GPU-based Monte Carlo simulation for Carbon Ion Therapy

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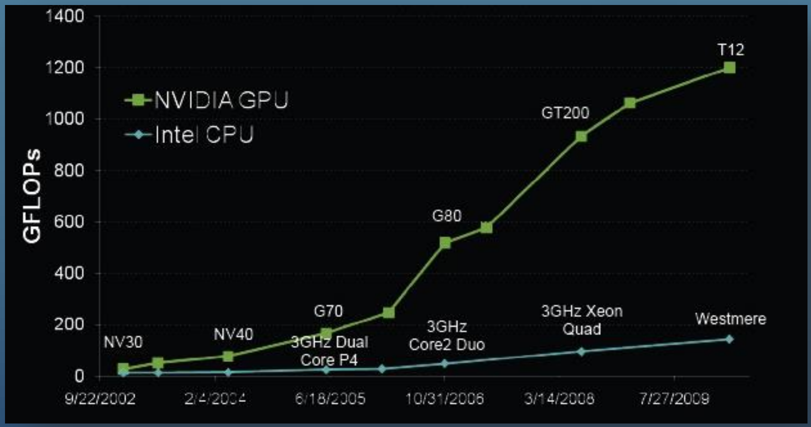
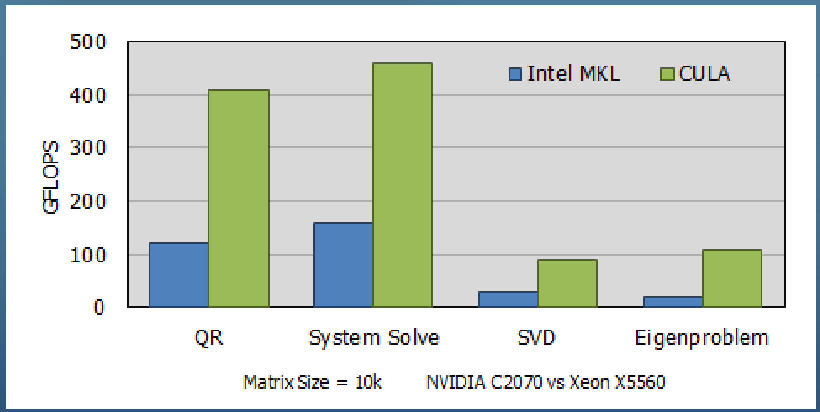
GPU

- A specialized accelerator (personal super-computer)



Comparison CPU/GPU peak processing power



Comparison CPU/GPU performance in linear algebra solver

Jia et. al. *PMB*, **59**, R151(2014)

GPU Monte Carlo project

- Since 2009
- Utilize GPU to accelerate MC simulations in medical physics
  - Use appropriate physics model to maintain accuracy
  - Design GPU-friendly implementations for high efficiency
- Apply developed tools to solve medical physics problems in radiotherapy

GPU Monte Carlo project

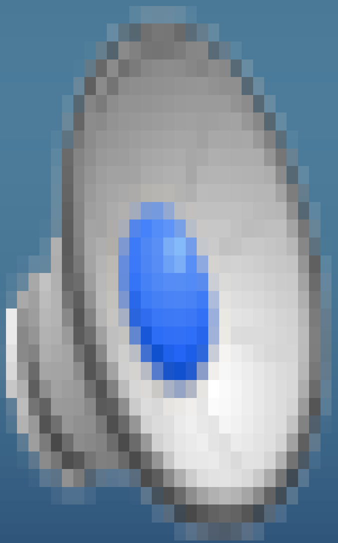
- A spectrum of GPU-based MC packages

2009	*2011*	*2012*	*2014*	*2015*
gDPM	gCTD gMCDRR	gPMC	goMC gBMC	goPMC goCMC

  - MV photon: gDPM, goMC
  - Particle therapy: gPMC/goPMC, goCMC
  - Brachytherapy: gBMC
  - kV imaging: gMCDRR/gCTD
  - Apply MC in different clinical and research problems
    - MC-based inverse plan optimization — Li et. al. PMB, 60, 2903(2015)
    - Cone beam CT scatter estimation — Xu et. al. PMB, 60, 3567(2015)
    - CT dose calculation — Montanari et. al. *PMB*, 59, 1239(2014)
    - Evaluation of brachytherapy dose accuracy — Tian et. al. *ABS meeting*(2014)

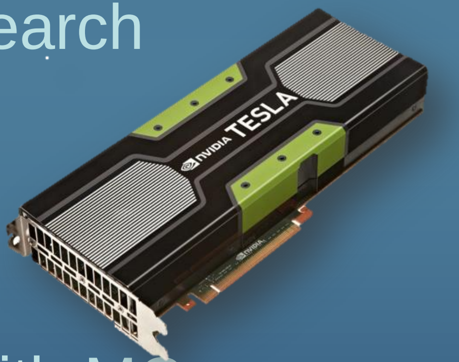
Power of a GPU

- Visualize the invisible radiation
- Real-time simulation of photon dose delivery using machine log



Carbon MC

- Monte Carlo simulation for carbon therapy
- Goal: Develop a Monte Carlo particle transport simulation system using novel graphics-processing unit (GPU) for carbon beam radiotherapy research and clinic



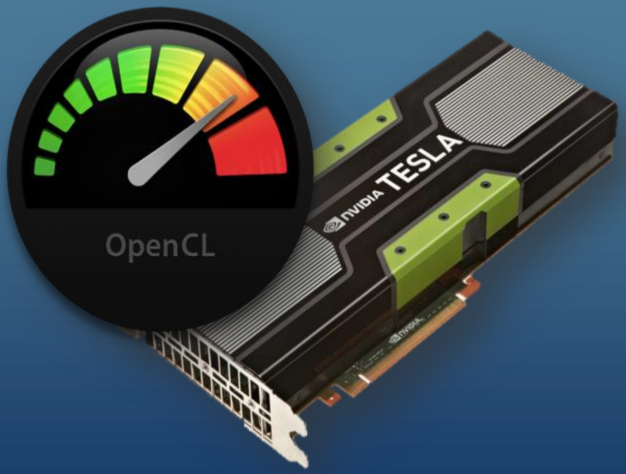
- Targeted features
  - *Accuracy:* Particle transport simulations with MC
  - *Efficiency:* GPU-based parallel processing platform

Carbon MC

- Targeted features (cont'd)
  - *Portability:* OpenCL environment to maintain compatibility with different computational platforms
  - *Versatility:* Score different quantities (dose, LET, particle spectrum, positron emitting nuclei distribution …) to support a variety of projects in physics, radiobiology, and clinic research

goCMC

- goCMC: GPU OpenCL Carbon-therapy MC
  - Started Feb 2015
  - In collaboration with Dr. Katia Parodi in LMU
  - GPU platform in OpenCL
  - Development in progress

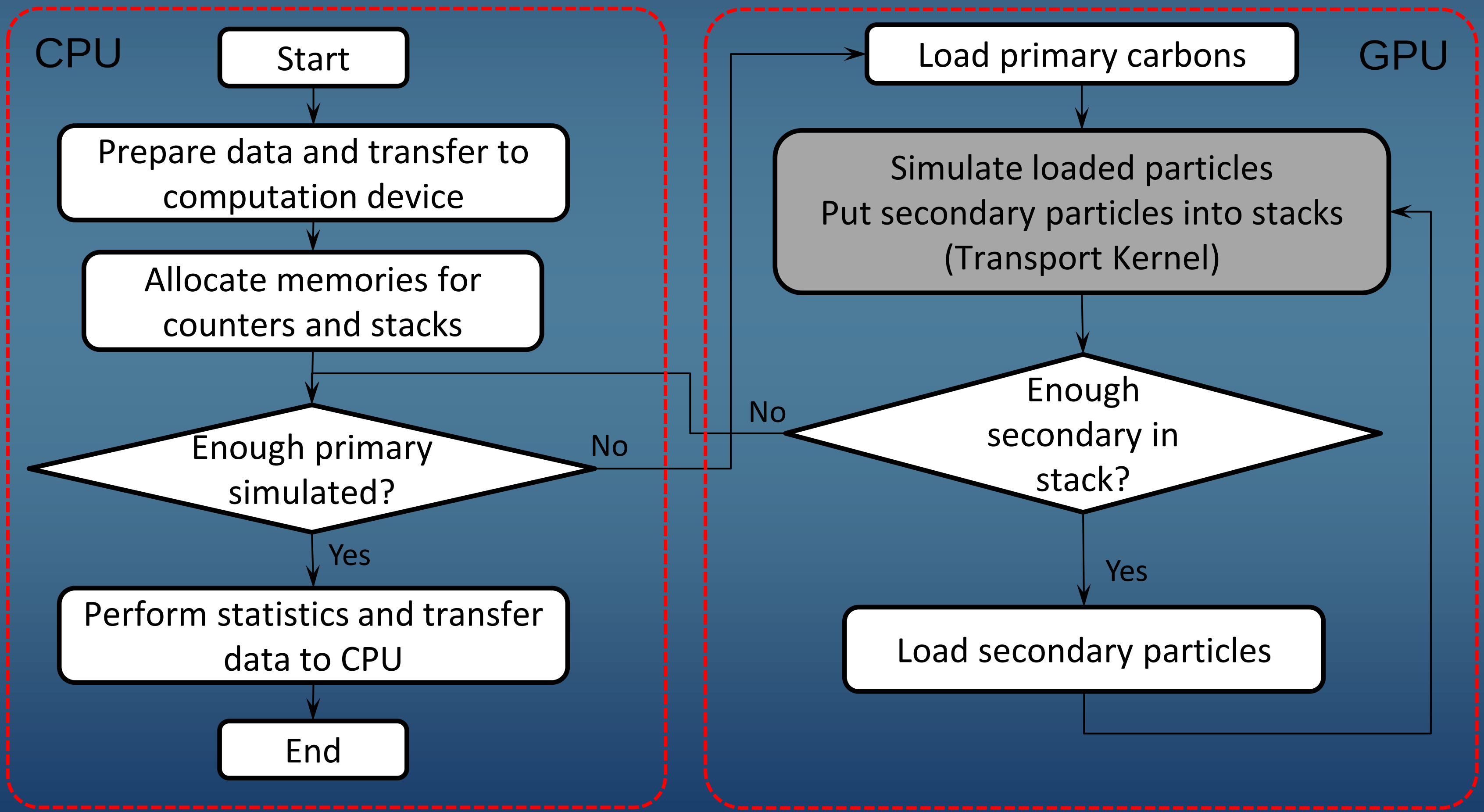


goCMC

- Particle transport simulation
  - Condensed history simulation for charged particle transport
  - Electrons locally deposit energy
  - Nuclear interaction
  - Continuously slowing down approximation for secondary charged particle
  - Ignore charged neutral particles
- Geometry: voxelized geometry
- Data-base:
  - Extracted from Geant4
  - Currently include C-H, C-O, C-C interactions
  - Tabulate total cross section, secondary particle yield, angular and energy distribution

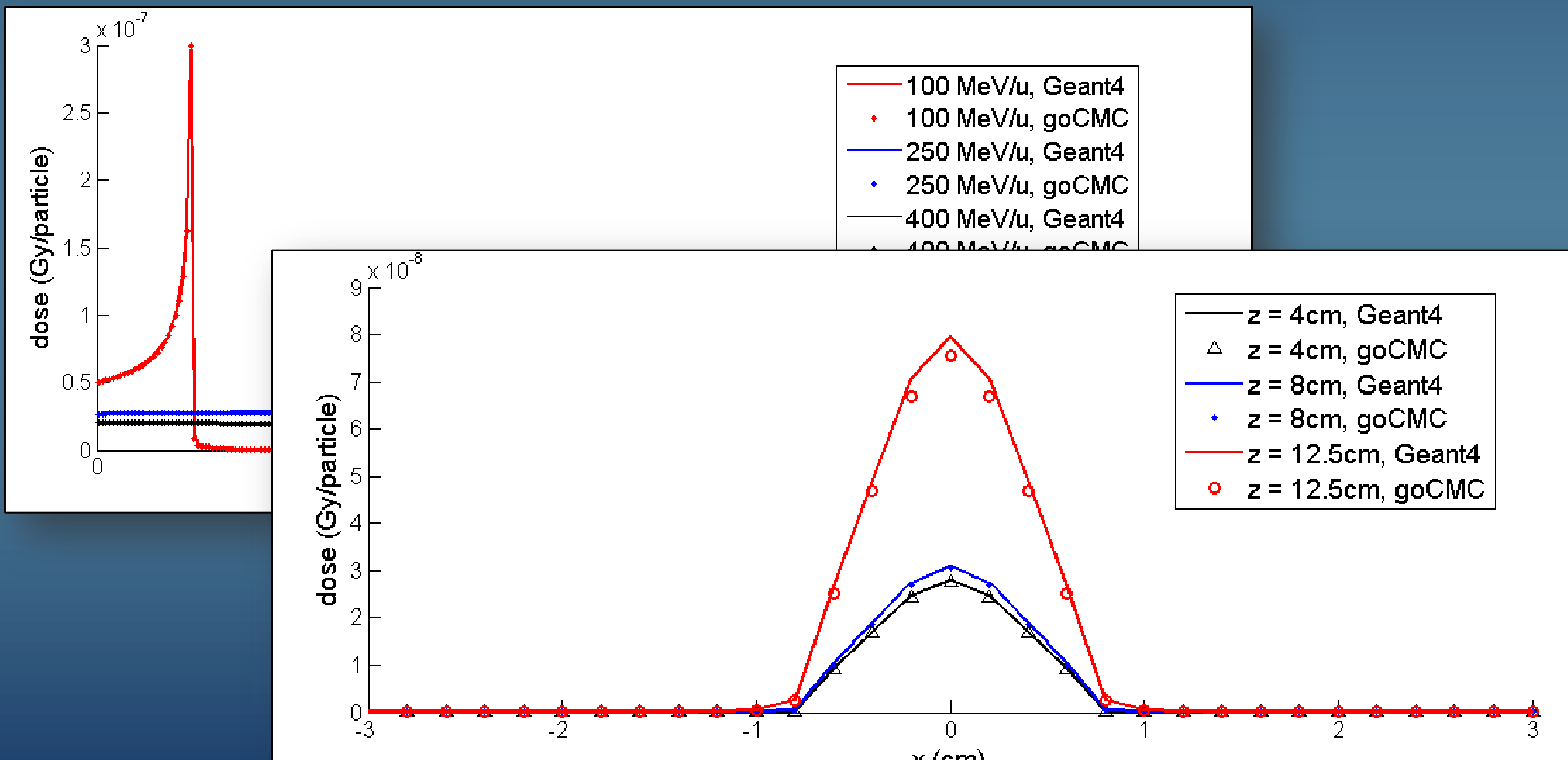
goCMC Implementation

- Simultaneous transport simulations of multiple charged particles



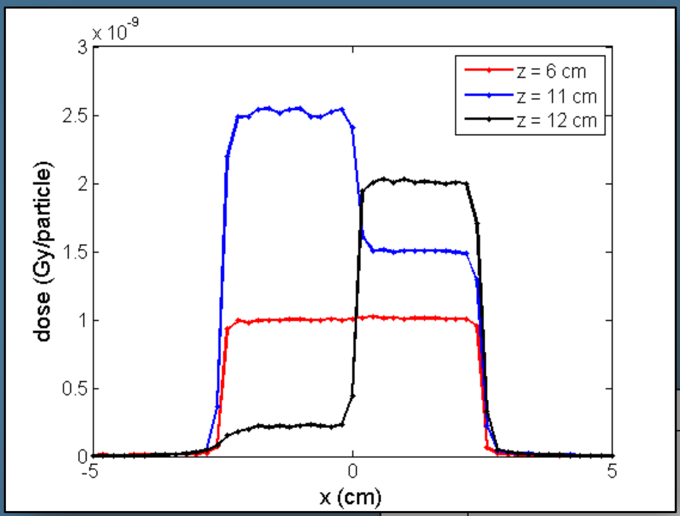
Results

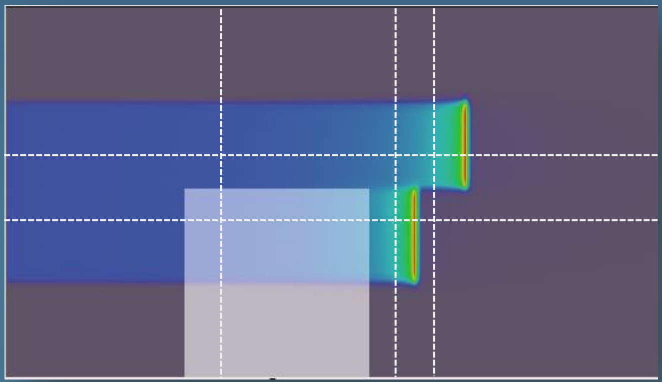
- Water phantom
  - Carbon beam *σ = 4 mm*

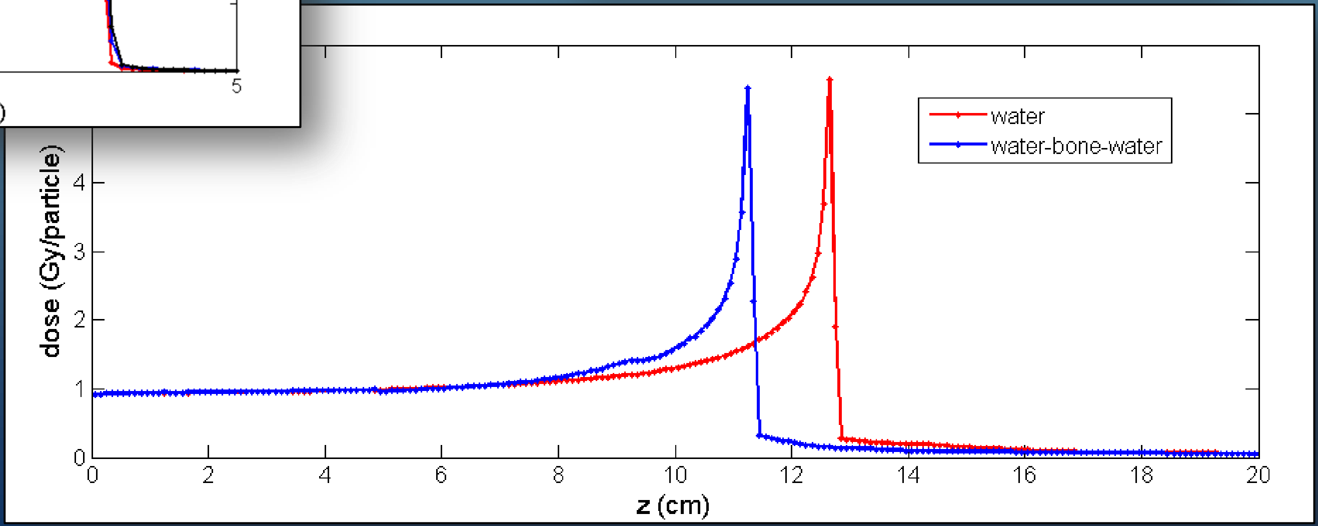


Results

- Water-bone-water half slab phantom
  - 250 MeV/u, 5×5 cm^2 beam, 5 cm thick half bone-slab

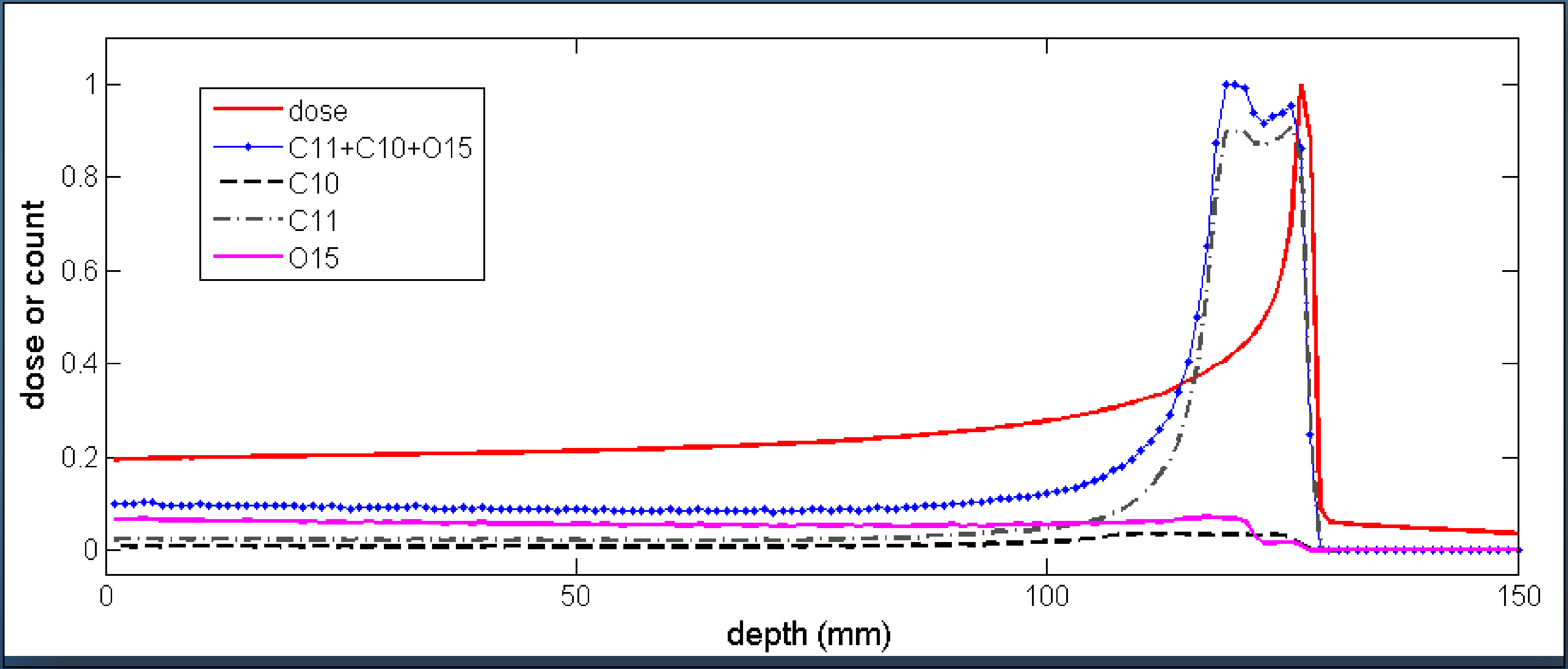






Results

- Positron emitter distribution
  - 250 MeV/u beam in water

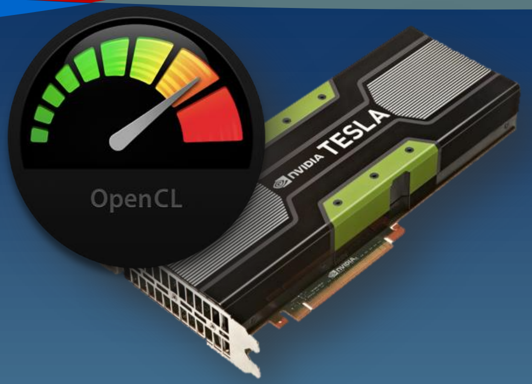


Results

Case #	Phantom	Energy (MeV/u)	Size	ΔR (mm)	ΔD (%)	Time (sec)
1	Water	100	Pencil-beam	0.1	1.3	21.5
2	Water	250	Pencil-beam	0.2	2.2	102.2
3	Water	400	Pencil-beam	0.4	2.4	206.3
4	Lung	200	5×5 cm^2			77.5
5	Bone	200	5×5 cm^2			45.3
6	Tissue	200	5×5 cm^2			47.5
7	Water-bone-water half slab	250	5×5 cm^2			46.2

10^7 primary carbons, <1% average uncertainty
One NVidia GTX Titan: 2688 CUDA cores, 6GB memory

Summary



- GPU is a great tool to accelerate MC simulations
- On-going development of goCMC
  - Achieved computation time of mins with acceptible accuracy
- Next step
  - Fine tune physics model and parameters
  - Optimize implementation
  - Comprehensive validations

Acknowledgement

- All the team members
  - UTSW: Steve B. Jiang, Arnold Pompos, Nan Qin
  - LMU: Katia Parodi, Marco Pinto, Georgios Dedes