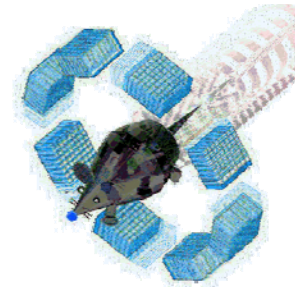


Status of GATE: a simulation toolkit for PET and SPECT



Giovanni Santin *



*with the assistance of the OpenGATE Collaboration
ESA / ESTEC
* Rhea System SA*

Giovanni.Santin@esa.int



Simulations in functional imaging

- Scanner design, image reconstruction, scatter correction, protocol optimisation,...
- Analytical models → approximations (geometry, materials,...)
- Monte Carlo: now widely used in parallel to analytical computations or experimental studies for PET/SPECT

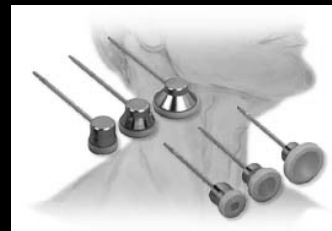


Dedicated programs:

PETsim, SimSET, EIDOLON, SIMIND, SimSPECT, SORTEO, MCMATV, PET-EGS, ...

- Fast development, optimised
- But: Simple geometry, Limits in physics
- Maintenance, Upgrades?

- Many issues are shared with radiotherapy applications



Two communities of simulation users

- Research groups
 - Limited particle physics background
 - Heavy duties from hospital
 - Need for ease of use
- Clinical use
 - Commercial interests/pressures
 - Official protocols
 - Speed in treatment planning
 - User-friendly interfaces for hospital usage

Zaidi, Med Phys 26 (1999)

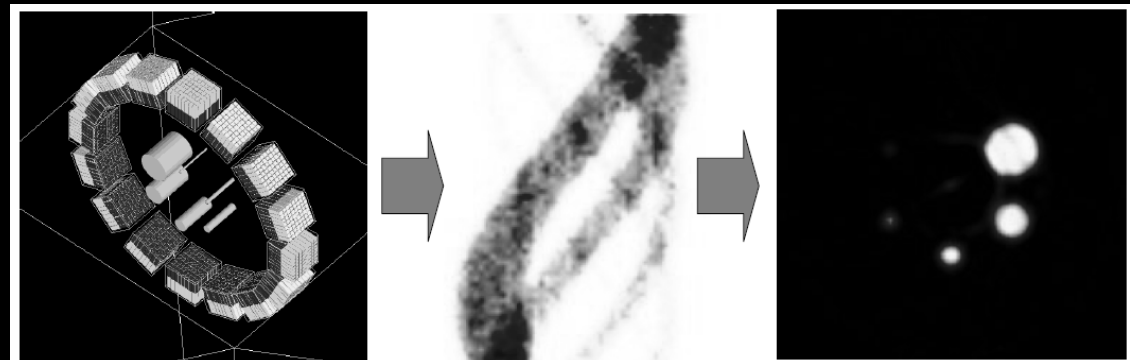
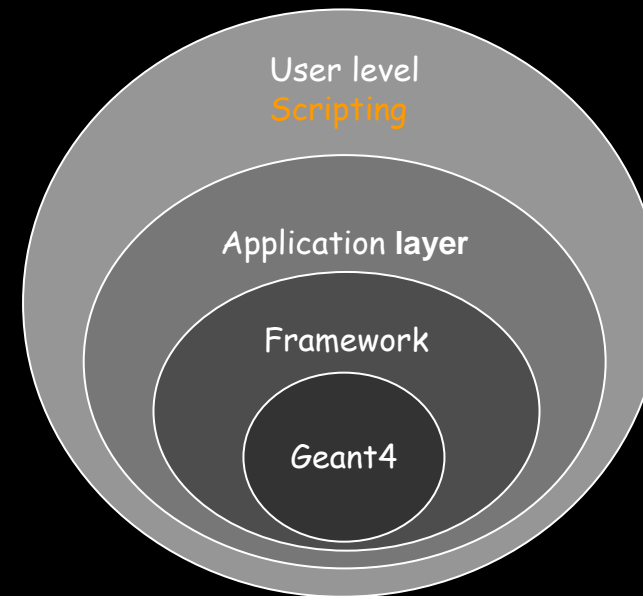
Buvat and Castiglioni, Q J Nucl Med 46 (2002)



PET, SPECT: the example of GATE

Geant4 Application for Tomographic Emission

- Ease-of-use, interactivity
 - Use of scripting
 - Interface to image reconstruction
- Modelling of Time
 - Decay kinetics, movement, dead time...
- Modular design
 - New extensions easily added
- Shared development
 - OpenGATE collaboration
 - Long-term support



<http://www.opengatecollaboration.org>



The OpenGATE collaboration

www.opengatecollaboration.org

- From 4 to now 22 labs worldwide
- Shared development
 - Long-term maintenance and support
 - Fields: PET, SPECT, dosimetry, ...
 - Development, validation, documentation, support

2001 – GATE preliminary specifications

2002 – OpenGATE collaboration

2004 – First public release GATE 1.0.0

2005 – GATE 2.1.0

2006 – GATE 3.0.0 (Geant4 8.0.p01)

GATE 3.1.0 beta (Geant4 8.1.p01)

2007 – GATE 4.X.X (April?)

...

- Official collaboration paper
 - Jan et al, Phys. Med. Biol. 49: 4543-4561, 2004.

- CPPM, Marseille, France
- DAPNIA CEA, Saclay, France
- IReS CNRS, Strasbourg, France
- Joseph Fourier University, Grenoble, France
- LPC CNRS, Clermont Ferrand, France
- SHFJ CEA, Orsay, France
- U650 Inserm, Brest, France
- U601 Inserm, Nantes, France
- U678 Inserm, Paris, France
- UMR5515 CNRS, CREATIS, Lyon, France
- Delft University of Technology, Delft, The Netherlands
- Ecole Polytechnique Fédérale de Lausanne, Switzerland
- Forschungszentrum Juelich, Germany
- Ghent University, Belgium
- National Technical University of Athens, Greece
- Vrije Universiteit Brussel, Belgium
- John Hopkins University, Baltimore, USA
- Memorial Sloan-Kettering Cancer Center, New York, USA
- University of California, Los Angeles, USA
- University of Massachusetts Medical School, Worcester, USA
- University of Santiago of Chile, Chile
- Sungkyunkwan University School of Medicine, Seoul, Korea



Users and user-support

Access to GATE

- Registration required
 - LGPL license
- Registered users section:
 - Source code
 - Documentation
 - Mailing lists
- More than 400 registered users (2005)

www.opengatecollaboration.org

- Documentation
 - User, Installation guides, FAQ, ...
 - Installed on Linux, Mac, Windows
- Mailing lists
 - gate-users
 - gate-release
 - gate-devel
 - + archives
- GATE Workshops
 - IEEE-MIC 2003, 2004, 2005
 - Next:
IEEE-MIC 06, San Diego, Nov 4th
- GATE Courses
 - Last: 16-17 March 2006,
Clermont-Ferrand

GATE Documentation - for registered users only



Search: for: in the

[Documentation index](#)

[User's Guide](#)

[Reference Manual](#)

[GATE-USERS Talk](#)

[FAQ](#)

[Installation Guide](#)

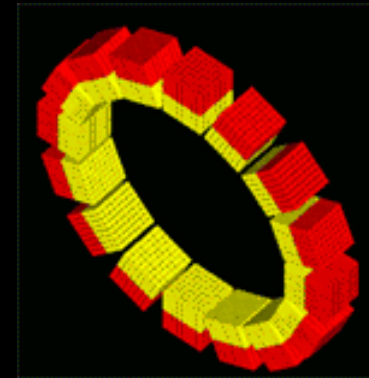


Timing

```
/gate/application/setTimeStart      0.    s  
/gate/application/setTimeStop      80.    s  
/gate/application/startDAQ
```



- Simulation time
 - A clock models the passing of time during experiments
 - The user defines the experiment timing
- Time-dependent, synchronised objects
 - Updated when time changes
- GATE can model
 - Radioactive decay (with Poisson time distribution)
 - Detector motion
 - Time-activity curves in different physiological regions
 - TOF PET
 - Physiological motions



Santin et al., IEEE Trans. Nucl. Sci. 50 (2003) 1516-1521
Staelens et al., Phys. Med. Biol. 48 (2003) 3021-3042
Strul et al., Nucl. Phys. B (Proc. Suppl.) 125 (2003) 75-79
Groiselle et al., Proc. Conf. Rec. IEEE NSS MIC 2004

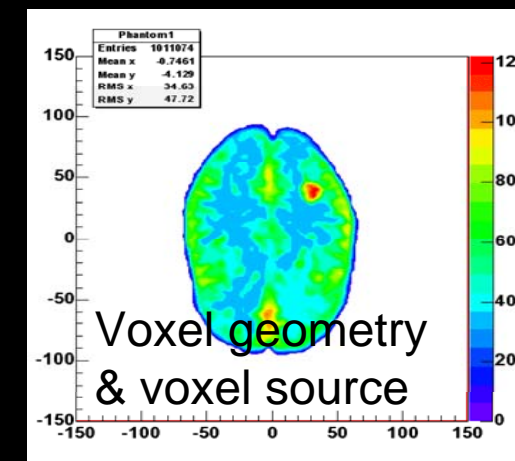
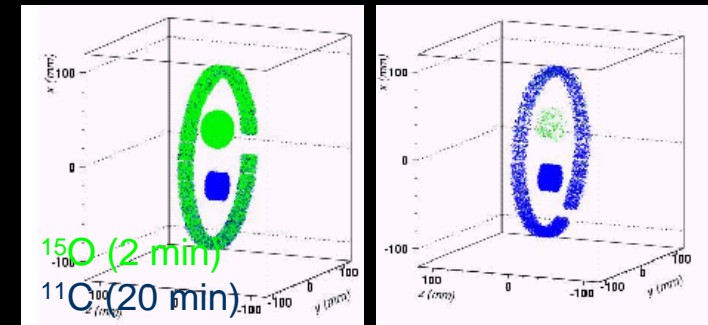


Source management

Santin et al., IEEE Trans. Nucl. Sci. 50 (2003)

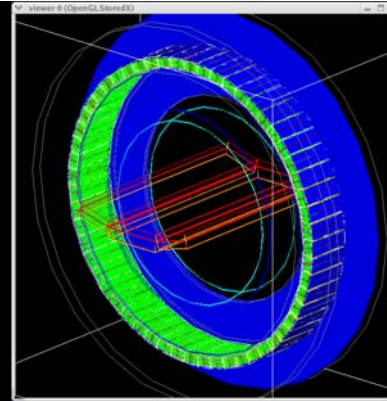
- Multiple sources
 - Controlled by source manager
 - Inserted via scripting
 - Complex geometries: customized GPS
- Optimized decay
 - Customized G4 Radioactive Decay Module
 - PET-specific sources
- New: Voxel sources
 - Overlaid onto the voxel geometry

```
/gate/source/addSource fluor18
/gate/source/fluor18/setActivity 5. becquerel
/gate/source/fluor18/gps/particle ion
/gate/source/fluor18/gps/ion 9 18 0 0
/gate/source/fluor18/gps/energytype Mono
/gate/source/fluor18/gps/monoenergy 0. MeV
/gate/source/fluor18/gps/angtype iso
/gate/source/fluor18/gps/number 1
/gate/source/fluor18/gps/centre 0. 0. 0. cm
/gate/source/fluor18/gps/type Volume
/gate/source/fluor18/gps/shape Sphere
/gate/source/fluor18/gps/radius 1. mm
/gate/source/fluor18/gps/confine head_P
```

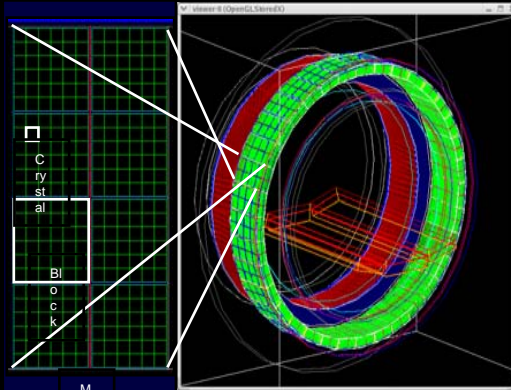




Moving scripted systems

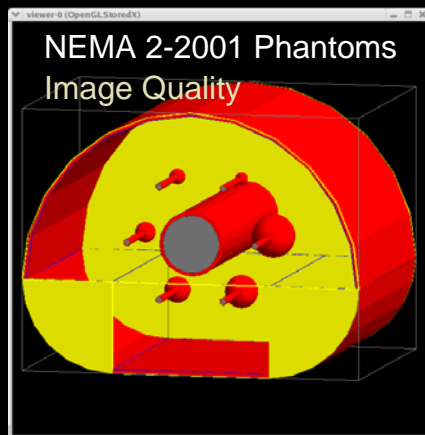


GE Advance/Discovery LS PET scanner
A.S.Kirov, et al. MSKCC, Med.Phys.33, 2006

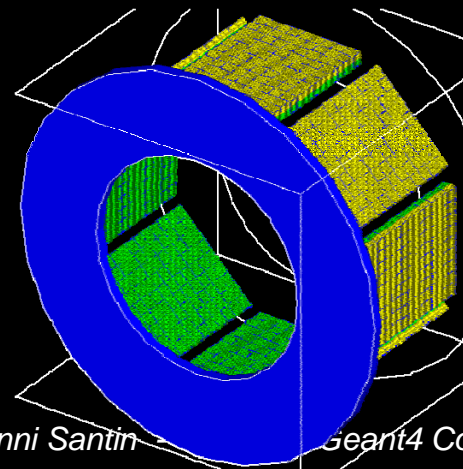
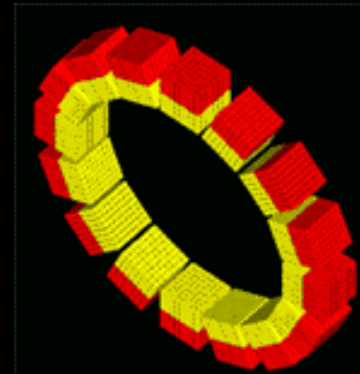


GE Advance/Discovery ST PET, 3D mode
C.R.Schmidlein, A.S.Kirov,, et al. MSKCC

A.S.Kirov, C.R.Schmidlein, S.Nehmeh et al.
MSKCC and GE Medical Systems



NEMA 2-2001 Phantoms
Image Quality

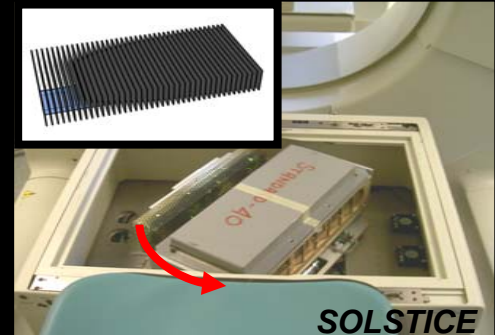


HRRT
D.Guez, S.Kerhoas,
F.Bataille, C.Comtat,
S.Jan
DAPNIA and SHJF

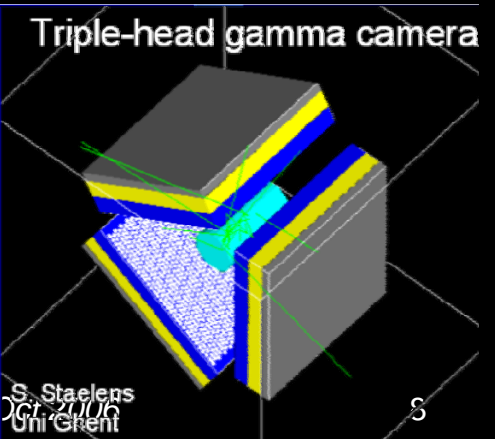
Giovanni Santin, Geant4 Collaboration Meeting, Lisbon, Oct 2008

```
# CRYSTAL
/block/daughters/name crystal
/block/daughters/insert box
/crystal/geometry/setXLength 30 mm
/crystal/geometry/setYLength 4.4 mm
/crystal/geometry/setZLength 4.4 mm
/crystal/setMaterial BGO

# REPEAT CRYSTAL INSIDE BLOCK
/crystal/repeaters/insert cubicArray
/crystal/cubicArray/setRepeatNumberX 1
/crystal/cubicArray/setRepeatNumberY 8
/crystal/cubicArray/setRepeatNumberZ 8
/crystal/cubicArray/setRepeatVector 0. 4.5 4.5 mm
```



SOLSTICE
R. Van Hoken, S. Staelens et al.
ELIS-MEDISIP, Ghent



Triple-head gamma camera

S. Staelens
Univ Ghent

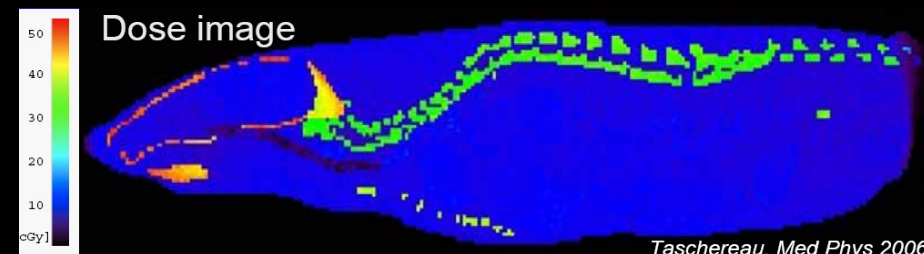
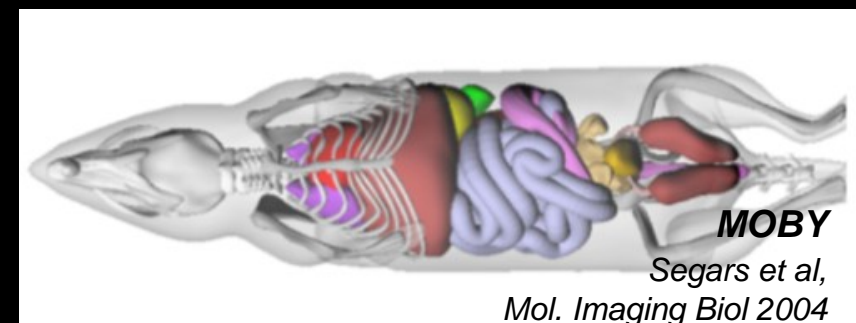
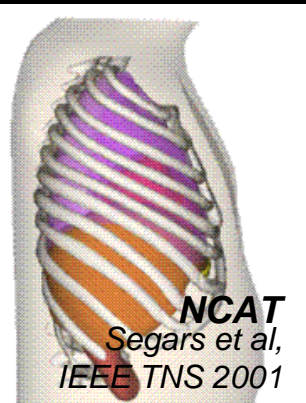
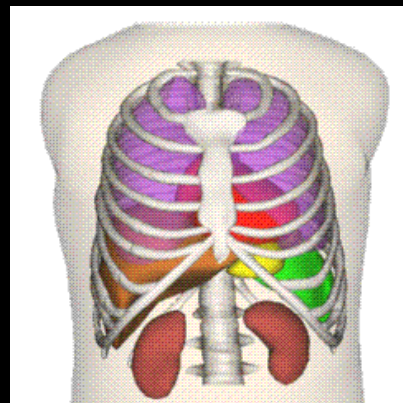
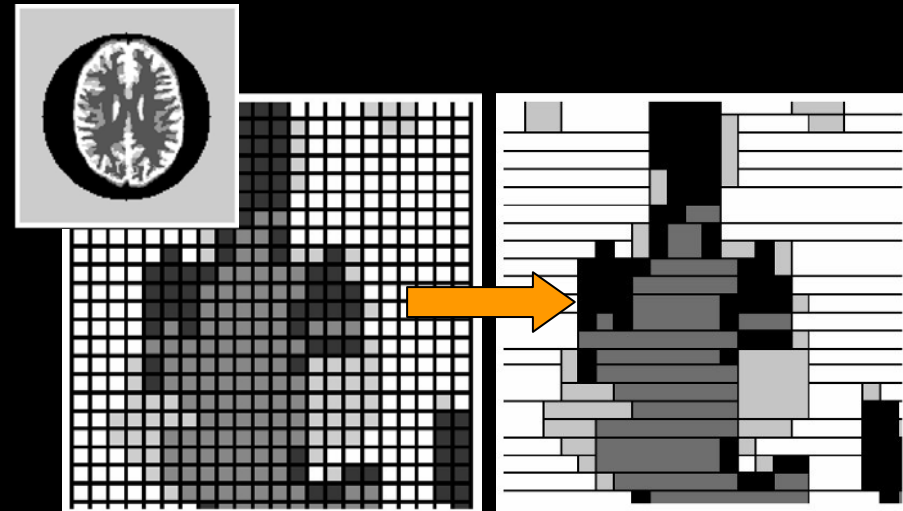


Voxels and phantoms

Staelens S et al., *J. Nucl. Med.* 44 (2003) 048
Taschereau et al., *Med. Phys.* 33 (2006)
Lamare et al., *EANM 2005, Istanbul, Turkey*

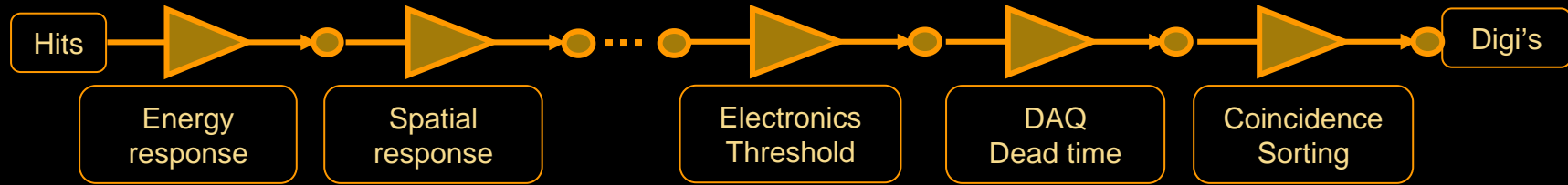
GATE includes interfaces to

- Generic voxel images
 - No dancing replicas anymore
 - Parameterised now used
 - Also with variable voxel size
- Specific phantoms
 - NCAT
 - MOBY
 - ...
- Integrated with
 - Source maps
 - Dosimetry





Signal processing



```

/gate/digitizer/modules/insert blurring
/gate/digitizer/blurring/setResolution 0.15

/gate/digitizer/modules/insert spblurring
/gate/digitizer/spblurring/setResolution 0.15

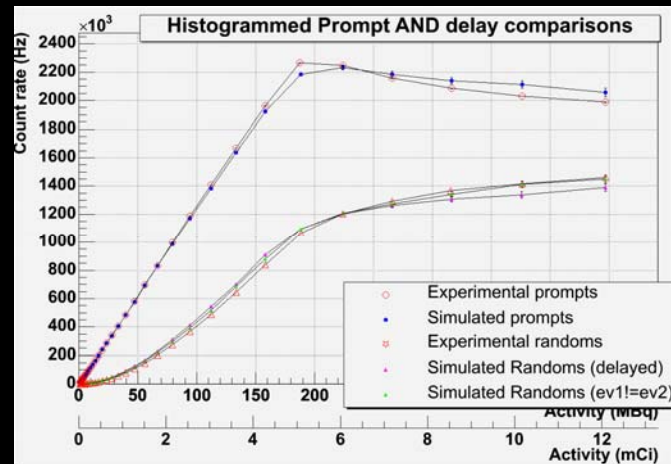
/gate/digitizer/modules/insert readout

/gate/digitizer/modules/insert thresholder
/gate/digitizer/thresholder/setThreshold 50. keV
  
```

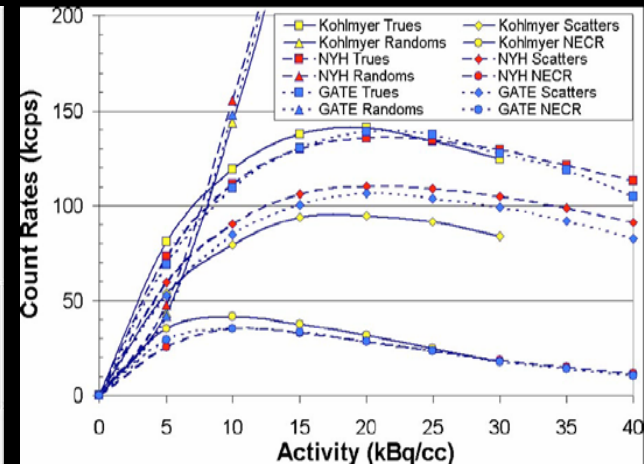
- Digitizer
 - Linear signal processing chain
 - Modular: set-up via scripting

- New
 - Dead time
 - New processing types
 - List Mode output
 - Interface to the STIR image reconstruction software

Simon et al.,
Nucl. Instr. Meth. A527 (2004)



D.Guez et al., HRRT,
CEA/DAPNIA and SHJF



GE Advance/Discovery
C.R.Schmidlein et al, Med. Phys.

Giovanni Santin - GATE - Geant4 Collaboration Meeting, Lisbon, October 2006





Other recent developments

- Optical photons in GATE (TU Delft)
- Improved digitiser chain for advanced signal processing (CEA/DAPNIA)
- New Graphical User Interface (NTU Athens)

- Working groups
 - Dosimetry (chair: D.Visvikis, Brest Univ.)
 - Efficiency optimisation (chair: S.Staelens, Ghent Univ.)
 - Cluster parallel computation (chair: F. Rannou, UCLA)



Cluster and efficiency working groups

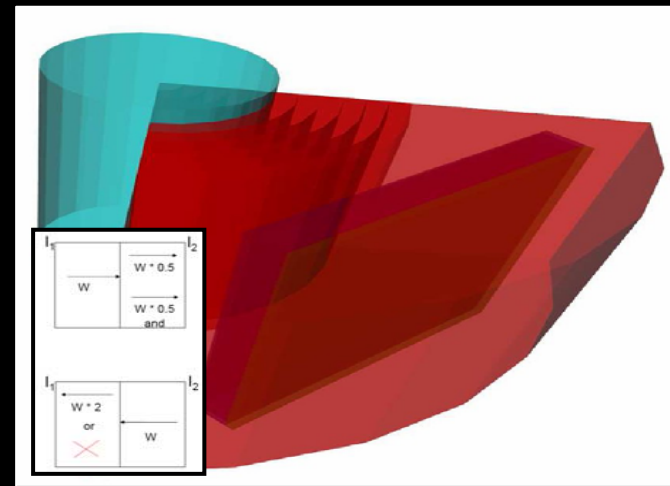
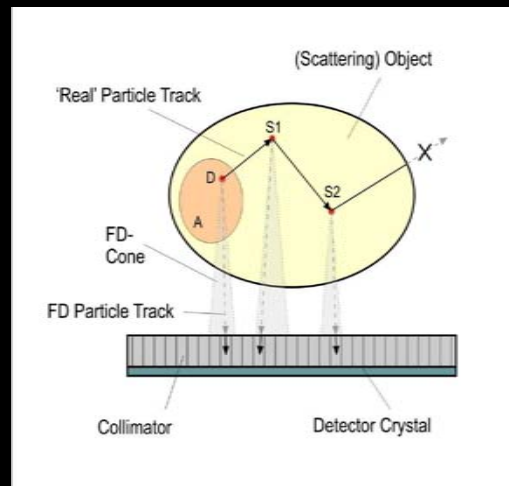
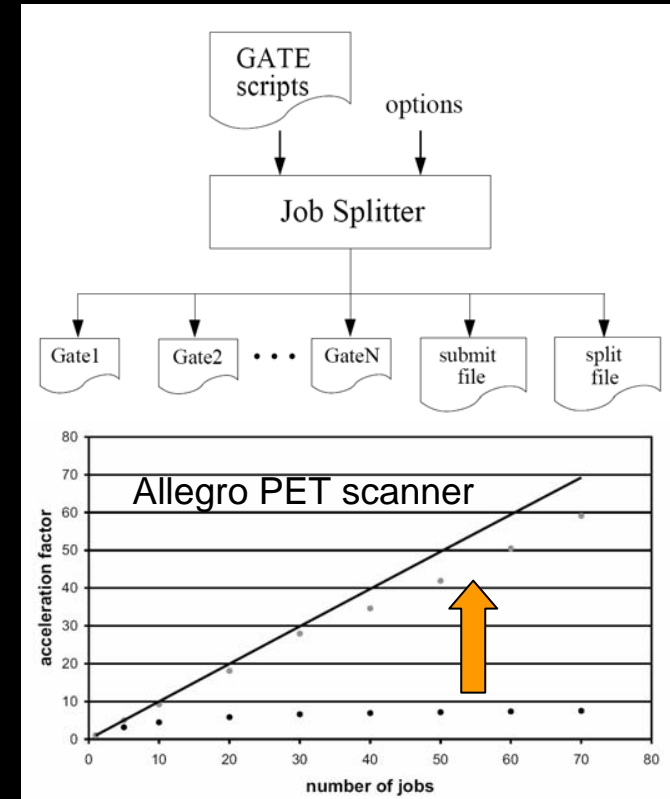
Cluster

- Platforms include openMosix, Condor, OpenPBS and Xgrid
- Transparent interface cluster – GATE
- Fast setup and fast merger code
→ almost linear scalability

Efficiency

- Group topics include
- Geometrical biasing
 - Forced detection

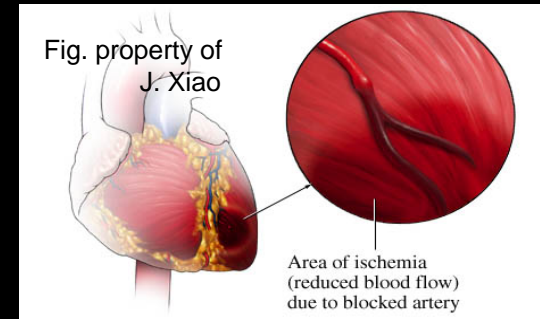
Staelens et al., Nucl. Instrum. Meth. A, in press
Goedicke, DeBeenhouwer et al., Empec 2005





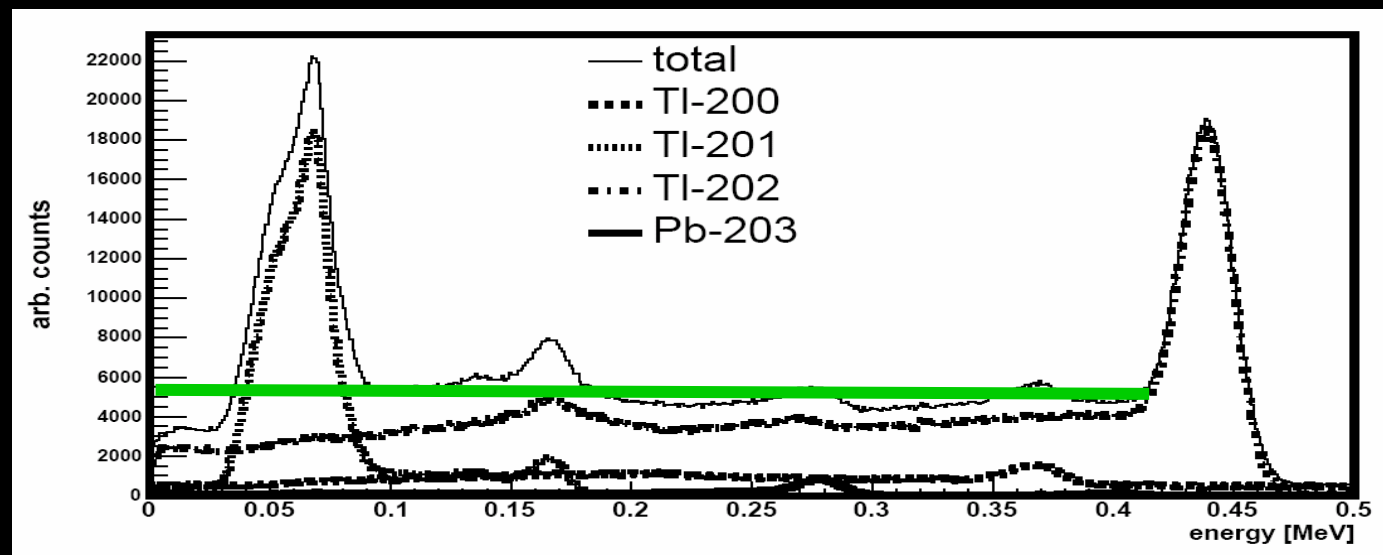
Clinical applications

Myocardial perfusion imaging (MPI)



Tl-201

- diagnostic tracer for intermediate- and late-stage patients
- 10 million MPS per year in US, 60% of them use Tl-201 Chloride
- Contamination (< 1%) of Tl-200 (26h), Tl-202 (12d) and Pb-203 (52h)
- Tl-202 significantly degrades Tl-201 images
 - High septal penetration (439keV gamma)
 - Model-based correction for iterative reconstr.



Staelens et al., SNM '06, San Diego, June 2006



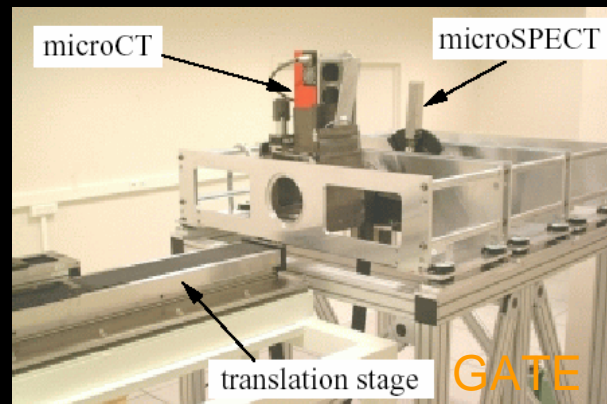
Hybrid machines

PET/CT



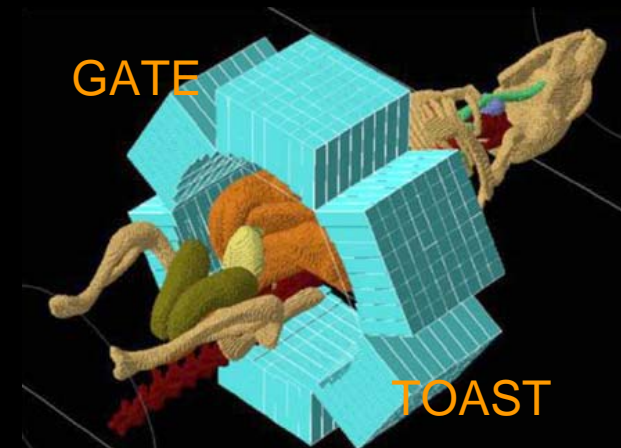
Lazaro et al, SNM 2005

SPECT/CT



Brasse et al, IEEE MIC Conf Rec 2004

OPET

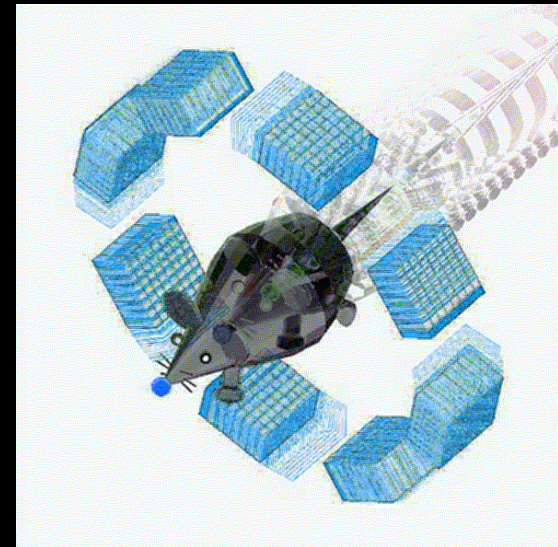


Arridge et al., Med. Phys. 2003
Alexandrakis et al, Phys Med Biol 2005

- Integrating Monte Carlo modelling tools for:
 - common coordinate system
 - common object description
 - consistent sampling
 - convenient assessment of multi-modality imaging
- Starting in GATE

Summary

- GATE has become a popular tool for Monte Carlo simulations in emission tomography
- Open source, collaborative approach
- Since 2002:
Significant upgrades, extensive validation and clinical applications
- Simulations will be more and more present in (nuclear) medical imaging in the future:
 - for designing imaging protocols and interpreting SPECT and PET scans,
 - in the very imaging process of a patient



www.opengatecollaboration.org