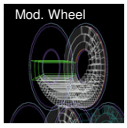
Monte Carlo *Treatment head simulation*

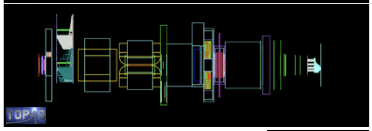
UC Davis eye treatment delivery system



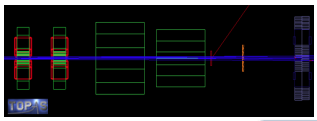


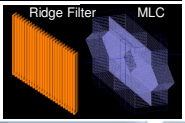
MGH gantry treatment delivery system



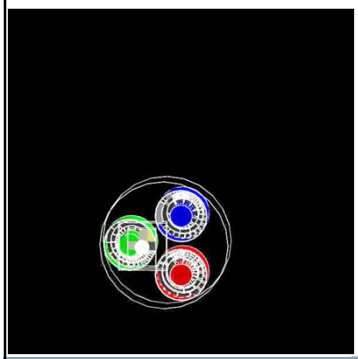


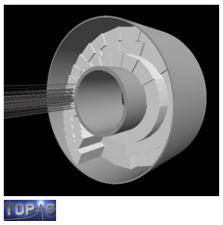
Samsung Medical Center





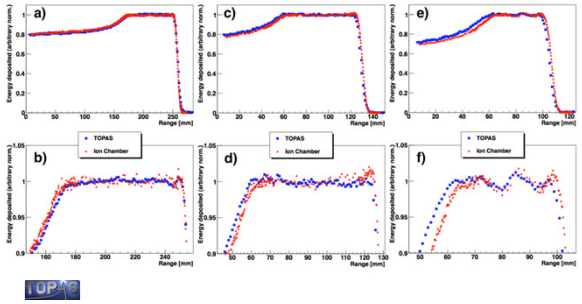
Monte Carlo *Treatment head simulation*





Monte Carlo — *Treatment head simulation*

Commissioning



TOPAS

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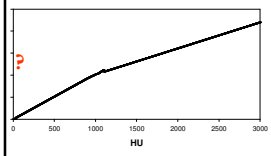
Monte Carlo — *Patient simulation*

CT conversion



Proton Analyt. Planning System
- HU versus rel. stopping power
  - → Dose-to-water

Monte Carlo
- HU versus mass density
- HU versus material
  - → Dose-to-medium (tissue)

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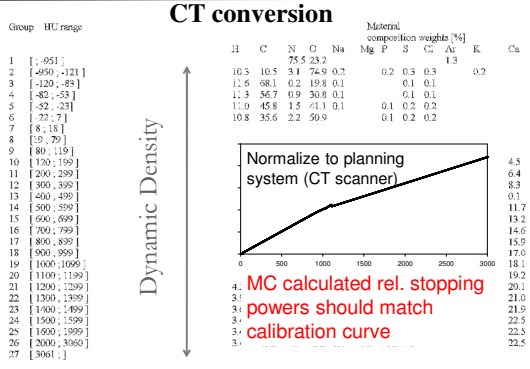
Monte Carlo — *Patient simulation*

CT conversion



MC calculated rel. stopping powers should match calibration curve

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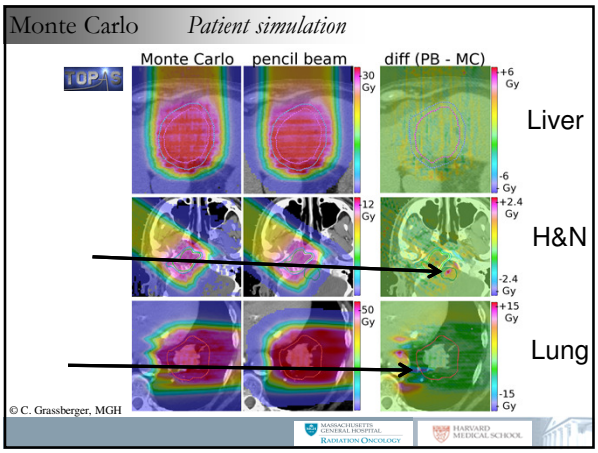
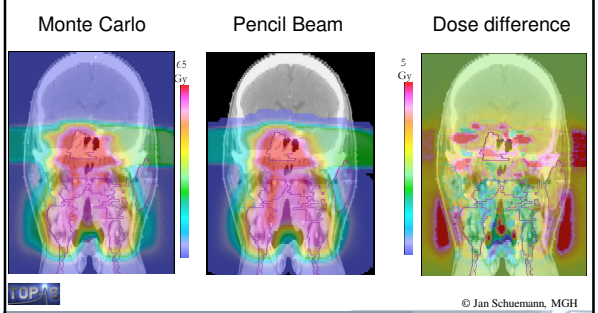
Monte Carlo *Patient simulation*

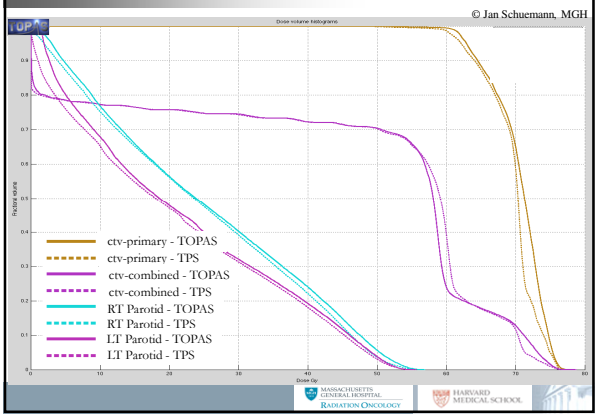


Monte Carlo *Patient simulation*

Head & Neck patient



Monte Carlo *Patient simulation*



Monte Carlo — *Patient simulation*

Efficiency of the Monte Carlo system in use at MGH:

Phase space for passive scattering: 3 hours (on average) on 15 CPU in parallel per field

Patient dose calculation: 2-3 hours (on average) on 15 CPU in parallel

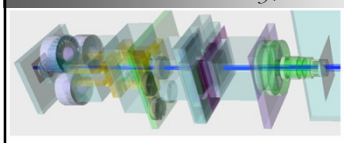
MGH Radiation Oncology Physics owns 200 CPUs (and has access to 500 more)

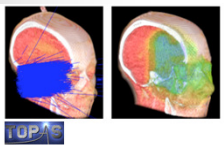
Monte Carlo — *Summary/Comments/Conclusions*

Existing Monte Carlo dose calculation engines

- no commercial Monte Carlo algorithms for proton therapy
- dedicated Monte Carlo codes for proton therapy
  - VMCpro
  - …
- multi-purpose Monte Carlo codes that can be adopted
  - FLUKA
  - MCNPX
  - GEANT4
  - Shield-Hit
  - …
- dedicated systems based on multi-purpose codes
  - PTsim
  - GAMOS
  - GATE
  - TOPAS
  - …

Monte Carlo — *Summary/Comments/Conclusions*

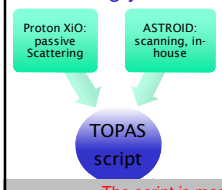




The MGH system
- TOPAS is based on Geant4
- no need for programming (parameter files; no compiling)
- simulates passive scattering treatment heads
- simulates scanned beam treatment heads
- CT-based dose calculation
- will become publicly available in 2013

Poster SU-E-T-473
(+ several posters/talks)

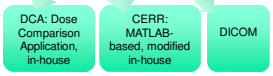
Linking your in-house MC to the planning system



Script actions:

- creates input files
  - scattering: range comp, aperture, beam current modulation
  - scanning: phase space input
- creates patient geometry from CT files
- includes absolute dose normalization
- submits simultaneous jobs to a cluster

The script is massive (several thousand lines of code).
Monte Carlo codes do not provide solutions for their connection to treatment planning systems



- reports dose-to-tissue / dose-to-water
- dose on planning grid and CT grid

Main take-home messages

- Due to steep dose gradients and the end of range of proton beams, the clinical significance of Monte Carlo dose calculation is higher in proton therapy compared to photon therapy; Monte Carlo can lead to margin reduction in proton therapy !
- Proton therapy treatment head simulation for passive scattering is cumbersome
- Patient dose calculation is still slow in routine use (at least for passive scattering systems)
- The link to the planning system is key