ADVANCING
CANCER
TREATMENT

PROTON MC IN RAYSTATION

MCMA, October 2017, Fredrik Tamm

Napoli, Italy

RaySearch
Laboratories

RAYSTATION

- RayStation TPS for photons, electrons, protons and carbon ions
- Around 40 proton clinics
- Proton MC relased in december 2016 in Raystation 6 for PBS.

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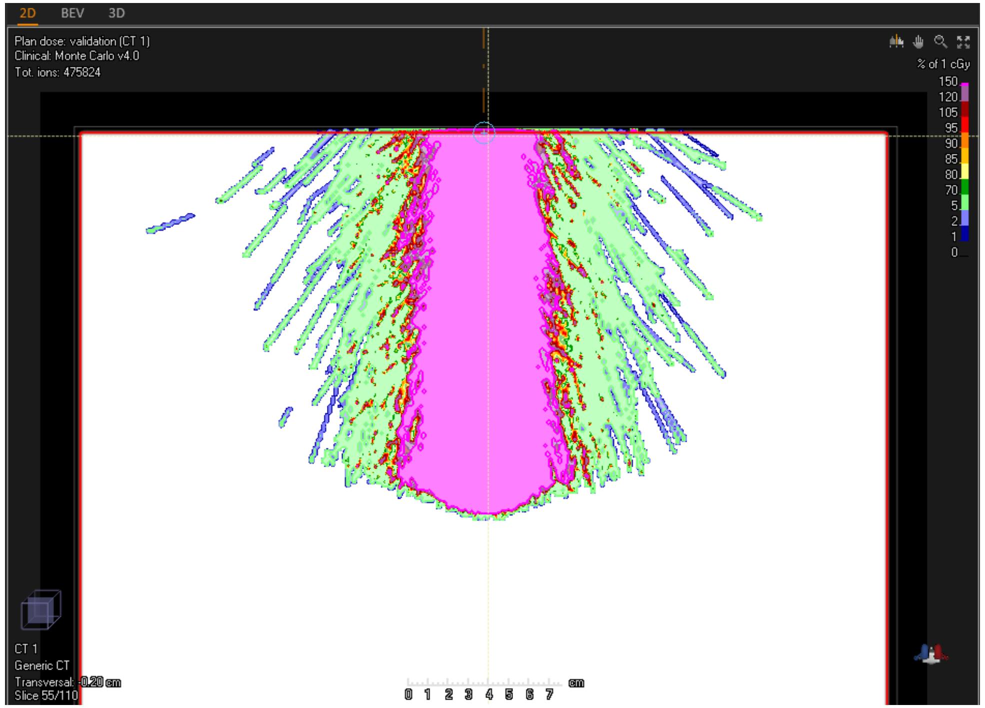
WHY MONTE-CARLO IN A TPS?

- Significant lateral inhomogeneities
  - Lung
- Range shifters
  - Errors up to 10% in the surface region with PBA for very large air gaps
  - Secondary ions over air gap
- Block apertures
  - Edge scatter effects
- Large or small field sizes



WHAT IS REQUIRED OF A MONTE-CARLO IN A TPS?

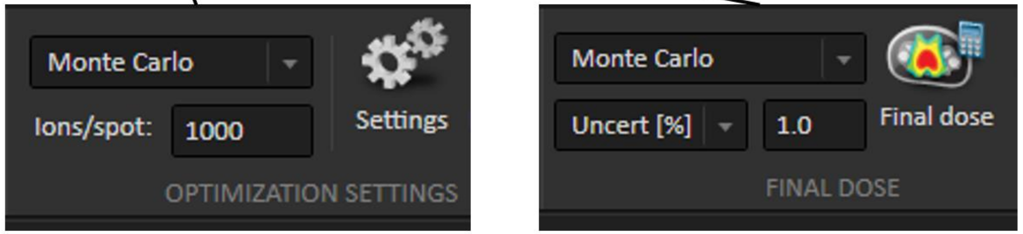
- Need to be able to optimize plans with the MC dose engine
- Compute dose to uncertainty

- Must be fast
- Must also be accurate

➔ Sensible tradeoffs between speed and accuracy are essential!

Q: Which physics needs to be modelled and how?

- Both **optimization** and **dose computation**!



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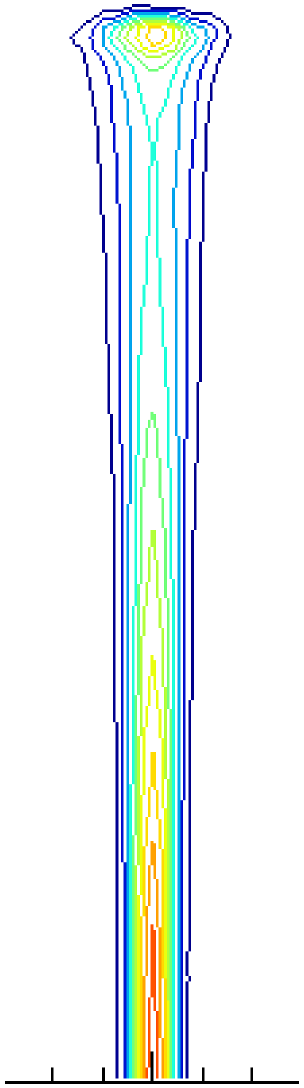
PHYSICS RATIONAL FOR FAST PROTON MONTE CARLO

- First order phenomena:
- Ionization energy loss
  - Range to the distal edge of the Bragg peak
- Multiple scattering
  - Penumbra, amplitude at Bragg peak
- Nuclear absorption
  - Amplitude at Bragg peak
- Secondary ions
  - Field size dependence



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PHYSICS CONTINUED

- Second order phenomena:
- Delta electrons
  - Range <1mm
- Heavier secondary ions
  - Range <1mm
- Gammas and neutrons
  - Very diffuse dose distribution

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TRANSPORT MECHANICS

- Multiple scattering and energy straggling over random hinge steps
- Energy loss and nuclear reactions at each voxel
- Secondary protons, deuterons and alphas are transported.
- Dose from heavier ions deposited locally
- Gammas and neutrons ignored

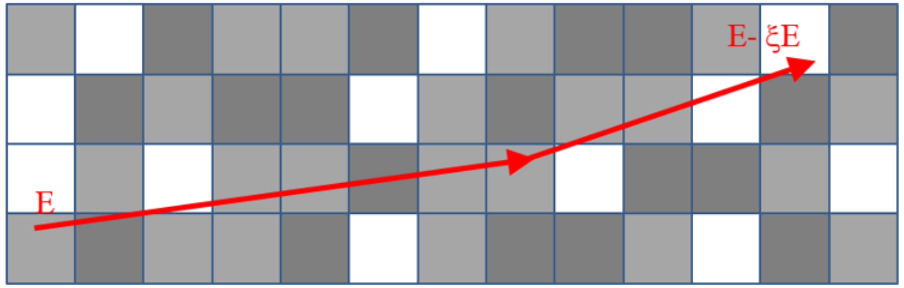

Figure 44. A random hinge step with two legs for a proton with energy E_i at the beginning of the step and losing energy $\Delta E = \xi E_i$ after the step. The deflection due to multiple scattering is applied at the hinge point.

The random hinge steps propagate the proton from its incident energy E down to and below a threshold energy of $E_{cut}^{RH} = 30.7\ \mathrm{MeV}$ which corresponds to a residual range in unit density water of about 9 mm. Below this energy the proton is transported without considering multiple scattering and energy loss straggling.

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MATERIAL AND GEOMETRY HANDLING

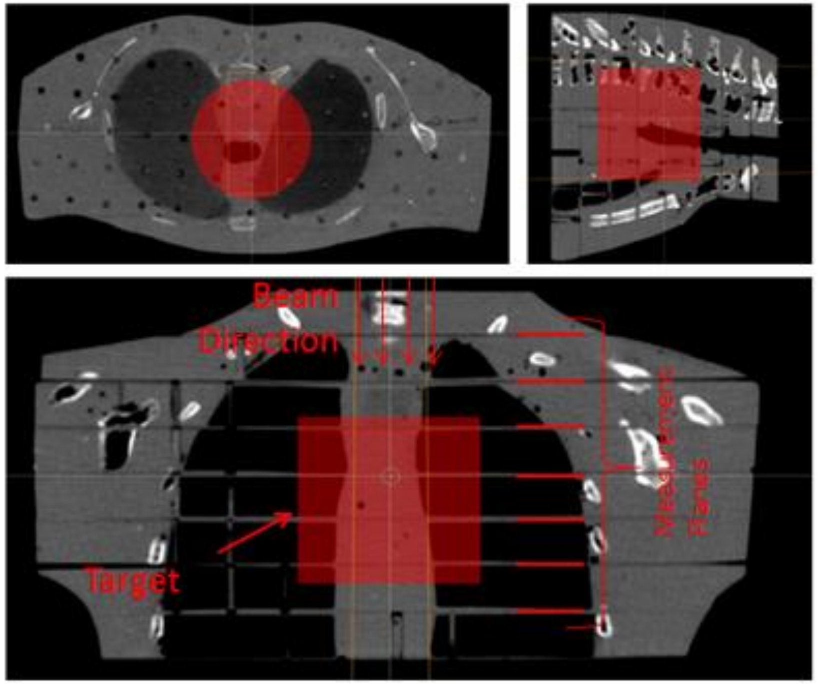
- Nuclear cross sections from ICRU63
- Same stopping power and material handling as in the Pencil Beam dose engine
- Material composition determined from CT-data
- Same physics and transports in all geometries (patient, range shifter, block etc)

IMPLEMENTATION DETAILS

- On CPU
- Xoroshiro128+ random number generator
- Same phase space for Pencil Beam and Monte Carlo -> same machine model can be used
- Phace space described by two gaussians and an energy spectra
- Score dose-to-water

MC RESULTS – LUNG

- Experimental study from Seattle



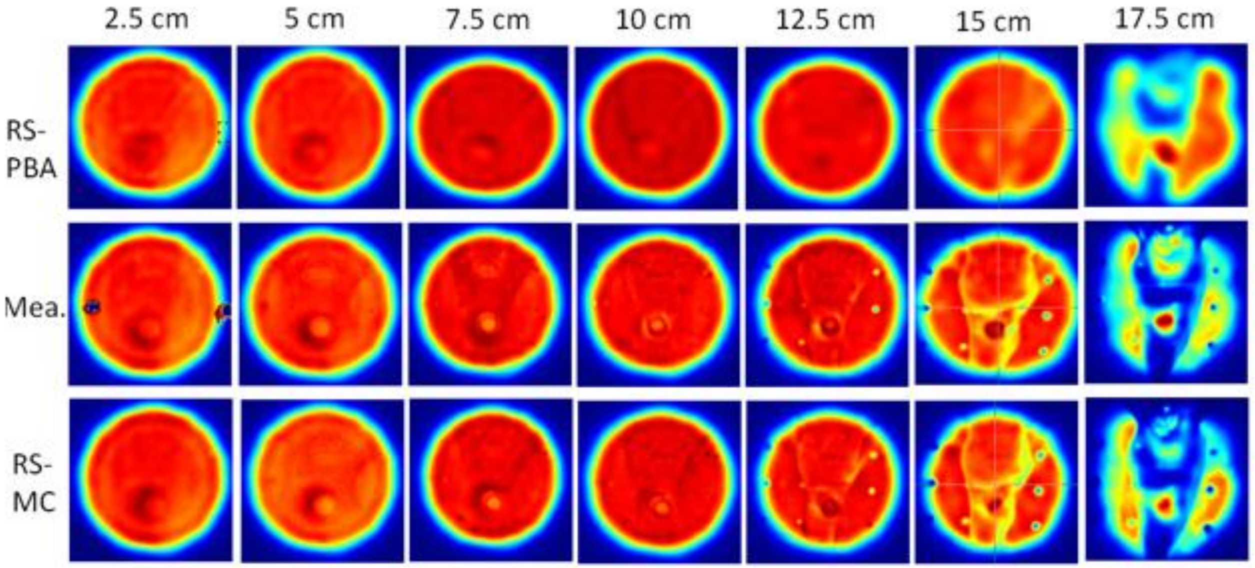


Figure 12. Dose planes obtained using RS-PBA (top), Gafchromic film (center), and RS-MC (bottom) after every slice of mediastinum section of AR phantom as shown in figure 4.

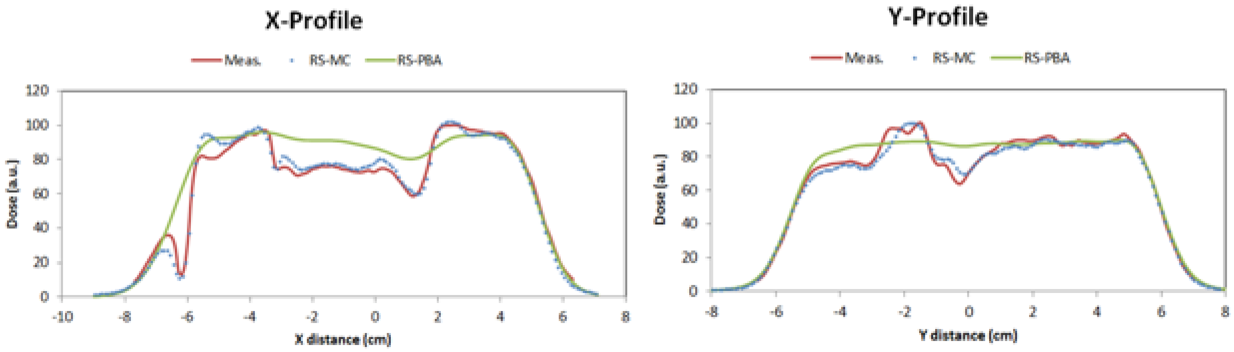
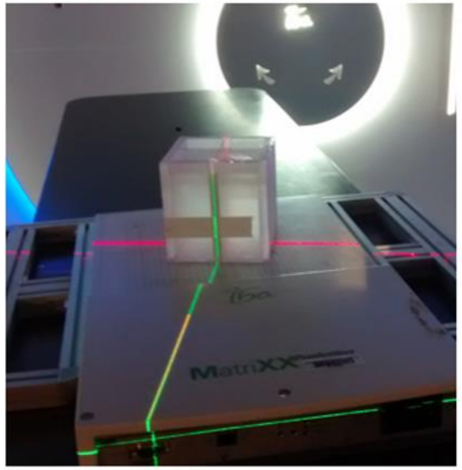
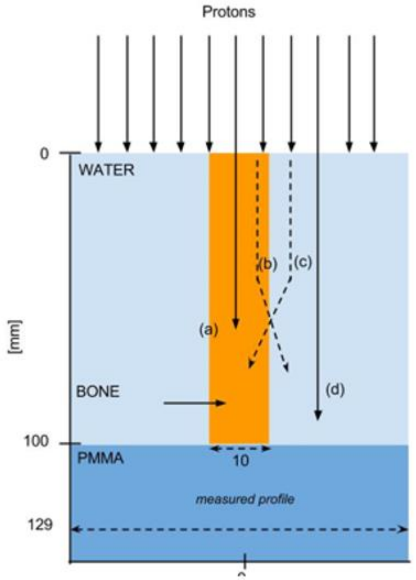


Figure 13. One dimensional dose profiles in −x and −y direction corresponding to depth 15 cm in mediastinum AR phantom. Shown are measurement (solid red), RS-MC (dotted blue), and RS-PBA (solid green).

Jatinder Saini et al,, Phys.Med. Biol 62 (2017) 7659-7681

EFFECTS OF INHOMOGENEITIES - MC VS. MEASUREMENTS





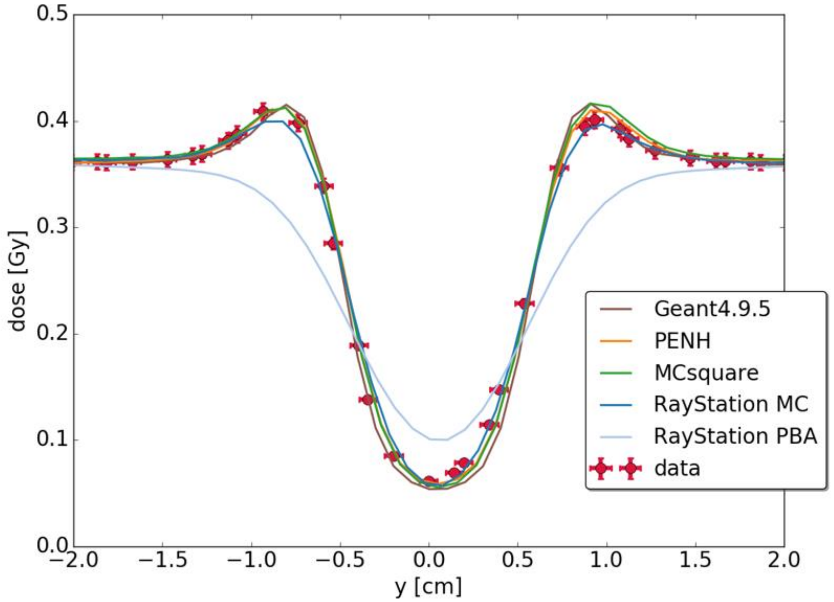


Figure 2. Dose profiles at 129mm depth averaged over 4mm for Geant4.9.5 (brown line), PENH (orange line), MCsquare (green line), RayStation MC (blue line), RayStation PBA (shadowed blue line) and experimental data (red circles points).

Sorriaux - Physica Medica -
European Journal of Medical Physics; EJMP-D-17-00087

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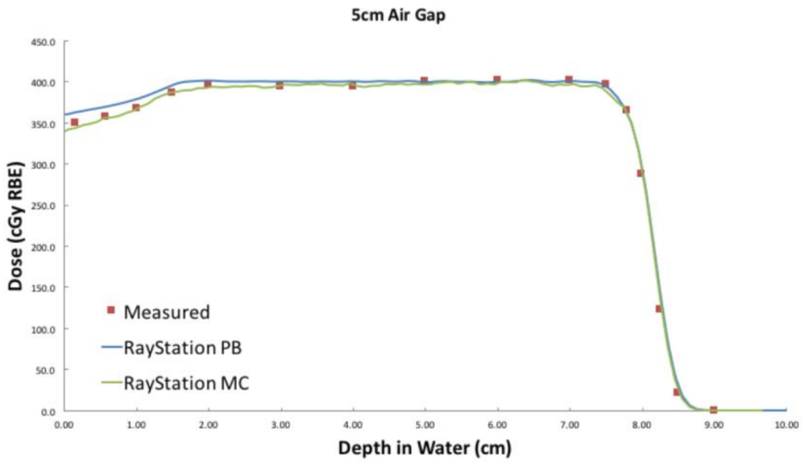
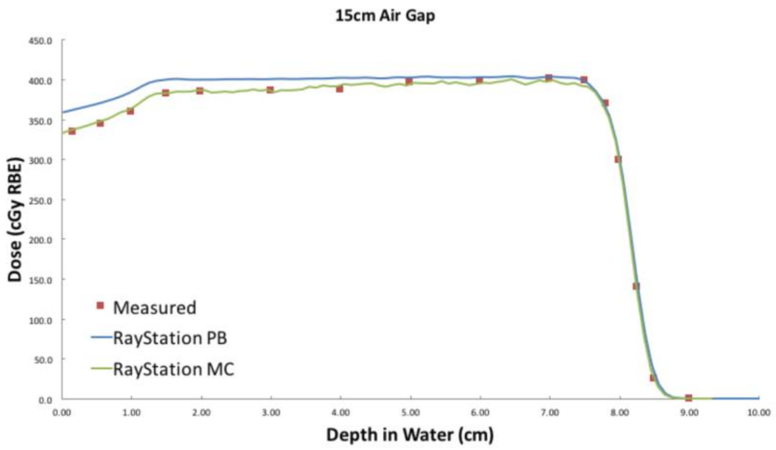
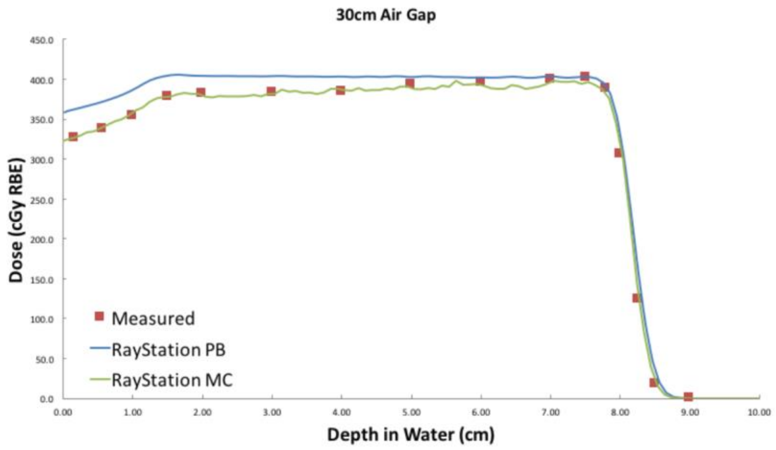
MC RESULTS – RANGE SHIFTER

- Experimental study from ProVision
  - Air gap study
  - Circular 10 cm field in water
  - Absolute dose measured with IC

“*Looks like the MC takes care of the air gap problem*”
Marc Blakey in email to Niek Schroder







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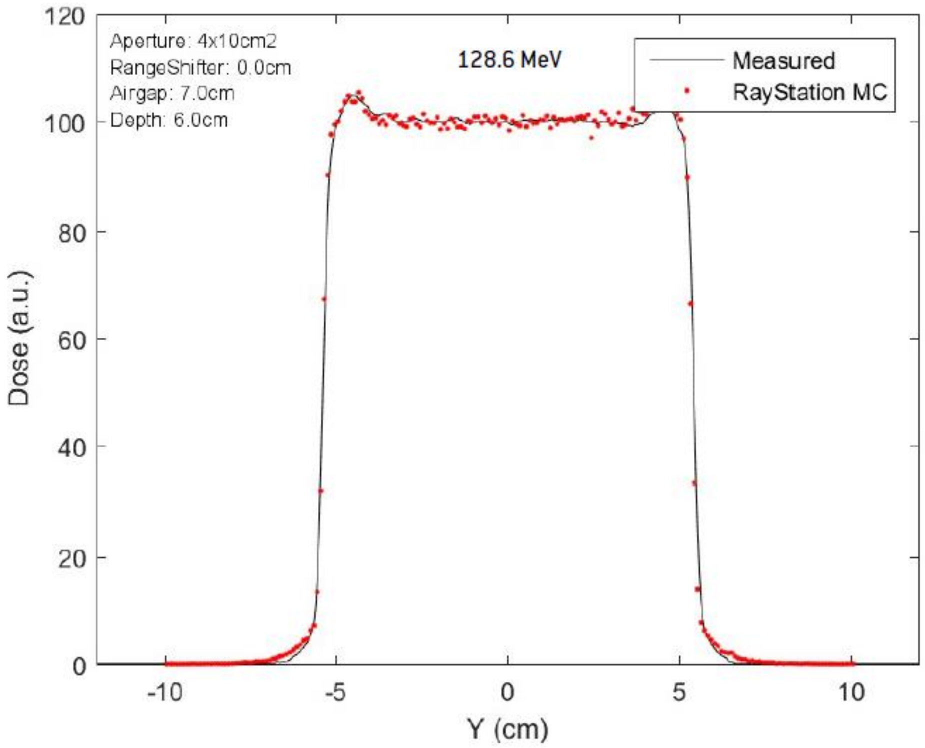
MC RESULTS – BLOCK APERTURE

- Validation done with North Western clinic
  - 92 different fields
  - 468 lateral profiles in X and Y
  - 56 depth dose curves
  - 36 absolute doses at the center of the field
- Results
  - Exceptionally high passing rate
    - Gamma(3%,3mm)
    - FWHM within 2 mm
    - Penumbra width within 2 mm
    - Absolute dose error within 3%
  - The very rare fails attributed to measurement error (confirmed by the clinic who made the measurements)
- Poster at PTCOG

"The Monte Carlo calculations for apertures matched the measured data almost exactly"

Niek Schroder



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MC RESULTS – PERFORMANCE

- Performance study by Seattle (SCCA)

Table 7. Comparison of calculation times for six different plans between RS-PBA and RS-MC. The plans were previously optimized using the RS-PBA algorithm.

Site	Plan Description	Isotropic Dose Calc Grid Size	Time (s): RS-PBA	Time (s): RS-MC (2%)	Time (s): RS-MC (1%)
Prostate	2 beams: Lt and Rt lateral	2 mm	28	20	80
Brain	Skull base target. 4 beams: PA, LAO, RAO and SAO	2 mm	10	17	42
H&N	3 beams: LPO, LAO and RAO	2 mm	70	50	172
Lung	2 beams: RPO and LPO	2 mm	43	30	92
Breast/ chestwall	Single oblique beam encompassing chestwall, super clav, axillary and IMC nodes	3 mm	7	16	41
CSI	3 PA beams: one each for brain, upper spine, and lower spine.	3 mm	17	21	77

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MORE POSSIBILITIES WITH MONTE CARLO

Ion Monte Carlo transport and scoring options

Choose options to be used for next ion MC dose calculation:

No. of histories for optimization calculation: 4000000

No. of histories for forward calculation: 10000

- [ ] Score track end distribution
- [ ] Score dose weighted LET
- [ ] Score track averaged LET
- [ ] Score control point energy at track ends
- [ ] Score control point index at track ends
- [ ] Score average energy
- [x] Score nuclear interaction distributions
  - Display instead of dose:
    - ○ Proton-Hydrogen interaction site distribution
    - ○ Proton-Nuclear (total) interaction site distribution
    - ○ Proton-Carbon interaction site distribution
    - ○ Proton-Nitrogen interaction site distribution
    - ○ Proton-Oxygen interaction site distribution
    - ○ Proton-Phosphorus interaction site distribution
    - ○ Proton-Calcium interaction site distribution
    - ○ Proton-intermediateZ interaction site distribution
    - ○ Proton-highZ interaction site distribution
- [ ] Score dose component distributions
- [ ] Score energy spectrum per voxel
- [ ] Score LET spectrum per voxel
- [x] Use DSB RBE model (R. Stewart / Univ. of Wash)...
  - Cell condition:
    - ○ Norm oxic
    - ○ Anoxic
- [ ] Use LEM4 RBE model (Scholz et al. / GSI)...
- [ ] Score Alanine detector correction factor per voxel

- [ ] Skip elastic scattering
- [ ] Skip energy straggling
- [ ] Skip nuclear absorption
- [ ] Use mono-energetic beam
- [ ] Collapse spots to pencils

>> Phase space files >>>>>>>

- [ ] Source phase space
- [ ] Entry phase space
- [ ] Exit phase space
- [ ] Patient/phantom planar phase space

>> Magnetic field definition >>>>>>>

- [ ] Perpendicular, B = 1.5 Tesla
- [ ] Perpendicular, B = 0.5 Tesla
- [ ] Parallel, B = 1.5 Tesla
- [ ] Parallel, B = 0.5 Tesla

THANK YOU!