Monte Carlo simulations in emission tomography and GATE: an overview

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Outline

- Evolution of the use of MC simulations in ET since 1995
- Evolution of the codes used for MC simulations in ET since 1995
- New features in MC simulators in ET
- New applications for MC simulations
- Upcoming developments in MC simulations
- Conclusion

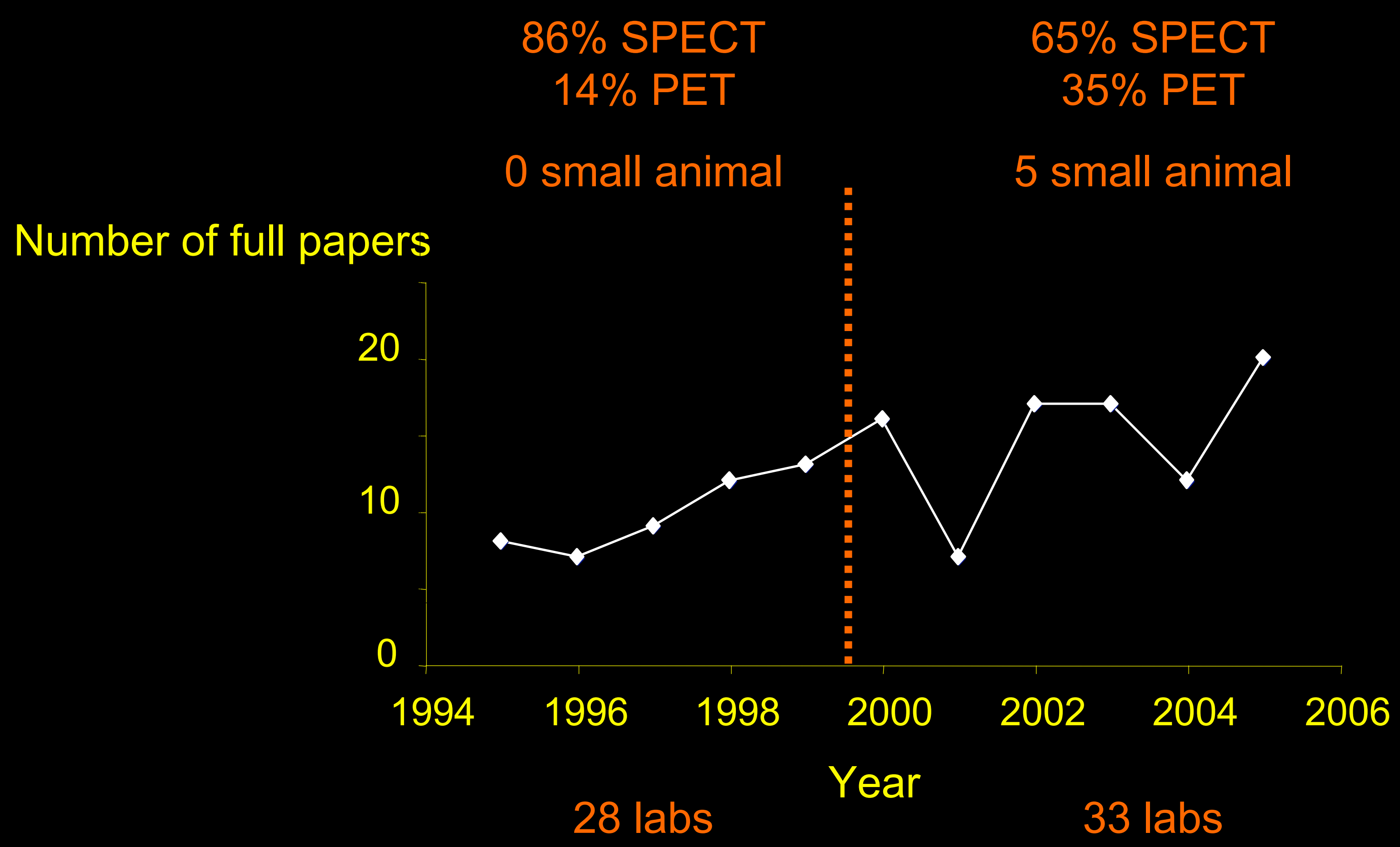
Evolution of the use of MC simulations in ET since 1995

Important role in SPECT and PET, for optimizing detector design, designing and assessing acquisition and processing protocols.

- Zaidi, Relevance of accurate Monte Carlo modeling in nuclear medical imaging. *Med Phys* 26 (1999) 574-608
- Buvat and Castiglioni, Monte Carlo simulations in SPET and PET. *Q J Nucl Med* 46 (2002) 48-61

Evolution of the use of MC simulations in ET since 1995

- 666 entries since 1995 at the date of the search (July 1995)
- Use of MC simulations to produce SPECT and PET images: 130 entries



Evolution of the codes used for MC simulations in ET since 1995

1995-1999

- 14 different codes:
  - 10 « home-made »
  - 4 publicly released or available from authors

2000-2004

- 15 different codes:
  - 8 « home-made »
  - 7 publicly released or available from authors

No « standard » code for Monte Carlo simulations in SPECT and PET

Most frequently used

SimSET

SIMIND

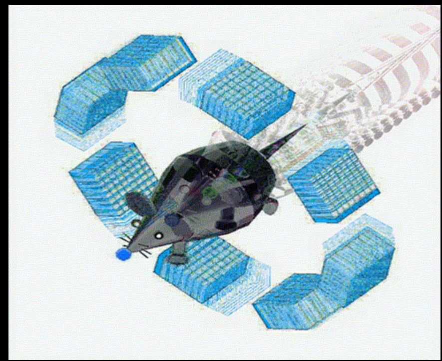
And recently

Geant 4

GATE

Penelope

Most recent code: GATE



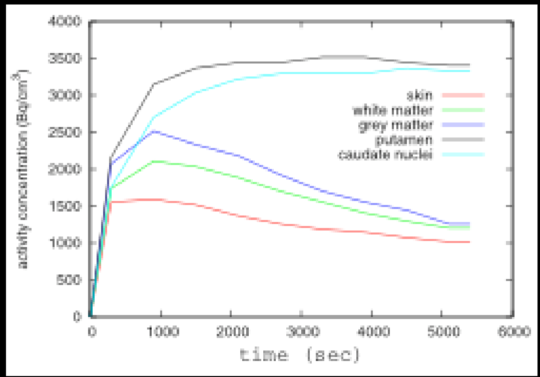
- Motivation in 2001: provide a public code
  - based on a standard code to ensure reliability
  - enabling SPECT and PET simulations (possibly even more)
  - accommodating almost any detector design (including prototypes)
  - modeling time-dependent processes
  - user-friendly
- Developed by the OpenGATE collaboration (21 labs)
- Based on GEANT4
- Publicly released May 2004: http://www.opengatecollaboration.org

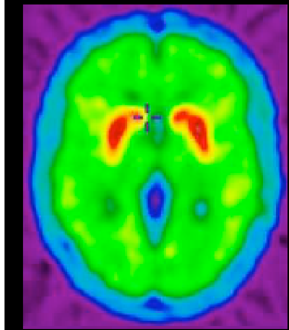
- More than 400 subscribers to the Gate users mailing list
- IEEE MIC 2004: 61 proceedings involving MC simulations in SPECT and PET
  11 used GATE, 9 used GEANT4, 8 used SimSET, 4 used SIMIND

Monte Carlo simulations today

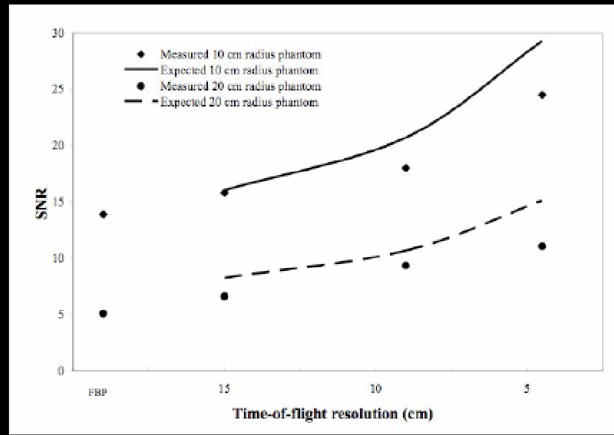
Modeling time dependent processes

Possible using SORTEO, SimSET and GATE

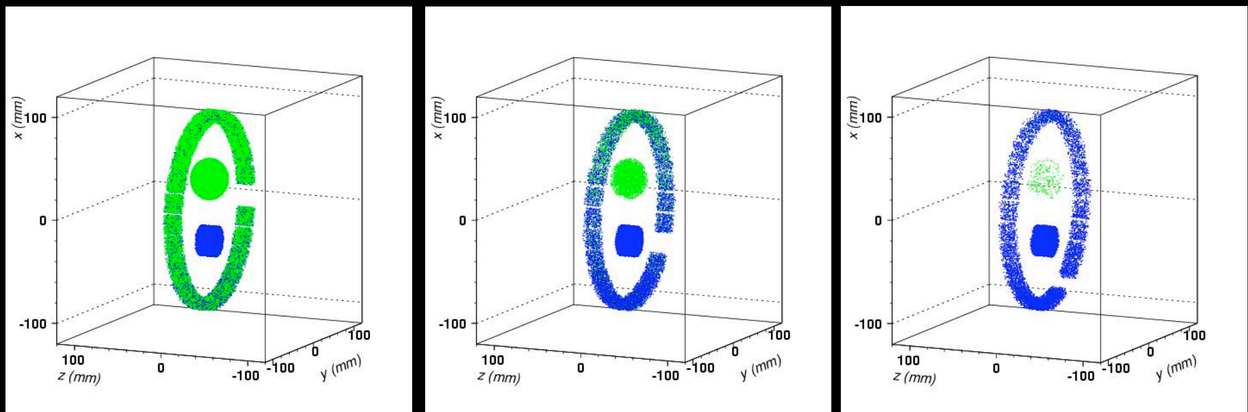




Reilhac et al, IEEE TNS 2005

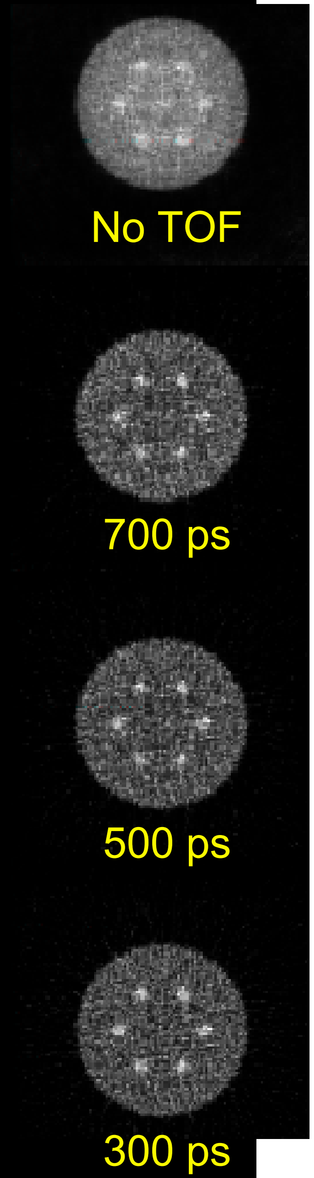


Harrison et al, IEEE MIC Conf Rec 2004



^{15}O (2 min)
^{11}C (20 min)

Santin et al, IEEE TNS 2003



Groiselle et al, IEEE MIC Conf Rec 2004

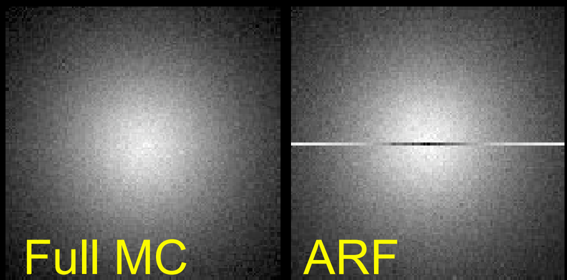
Increasing the throughput of the simulations

Using acceleration methods

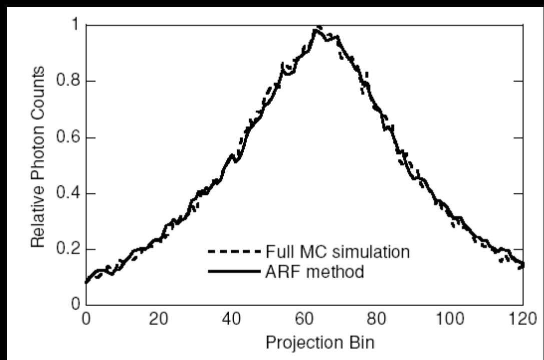
- Variance reduction techniques such as importance sampling (e.g. in SimSET)
  ➡ speed-up factors between 2 and 15

- Fictitious cross-section (or delta scattering)

Combining MC and non MC modeling

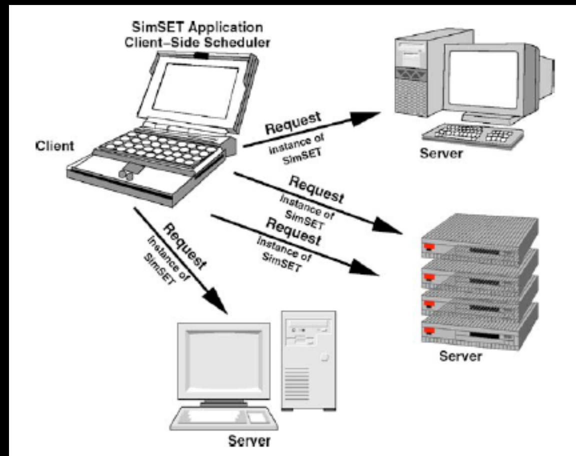


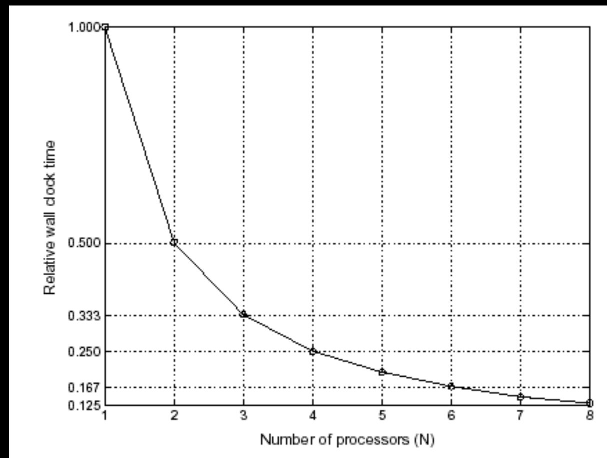
Song et al, Phys Med Biol 2005



increase in efficiency > 100

Parallel execution of the code

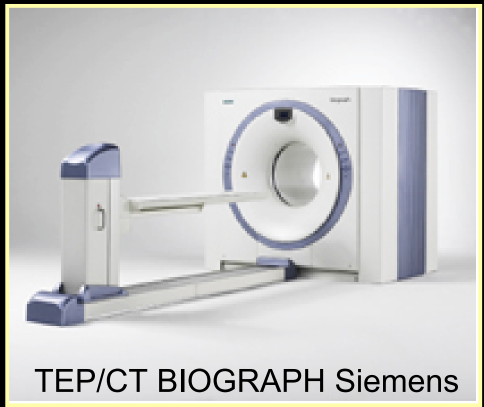


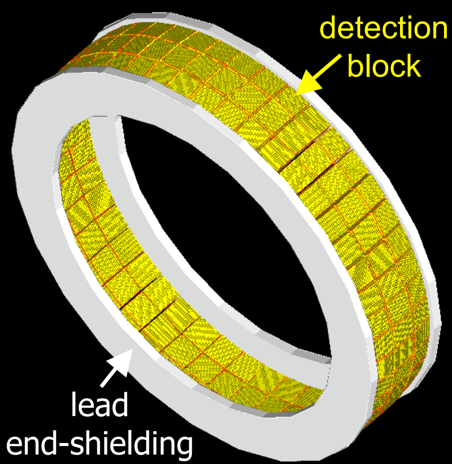


Thomason et al, Comp Methods Programs Biomed 2004

Modeling original detector designs

Non-conventional geometries



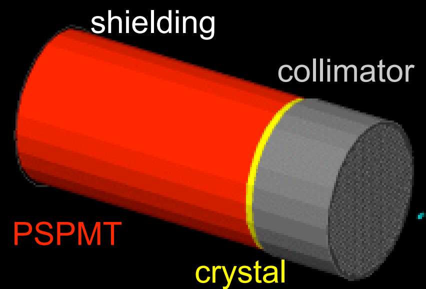


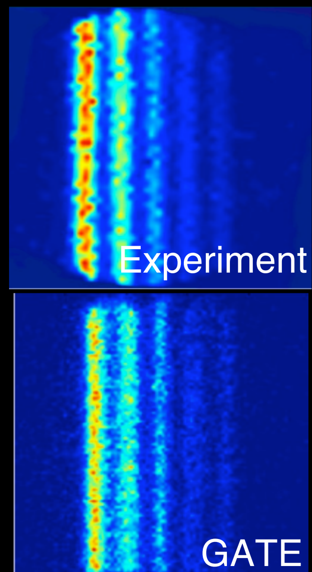
Spherical geometry of the Hi-Rez PET scanner

Lazaro et al, SNM 2005

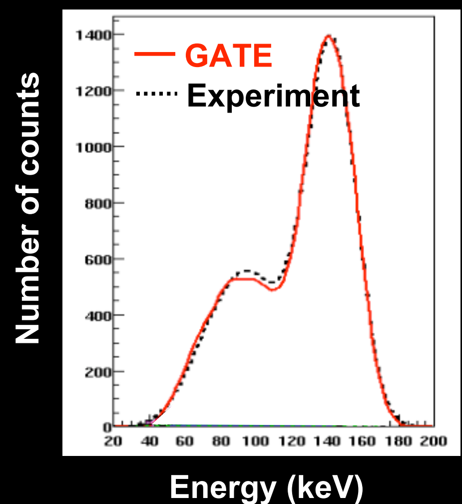
Prototypes

IASA CsI(TI) gamma camera



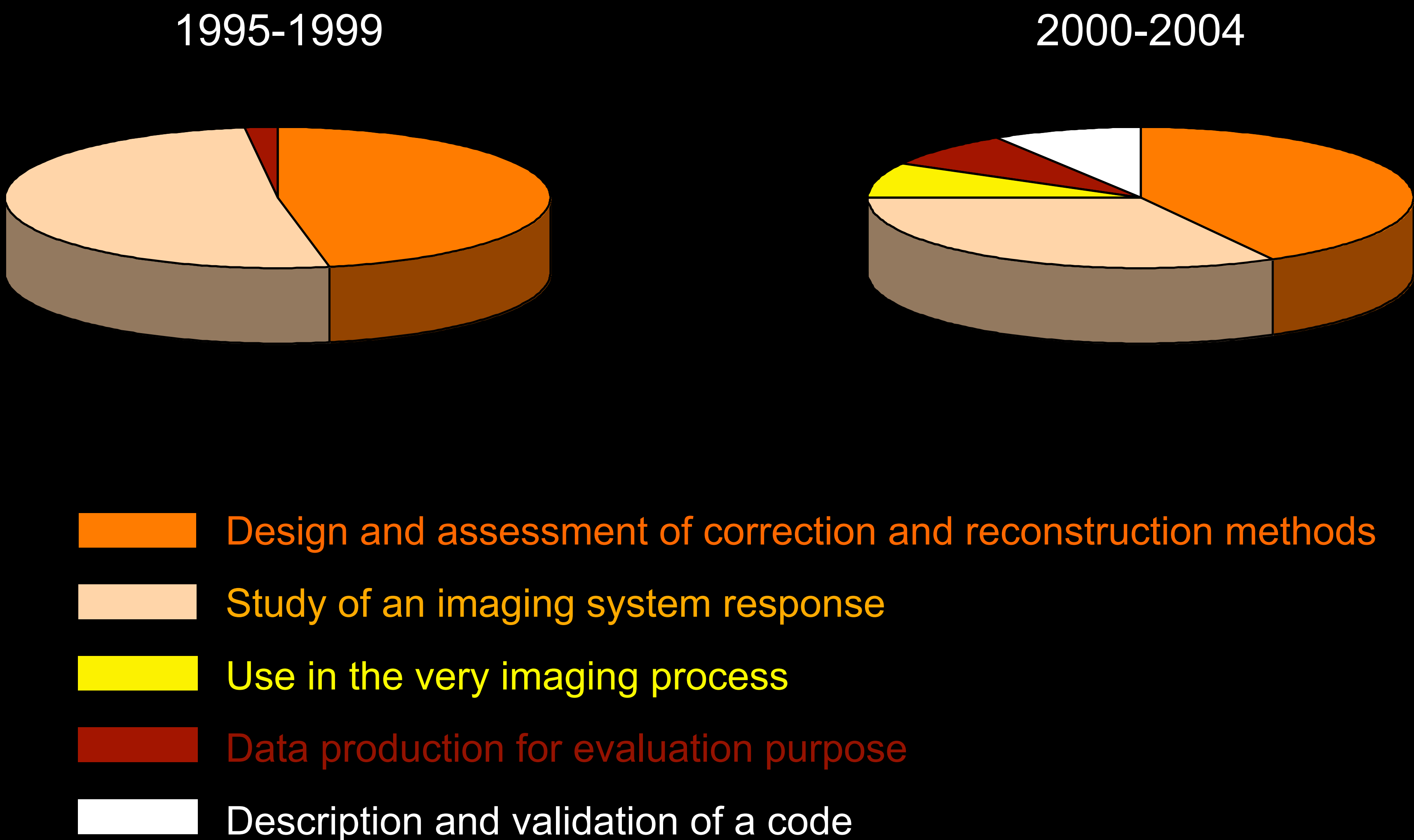


Energy spectrum

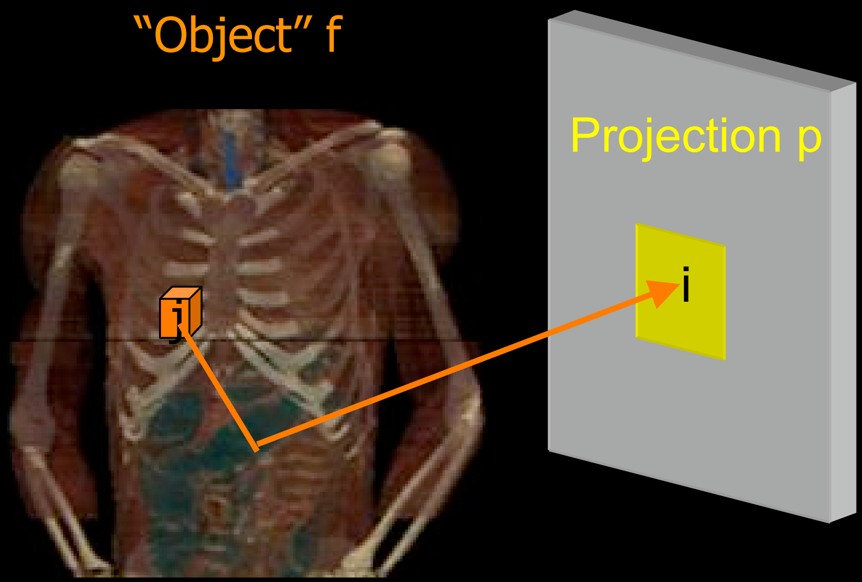


Lazaro et al, Phys Med Biol 2004

New applications for Monte Carlo simulations



Using Monte Carlo simulations for calculating the system matrix



$$p = \mathbf{R}\, f$$

R(i,j): probability that a photon emitted in voxel j be detected in pixel i

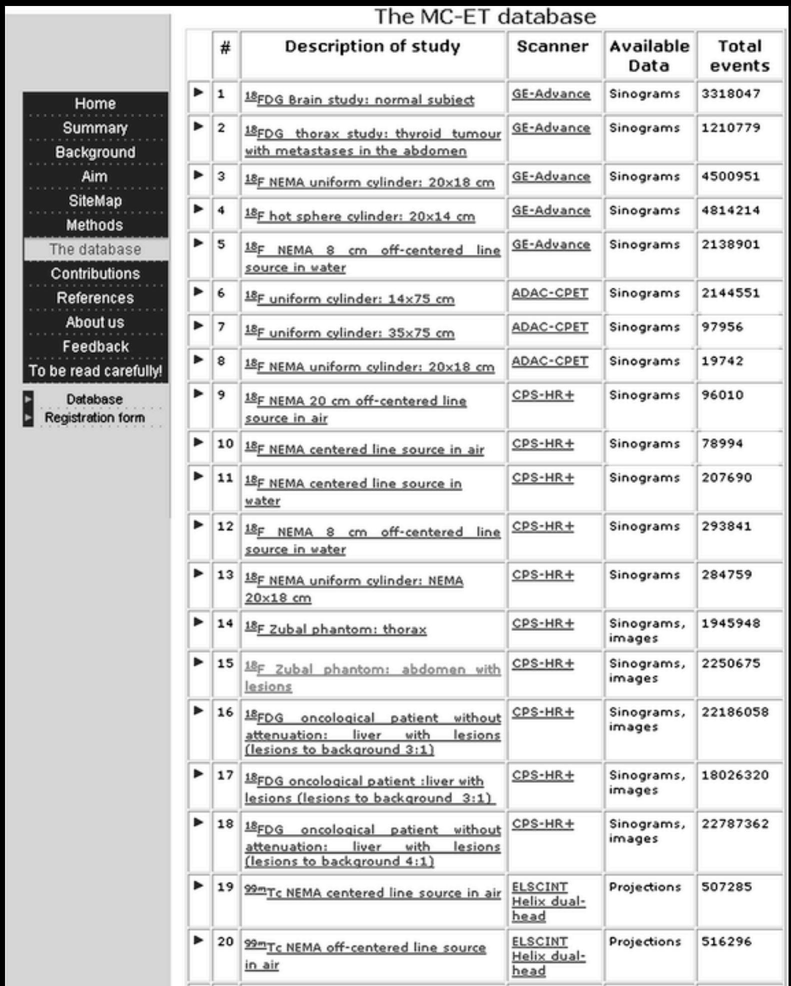
Calculating R using Monte Carlo simulations:

- for non conventional imaging design (small animal)
- to account for fully 3D and patient-specific phenomena difficult to model analytically (mostly scatter)

e.g., Lazaro et al Phys Med Biol 2005, Rafecas et al IEEE TNS 2004, Rannou et al IEEE MIC Conf Rec 2004

Using Monte Carlo for feeding database

http://www.ibfm.cnr.it/mcet/index.html



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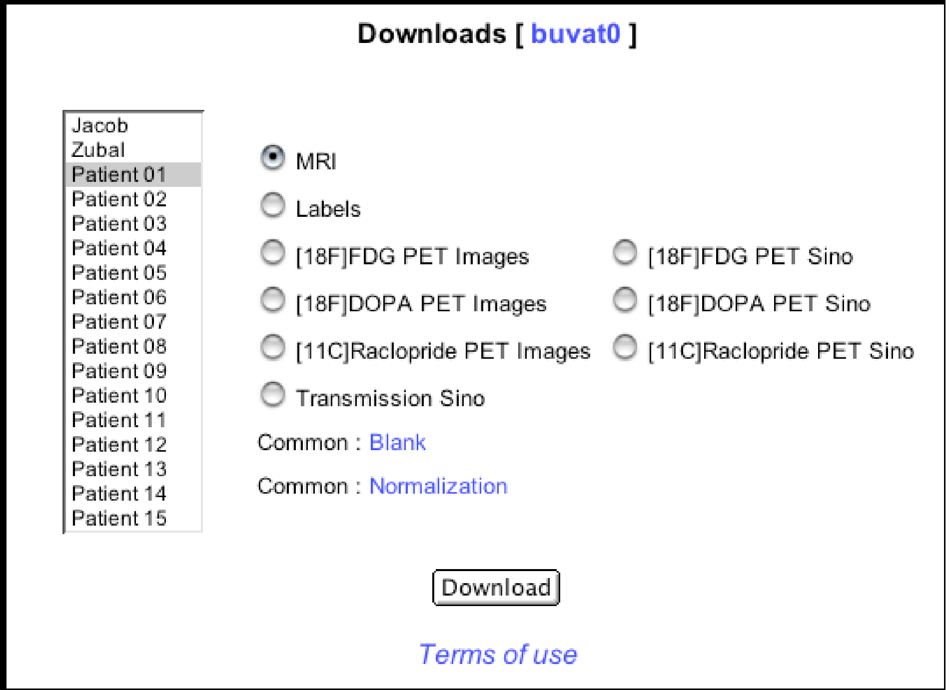
Feedback
To be read carefully!
Database
Registration form

The MC-ET database

#	Description of study	Scanner	Available Data	Total events
1	^{18}FDG Brain study: normal subject	GE-Advance	Sinograms	3318047
2	^{18}FDG thorax study: thyroid tumour with metastases in the abdomen	GE-Advance	Sinograms	1210779
3	^{18}F NEMA uniform cylinder: 20x18 cm	GE-Advance	Sinograms	4500951
4	^{18}F hot sphere cylinder: 20x14 cm	GE-Advance	Sinograms	4814214
5	^{18}F NEMA 8 cm off-centered line source in water	GE-Advance	Sinograms	2138901
6	^{18}F uniform cylinder: 14x75 cm	ADAC-CPET	Sinograms	2144551
7	^{18}F uniform cylinder: 35x75 cm	ADAC-CPET	Sinograms	97956
8	^{18}F NEMA uniform cylinder: 20x18 cm	ADAC-CPET	Sinograms	19742
9	^{18}F NEMA 20 cm off-centered line source in air	CPS-HR+	Sinograms	96010
10	^{18}F NEMA centered line source in air	CPS-HR+	Sinograms	78994
11	^{18}F NEMA centered line source in water	CPS-HR+	Sinograms	207690
12	^{18}F NEMA 8 cm off-centered line source in water	CPS-HR+	Sinograms	293841
13	^{18}F NEMA uniform cylinder: NEMA 20x18 cm	CPS-HR+	Sinograms	284759
14	^{18}F Zubal phantom: thorax	CPS-HR+	Sinograms, images	1945948
15	^{18}F Zubal phantom: abdomen with lesions	CPS-HR+	Sinograms, images	2250675
16	^{18}FDG oncological patient without attenuation: liver with lesions (lesions to background 3:1)	CPS-HR+	Sinograms, images	22186058
17	^{18}FDG oncological patient :liver with lesions (lesions to background 3:1)	CPS-HR+	Sinograms, images	18026320
18	^{18}FDG oncological patient without attenuation: liver with lesions (lesions to background 4:1)	CPS-HR+	Sinograms, images	22787362
19	^{99m}Tc NEMA centered line source in air	ELSCINT Helix dual-head	Projections	507285
20	^{99m}Tc NEMA off-centered line source in air	ELSCINT Helix dual-head	Projections	516296

Castiglioni et al, Eur J Nucl Med Mol Imaging 2005

http://sorteo.cermep.fr

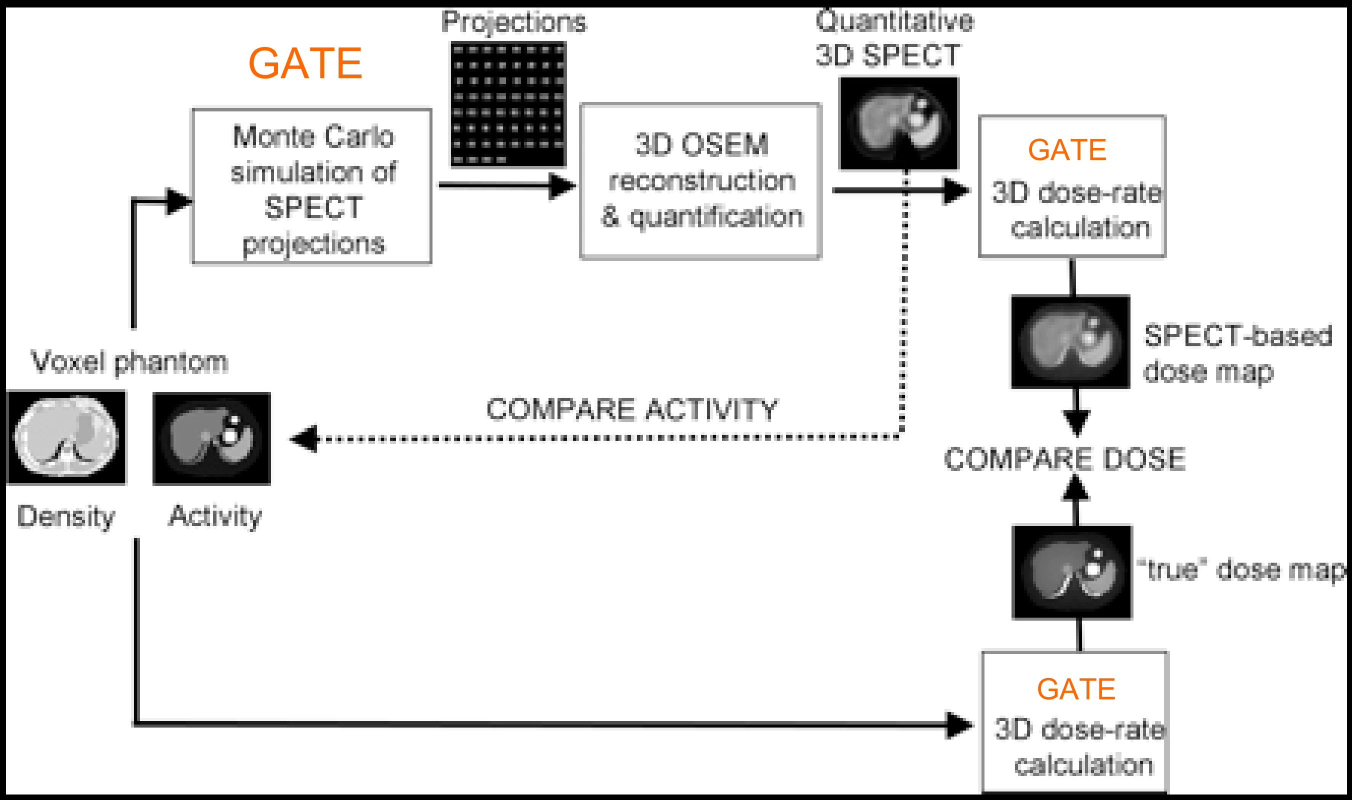


Reilhac et al, IEEE TNS 2005

What next?

Bridging the gap between MC modelling in imaging and dosimetry

Accurate dosimetry in 131I radionuclide therapy using patient-specific, 3-dimensional methods for SPECT reconstruction and absorbed dose calculation



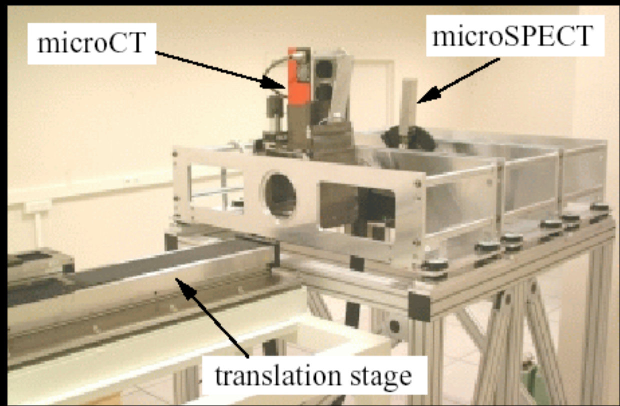
Dewaraja et al, J Nucl Med 2005

Modeling hybrid machines (PET/CT, SPECT/CT, OPET)

PET/CT

SPECT/CT

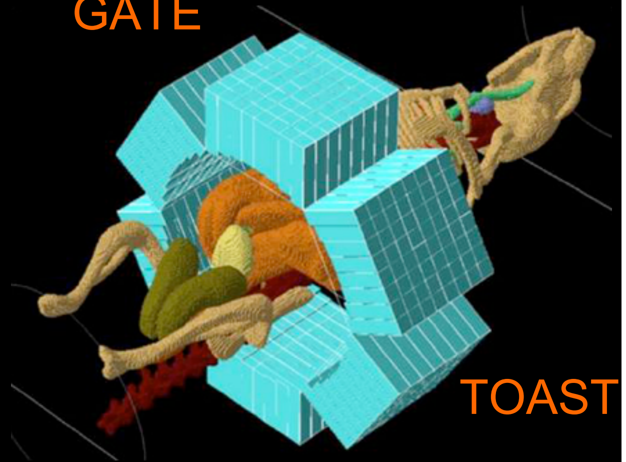
GATE



Brasse et al, IEEE MIC Conf Rec 2004

OPET

GATE



Alexandrakis et al, Phys Med Biol 2005

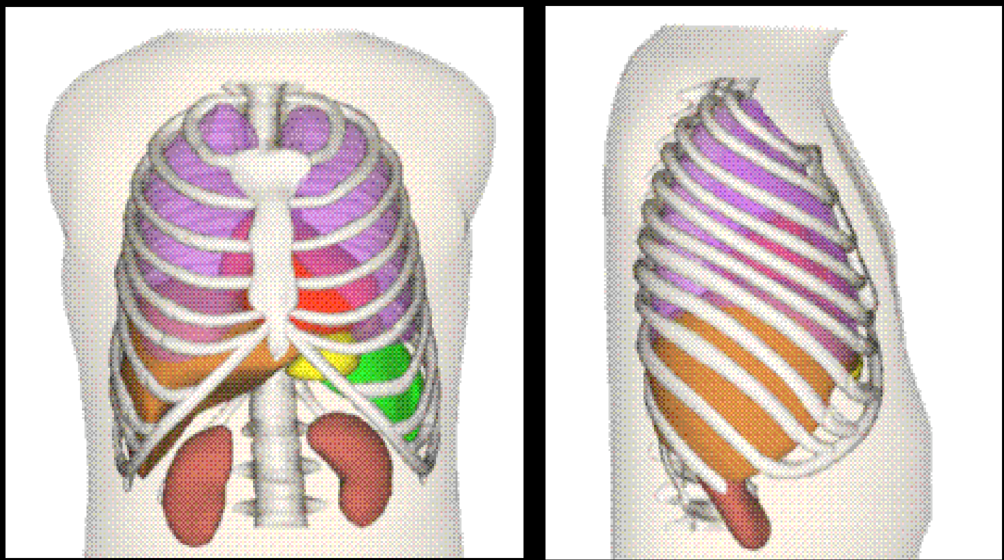
Integrating Monte Carlo modeling tools for:

- common coordinate system
- common object description
- consistent sampling
- convenient assessment of multimodality imaging

Designing realistic phantoms

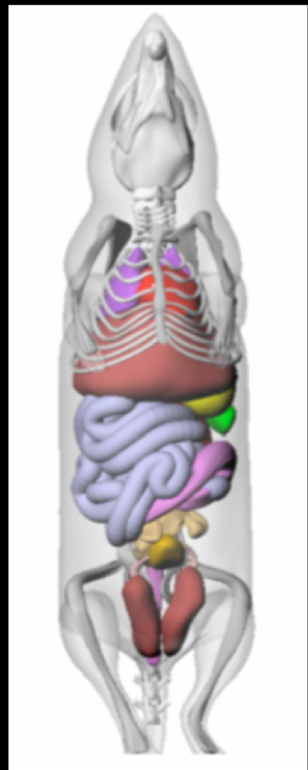
Interfacing realistic phantoms with simulator input

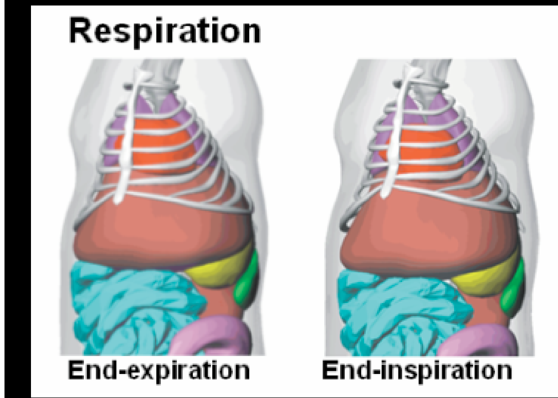
NCAT



Segars et al, IEEE TNS 2001

MOBY



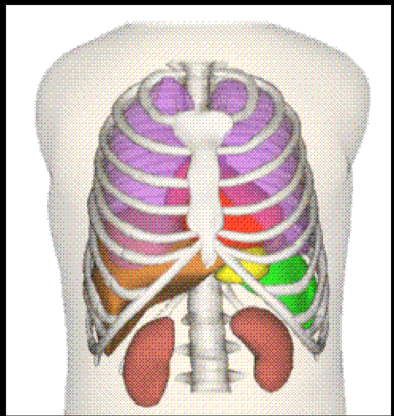


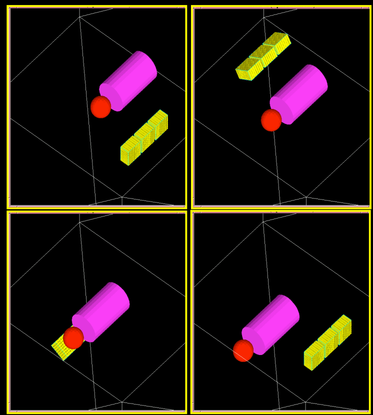
Segars et al, Mol Imaging Biol 2004

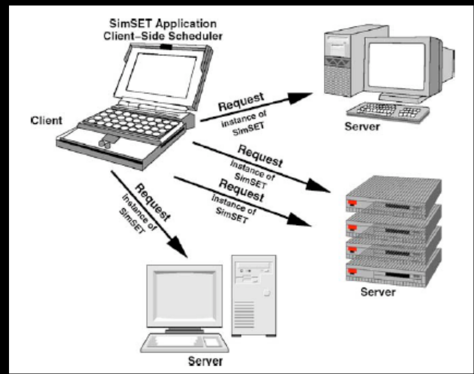
Making it easier to model a wide range of body habitus and physiological motions

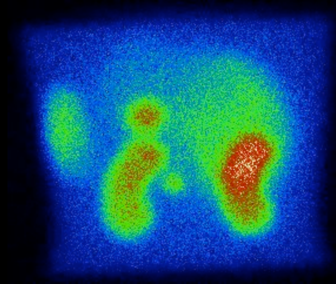
Conclusion

• Monte Carlo simulation is a more and more accurate modelling tool in SPECT and PET









• They will be more and more present in (nuclear) medical imaging in the future:

- as a invaluable guide for designing imaging protocols and interpreting SPECT and PET scans,
- in the very imaging process of a patient

Acknowledgments

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