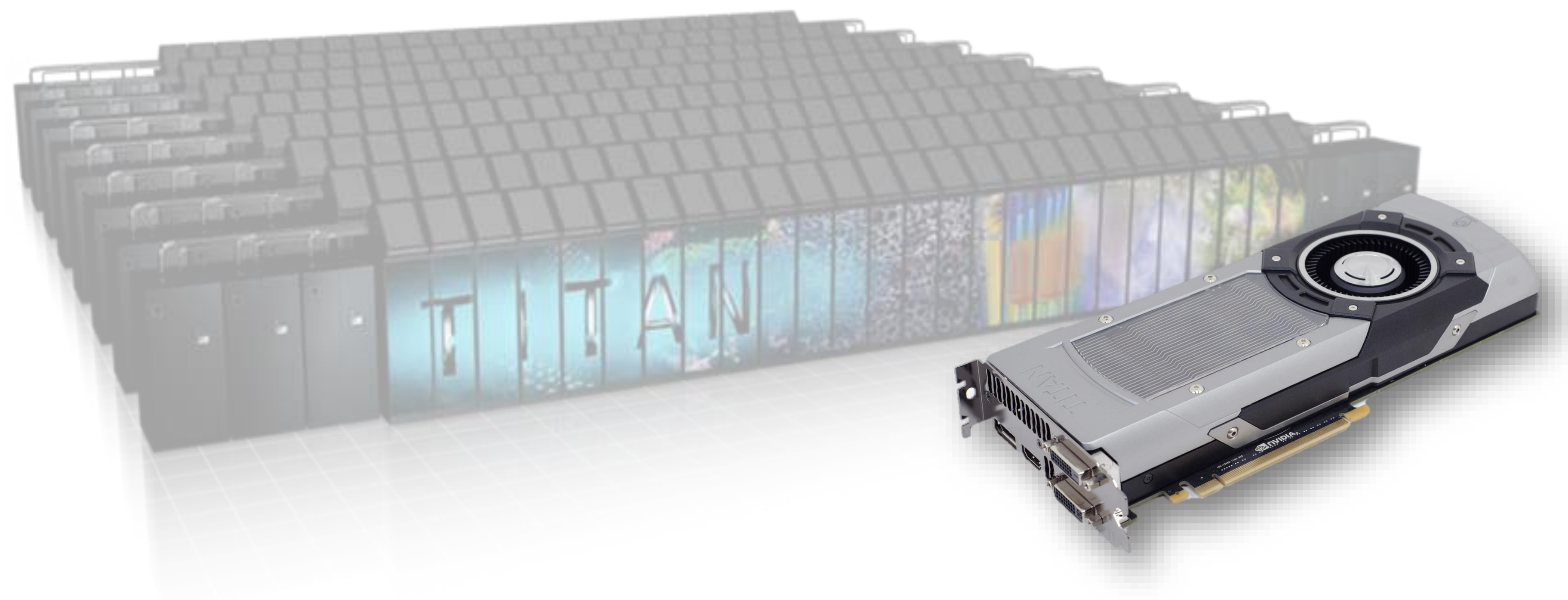
Recent progress on GPU-based Monte Carlo Simulations for Radiation Therapy

Xun Jia, Ph.D.
Xun.Jia@UTSouthwestern.edu

Outline

- Recent progress
- Two packages
- Considerations
- Conclusion



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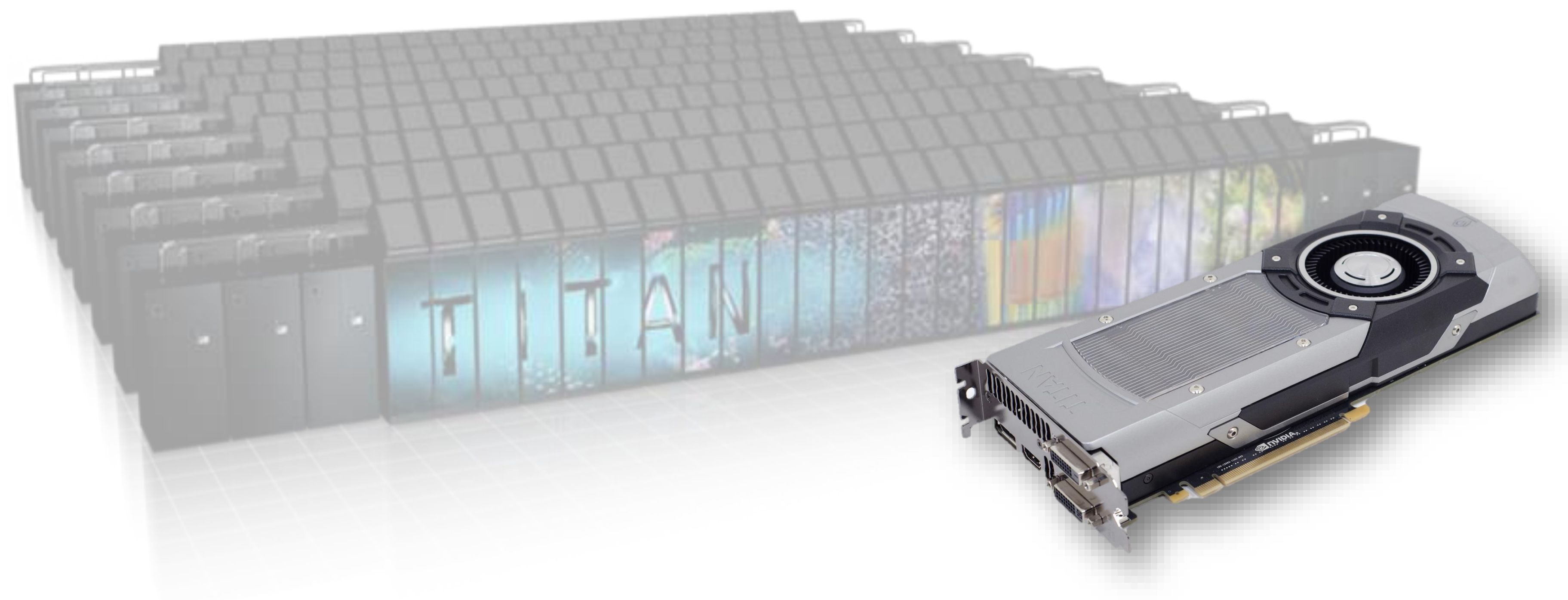
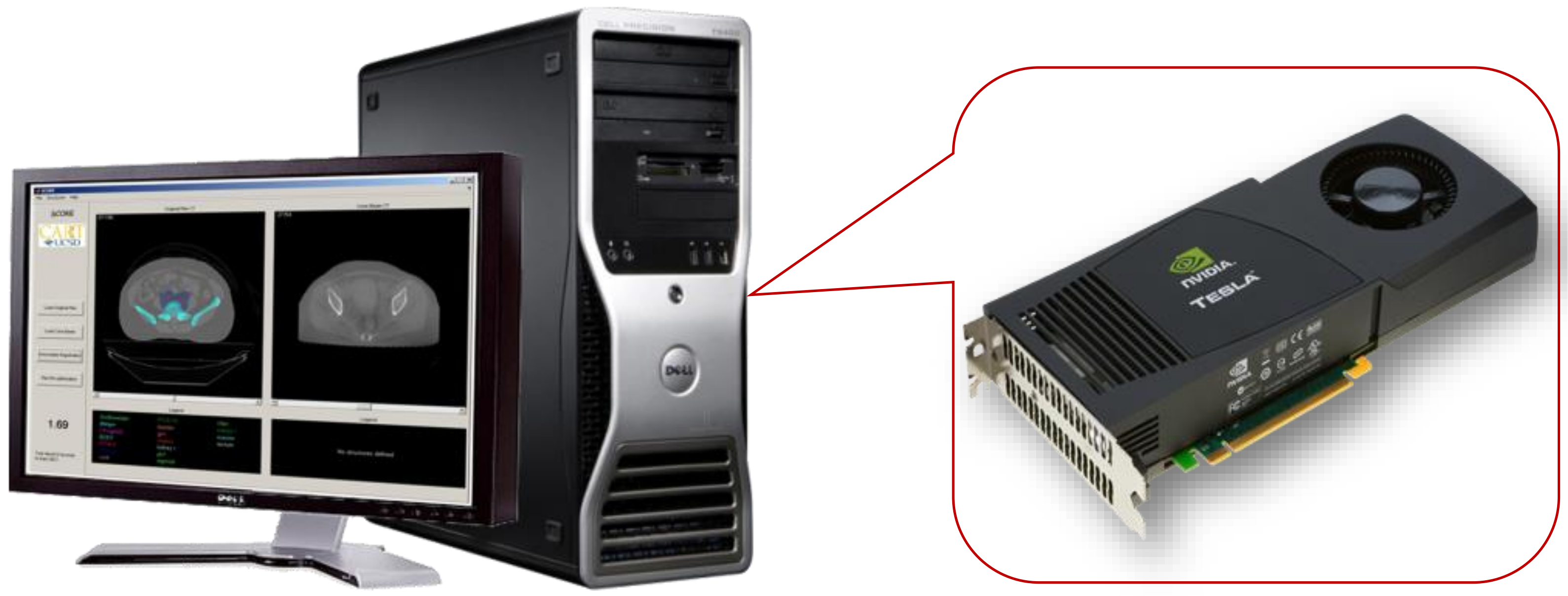


GPU



GPU

	Core	Clock Rate (MHz)	Memory (MB)	Processing power (GFLOPS)	Price ($)
Geforce GTX TITAN black (Feb 2014)	• 2880	• 889	• 6144	• 5120 (SP) • 1706 (DP)	• 999
Geforce GTX 1080 Ti (Mar 2017)	• 3584	• 1417	• 11264	• 10609 (SP) • 332 (DP)	• 699

GPU-MC project at UTSW

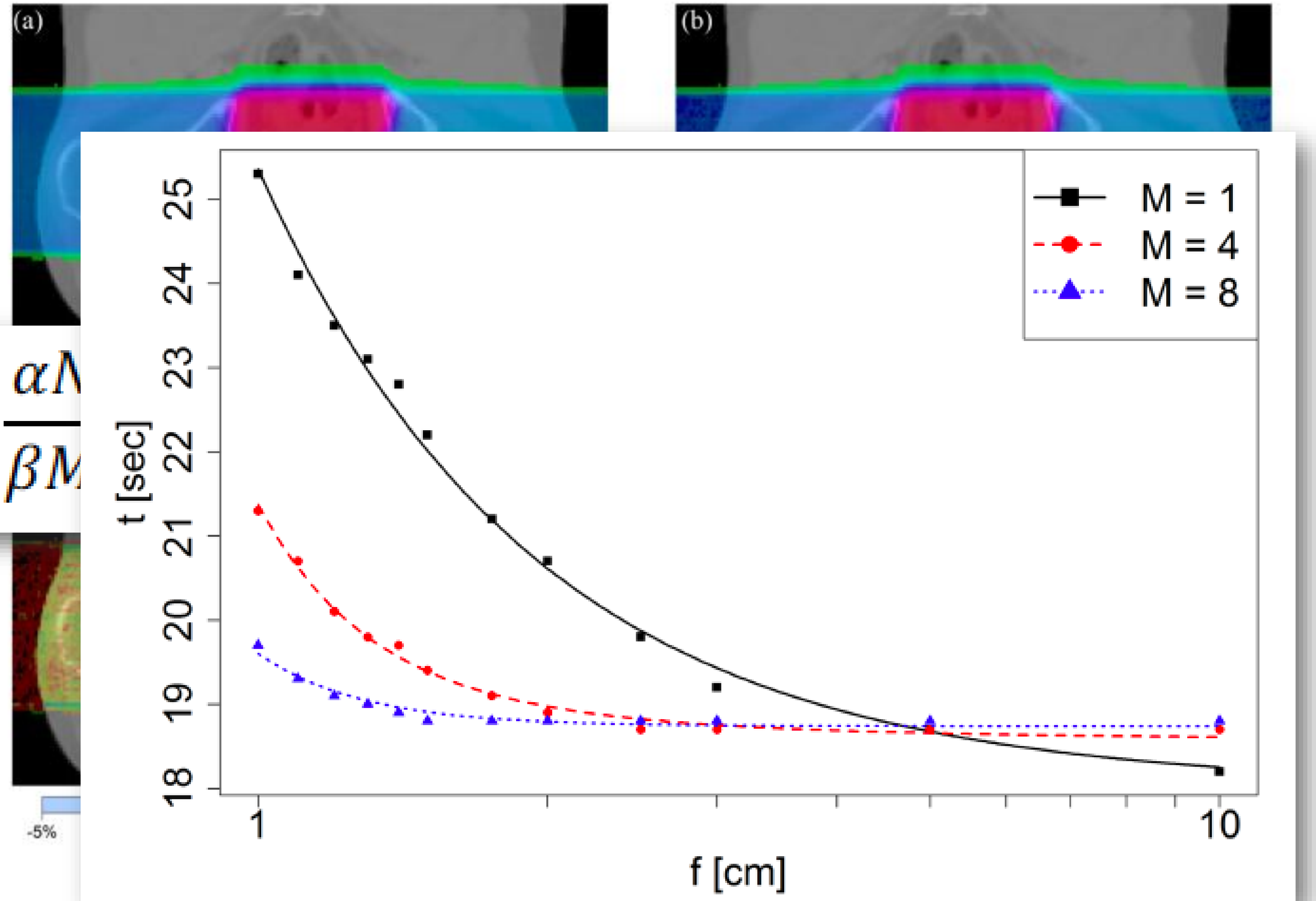
2009	*2011*	*2012*	*2014*	*2015*	*2016*
gDPM	gCTD gMCDRR	gPMC	goMC gBMC	goCMC	goMicroMC

- Particle types: photon, electron, proton, carbon ion, free radical…
- Energy ranges: eV → keV → MeV → GeV
- Spatial scales: nm (DNA level) → m (human level)
- Clinical applications: external beam therapy, brachytherapy

Particle therapy

- gPMC → goPMC
- Race condition

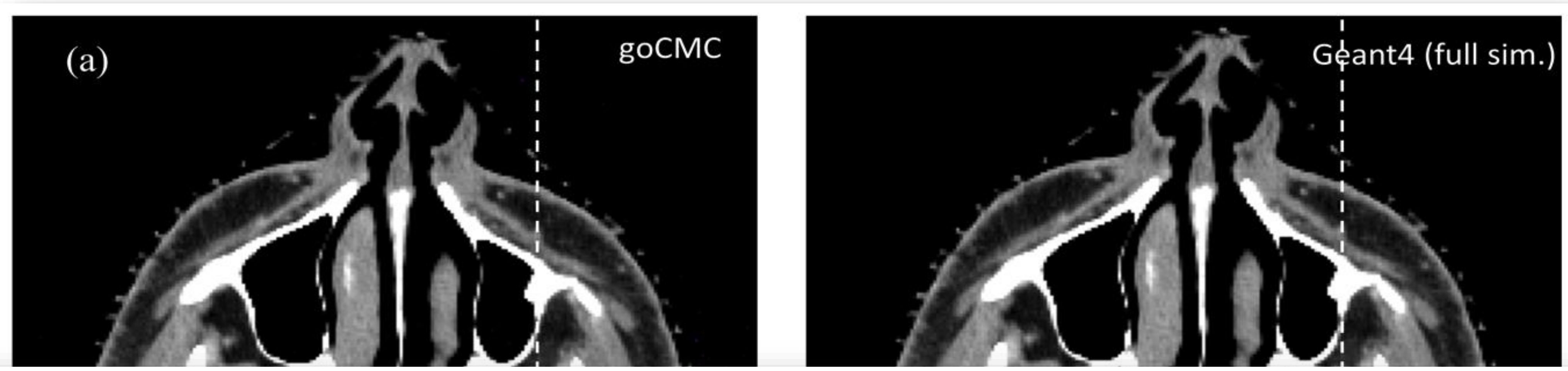
$$t = \frac{N\Delta t}{N_t}\left(1 - \frac{\alpha}{Mf^2}\right) + \frac{\alpha N}{\beta M}$$

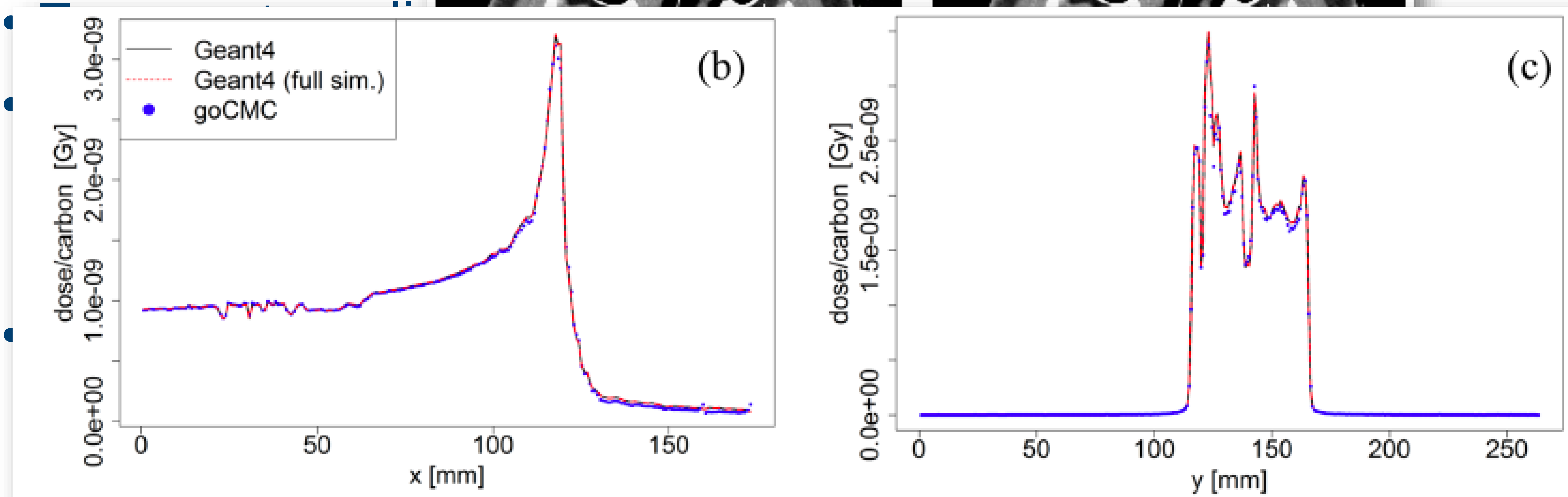


Qin et. al. PMB, 61, 7437 (2016)

Particle therapy

- goCMC
  - CSDA





- Simulation time of 10^7 C_{12}: 11~162 sec (100~400 MeV/u)

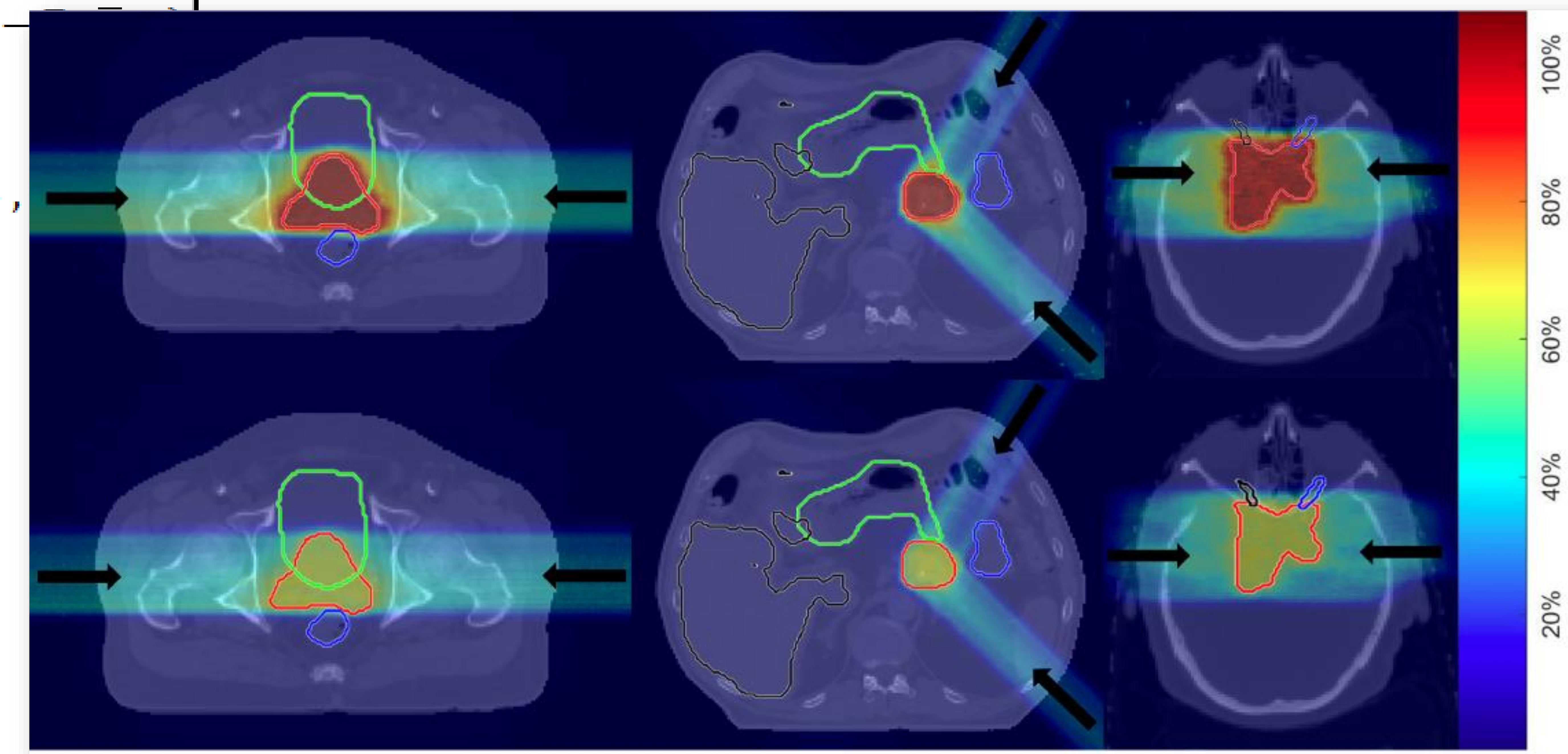
Qin et. al. PMB, 62, 3628(2017)

Particle therapy

- Biological dose calculation with RMF model

$$\alpha_q = \frac{\Sigma}{\Sigma_X}\left[\alpha_X + 2\frac{\beta_X}{\Sigma_X}(\Sigma\, \bar{z}_f - \ldots\right]$$

$$\beta_q = \left(\frac{\Sigma}{\Sigma_X}\right)^2 \beta_X\,,$$



Qin et. al. To appear in Red Journal (2017)

Particle therapy

- Biological inverse optimization

$$f(N) \equiv \sum_i w_i \left| \ln S(\boldsymbol{x}, \boldsymbol{N}) - \ln S_p(\boldsymbol{x}) \right|^2_{\boldsymbol{x} \in \mathrm{OTV}_i}$$

$$+ \sum_i w_i \left| \left(\ln S(\boldsymbol{x}, \boldsymbol{N}) - \ln S_p(\boldsymbol{x}) \right) \Theta\left(- \ln S(\boldsymbol{x}, \boldsymbol{N}) + \ln S_p(\boldsymbol{x}) \right) \right|^2_{\boldsymbol{x} \in \mathrm{OAR}_i},$$

$$- \ln S(\boldsymbol{x}, \boldsymbol{N}) = \langle \boldsymbol{a}_D(\boldsymbol{x}), \boldsymbol{N} \rangle + \langle \sqrt{\boldsymbol{b}_D(\boldsymbol{x})}, \boldsymbol{N} \rangle^2.$$

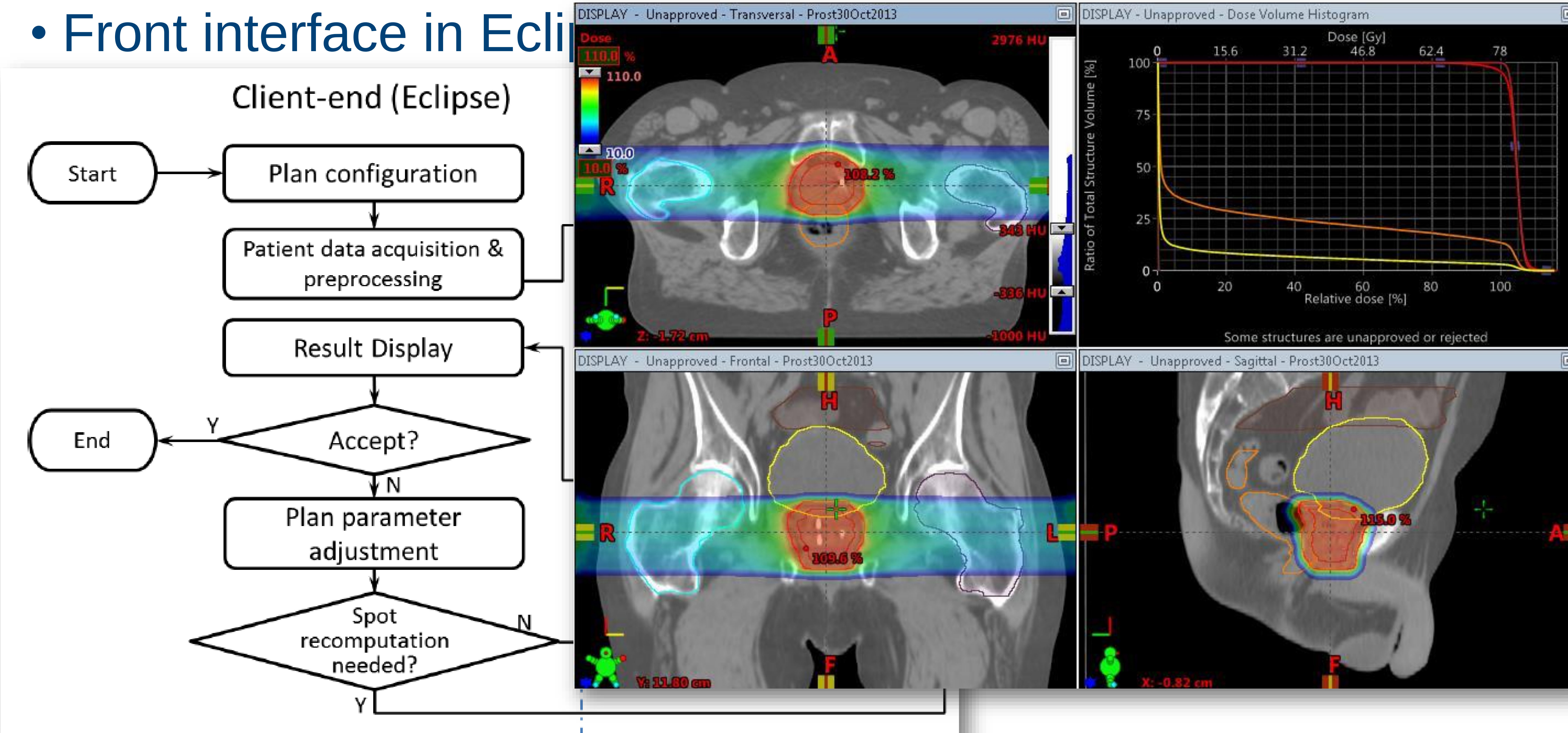
$$f(N) = \left| \sqrt{\boldsymbol{W}} \cdot \left(\boldsymbol{AN} + \boldsymbol{BN} \cdot \boldsymbol{BN} - \left(\boldsymbol{\alpha}_X \cdot \boldsymbol{D}_p + \boldsymbol{\beta}_X \cdot \boldsymbol{D}_p^2 \right) \right) \cdot \boldsymbol{\Theta} \right|^2,$$

- Full GPU-MC based biological optimization

Qin et. al. To appear in Red Journal (2017)

Particle therapy

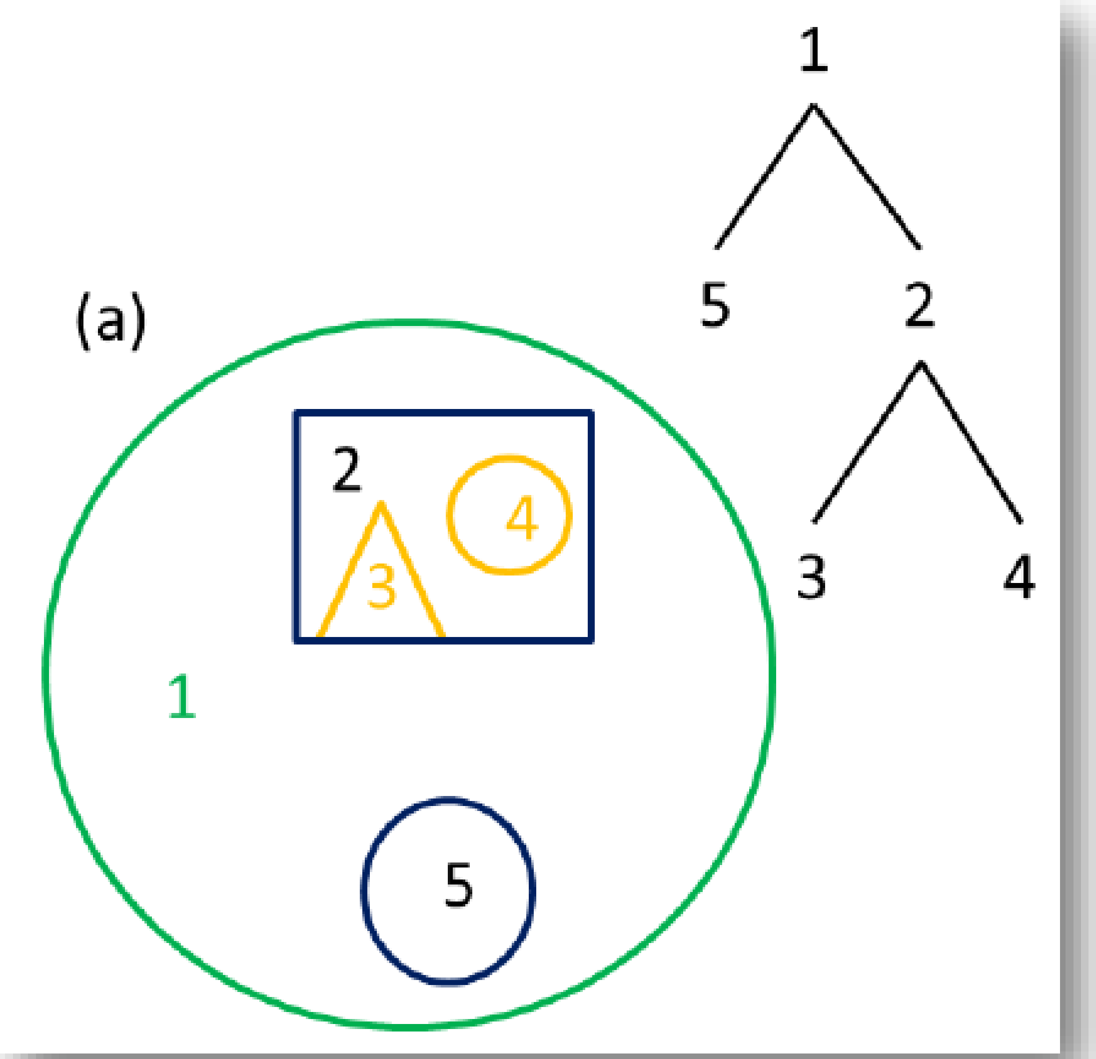
- Front interface in Ecli



Qin et. al. To appear in Red Journal (2017)

Geometry modeling

- Voxelized geometry → Quadratic geometry
- Stored in a tree structure
- Two key geometry functions
- Time vs memory type

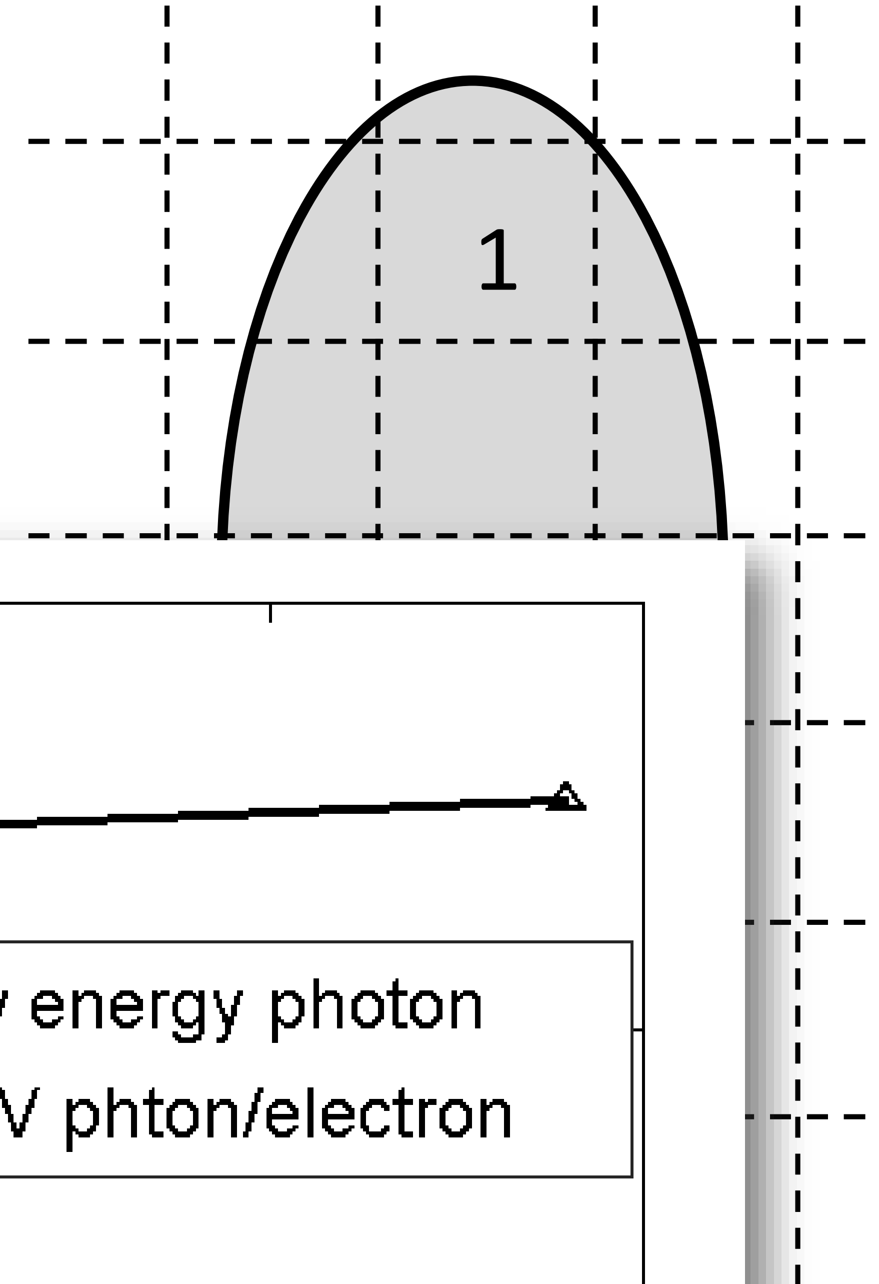


Case	Parameterized geometry (μs/history)			Voxelized geometry (μs/history)	α_1
	Global memory	Texture memory	Shared memory		
Brachytherapy photon transport	5.546	3.792	2.121	0.761	2.79
Coupled electron-photon transport	0.292	0.234	0.198	0.060	3.29

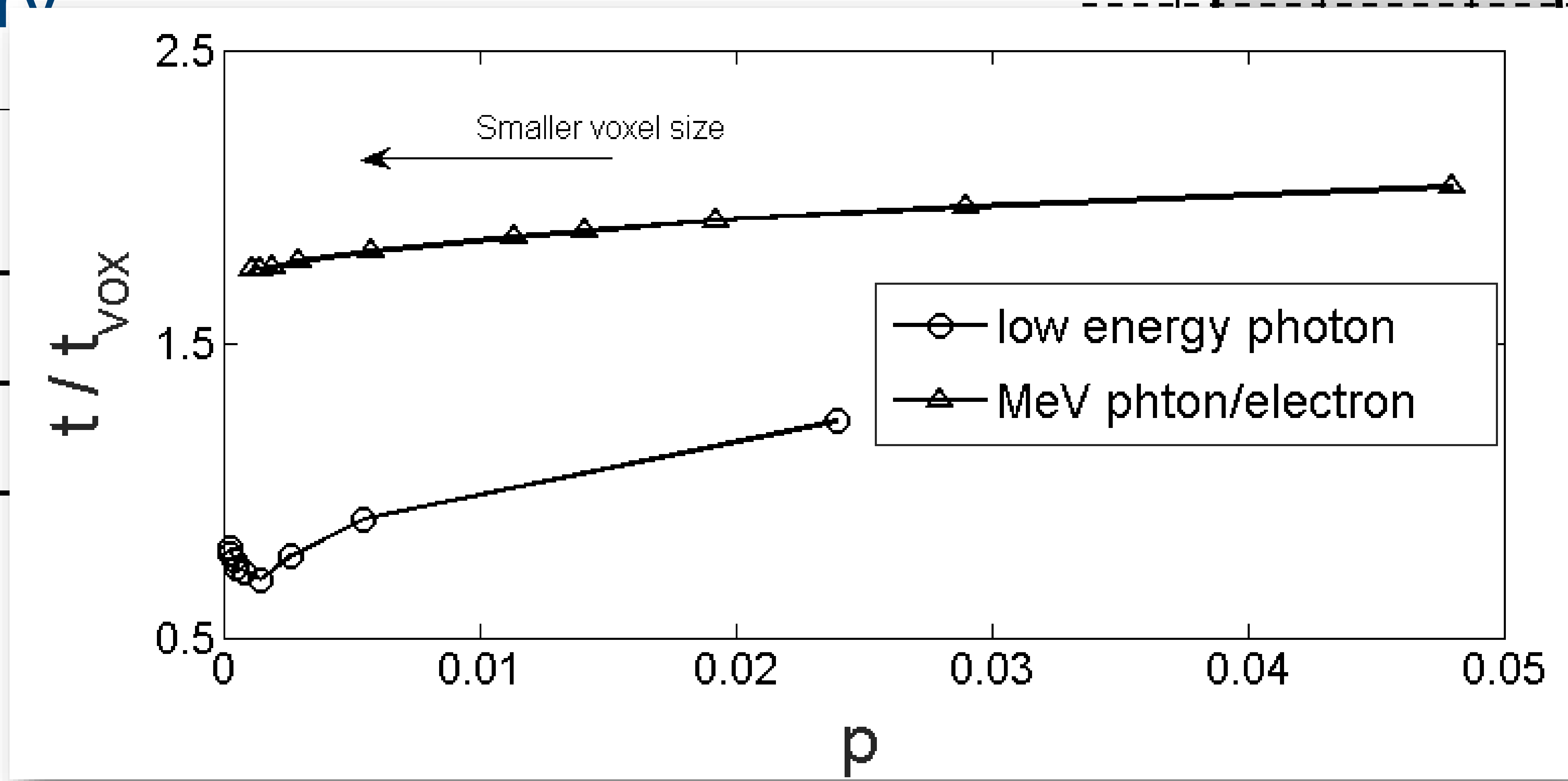
Chi et. al., PMB 61, 5851 (2016)

Geometry modeling

- Memory-speed tradeoff
  - An auxiliary array of body index in texture memory



Case
Brachytherapy photon transport
Coupled electron-photon transport

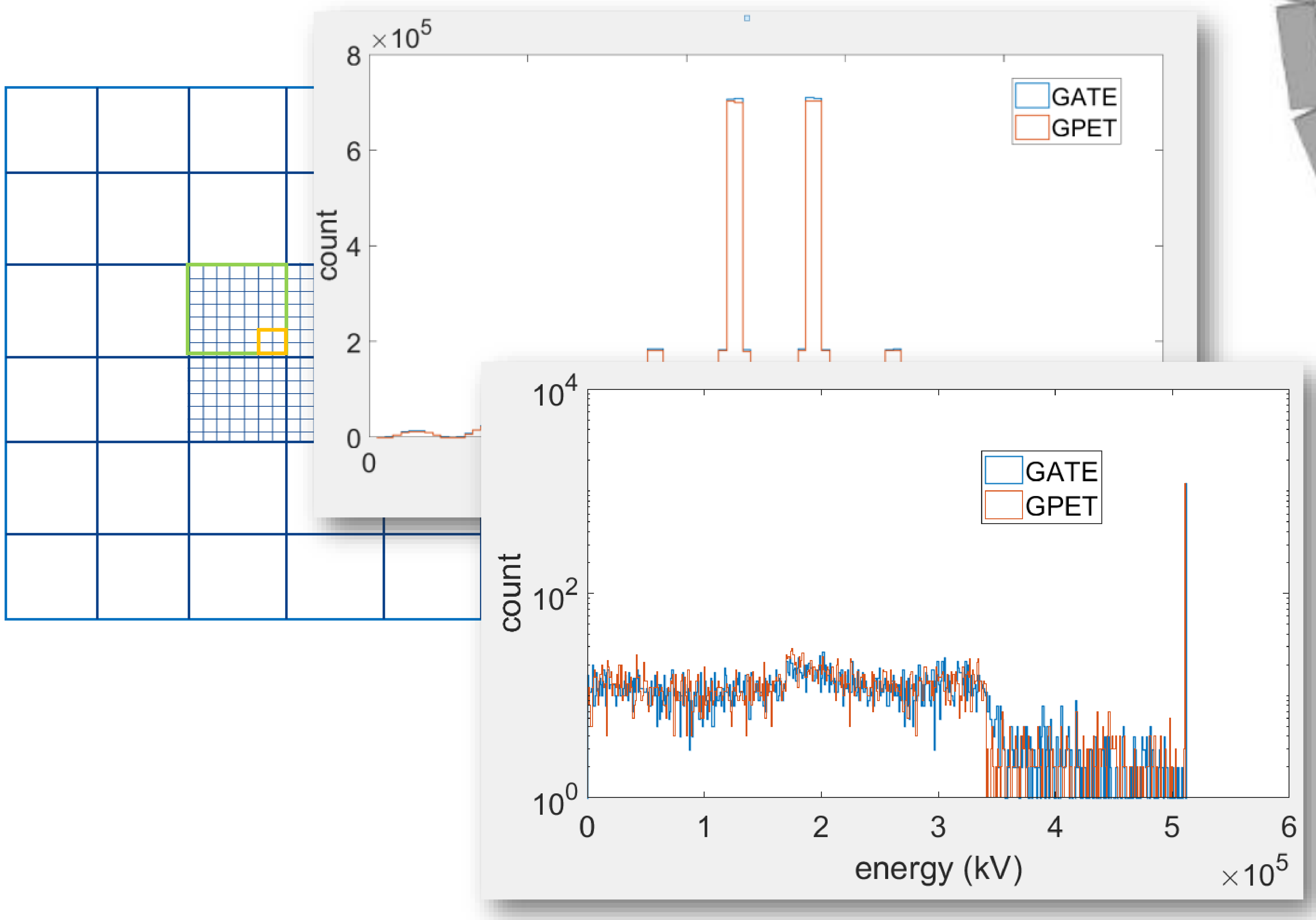


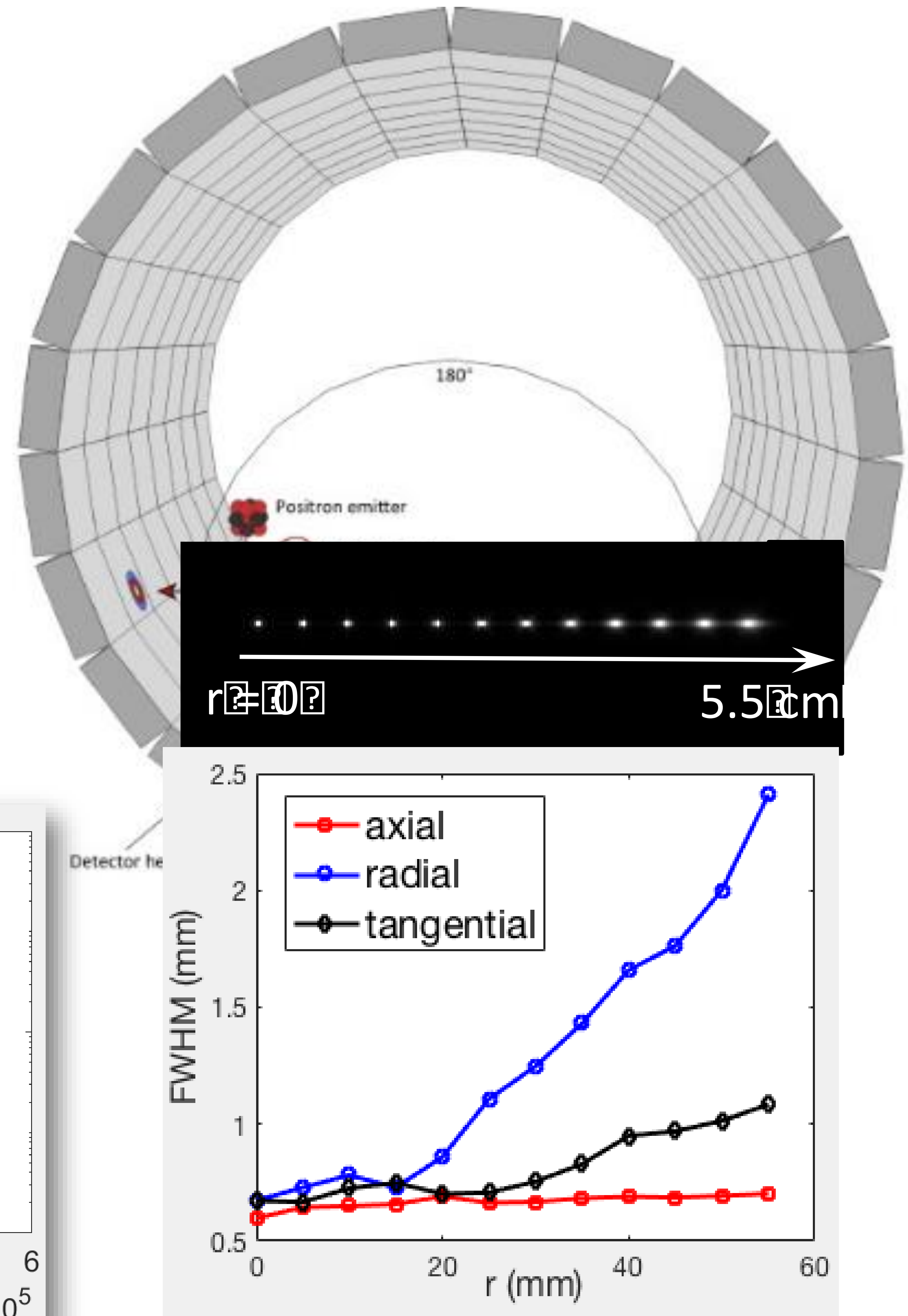
  - Time vs memory size

Chi et. al., PMB 61, 5851 (2016)

Geometry modeling

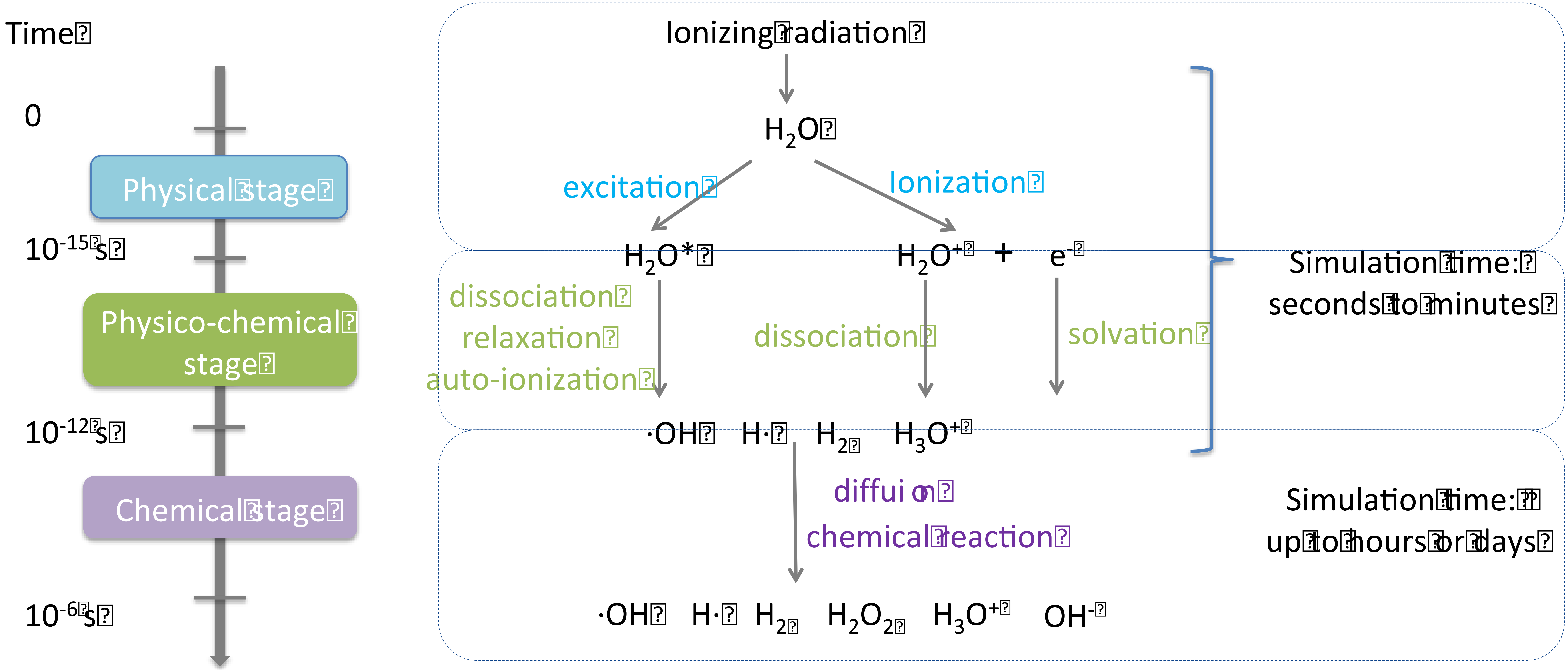
- Applications
  - PET detector simulation





Microscopic MC

- gMicroMC

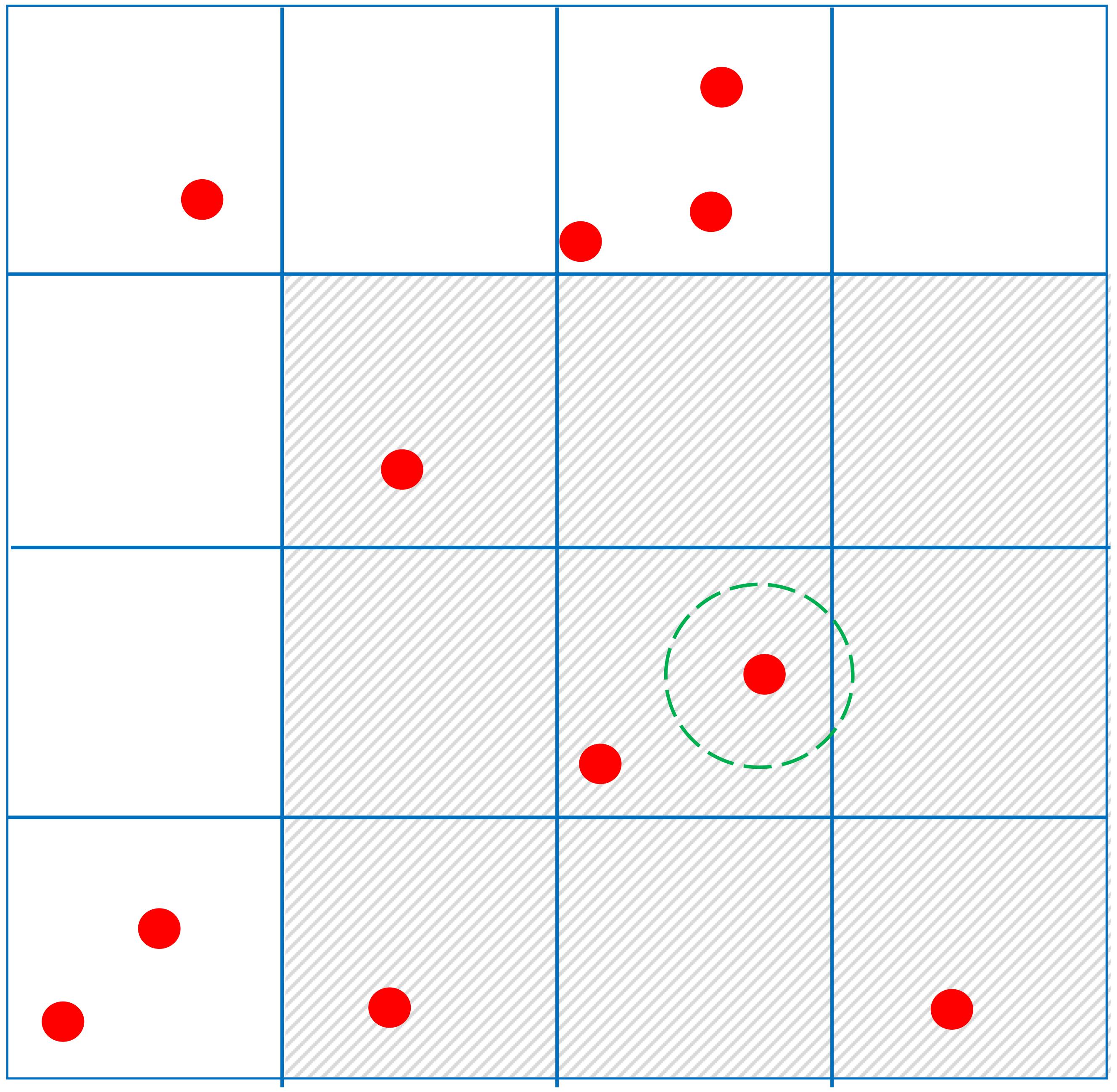


Tian et. al., PMB 62, 3081 (2017)

Microscopic MC

- Chemistry stage
  - Step-by-step diffusion reaction model
  - Brownian bridge considered
- Complexity due to chemical interactions
  - Particle binning with reaction radius
  - Search reactant within neighbors

	N	Simulation time (s)		Speed-up
		Geant4-DNA	gMicroMC	
750 keV electron	101829	102865.4	599.2	171.1
5MeV proton	56122	96446.5	489.0	197.2



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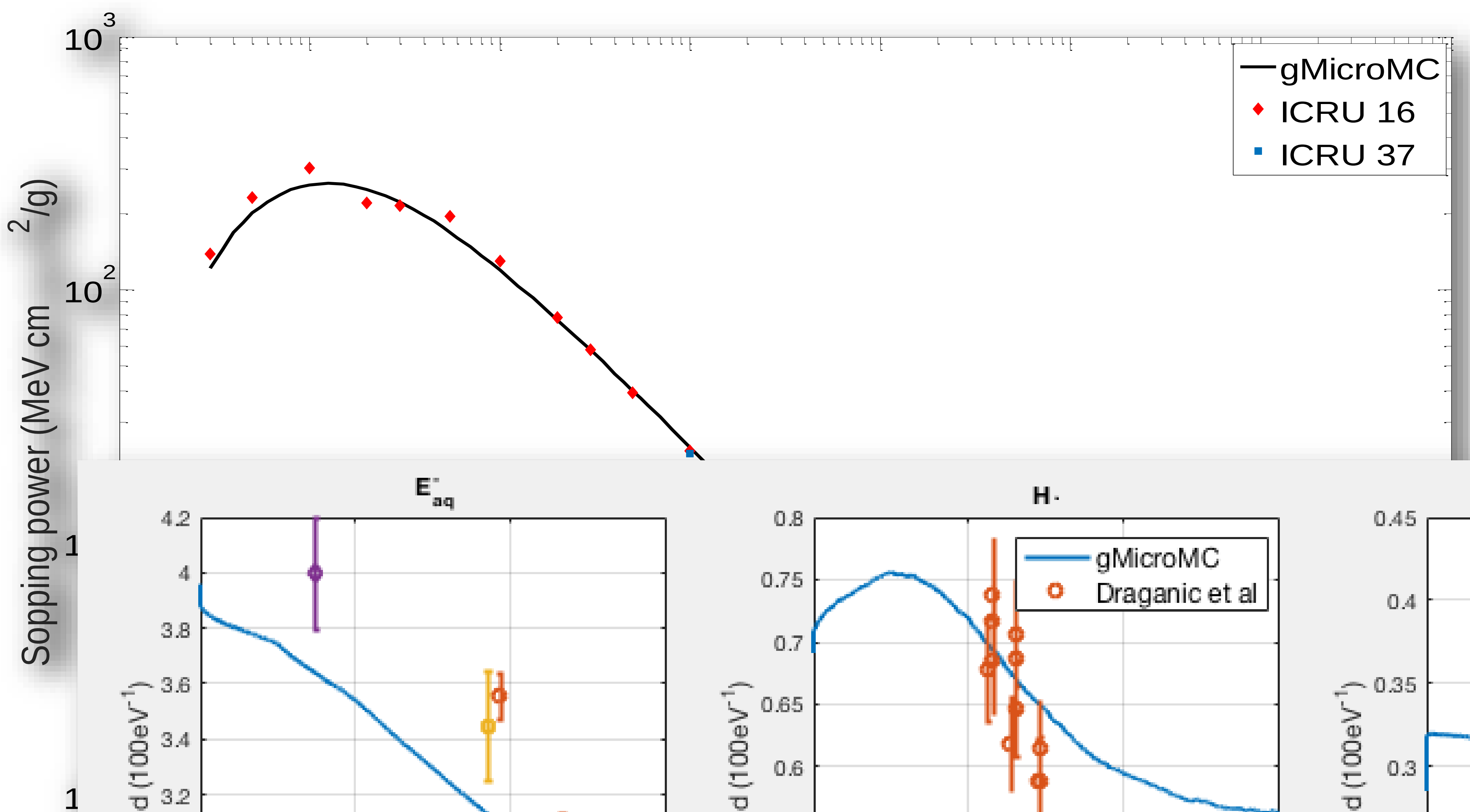
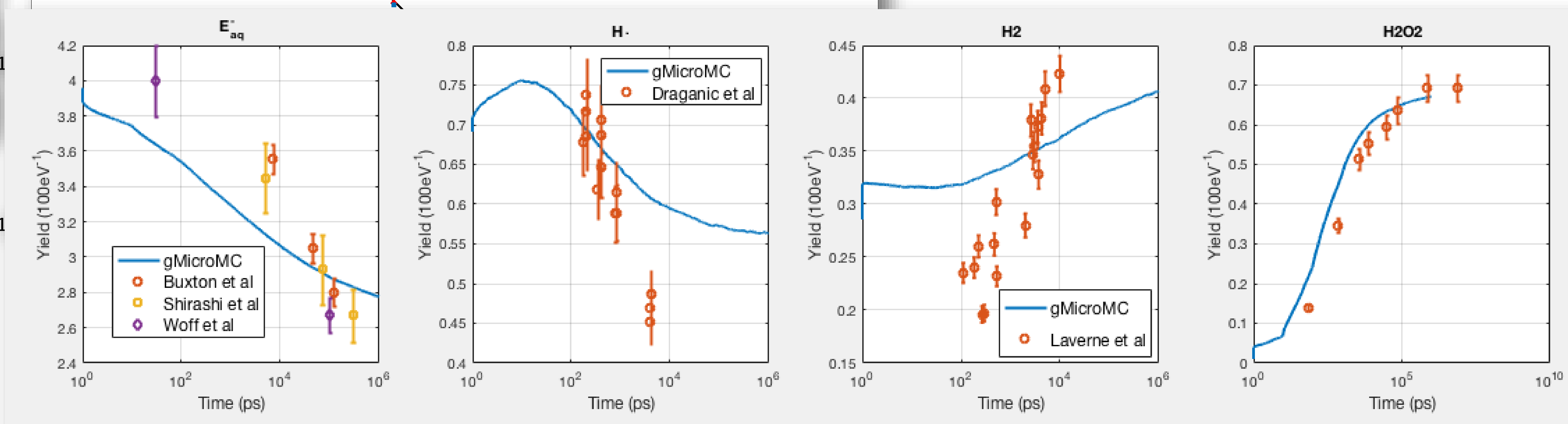
Microscopic MC





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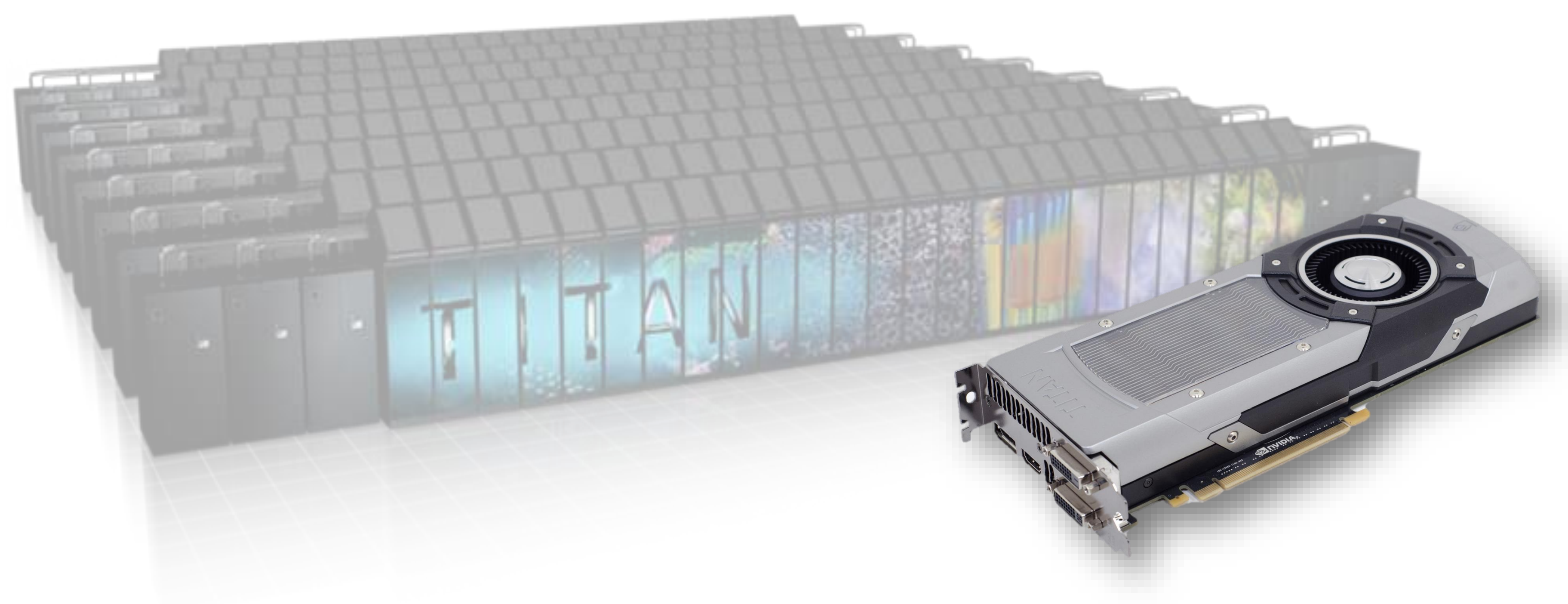
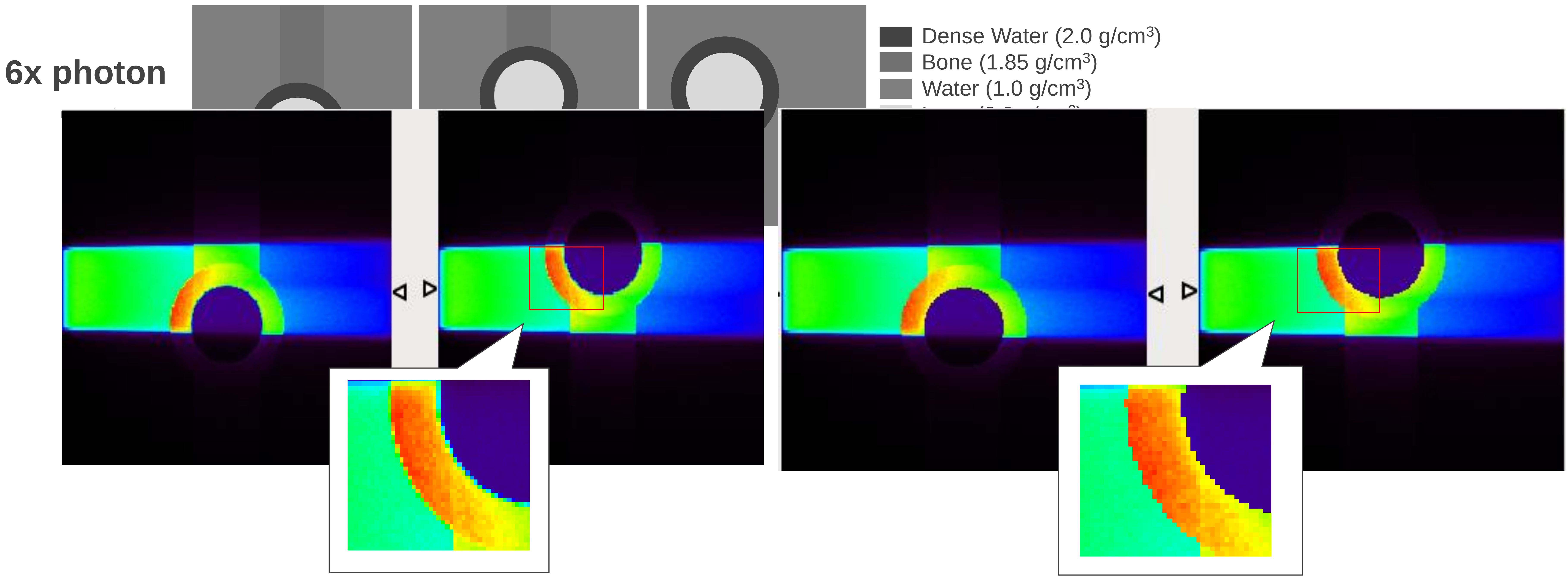


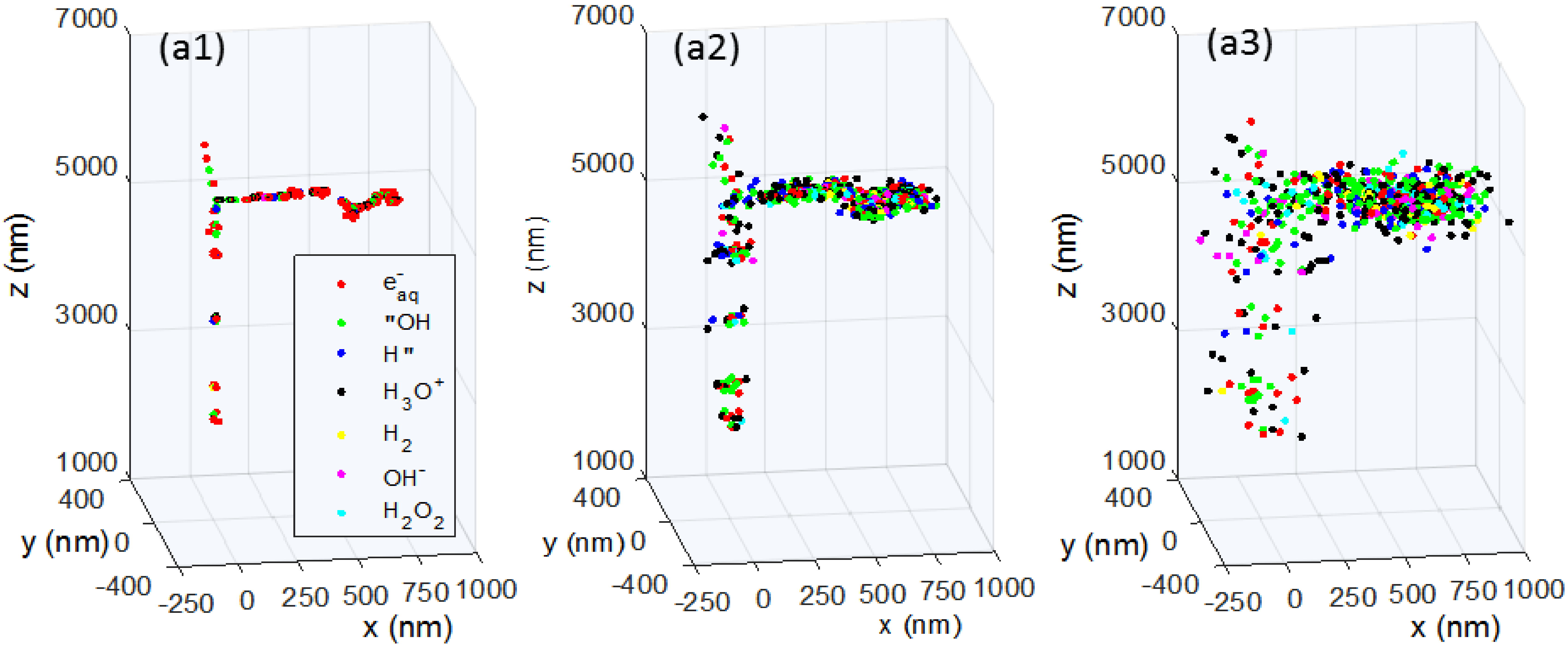
Two packages

- goMC
  - Coupled photon/electron transport with quadratic/voxelized geometry



Two packages

- gMicroMC



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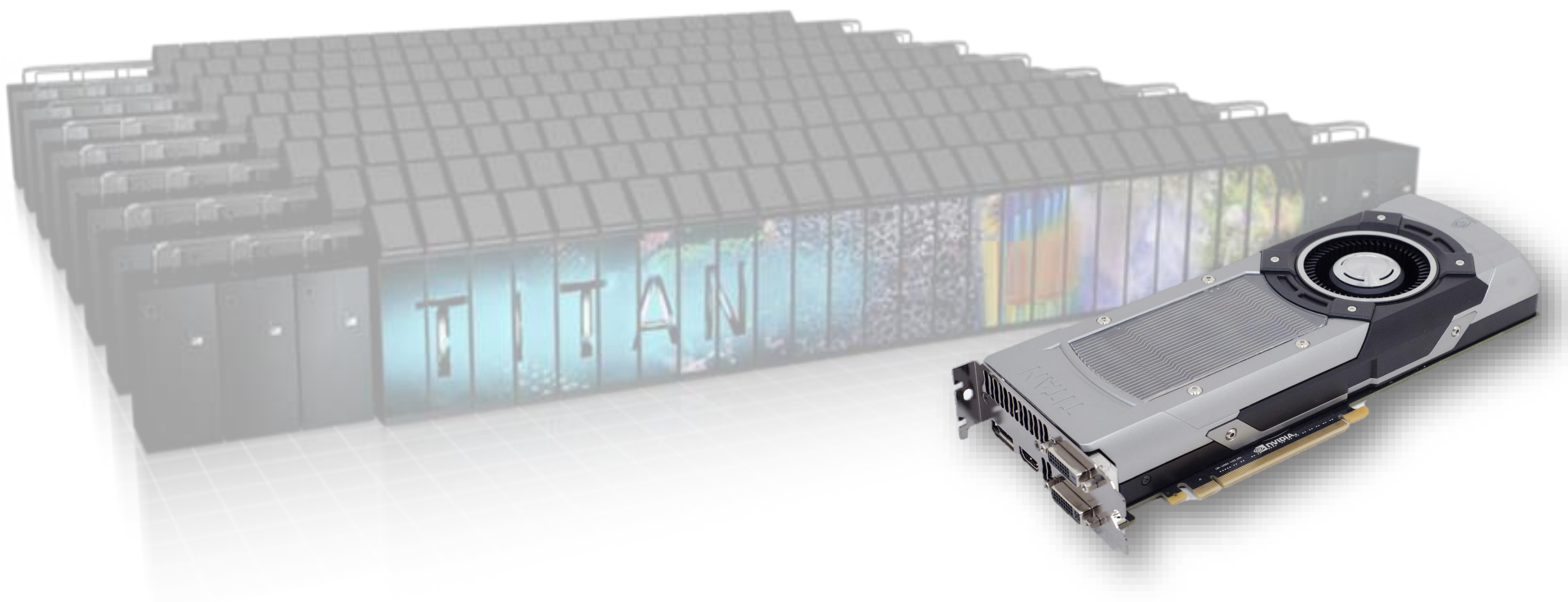
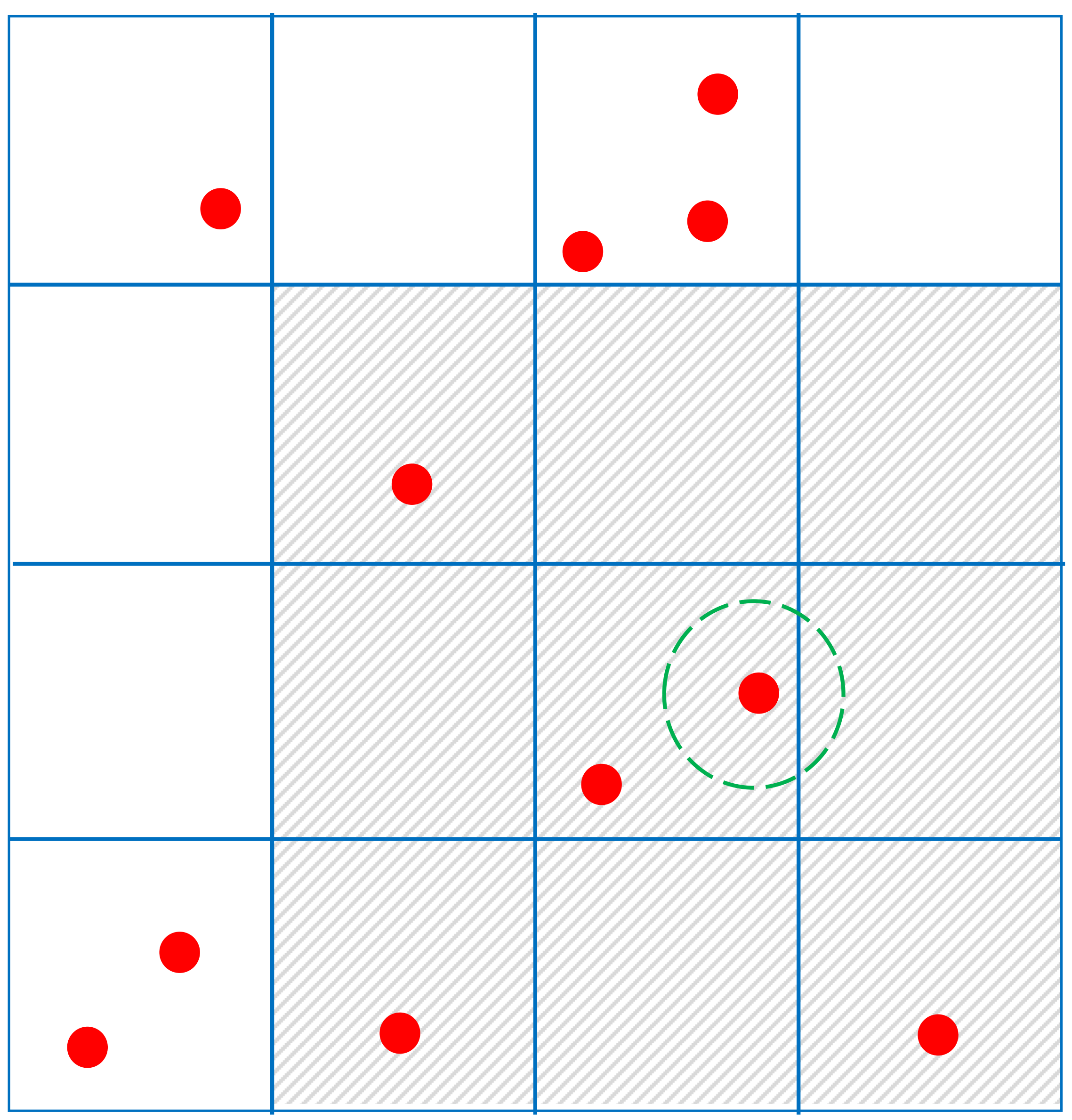
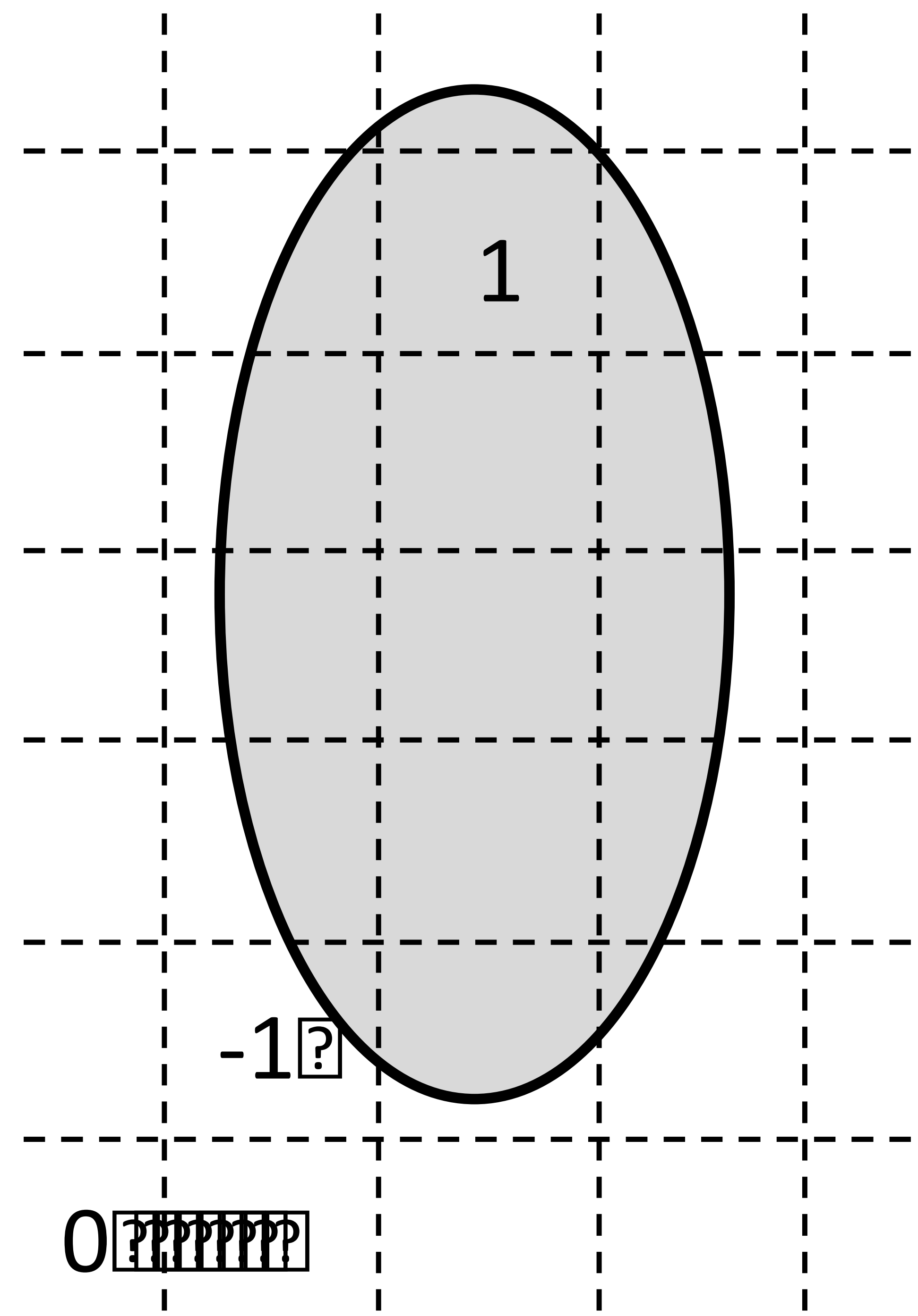


Considerations

- MC in the rapid (GPU) parallelization era
  - New algorithms vs Embarrassing parallelization
  - Speed-memory tradeoff





Considerations

- MC in the rapid (GPU) parallelization era
  - Single vs double precision

- Cross platform
  - OpenCL

Beam	No. of particles
15MeV electron	5×10^6
6MV photon	5×10^8

Beam	No. of particles	Phantom	goMC (s)				
			NVidia GeForce GTX TITAN	AMD Radeon R9 290x	AMD Radeon HD 7570	Intel i7-3770 CPU (4 cores, 8 threads)	Intel i7-3770 CPU (single thread)
15MeV electron	5×10^6	Water	4.3 ± 0.1	4.7 ± 0.2	123.9 ± 1.4	51.7 ± 1.7	213.4 ± 5.2
		Slab	4.9 ± 0.1	5.3 ± 0.1	142.4 ± 0.8	59.2 ± 0.9	224.5 ± 7.6
6MV photon	5×10^8	Water	36.9 ± 0.0	31.4 ± 0.1	1441.0 ± 3.2	471.4 ± 4.0	2139.1 ± 2.4
		Slab	50.2 ± 0.2	36.3 ± 0.3	1766.6 ± 0.7	511.6 ± 9.4	2943.4 ± 17.9
		Half-Slab	48.6 ± 0.2	36.0 ± 0.2	1781.4 ± 17.8	521.1± 6.8	2981.5 ± 10.3

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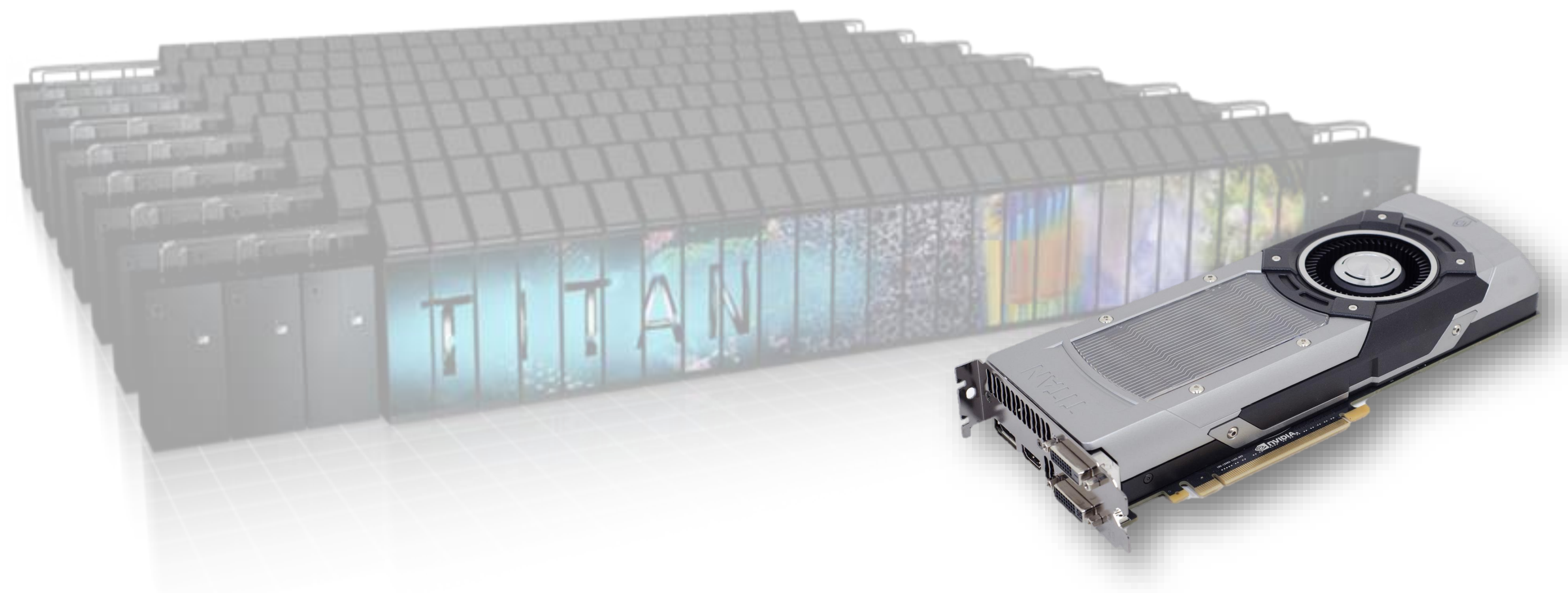
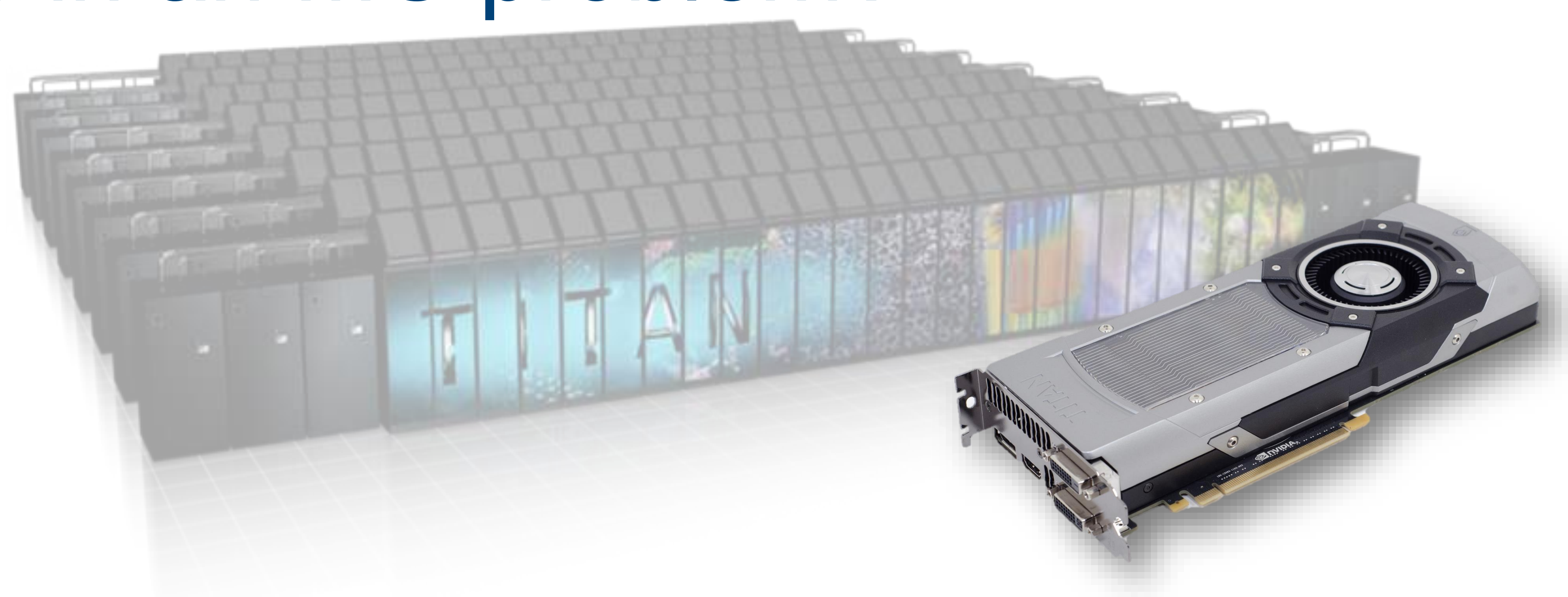


Conclusion

- Continuous development of GPU-based MC
  - New physics regimes
  - New capabilities
  - New applications

- Two packages open for testing and collaborations

- How to best use GPU's power in an MC problem?



Conclusion

- Speed is …
  - Speed
  - Accuracy
  - Big data

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Review paper

A review of GPU-based medical image reconstruction

Philippe Després [a, c], Xun Jia [b]

[a] Département de physique, de génie physique et d'optique, Université Laval – 1045, avenue de la Médecine, Québec (Québec) G1V 0A6, Canada

[b] Department of Radiation Oncology, University of Texas Southwestern Medical Center, 2280 Inwood Rd., MC 9303, Dallas, TX 75390, USA

[c] Département de radio-oncologie, CHU de Québec - Université Laval, 11 Côte du Palais, Québec (Québec), G1R 2J6, Canada

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