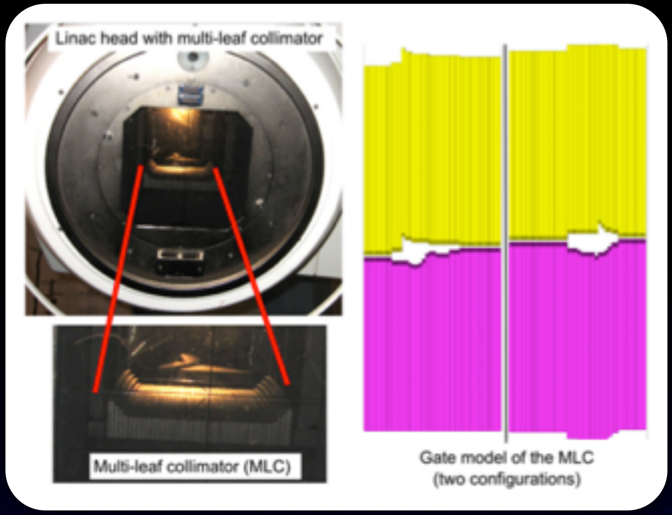
Hybrid GATE

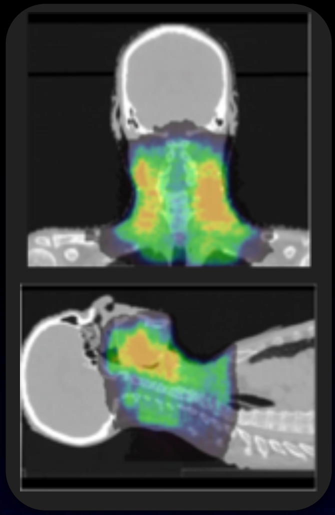
A GPU/CPU implementation for imaging and therapy applications

Julien Bert[1], Hector Perez-Ponce[2], Sébastien Jan[3], Ziad El Bitar[4], Pierre Gueth[5], Vesna Cuplov[3], Hocine Chekatt[4], Didier Benoit[6], David Sarrut[5], Yannick Boursier[2], David Brasse[4], Irène Buvat[6], Christian Morel[2], and Dimitris Visvikis[1]

[1] LaTIM, UMR1101 INSERM, CHRU Brest, France
[2] CPPM, Aix-Marseille Université, CNRS/IN2P3, France
[3] DSV/I2BM/SHFJ, Commissariat à l'Energie Atomique, Orsay, France
[4] IPHC, UMR7178 CNRS/IN2P3, Strasbourg, France
[5] CREATIS, CNRS UMR5220, INSERM U630, Université Lyon 1, Centre Léon Bérard, Lyon, France
[6] IMNC, CNRS UMR8165, Universités Paris 7 and Paris 11, Orsay, France

Introduction





GATE[1]

- Open source project (GPL)
- Monte Carlo simulation platform based on Geant4[2]
- Medical imaging and particle therapy

http://www.opengatecollaboration.org

[1] Jan S et al., Phys. Med. Biol. 2011
[2] Allison J et al. IEEE TNS, 2006

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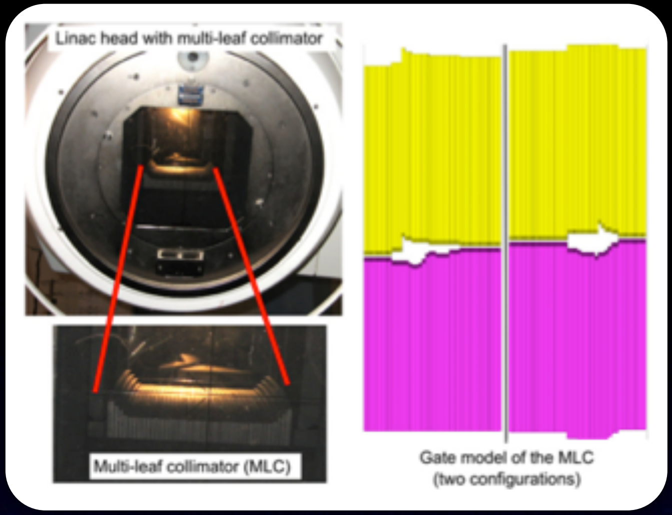

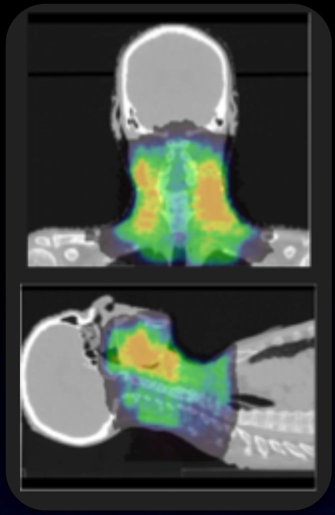

Monte Carlo simulation

- Very computationally demanding
  research and clinical environment applications

- Computer cluster
  financial burden and availability issues

[1] Jan S et al., Phys. Med. Biol. 2011
[2] Allison J et al. IEEE TNS, 2006

Objective

Graphics Processing Unit (GPU)

- High processing performance at a reduced cost

- Used GPU for Monte Carlo simulation[1-3]
- Medical applications within GATE software
- Enhance GATE computational efficiency

A small cluster on a single conventional workstation

[1] Jahnke L et al. Phys. Med. Biol. 2012
[2] Hissoiny S et al. Med. Phys. 2011
[3] Toth B et al. Conference on Computer Graphics and Geometry 2010

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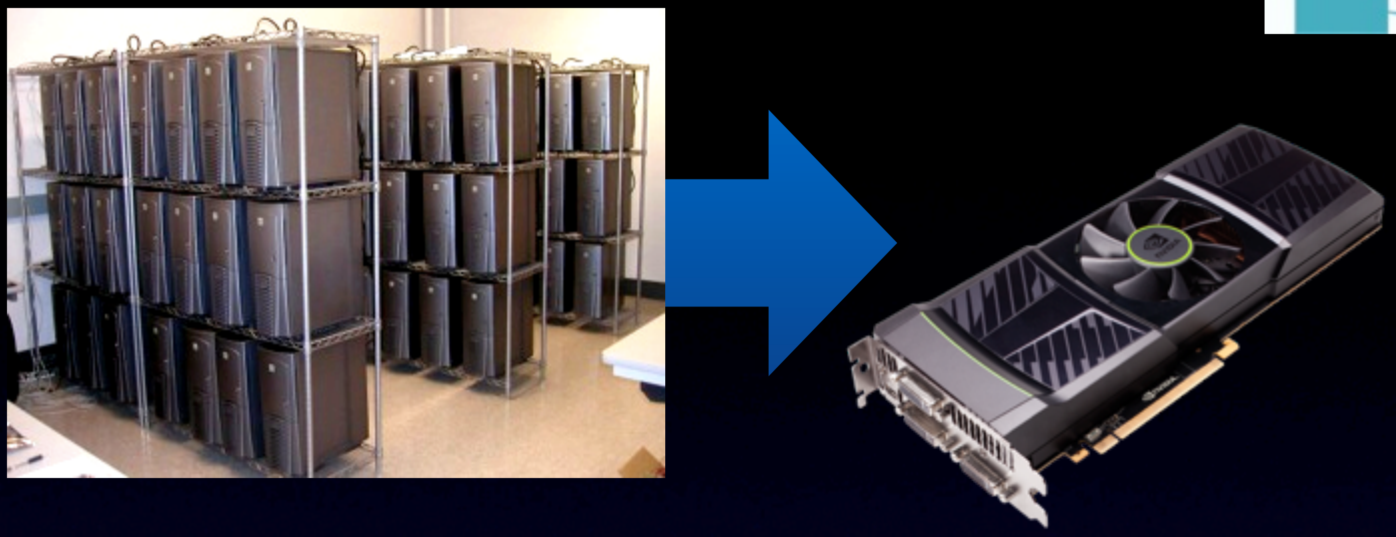
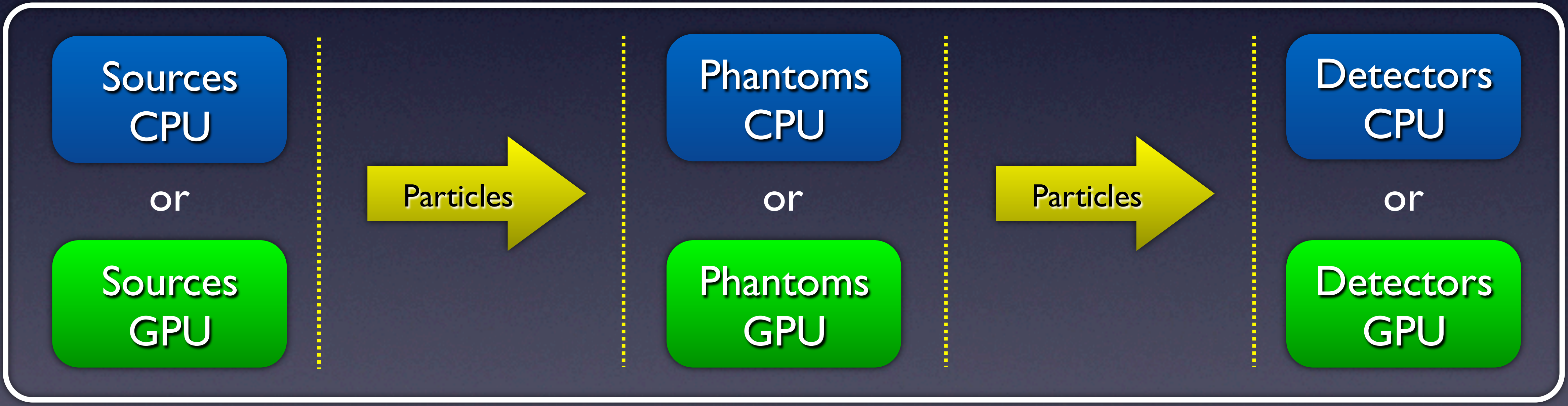


A small cluster on a single conventional workstation

Hybrid GATE



- Possible to track particles alternatively on GPU or CPU
- No limitation on simulation possibilities

[1] Jahnke L et al. Phys. Med. Biol. 2012
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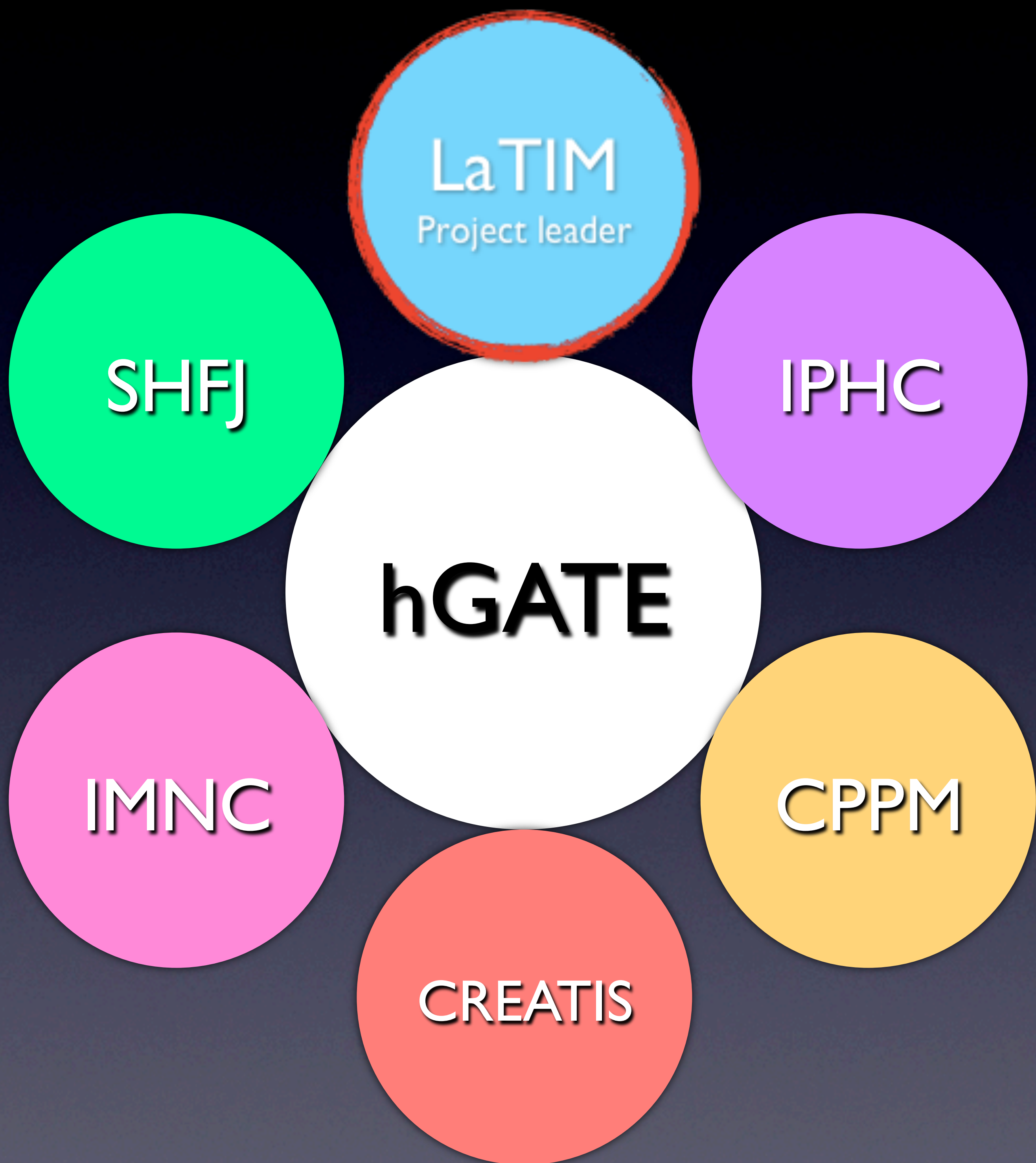
Hybrid GATE



French ANR-09-COSI-004
february 2010 – march 2013
(36 months)

hybrid GATE

feasibility studies to speed up GATE simulation by using CPU/GPU

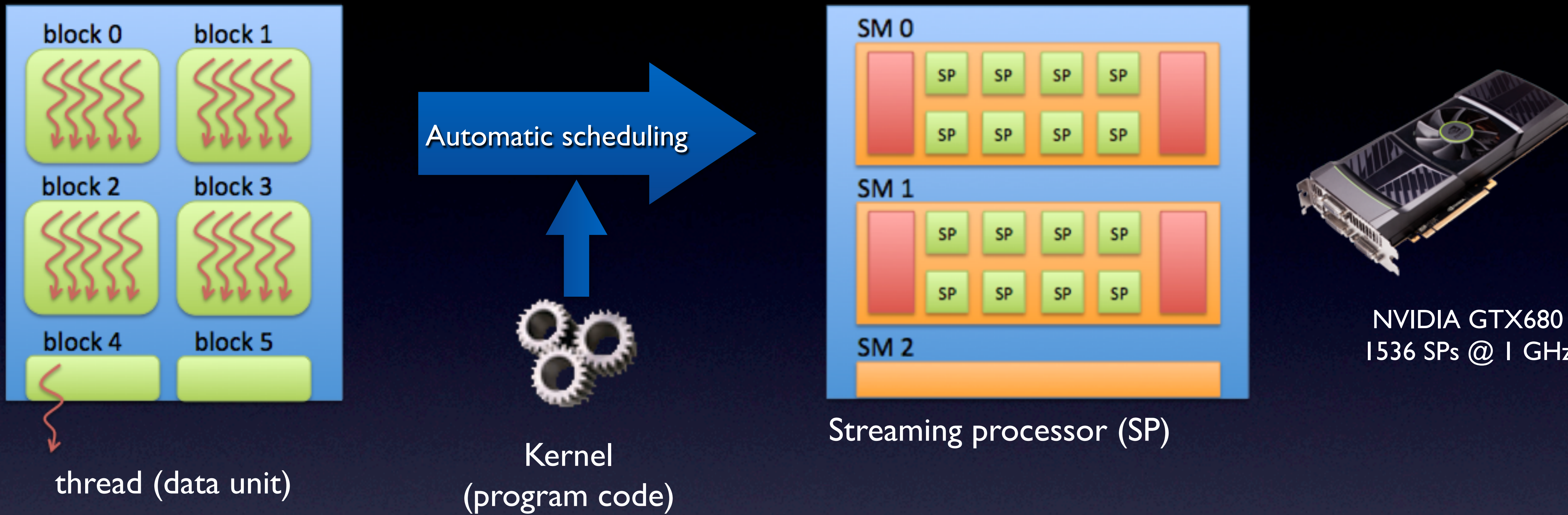
Partners:

LaTIM - D.Visvikis (+1) - PL
IPHC - D. Brasse (+3)
CPPM - C. Morel (+2)
CREATIS - D. Sarrut (+3)
IMNC - I. Buvat (+2)
SHFJ - S. Jan (+1)

http://hgate.univ-brest.fr

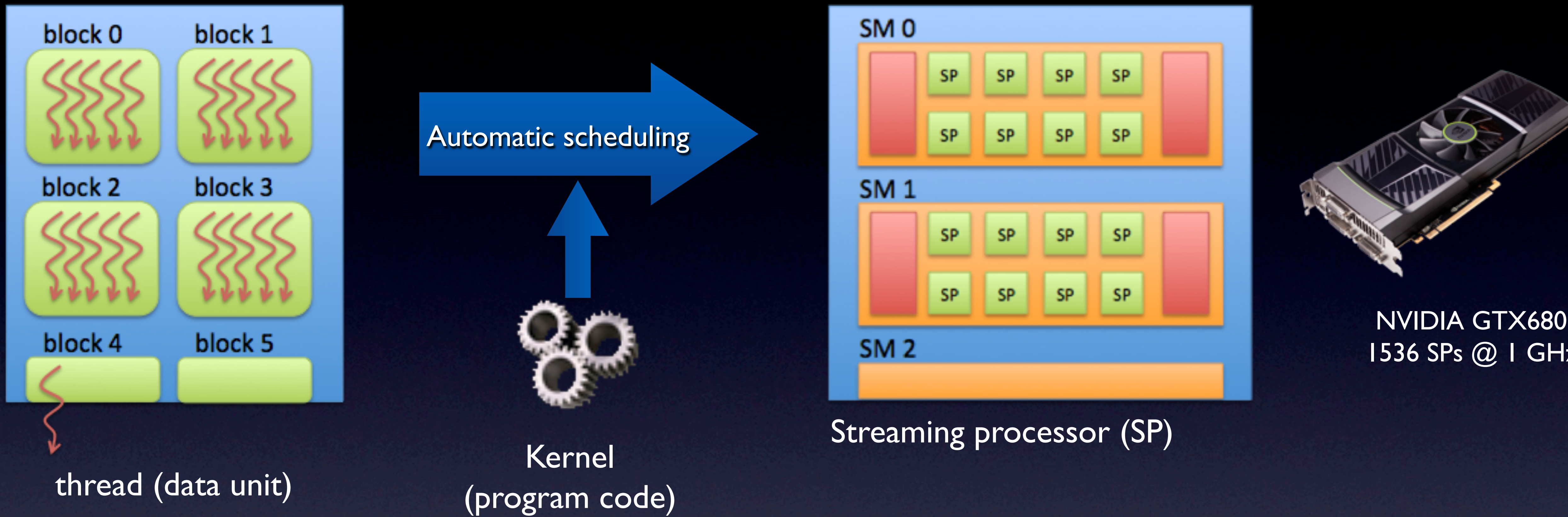
Hybrid GATE

GPU architecture

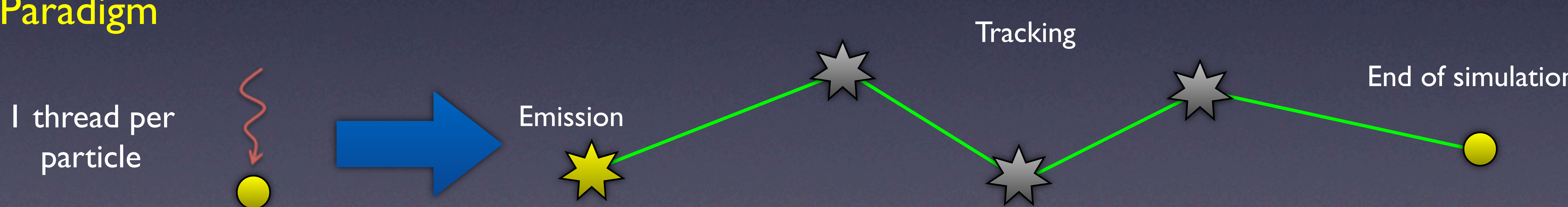


Hybrid GATE

GPU architecture



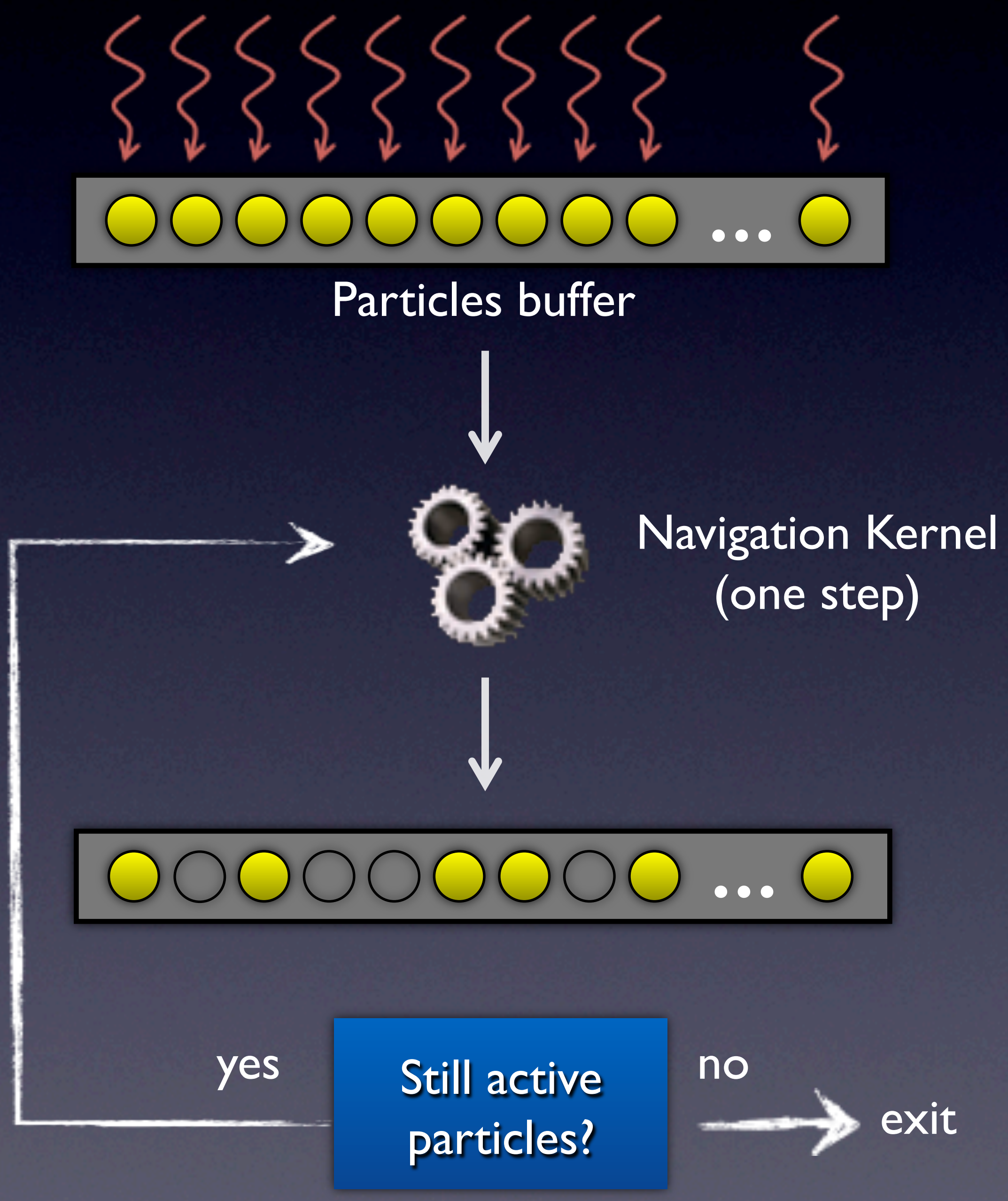
Paradigm



Thousands of particles are simulated in parallel

Hybrid GATE

Monte Carlo simulation on GPU



Hybrid GATE

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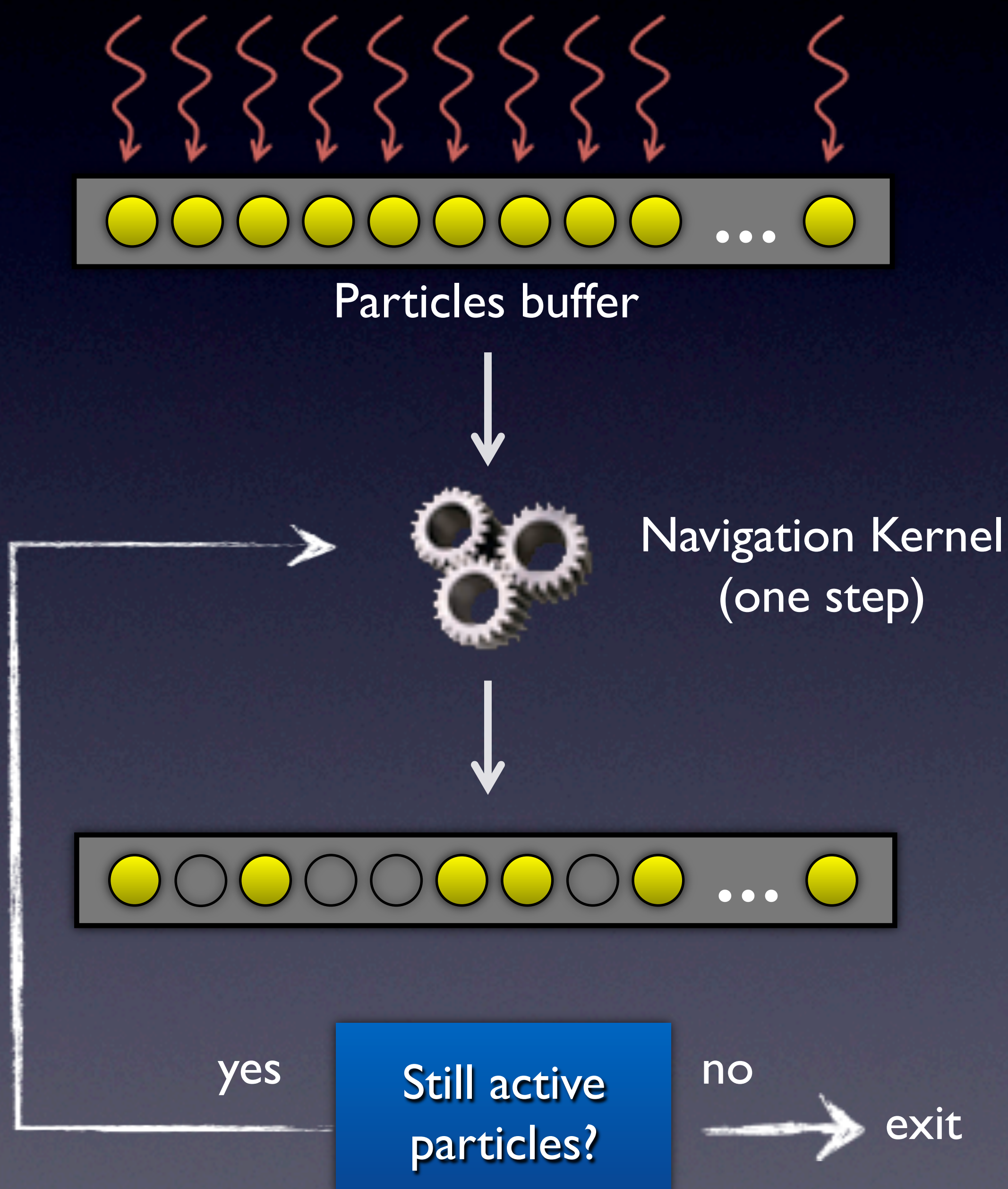
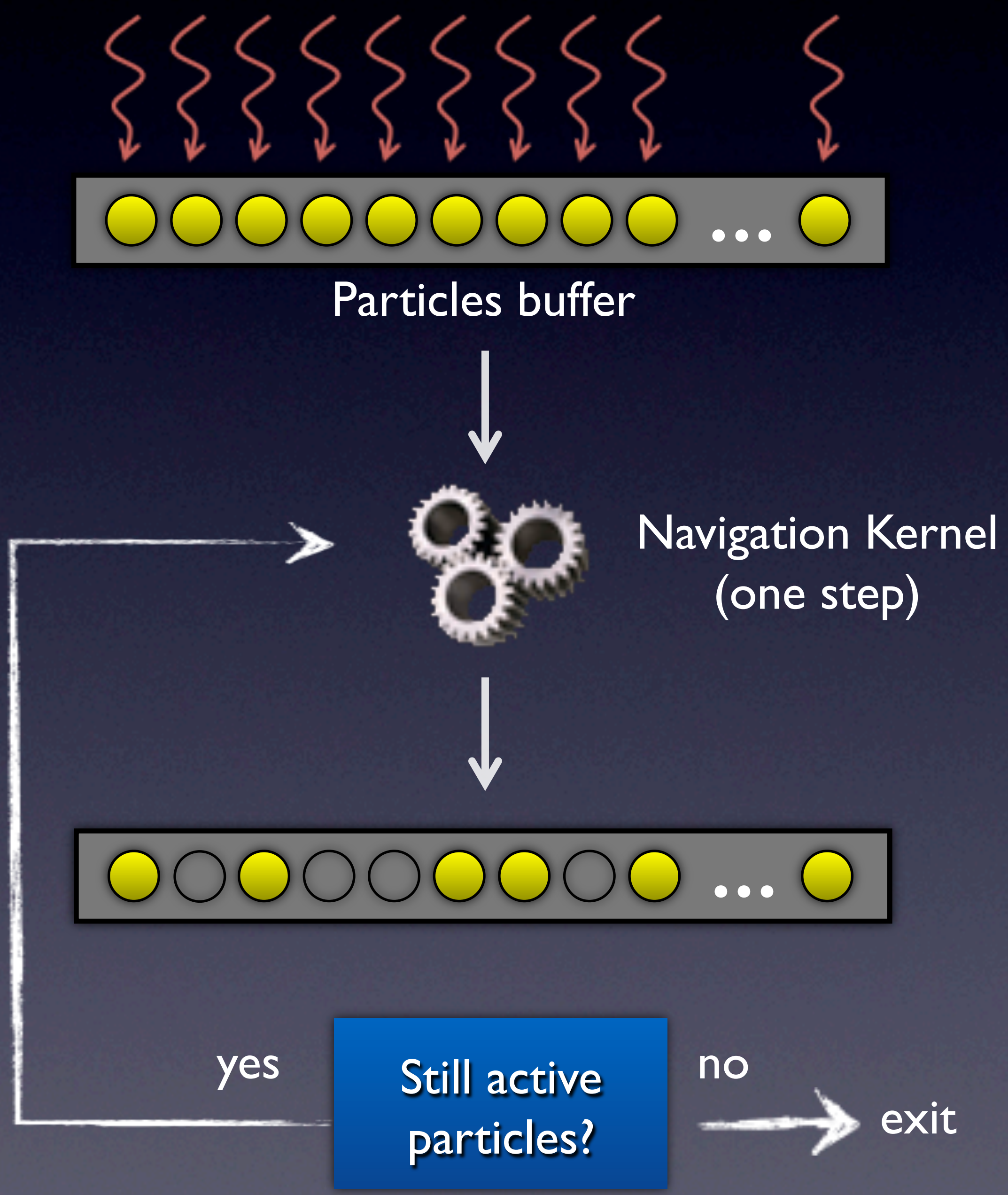


Photon' navigation kernel

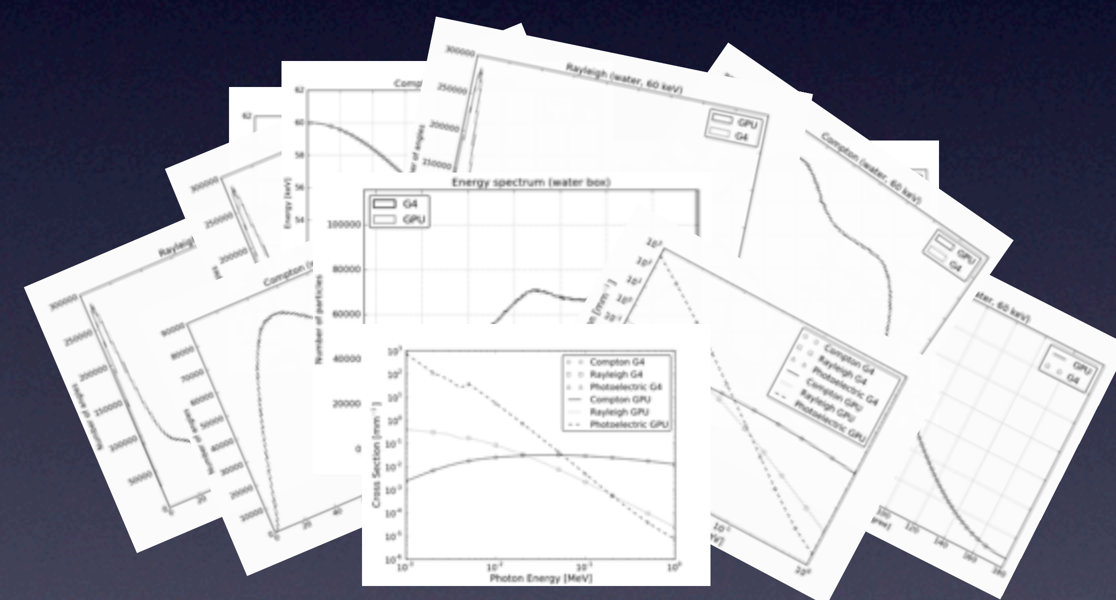
1. Read particle' properties
   energy, position, etc
2. Determine the particle location
   geometry, fetch material information
3. Compute cross sections
   Compton, photoelectric and Rayleigh
4. Compute the next interaction distance
   Including geometry boundary
5. Determine the next discrete process
6. Move the particle
   Check world boundary
7. Resolve the discrete process
   Compton, photoelectric and Rayleigh

Hybrid GATE

Monte Carlo simulation on GPU



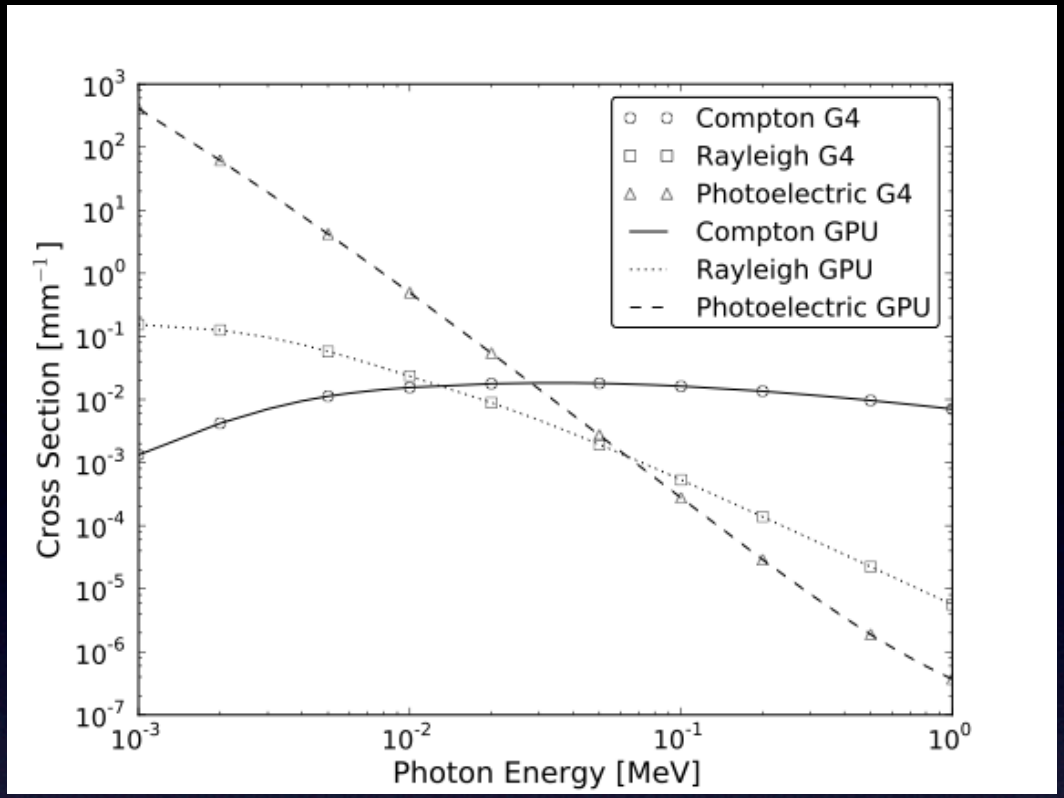
GPU framework[1] based on Geant4
- Geant4 code on GPU (C++ → C → CUDA)
- Pseudo random number generator
- Electromagnetic effects for photon
- Voxelized geometry navigation



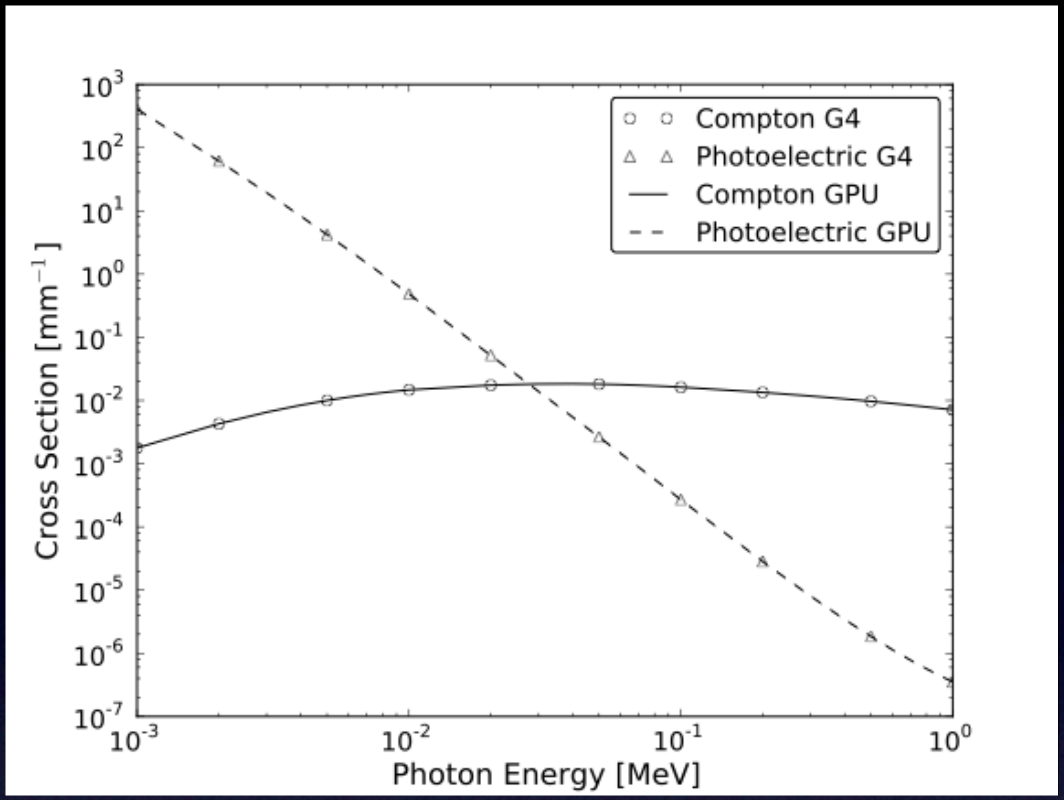
Full agreement between GPU code and Geant4

[1] *Bert J et al.*
Geant4-based Monte Carlo simulations on GPU for medical applications
Phys. Med. Biol. 58 (2013) 5593-5611

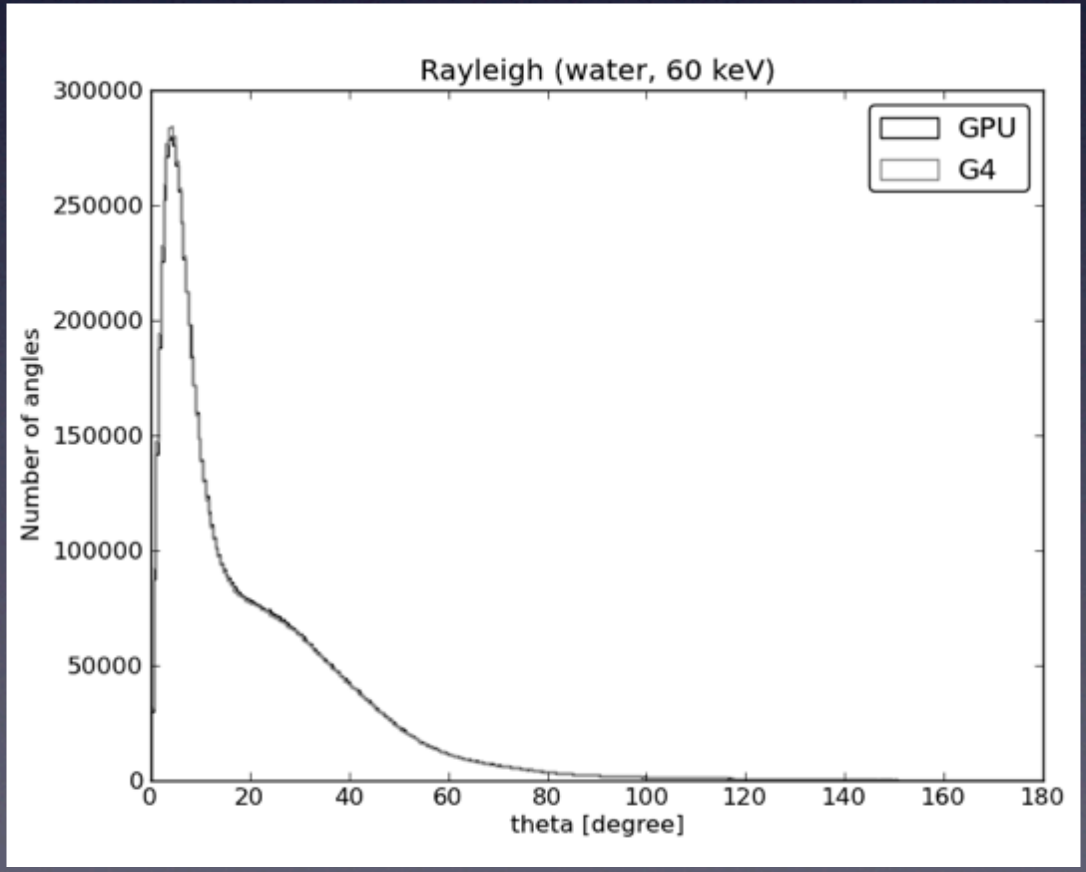
Hybrid GATE



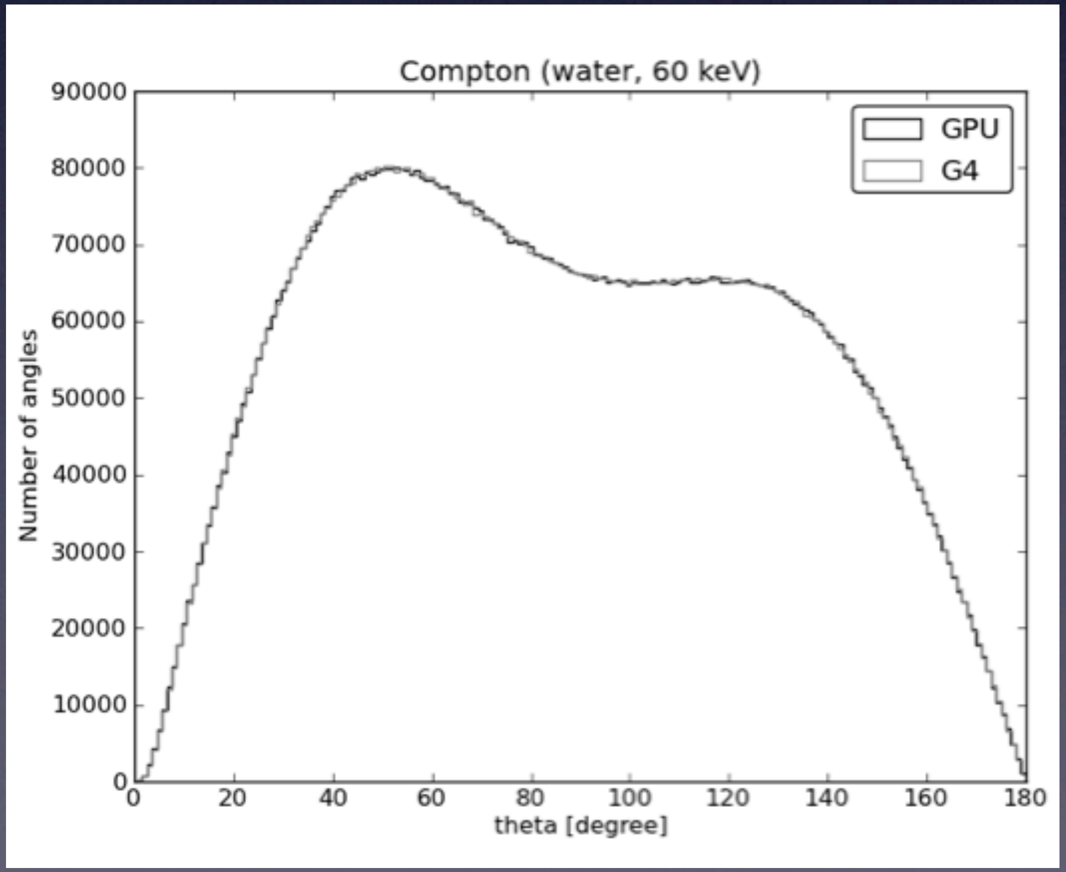
Cross sections from standard model



Cross sections from Livermore model



Rayleigh scattering



Compton scattering

Hybrid GATE

GPU module for GATE

- Based on this generic GPU framework
- Specific GPU module for medical applications
- Tracking particles inside a voxelized volume (PET, SPECT, CT, and Radiotherapy)
- Voxelized source of particle (PET and SPECT)

Hybrid GATE

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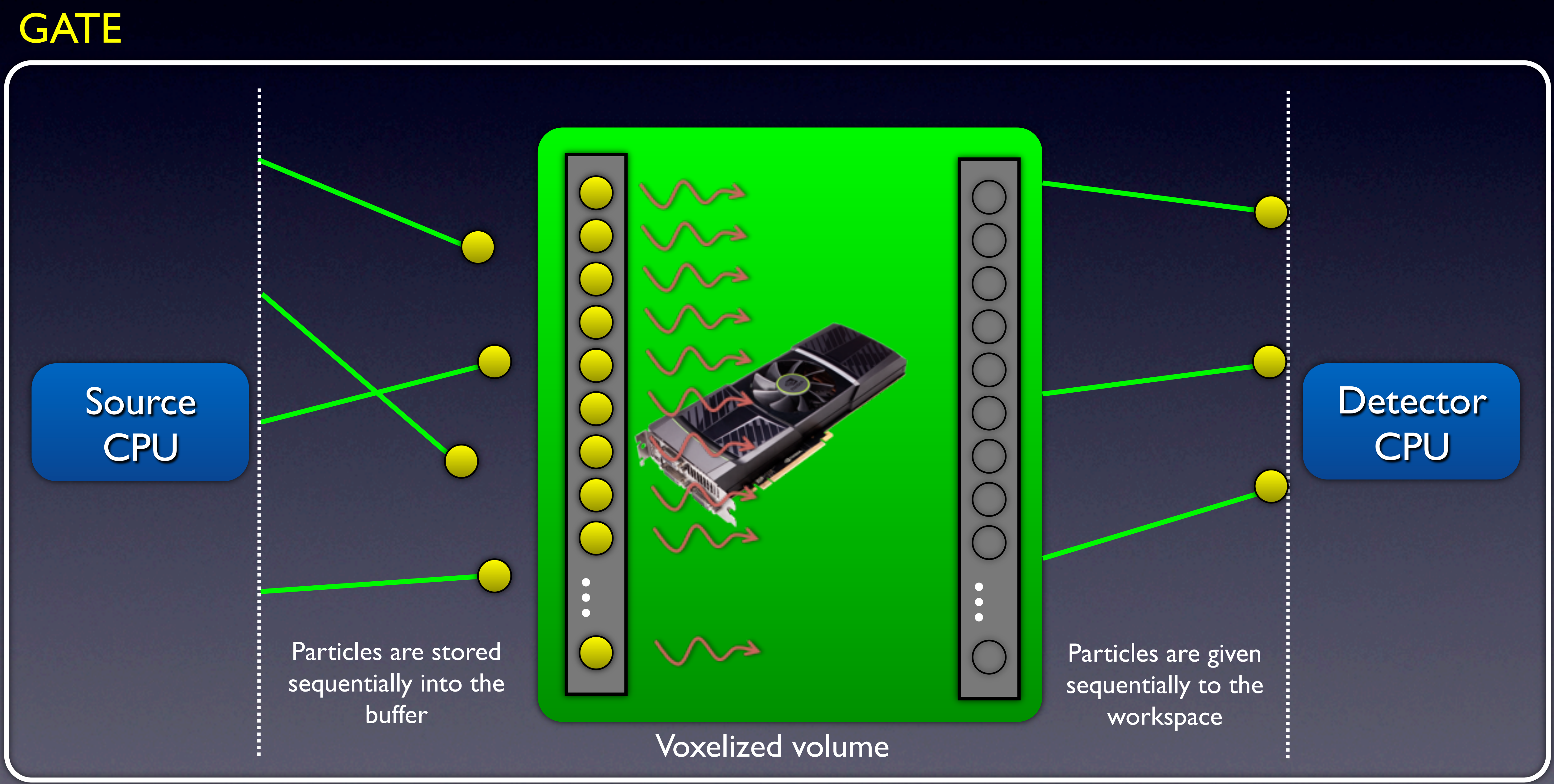


PET imaging

Source + phantom

- Voxelized phantom from NCAT (thorax)
- 46x63x128 voxels of 4^3 mm^3
- Tumor in the left lung
- Activity maps (tumor contrast 3:1)
- Back-to-back photon gamma (511 keV)

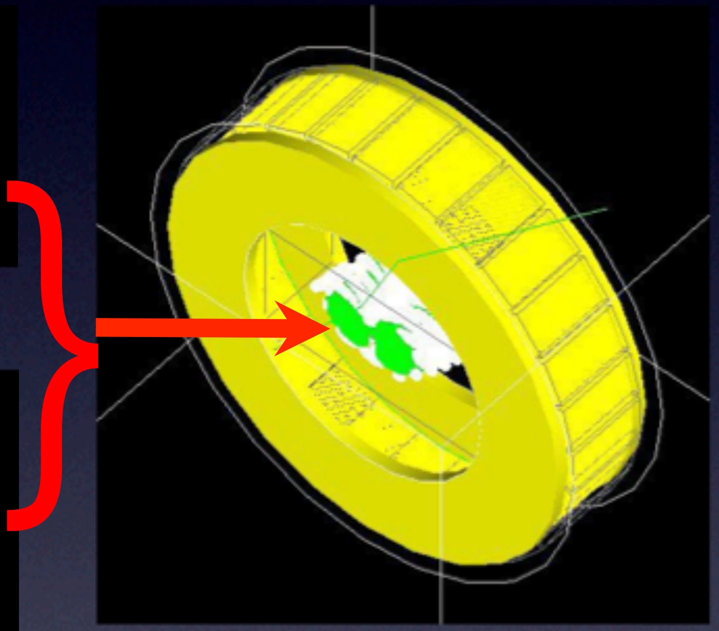
Detector

- Philips GEMINI PET scanner

Setup

Voxelized phantom

Voxelized activity maps



PET system modeling

PET imaging

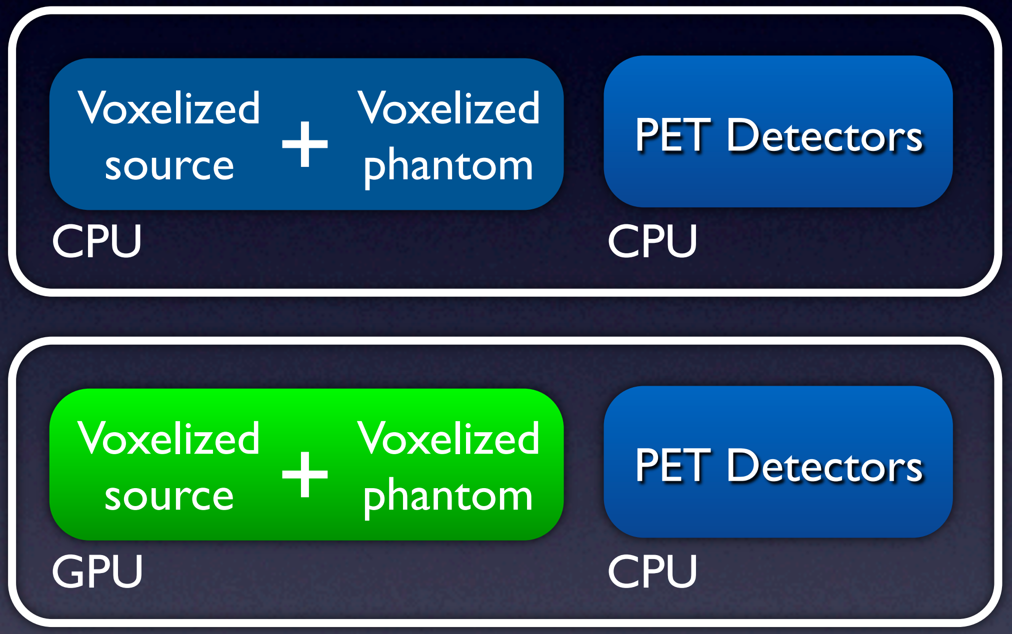
Simulation

- Fictitious tracking[1]
- Photoelectric effect and Compton scattering
- Acquisition for 10 min

Evaluation study

- Run time to track particles (source+phantom)
- Phantom phase space
- Store coincidences into sinogram

GATE simulation



CPU Intel Core i7 - 3.4 GHz
GPU NVIDIA GTX580 512 cores 1.23 GHz

[1] Carter L L et al., Nuclear Science and Engineering 1972

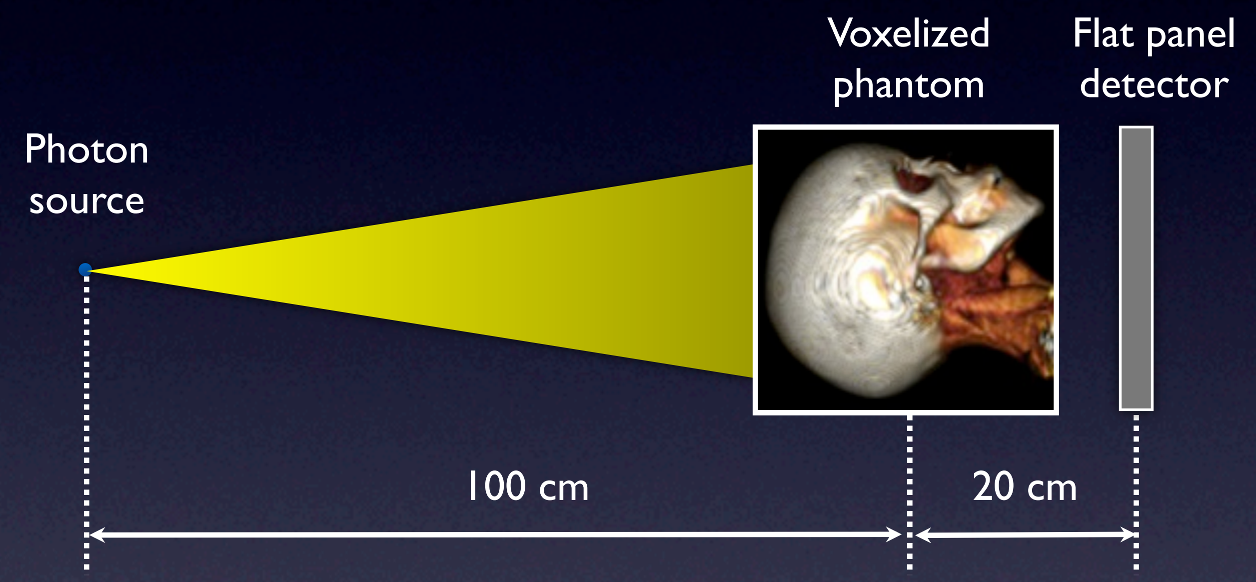
Transmission imaging

Source
- Cone beam (7° aperture angle)
- Photons (mono energy at 80 keV)

Phantom
- Voxelized phantom derived from CT (head & neck)
- 126x126x111 voxels of 2^3 mm^3

Detector
- Fictive flat panel (counting particles per pixel)
- 300x300 pixels of 1^2 mm^2

Setup



Transmission imaging

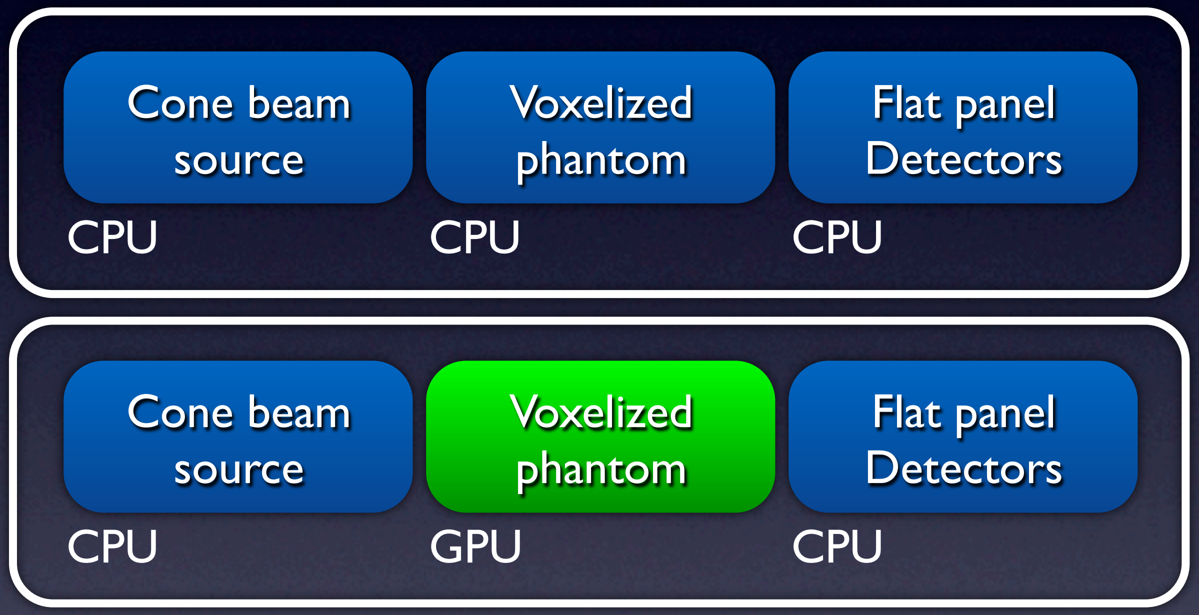
Simulation

- Regular voxelized navigator (based on Geant4)
- Photoelectric effect and Compton scattering
- Acquisition for 500 million emitted photons

Evaluation study

- Run time to track particles (phantom)
- Phantom phase space
- 2D projection

GATE simulation



CPU Intel Core i7 - 3.4 GHz
GPU NVIDIA GTX580 512 cores 1.23 GHz

PET imaging

Run time to track particles:

Voxelized source + Voxelized phantom
GATE

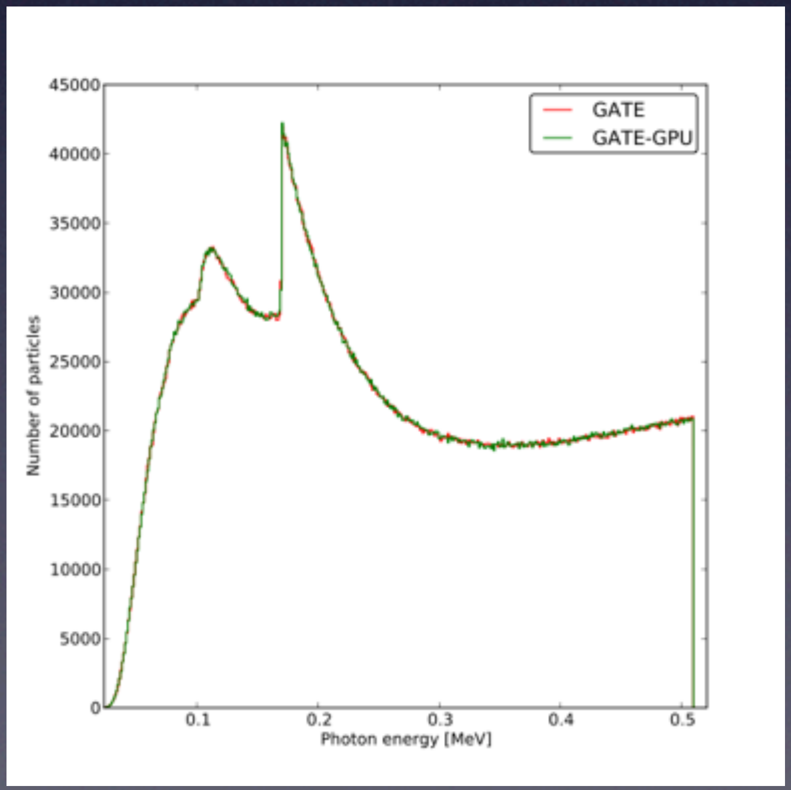
75.4 s / 10^6 particles

Voxelized source + Voxelized phantom
GATE-GPU

1.23 s / 10^6 particles

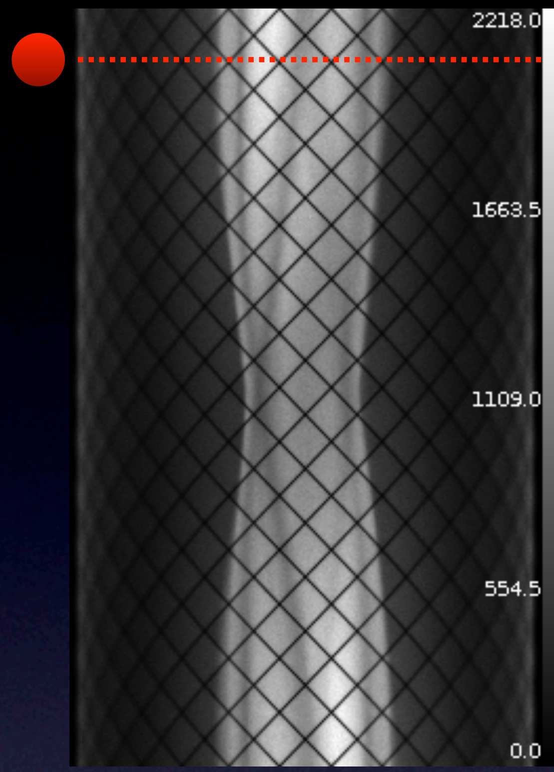
Speedup **x61.3**
hours in minutes

Phase spaces:

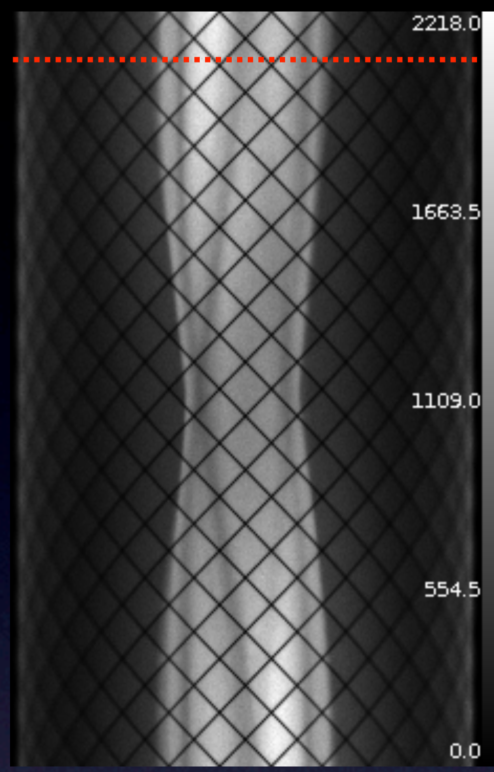


Scattered photon energy distributions (400 bins)

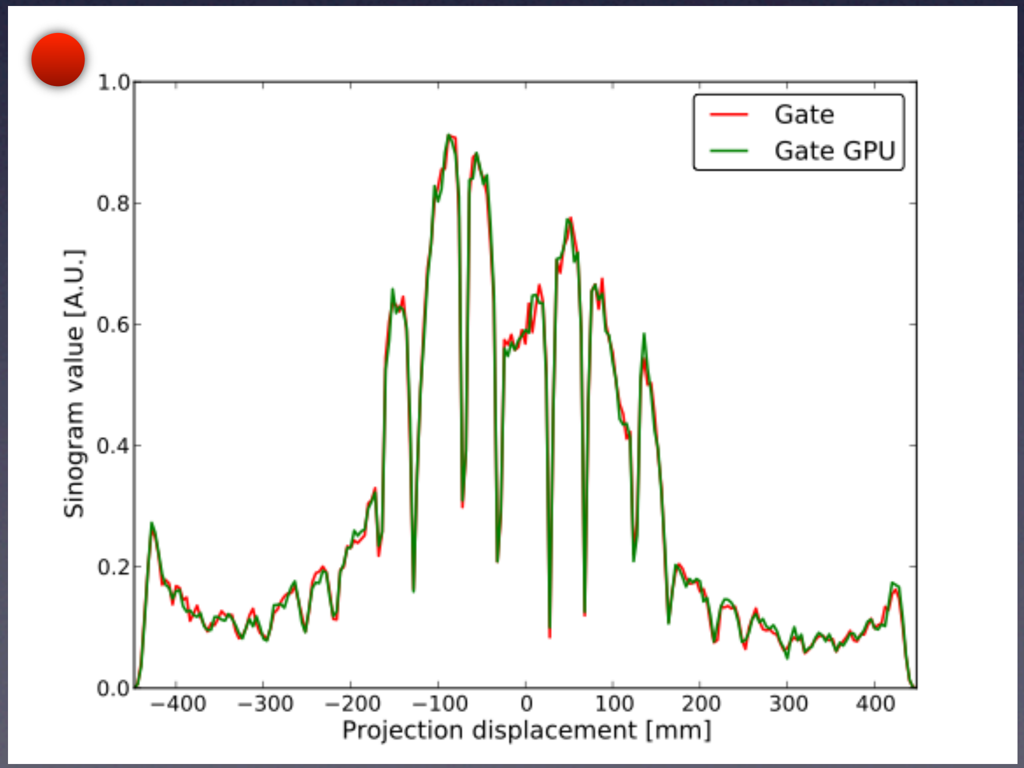
Coincidence sinograms:



GATE



GATE-GPU



Profiles

Transmission imaging

Run time to track particles:

Voxelized phantom

GATE

89.4 s / 10^6 particles

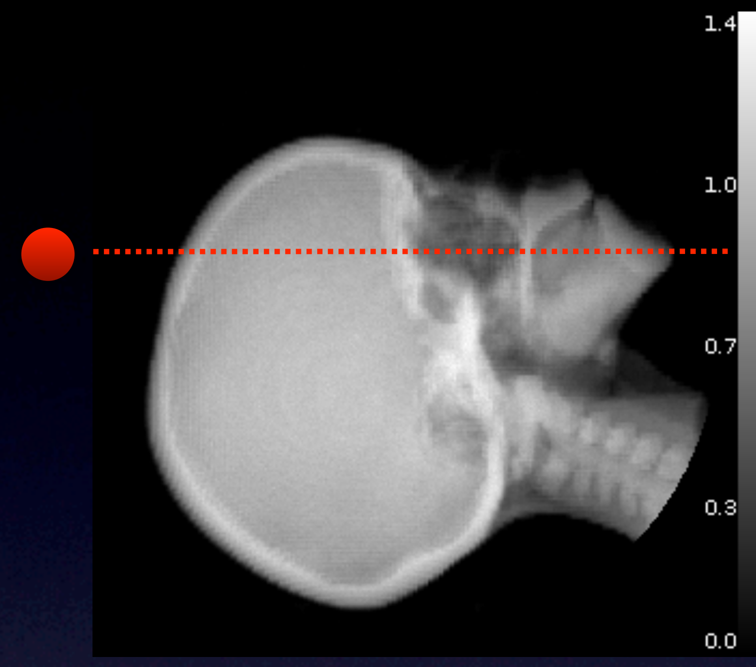
Voxelized phantom

GATE-GPU

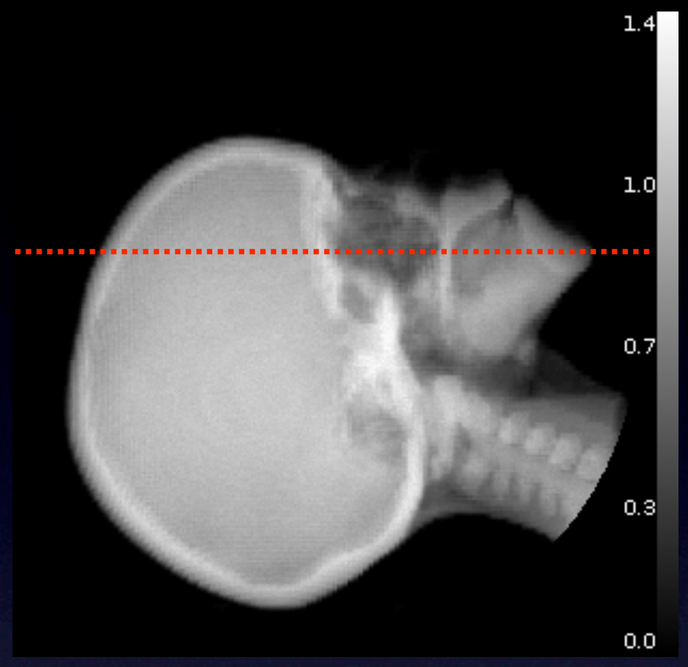
1.16 s / 10^6 particles

Speedup **x77.1**
hours in minutes

2D projections

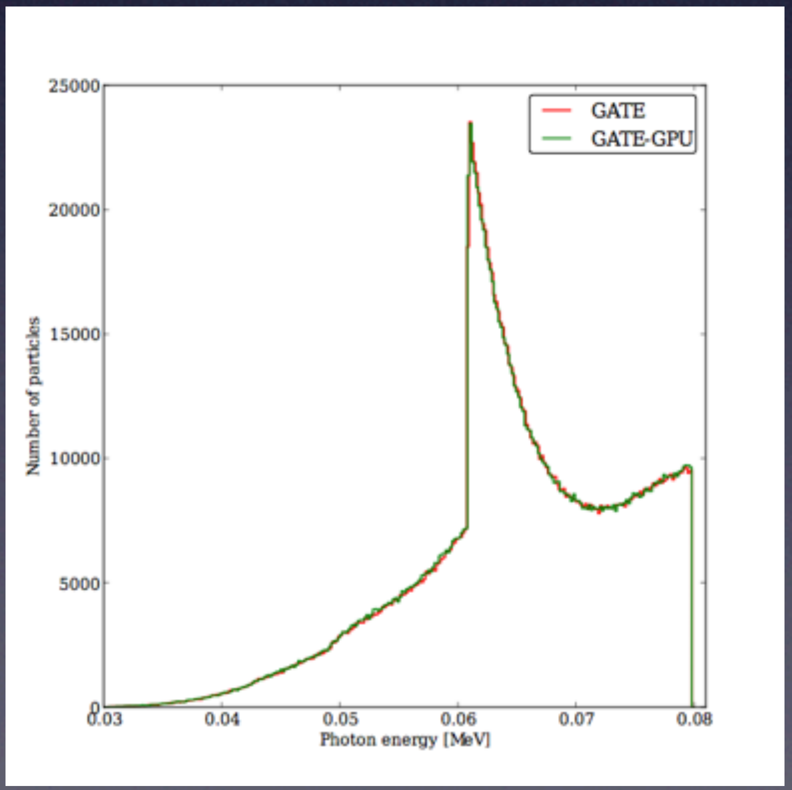


GATE



GATE-GPU

Phase spaces:



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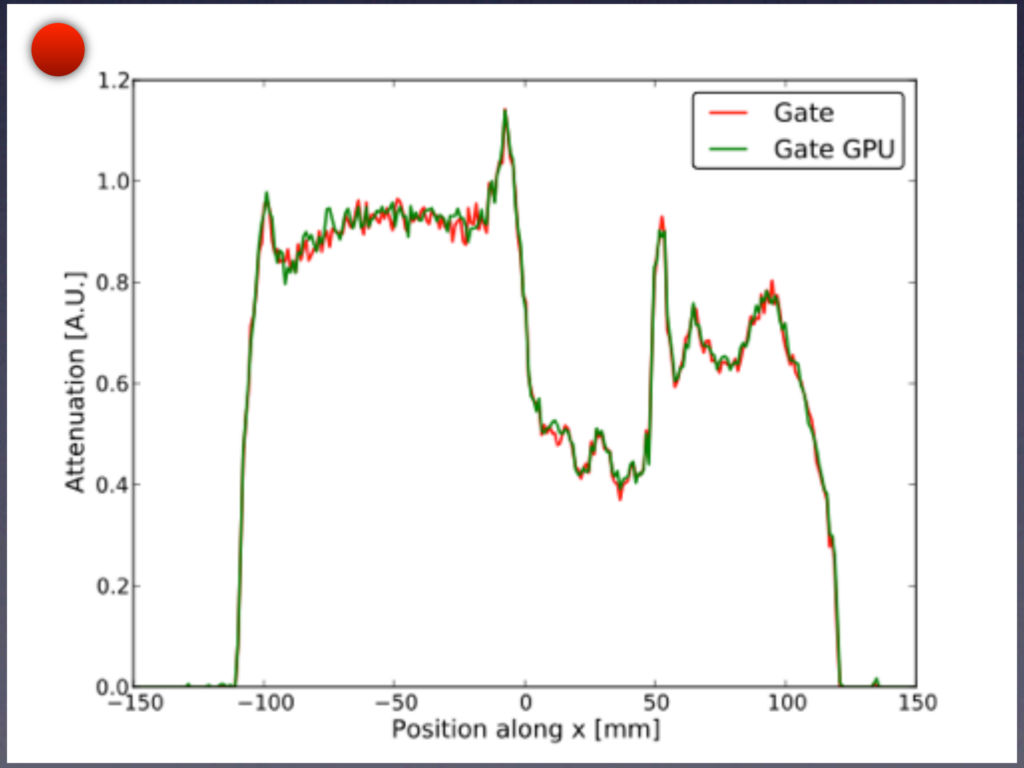
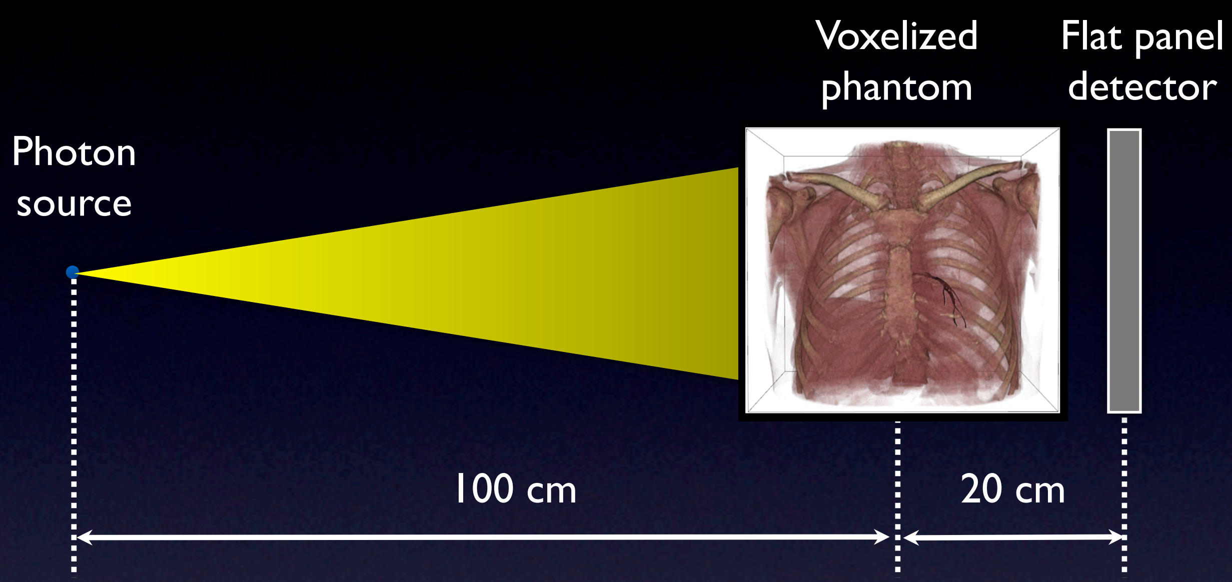


Profiles

Transmission imaging

Setup



Cone beam source — GPU

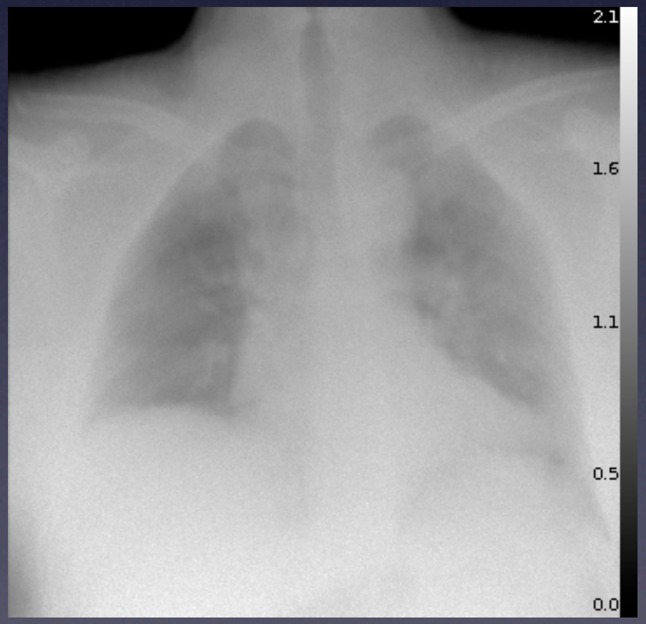
Voxelized phantom — GPU

Flat panel Detectors — GPU

2.10^9 photons

GATE (CPU)

~12 days



GPU code

x800

~22 min

660 ms / 10^6 particles

CPU Intel Core i7 - 3.4 GHz
GPU NVIDIA GTX580 512 cores 1.23 GHz

Conclusion and further work

Conclusion

- GPU modules within GATE:
  For PET application x61 faster
  For CBCT application x77 faster

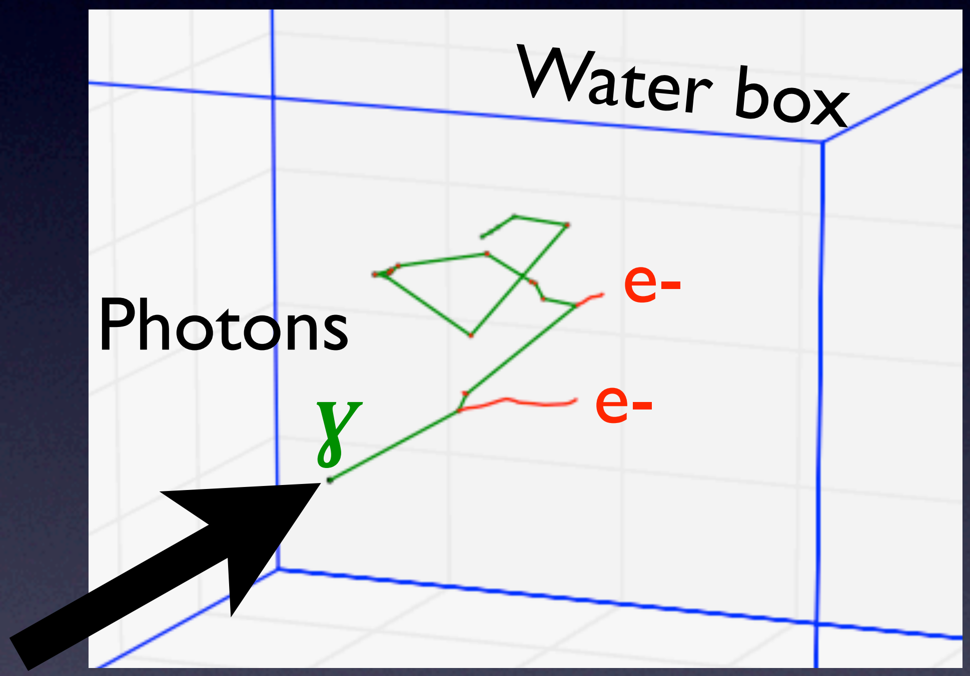
- Both modules will be released in GATE v7 (in 2014)

February 2010 – march 2013

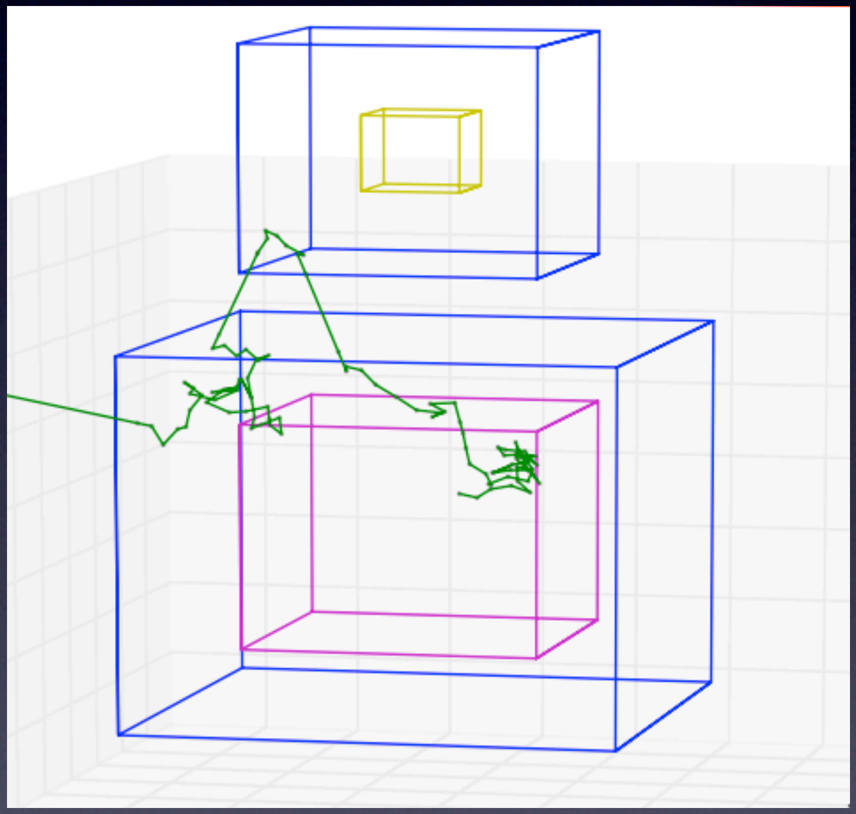
Conclusion and further work

Physics processes
- Handle secondary particles
- Effects for optical photons
- Effects for electrons
- Effects for protons
- Dose deposition (Track Length Estimator)

Navigation
- Electron, proton navigation
- Analytical and hierarchical geometry
- Complex geometry (Mesh)
- Optimizations (Octree)
- Hybrid navigator (analytical/voxelized)



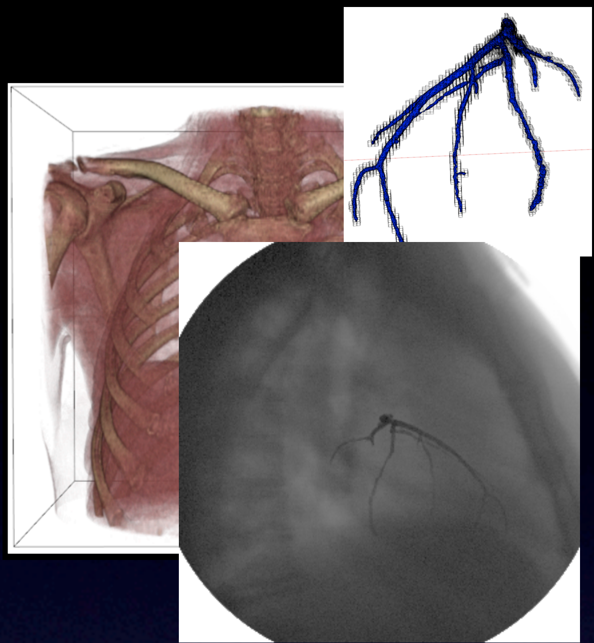
Secondary particles on GPU



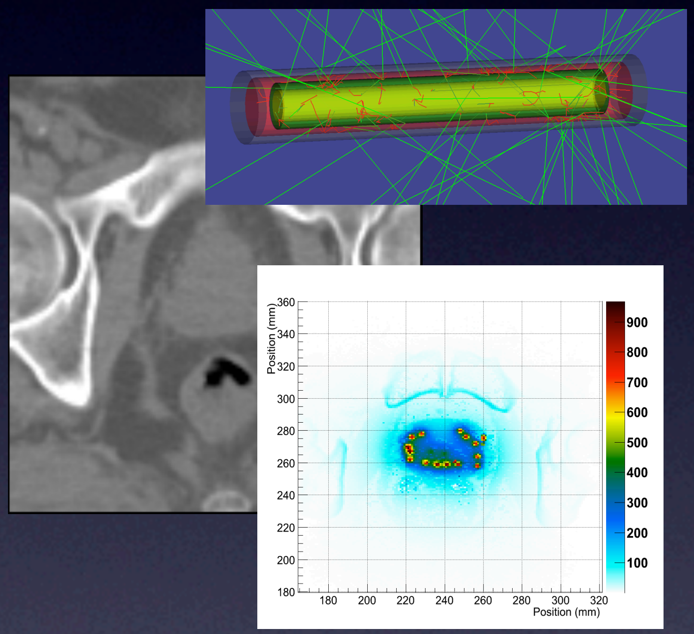
Analytical navigator on GPU

Targeting different bio-medical applications (imaging and particle therapy)

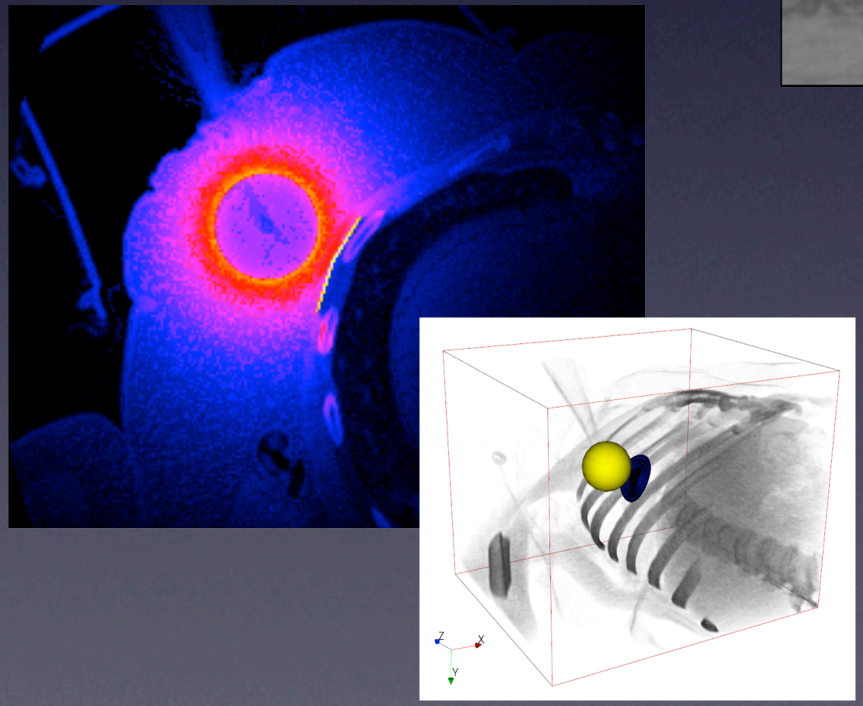
Conclusion and further work



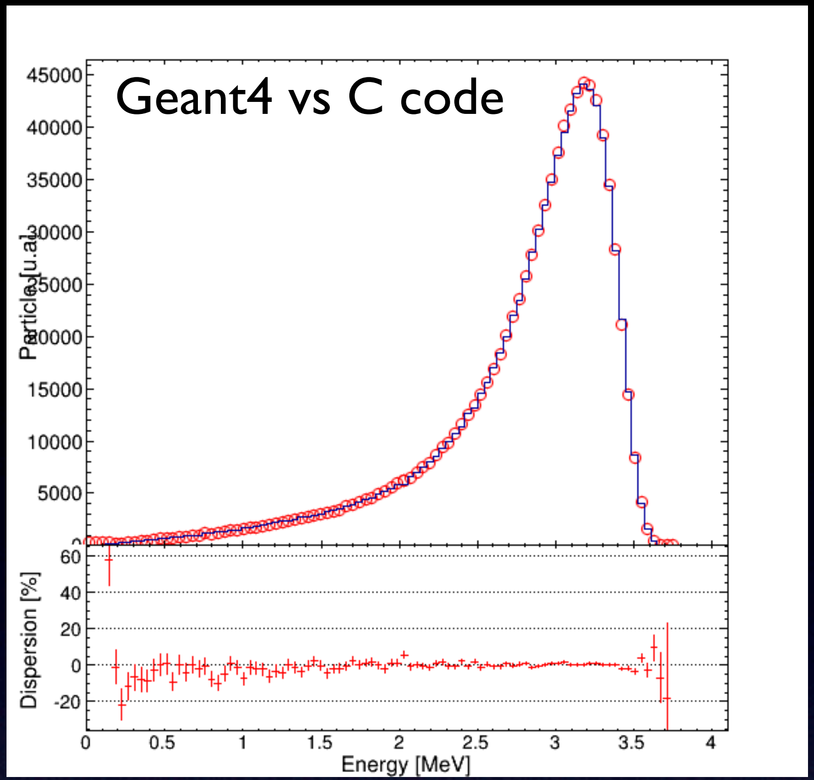
Transmission imaging



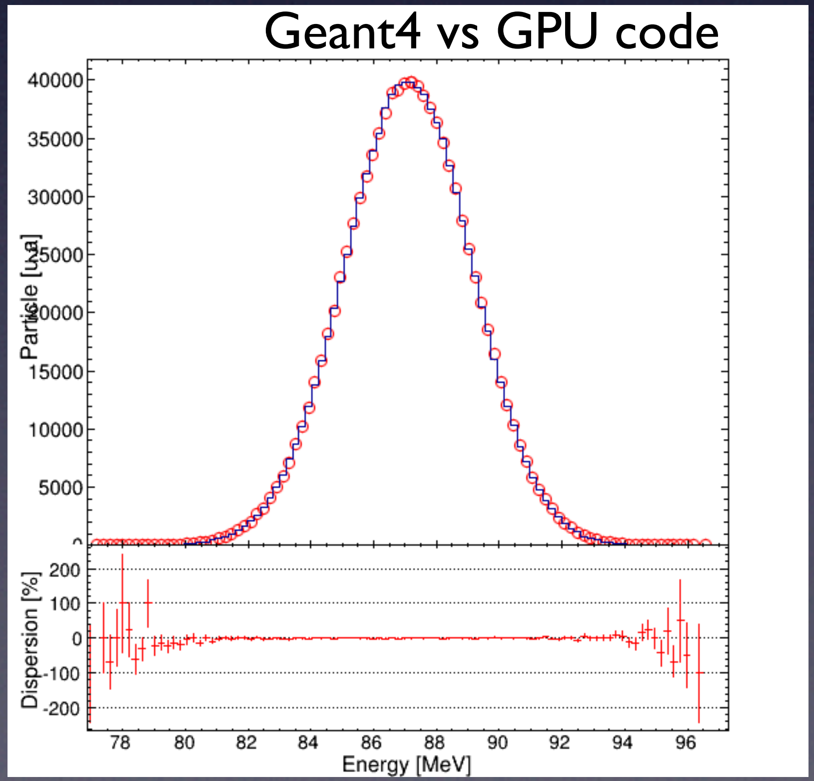
Brachytherapy



Intra-operative radiotherapy



Electrons - Energy distribution behind a water box (beam of 6 MeV)



Protons - Energy distribution behind a water box (beam of 200 MeV)

Thank for your attention

Julien Bert[1], Hector Perez-Ponce[2], Sébastien Jan[3], Ziad El Bitar[4], Pierre Gueth[5], Vesna Cuplov[3], Hocine Chekatt[4], Didier Benoit[6], David Sarrut[5], Yannick Boursier[2], David Brasse[4], Irène Buvat[6], Christian Morel[2], and Dimitris Visvikis[1]

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