POLITECNICO DI MILANO





Improving carbon relative stopping power estimates for patients, using daily carbon imaging with pre-treatment single energy CT.

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David C. Hansen, Paul Doolan, Marco Riboldi, Joao Seco

Outline

1. Motivation and Aim

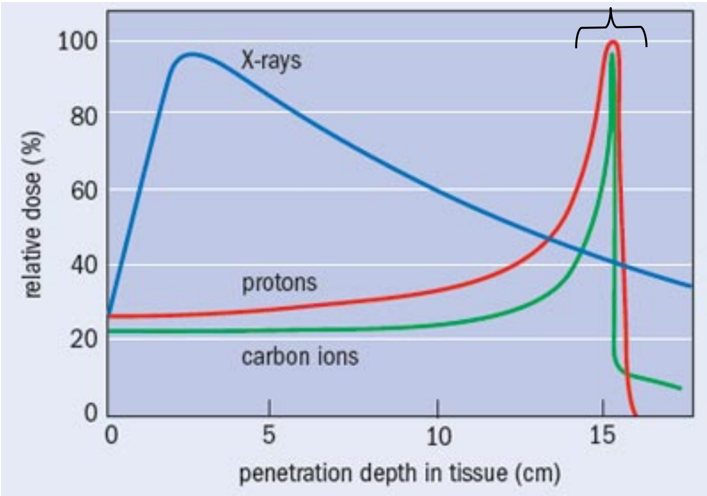
2. Materials and Methods

3. Results and Discussion

4. Conclusions and Future Work

Charged Particle Therapy

Bragg Peak



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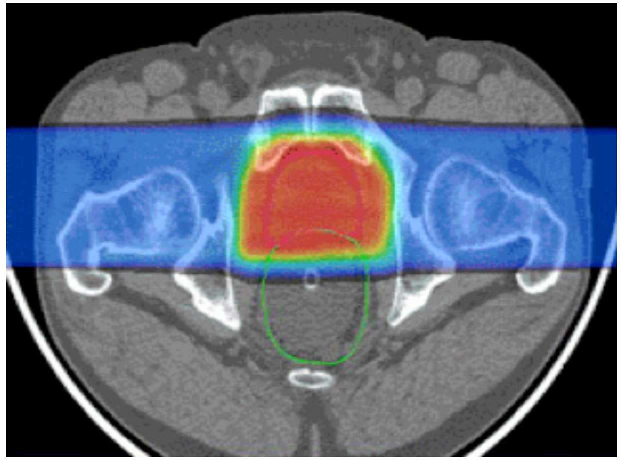

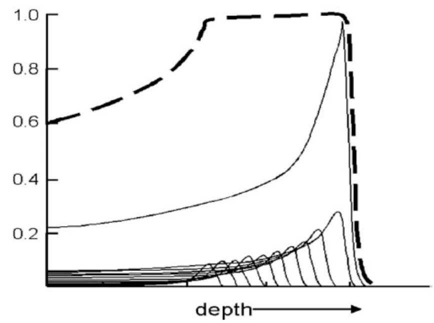

SOBP – Spread-out Bragg Peak

M. Goitein. A Physcist's Eye View. Springer, New York, 2008.

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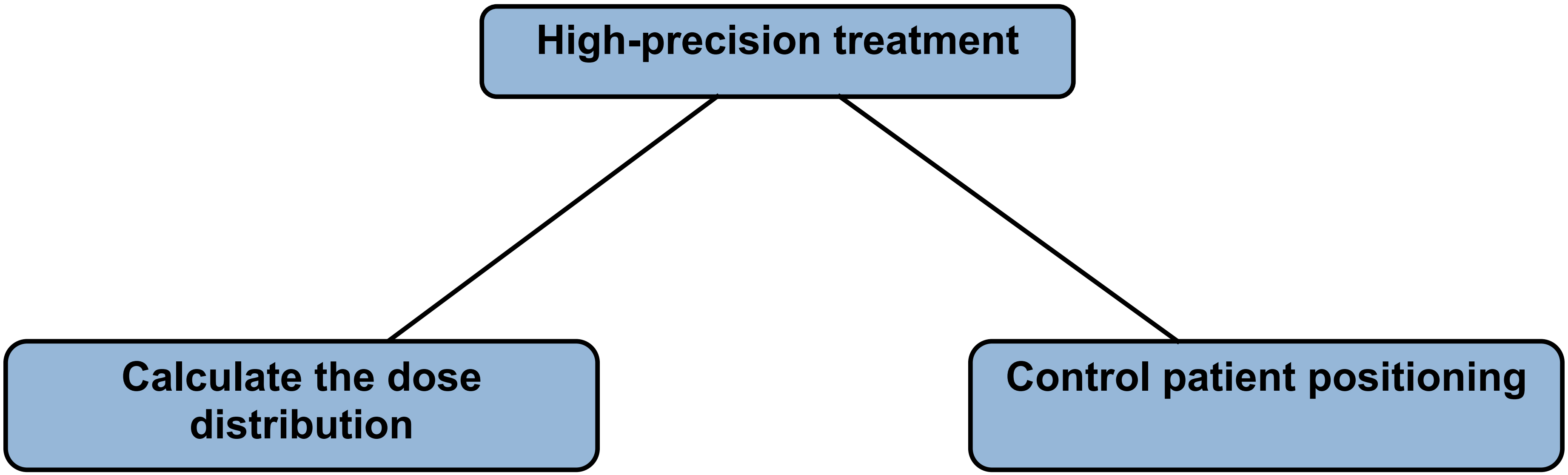

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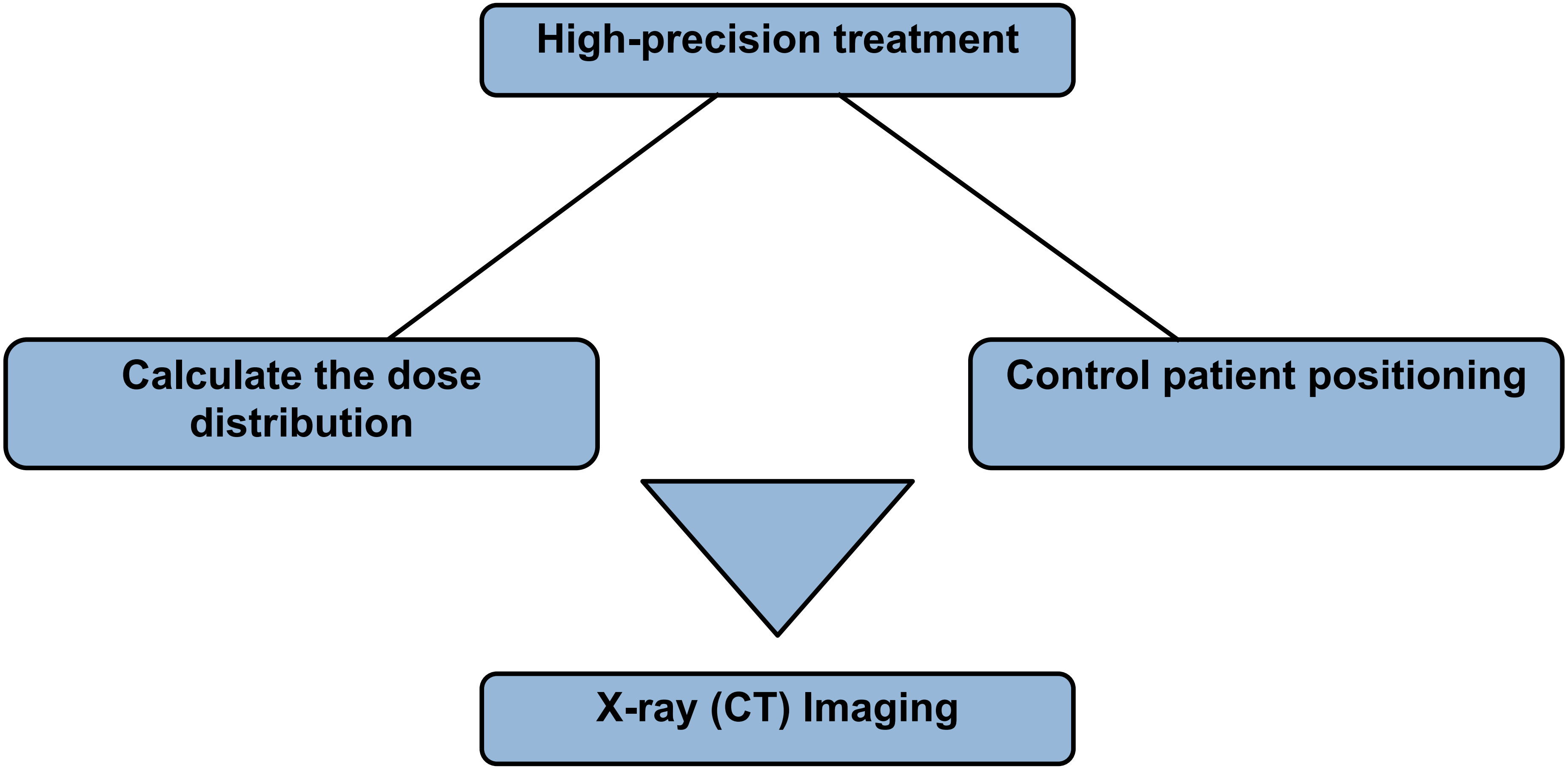

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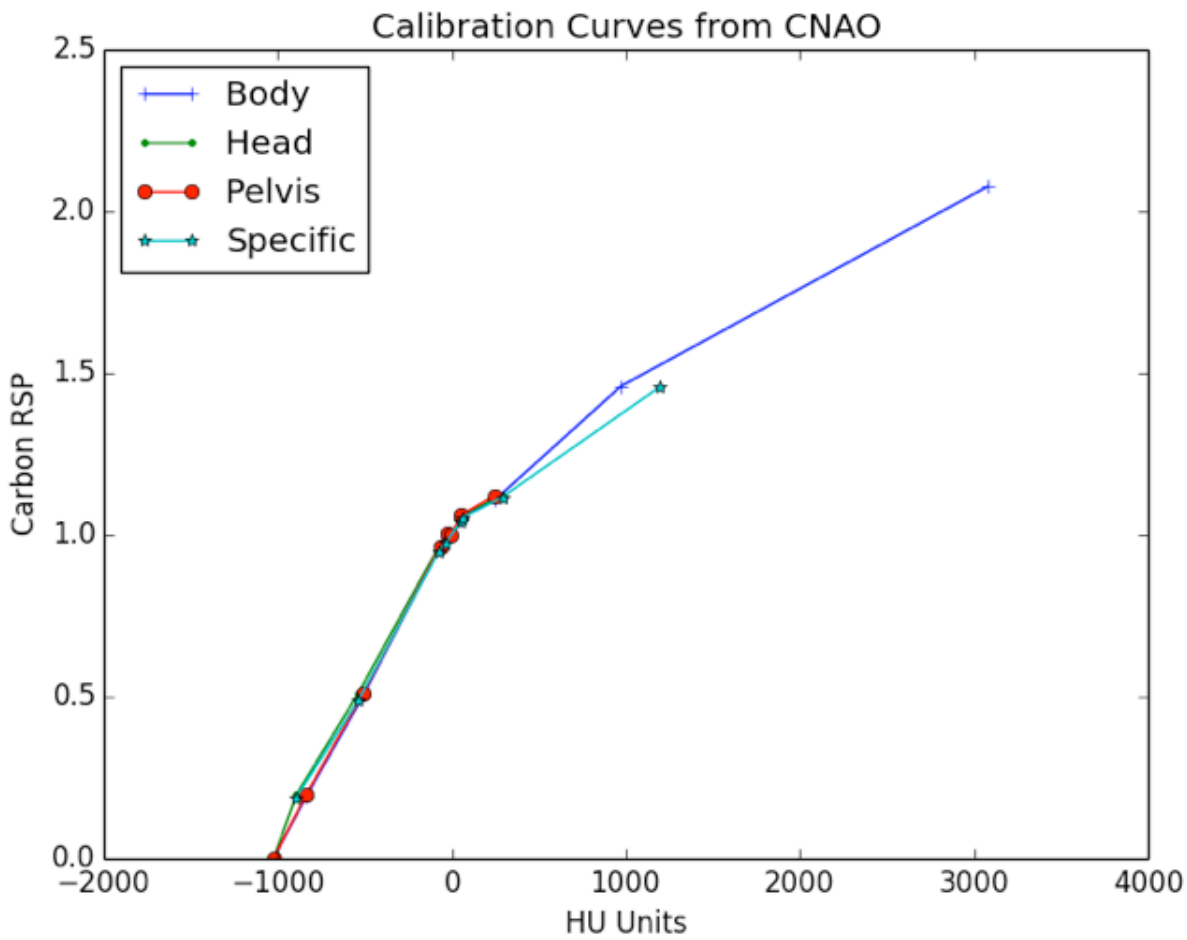

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5-26% uncertainty

(Jakel,Reiss, 2007; Koybasi, 2014)

Possible Solution:

Daily: Carbon Radiography

Weekly/bi-weekly: Carbon Tomography

- RSP distribution of the patient (prior and in between treatments);
- In combination with fast computational hardware, may be able to check the adequacy of the treatment before its delivery, or even modify beam angles to optimize the treatment delivery;
- Pretreatment monitoring of Patient Setup;
- High density resolution and low dose images. (Schneider, 1994)

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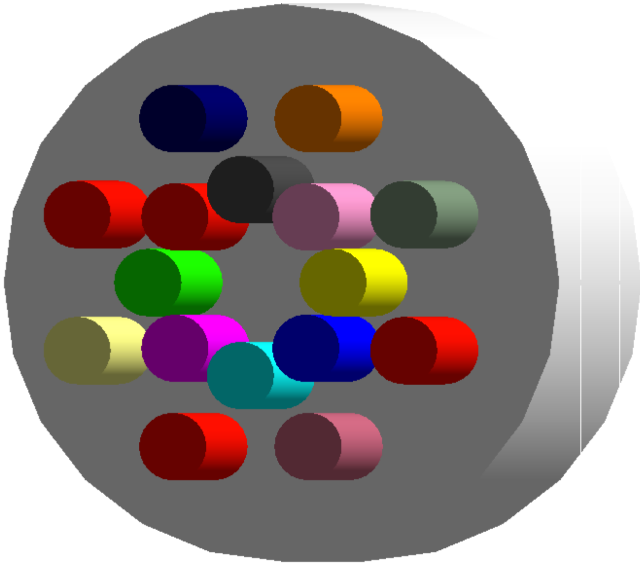
How

Optimizing pre-calculated carbon RSP from clinical calibration curves.

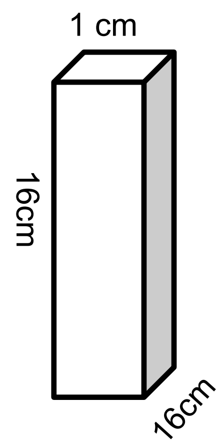
E.g. Prostate has a 20cm WEL -> ~8mm expansion is reduced to ~ 1 - 2mm

2.2. Calibration Phantoms

- **GAMMEX PHANTOM**
  - 33x33x33 cm^3
  - 13 Materials with known composition (Watanabe *et al.*)

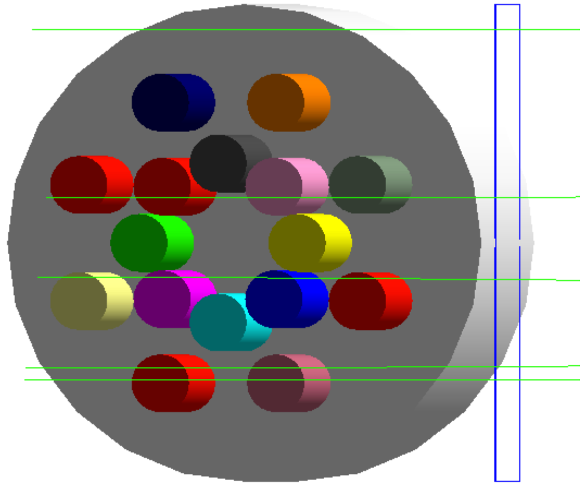


- **SLAB PHANTOM**
  - CB2-30% $CaCO_3$; CB2-50% $CaCO_3$; Inner Bone; Cortical Bone ; LN-450; LN-300; Adipose; CT solid water; Water



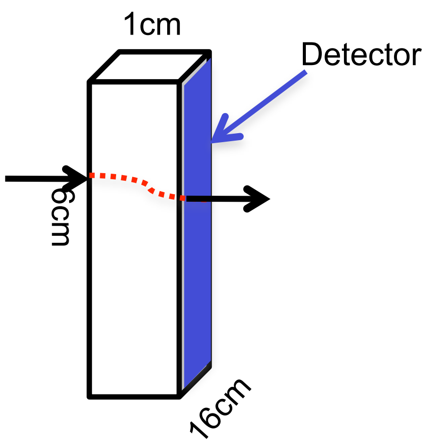
2.3. Reference Carbon Radiography and theoretical RSP

- Monte Carlo simulation with Geant4 v.4.9.6, validated for carbon ion therapy (Lechner, A. 2010)



- Theoretical RSP ➔ Stopping Power (SP) of Carbon crossing **SLAB phantom**

$$RSP_{tissue} = \frac{SP(E)_{tissue}}{SP(E)_{water}}$$



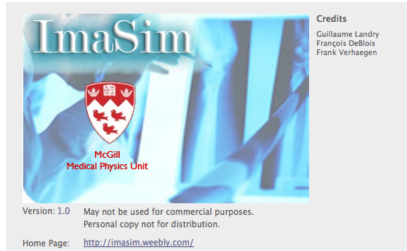
- Reference Carbon Radiography from **GAMMEX phantom**
  - ○ E_{in}, E_{out}, Entrance/Exit coordinates and directions

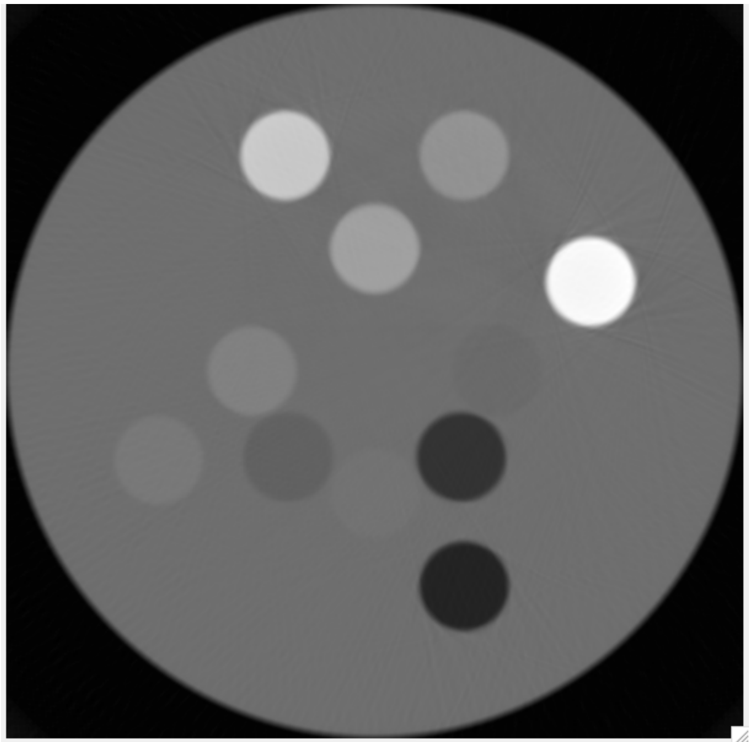
2.4. Single Energy Computed Tomography (SECT)

- ImaSim (Landry,2009) to reproduce 120kVp CT image of the phantoms

- Filtered backprojection reconstruction with Shepp-Logan filter.

- HU unit for each material for theoretical calibration curve





2.5. Carbon Digitally Reconstructed Radiography (CDRR)

2.5.1 Particle Propagation/Path

- **Particle by Particle - > GPU-based**

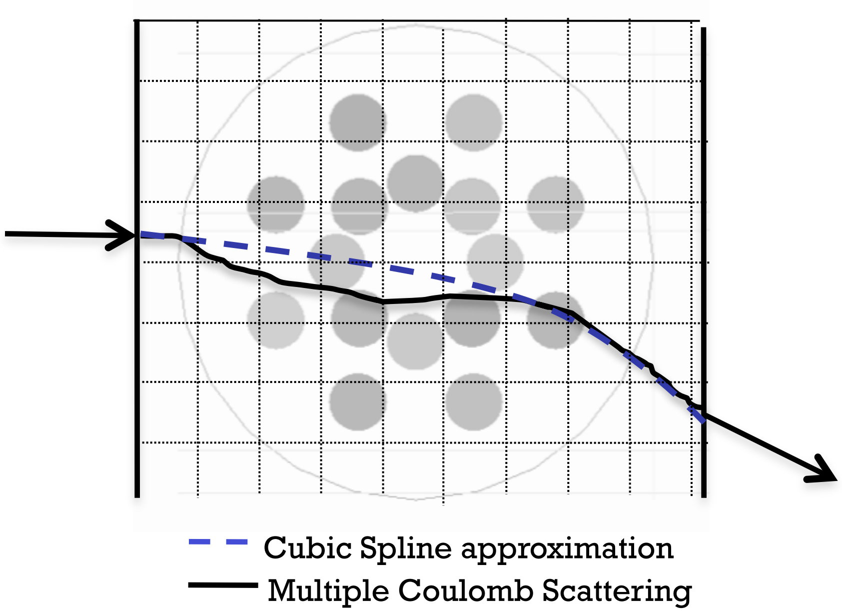
- **Entrance and Exit**
  - Coordinates
  - Direction

- **Cubic Spline Path**
  - Allows linear and non linear trajectories

$$\vec{A}t^3 + \vec{B}t^2 + \vec{C}t + \vec{D} = \vec{S}(t)$$

- **Track of Voxel ID along path**

Possible path



2.5. Digitally Reconstructed Radiography

2.5.2 Energy Loss

- **Compute Total Energy loss of each Carbon**

  - Binning of the path, allowing multiple steps per voxel (Δt)
  - Voxel ID from propagation
  - HU to RSP_{tissue} from CT

$$E_{out} = E_{initial} - \sum \left(RSP_{tissue} \times SP(E)_{water} \times \Delta t \right)$$

- **New Energy distribution - > Carbon Digitally Reconstructed Radiograph**

2.1. RSP Optimization

- **Gradient Descent Optimization**

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CT Image

Initial RSP with variation (fixed step size)

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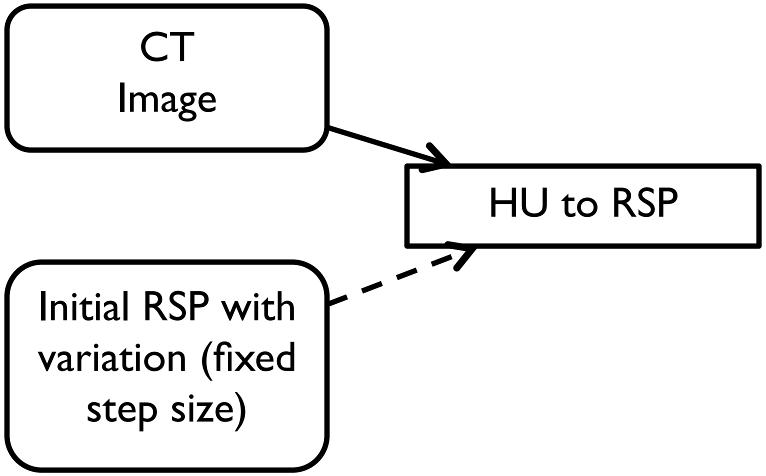

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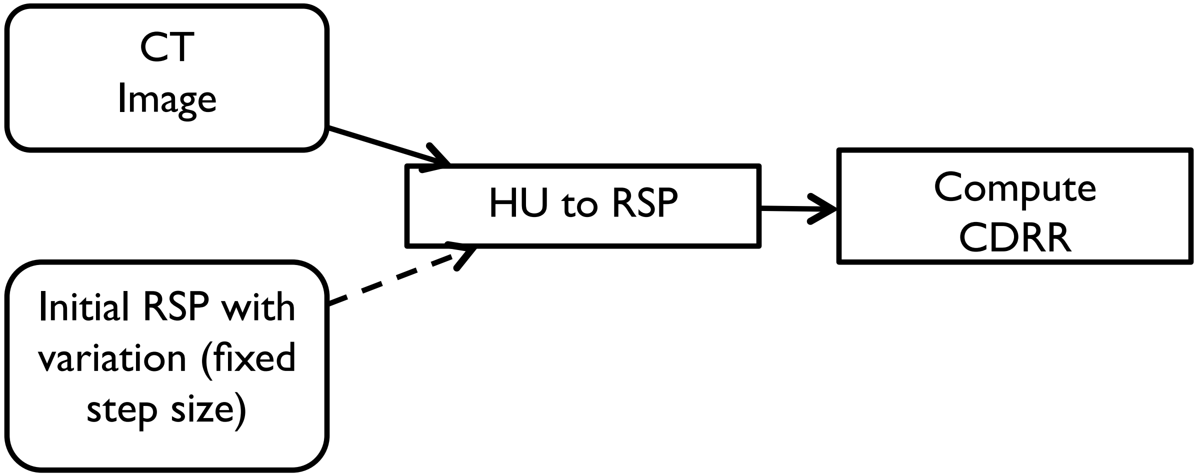

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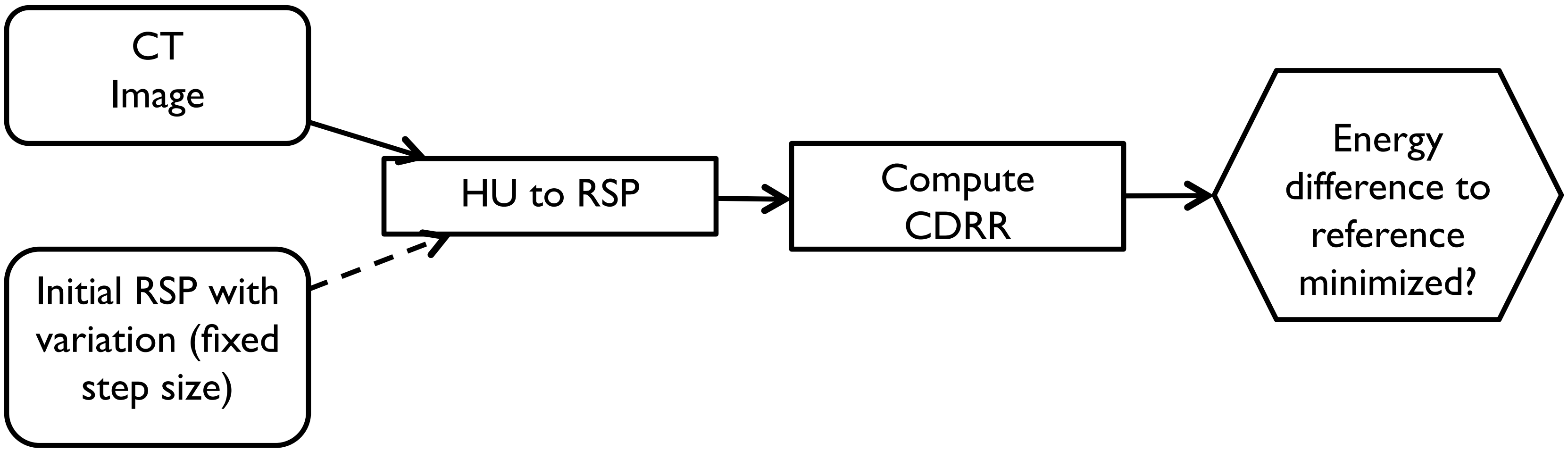

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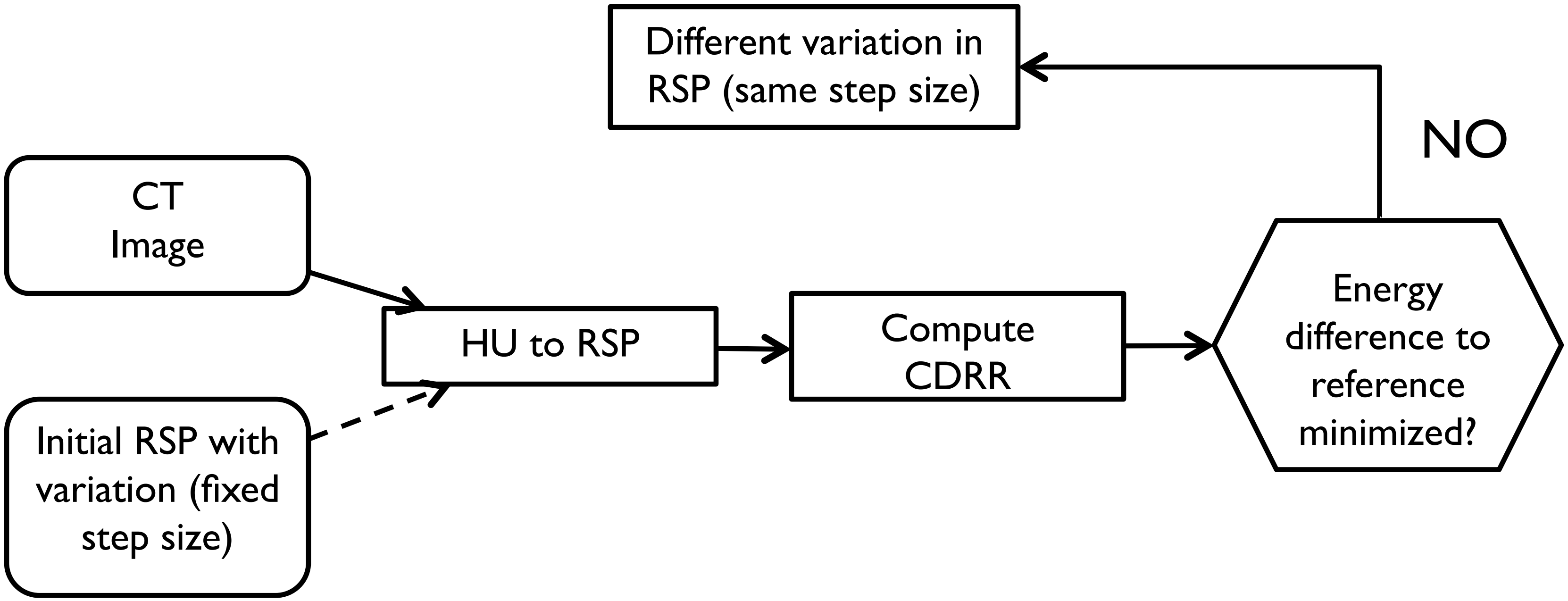

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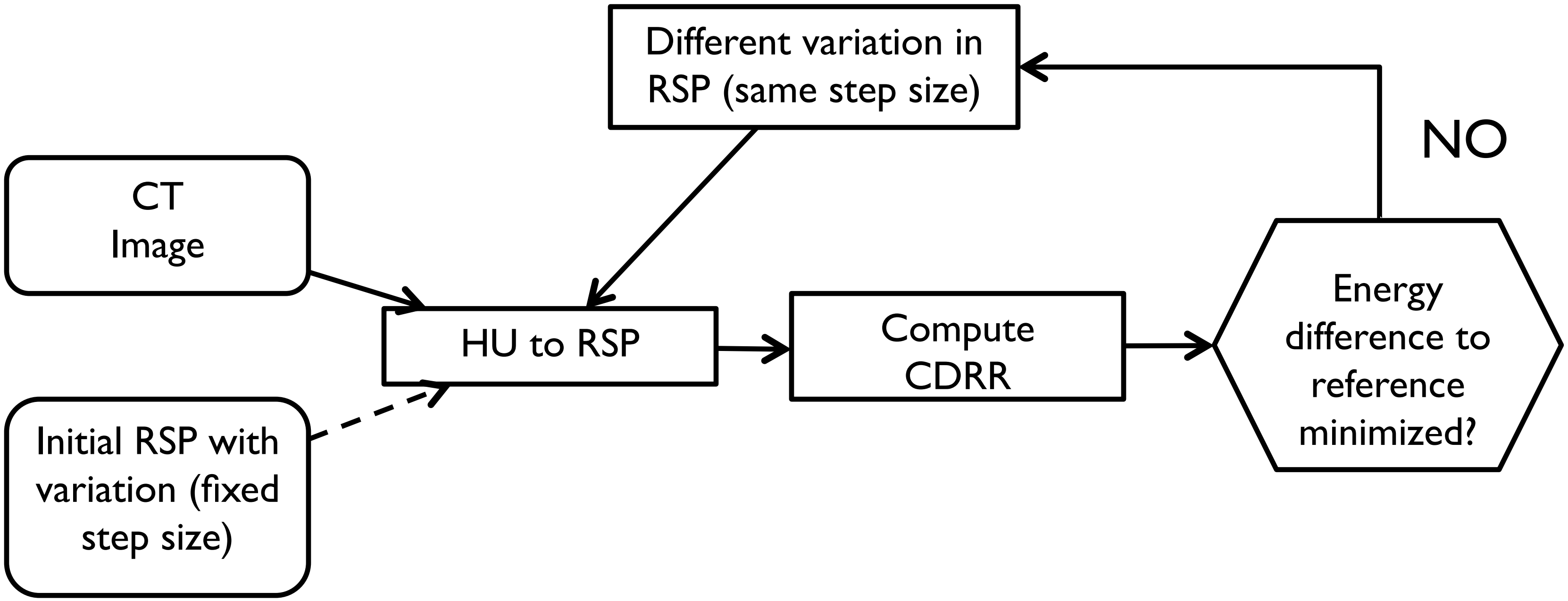

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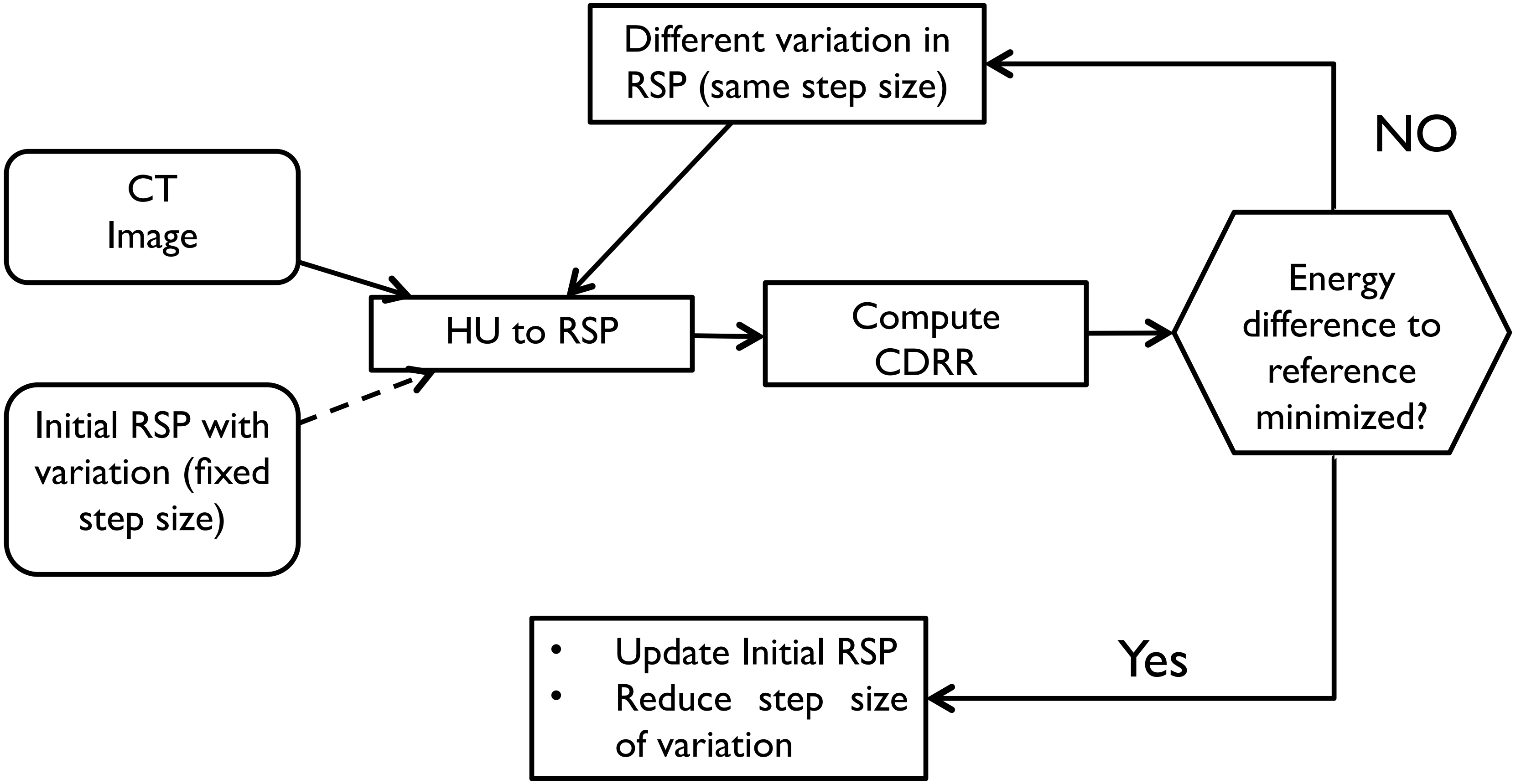

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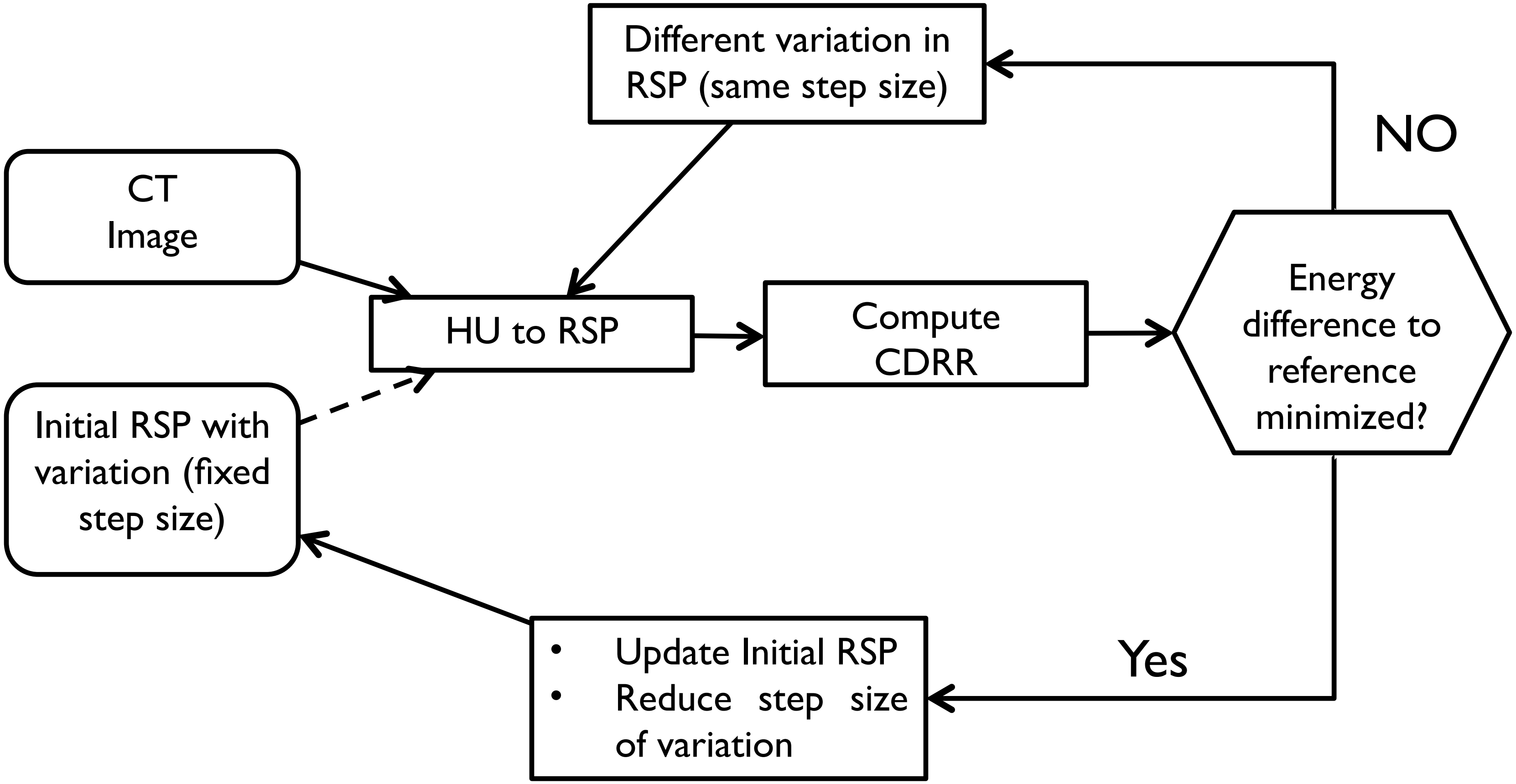
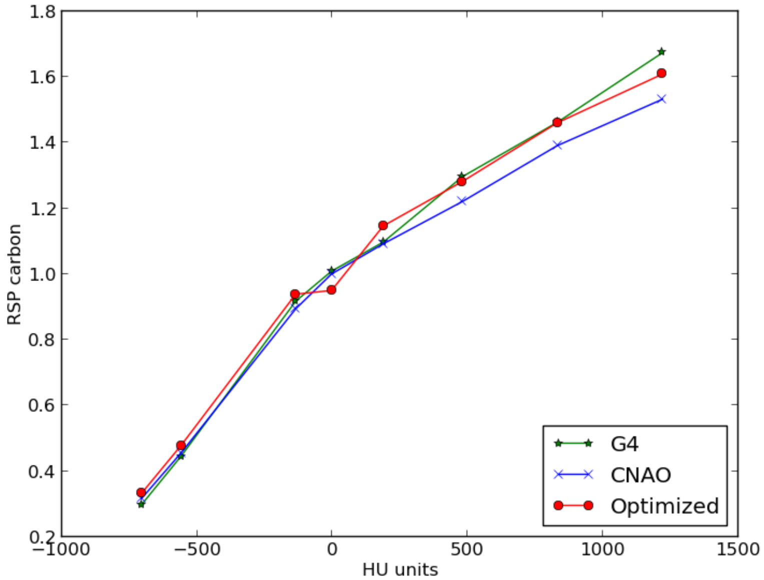


3.1. HU - RSP calibration

3 iterations



	RSP CNAO	RSP G4	RSP Opt	Error CNAO	Error Opt
LN-300	0.32	0.30	0.33	-6.32	-10.42
LN-450	0.46	0.45	0.48	-2.25	-6.86
Adipose	0.89	0.92	0.94	2.54	-2.28
CTsolidWater	1.00	1.01	0.95	0.86	6.18
Inner Bone	1.09	1.10	1.15	0.49	-4.29
CB2-30	1.22	1.30	1.28	5.84	1.15
CB2-50	1.39	1.46	1.46	4.86	0.10
Cortical Bone	1.53	1.67	1.61	8.46	4.04

Mean Energy Error: **CNAO -0.77** → **Optimized -0.04** **=** **Reduction 95%**

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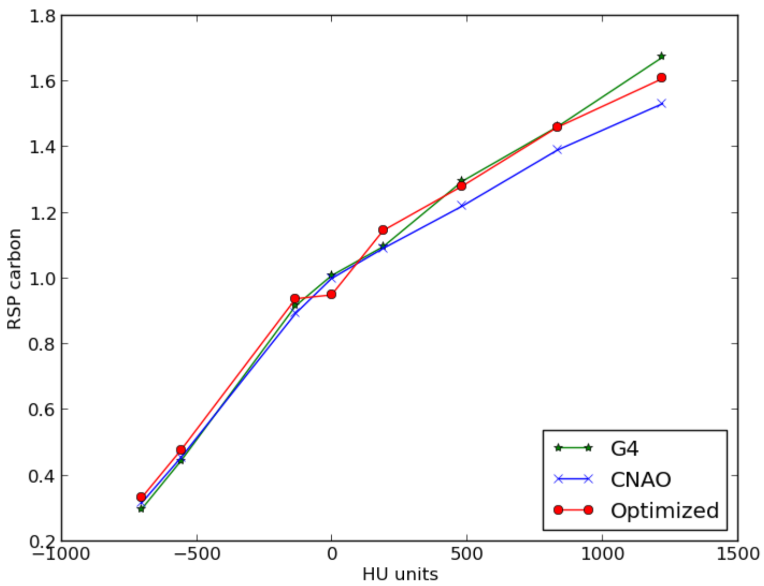

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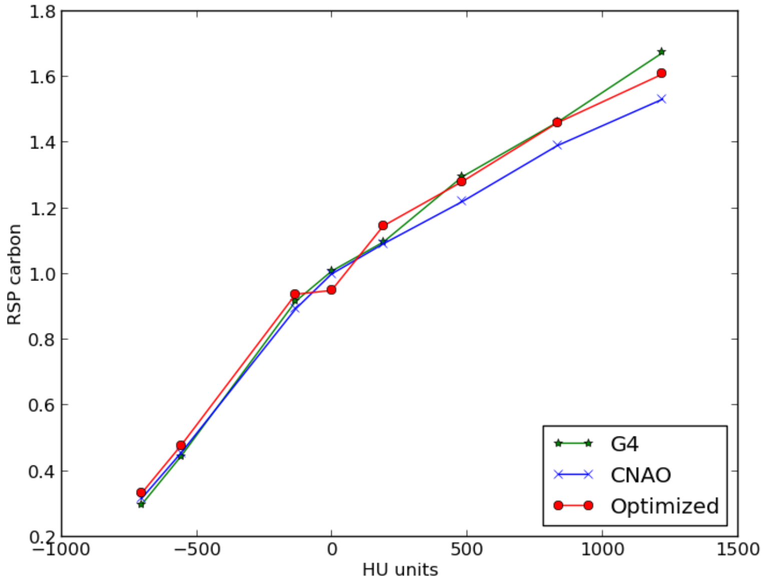

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Question

What should we really minimize? The mean Energy difference? Range difference?

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•Experimental RSP (for reference) for a carbon beam will be obtained and the possibility to use this method on alpha particles will also be considered.

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We are still far from our aim of reducing range errors to <0.5%

Acknowledgements

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Massachusetts General Hospital

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Thank you so much for your attention/time!

Questions?