

Monte Carlo Simulation

Dr Andrew Robinson

*Optimisation in Imaging - HSST
The Christie, March 2018*

- What is Monte Carlo simulation?
- Why use it for medical imaging?
- Examples (demos)
- Validation of simulations
- Tools you can use

What is Monte Carlo simulation?

What is Monte Carlo simulation?

Based on the Monte Carlo method

What is Monte Carlo simulation?



What is Monte Carlo simulation?



what is the monte carlo method

Web Apps Examples Random

Input interpretation:

Monte Carlo method

Open code

Definition:

Any method which solves a problem by generating suitable random numbers and observing that fraction of the numbers obeying some property or properties. The method is useful for obtaining numerical solutions to problems which are too complicated to solve analytically. It was named by S. Ulam, who in 1946 became the first mathematician to dignify this approach with a name, in honor of a relative having a propensity to gamble. Nicolas Metropolis also made important contributions to the development of such methods.

The most common application of the Monte Carlo method is Monte Carlo integration.

More information »

Related topics:

Monte Carlo integration | quasi-Monte Carlo method | stochastic geometry | uniform distribution theory

What is Monte Carlo simulation?



simulation

Web Apps Examples Random

Input interpretation:
simulation (English word)

Open code

Definitions:

- 1 noun the act of imitating the behavior of some situation or some process by means of something suitably analogous (especially for the purpose of study or personnel training)
- 2 noun (computer science) the technique of representing the real world by a computer program
- 3 noun representation of something (sometimes on a smaller scale)
- 4 noun the act of giving a false appearance

American pronunciation:
sɪmjuhl'eyshuhn (IPA: sɪmjuh'l̩ eɪʃən)

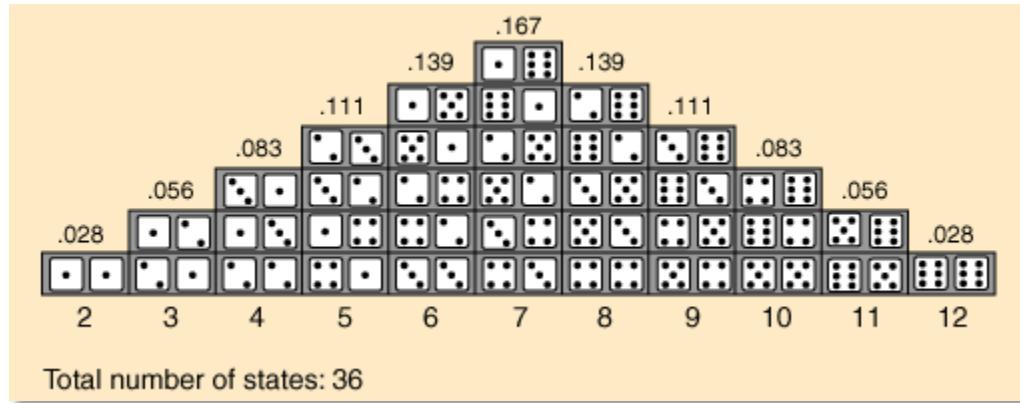
Hyphenation:
sim-u-la-tion (10 letters | 4 syllables)

What is Monte Carlo simulation?

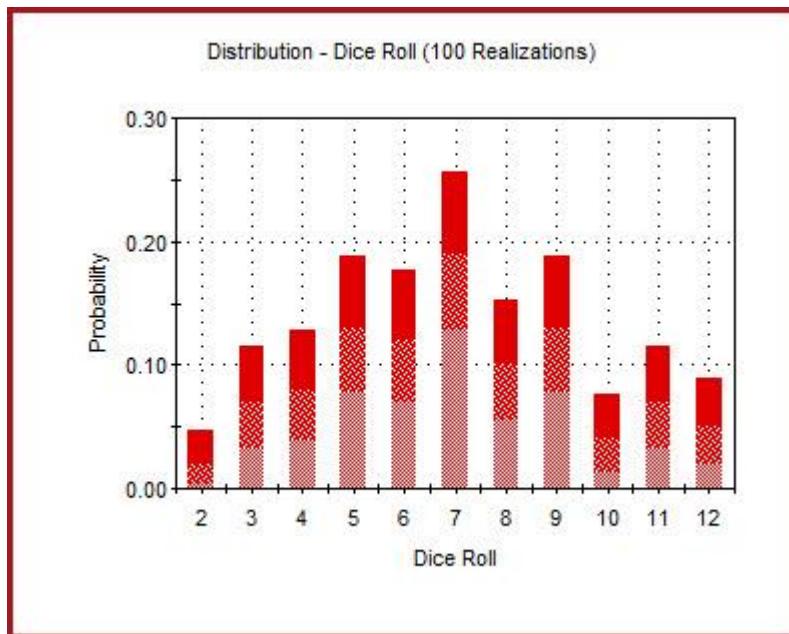
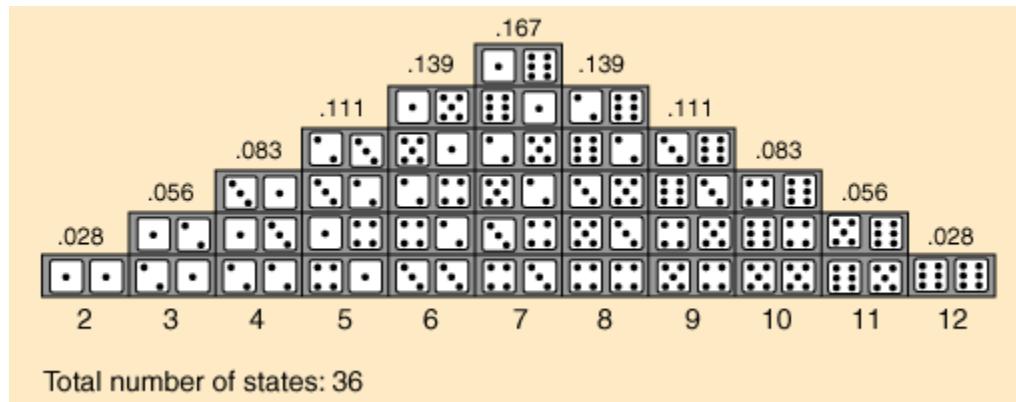
“A method which solves a problem by generating suitable random numbers and observing that fraction of the numbers obeying some property or properties. The method is useful for obtaining numerical solutions to problems which are **too complicated to solve analytically.**”

“A technique of **representing the real world by a computer program.**”

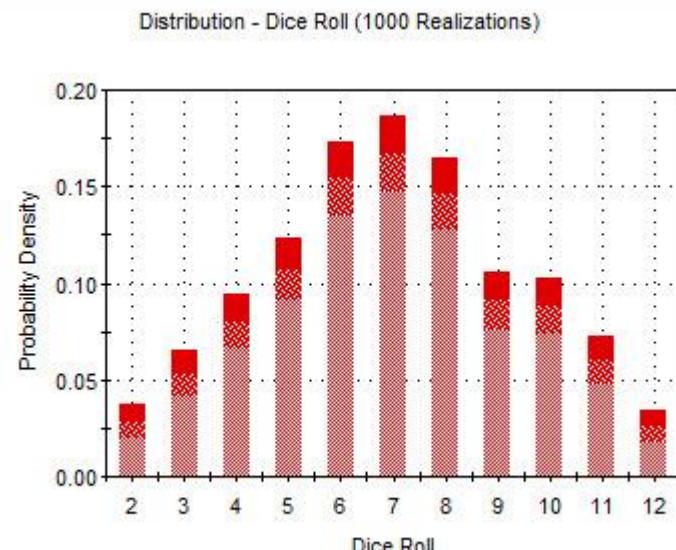
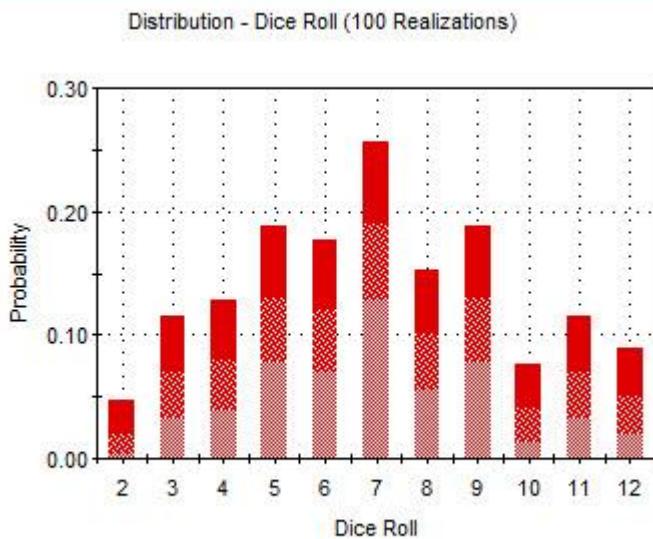
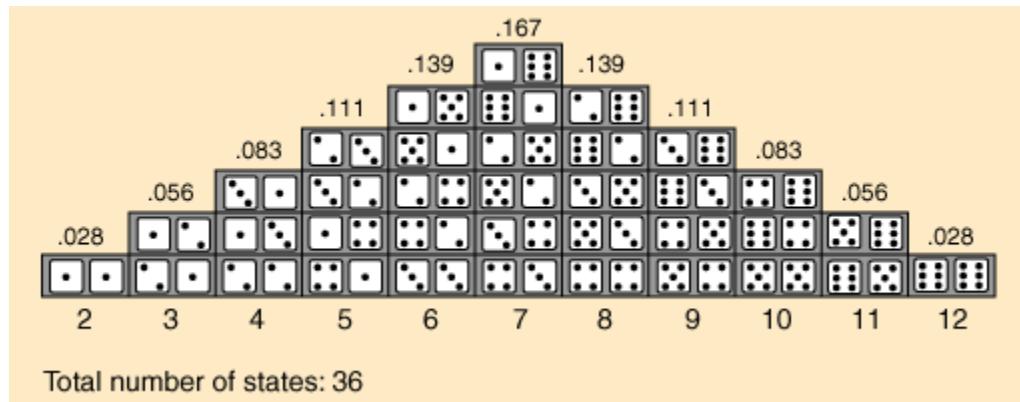
Simple Example



Simple Example



Simple Example



- What is Monte Carlo simulation?
- Why use it for medical imaging?
- Examples (demos)
- Validation of simulations
- Tools you can use

Why use it for medical imaging?

Doesn't require patients

No camera time

Extra information (physically non-observable)

Easily modify the system

Can provide a “ground truth”

No radiation dose (patient or operator)

Infinitely repeatable

Optimise imaging protocols

- ❑ What is Monte Carlo simulation?
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- ❑ Examples (demos)**
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Blue = Positive Charge

Green = Neutral Charge

Red = Negative Charge

Optimisation of imaging windows using Monte Carlo Simulation

Optimisation of imaging windows using Monte Carlo Simulation

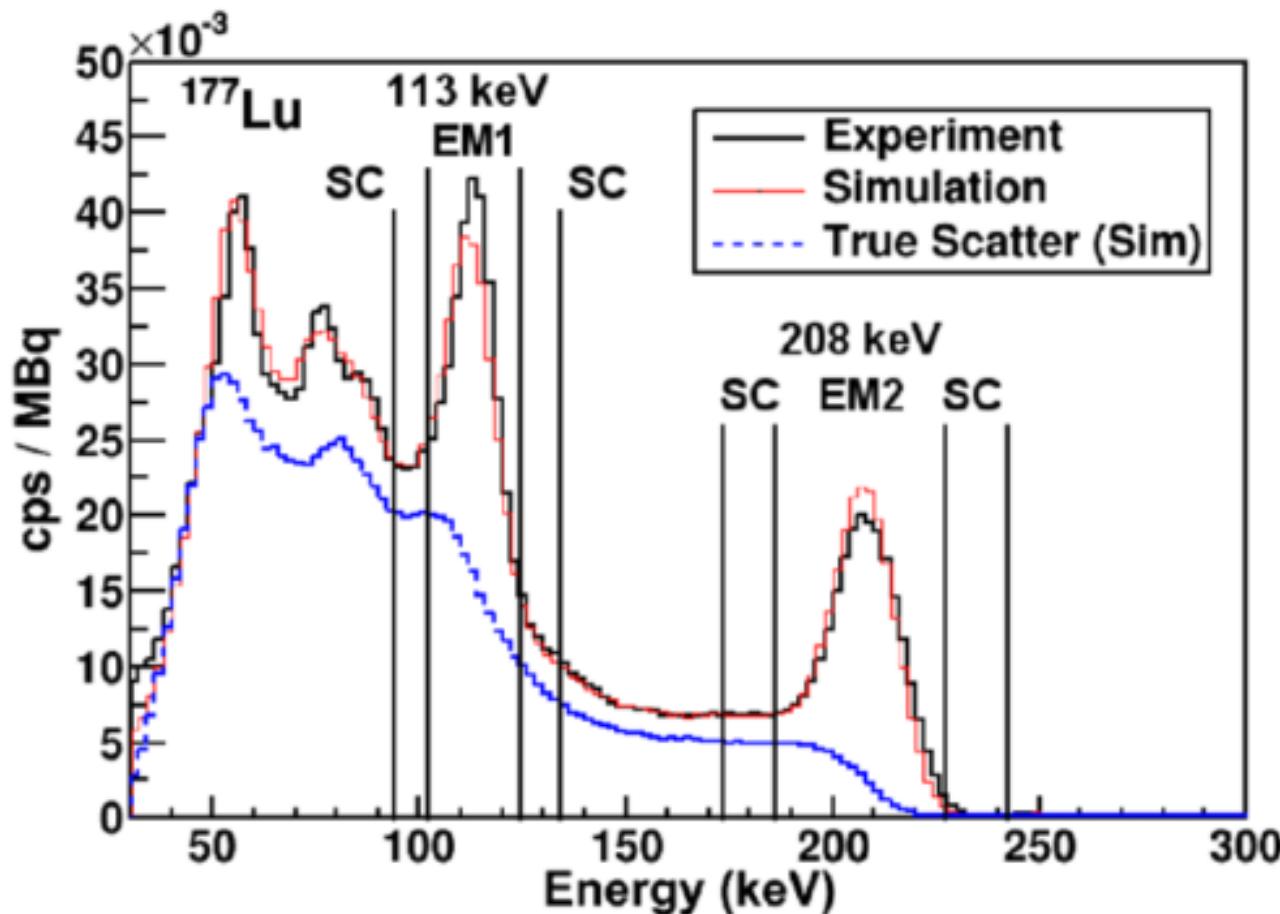
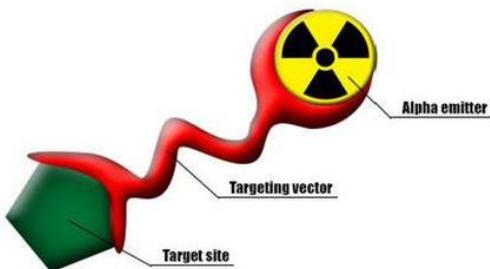


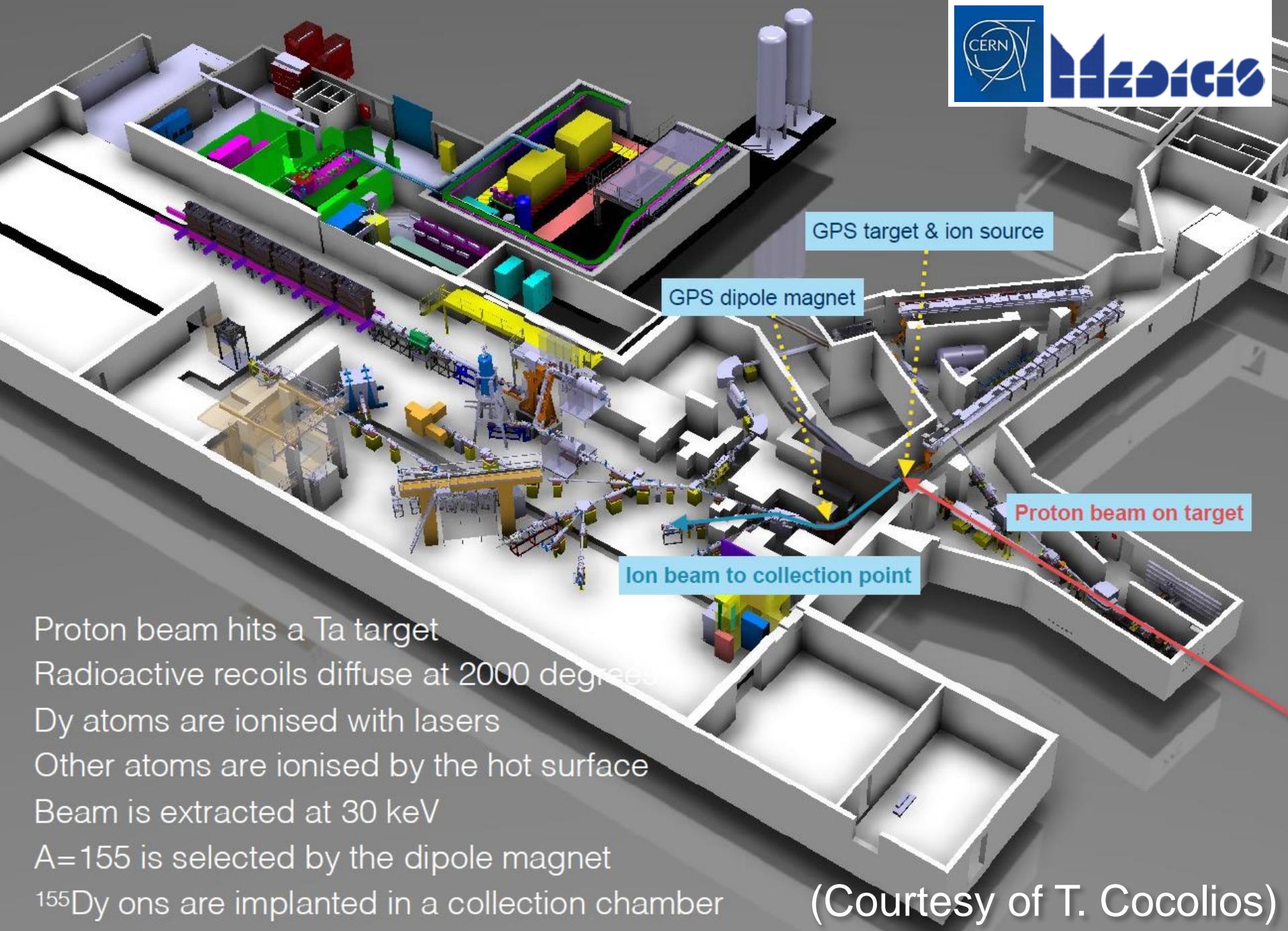
Figure 5. Emission spectrum for a water filled phantom measured

Tb₆₅ (Theranostic Isotope Quartet)



Z	151Tm	152Tm	153Tm	154Tm	155Tm	156Tm	157Tm	158Tm	159Tm	160Tm	161Tm	162Tm	163Tm	164Tm	165Tm	166Tm	167Tm
87	150Er	151Er	152Er	153Er	154Er	155Er	156Er	157Er	158Er	159Er	160Er	161Er	162Er	163Er	164Er	165Er	166Er
85	149Ho	150Ho	151Ho	152Ho	153Ho	154Ho	155Ho	156Ho	157Ho	158Ho	159Ho	160Ho	161Ho	162Ho	163Ho	164Ho	165Ho
83	148Dy	149Dy	150Dy	151Dy	152Dy	153Dy	154Dy	155Dy	156Dy	157Dy	158Dy	159Dy	160Dy	161Dy	162Dy	163Dy	164Dy
81	147Tb	148Tb	149Tb 149	150Tb	151Tb	152Tb 152	153Tb	154Tb	155Tb 155	156Tb	157Tb	158Tb	159Tb	160Tb	161Tb 161	162Tb	163Tb
	146Gd	147Gd	148Gd	149Gd	150Gd	151Gd	152Gd	153Gd	154Gd	155Gd	156Gd	157Gd	158Gd	159Gd	160Gd	161Gd	162Gd
	145Eu	146Eu	147Eu	148Eu	149Eu	150Eu	151Eu	152Eu	153Eu	154Eu	155Eu	156Eu	157Eu	158Eu	159Eu	160Eu	161Eu
	144Sm	145Sm	146Sm	147Sm	148Sm	149Sm	150Sm	151Sm	152Sm	153Sm	154Sm	155Sm	156Sm	157Sm	158Sm	159Sm	160Sm
	143Pm	144Pm	145Pm	146Pm	147Pm	148Pm	149Pm	150Pm	151Pm	152Pm	153Pm	154Pm	155Pm	156Pm	157Pm	158Pm	159Pm
	82	84	86	88	90	92	94	96									N

	Decay Mode	Half-life	MRT Application
149Tb	α , β^+ (17%, 7%)	4.12 hours	Therapy (α)
152Tb	β^+ (17%)	17.5 hours	PET Imaging
155Tb	EC (100%)	5.32 days	SPECT Imaging
161Tb	β^- (100%)	6.89 days	Therapy (β^-)



Medical physics questions for ^{155}Tb

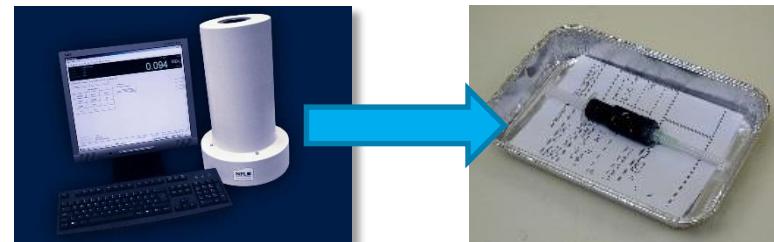
How to image it?

- Which gamma-rays to look at?
- What energy gate to set?
- Which collimators to use?

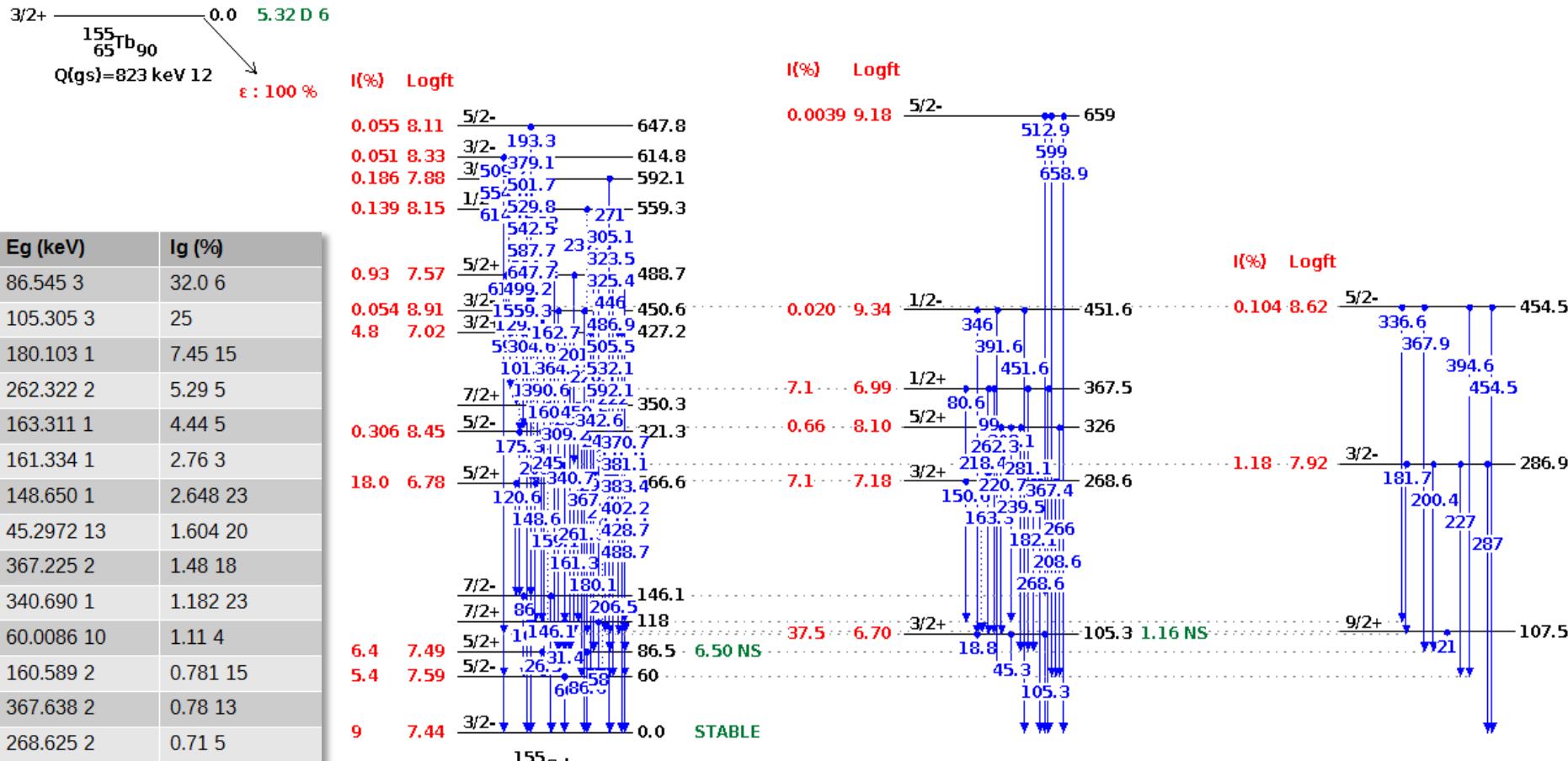


How to measure activity?

- Is there a primary standard?
- What dial factors to use on a hospital calibrator?



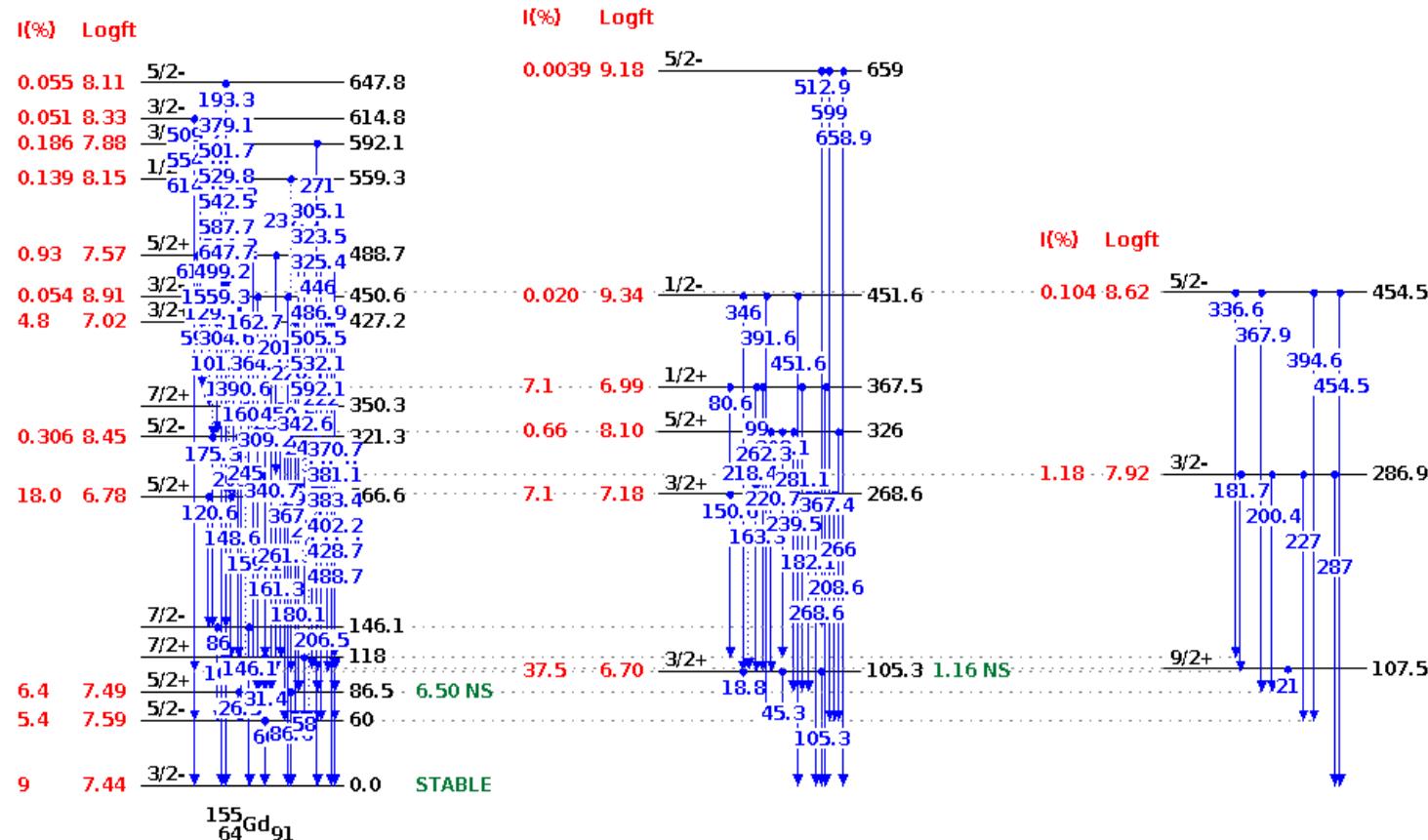
155Tb (SPECT Imaging)



Eg (keV)	Ig (%)
86.545 3	32.0 6
105.305 3	25
180.103 1	7.45 15
262.322 2	5.29 5
163.311 1	4.44 5
161.334 1	2.76 3
148.650 1	2.648 23
45.2972 13	1.604 20
367.225 2	1.48 18
340.690 1	1.182 23
60.0086 10	1.11 4
160.589 2	0.781 15
367.638 2	0.78 13
268.625 2	0.71 5
220.778 2	0.508 5
181.694 1	0.422 5
26.533 6	0.394 13
286.999 4	0.317 6
281.087 2	0.302 4
208.089 2	0.231 13

^{155}Tb (SPECT Imaging)

$3/2^+$	0.0	5.32 D 6
$^{155}\text{Tb}_{90}$		
$Q(\text{gs}) = 823 \text{ keV}$	12	
		$\epsilon : 100\%$
Eg (keV)	Ig (%)	
86.545 3	32.0 6	
105.305 3	25	
180.103 1	7.45 15	
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 - ✓ Geometry
 - ✓ Detector modelling
 - ✓ Physics models (dependent on energy range)

Comparison with experimental data

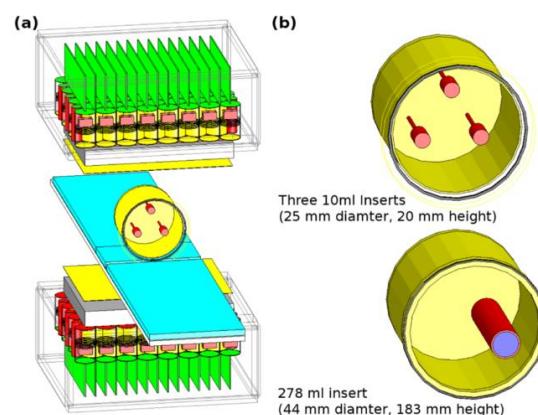
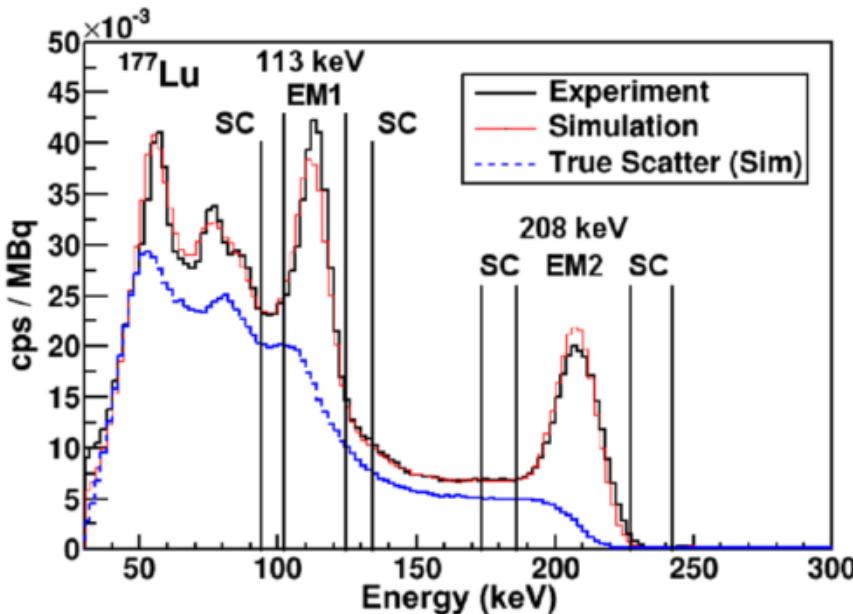
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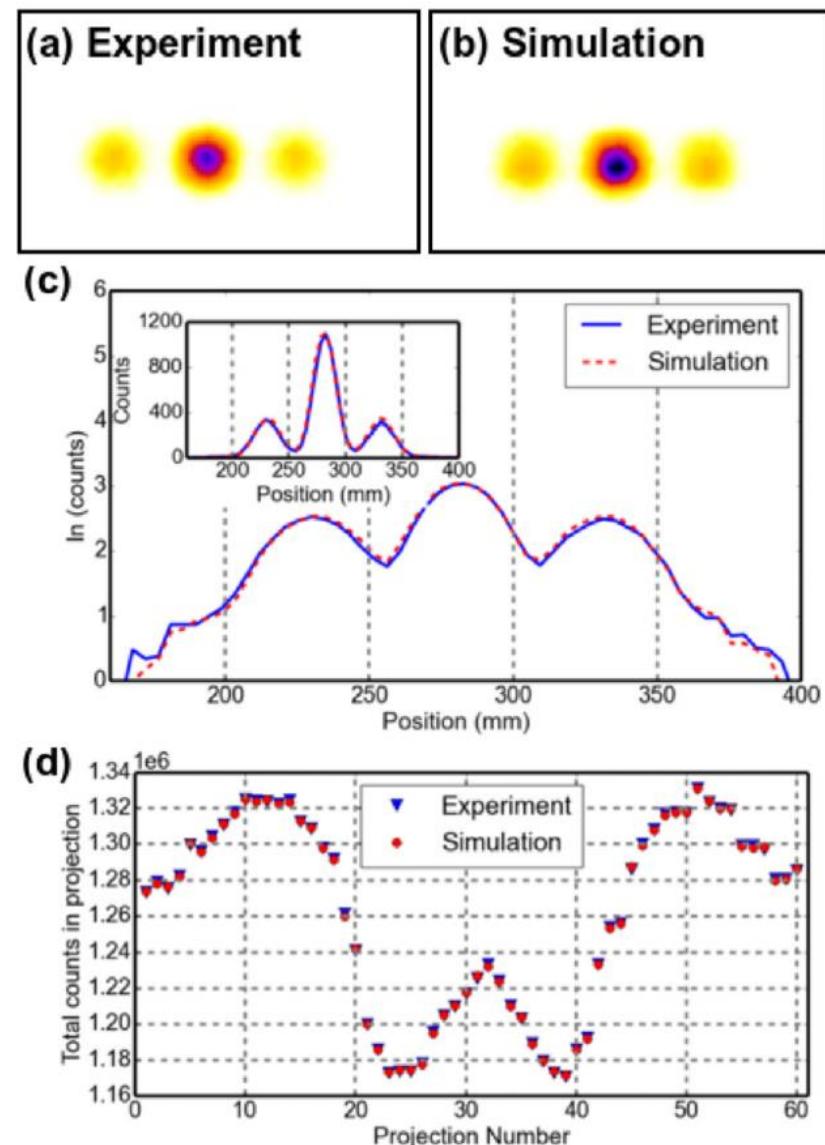
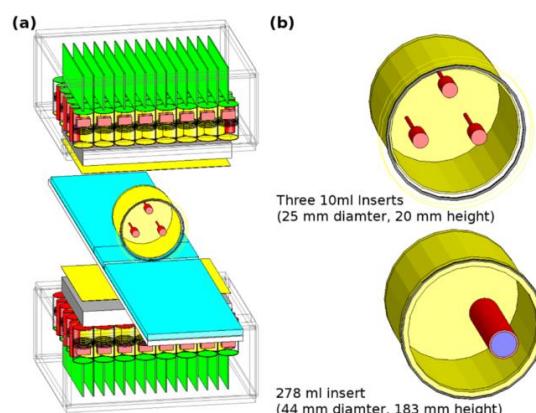
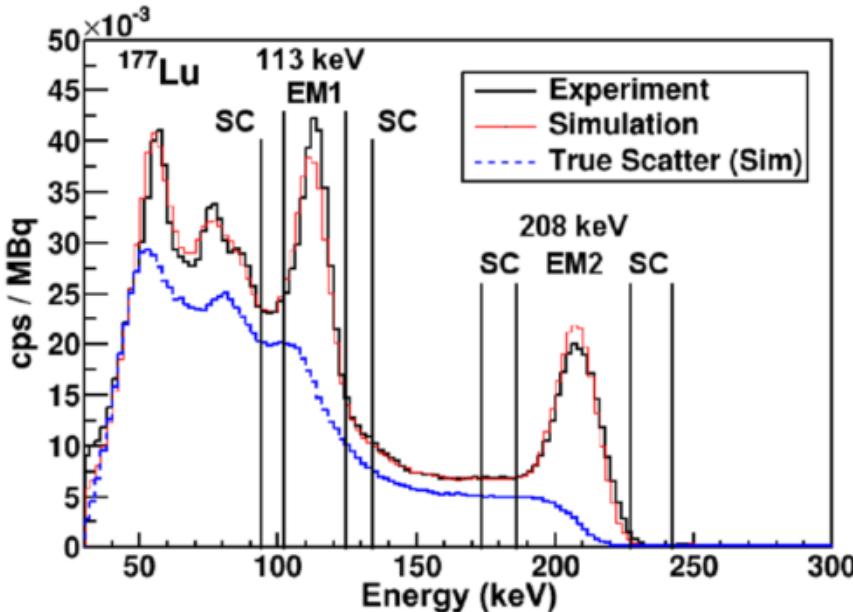
The influence of triple energy window scatter correction on activity quantification for ^{177}Lu molecular radiotherapy

Andrew P Robinson¹, Jill Tipping², David M Cullen¹
and David Hamilton²



The influence of triple energy window scatter correction on activity quantification for ^{177}Lu molecular radiotherapy

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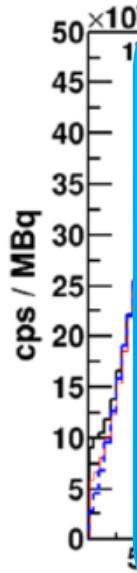


The influence of triple energy window scatter correction on activity quantification for ^{177}Lu molecular radiotherapy

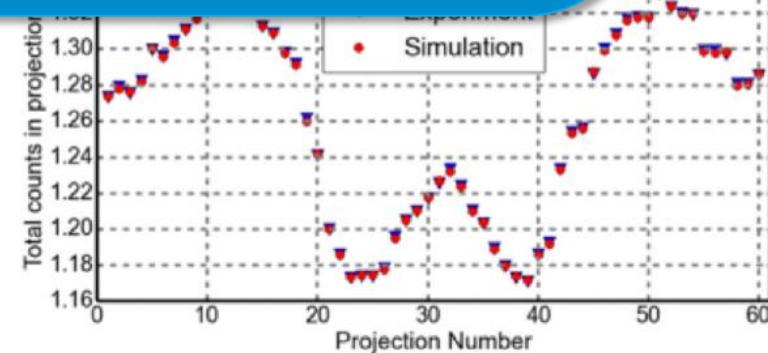
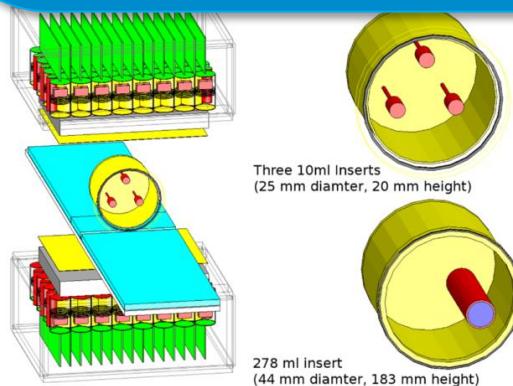
Andrew P Robinson¹, Jill Tipping², David M Cullen¹
and David Hamilton²

(a) Experiment

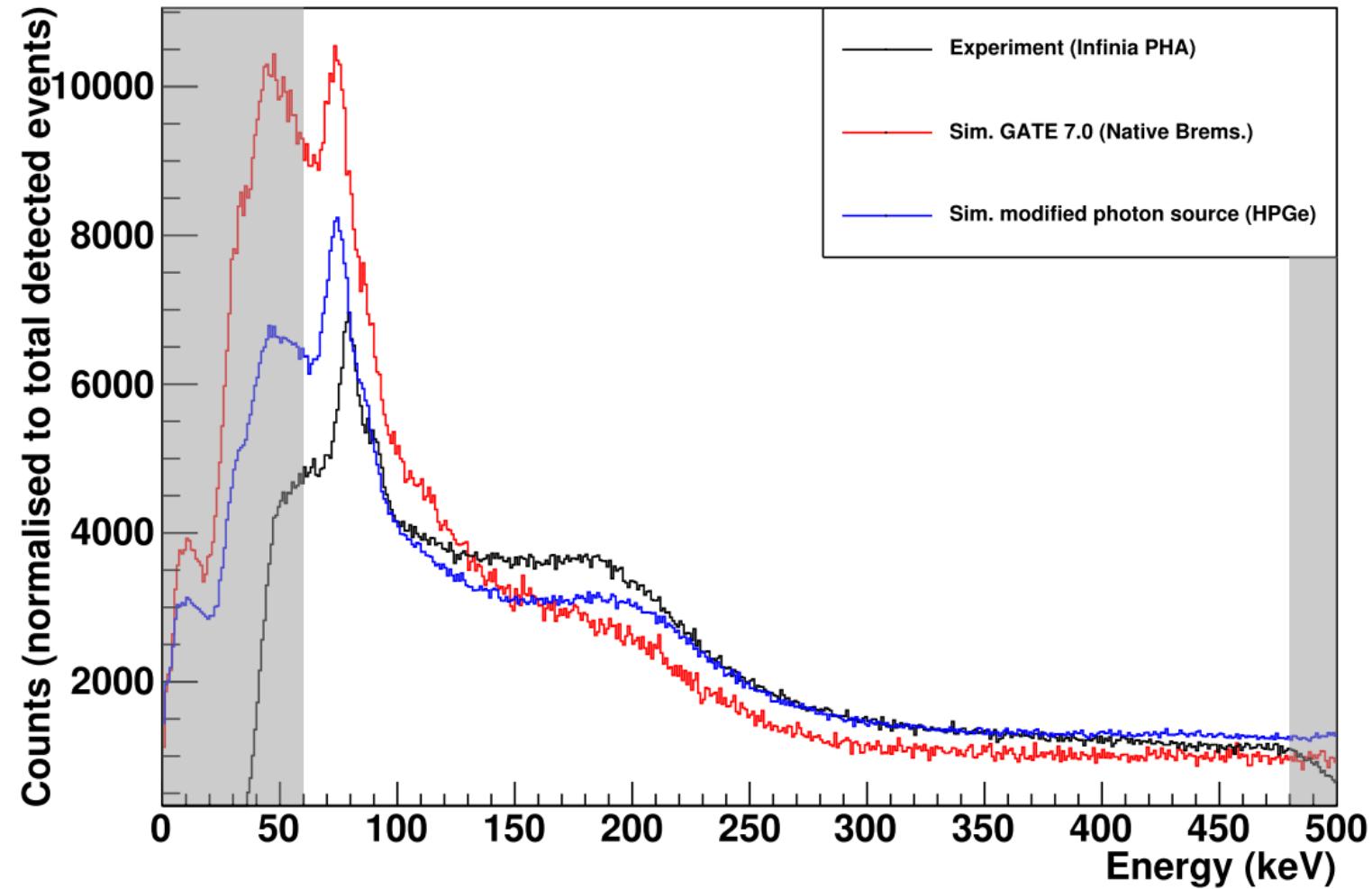
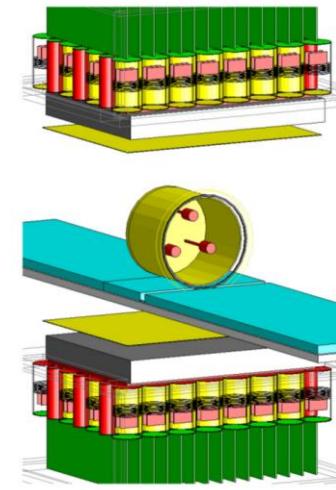
(b) Simulation



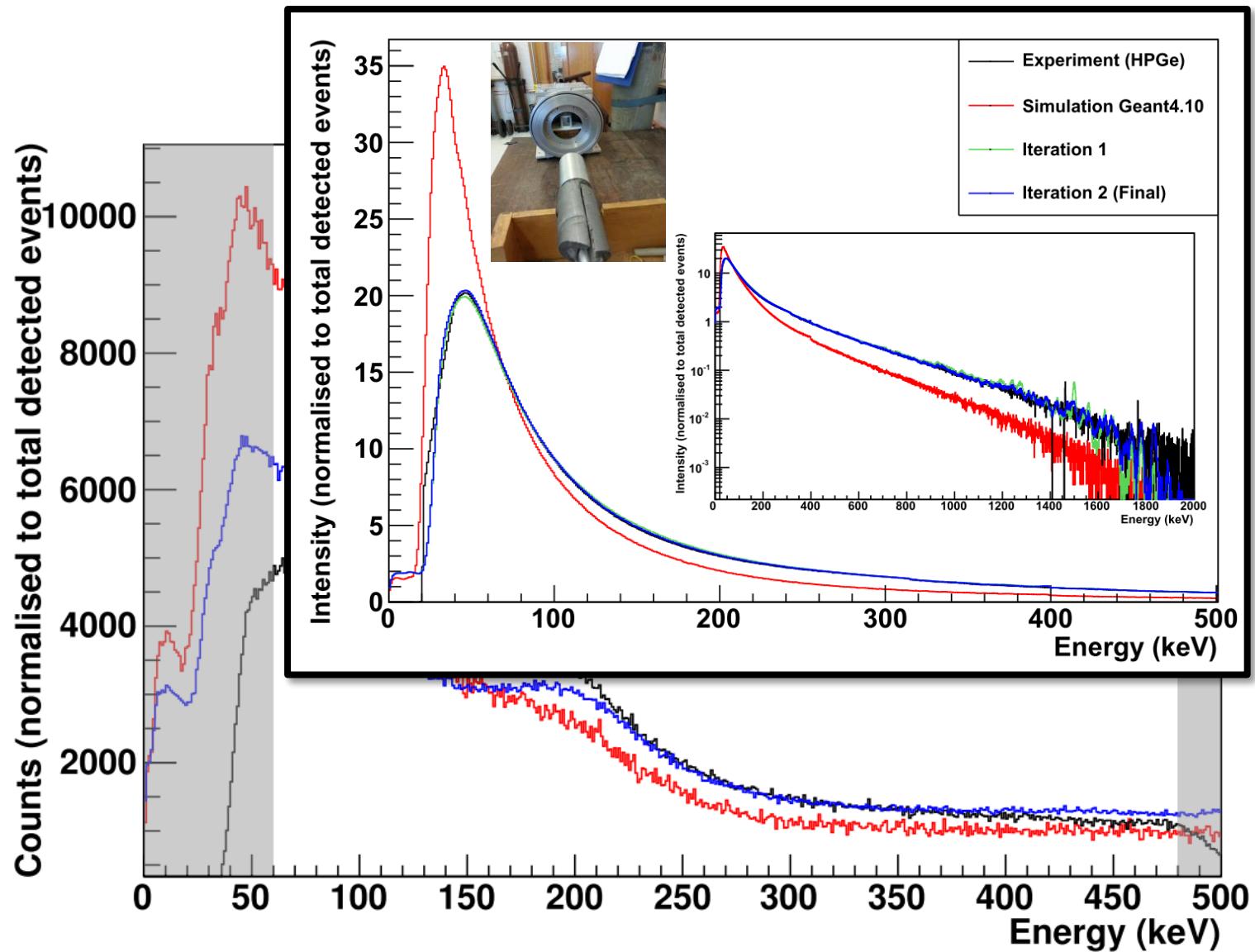
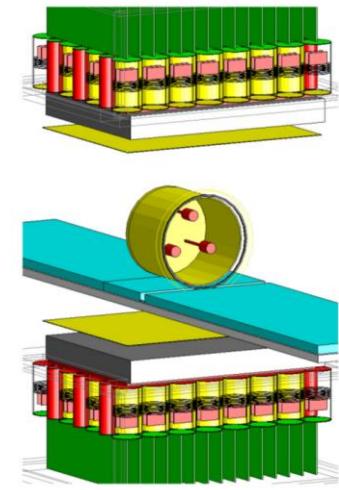
“Validates the global photon transport, geometry and material composition of the model for the full range of direct observables from a commercial SPECT camera.”



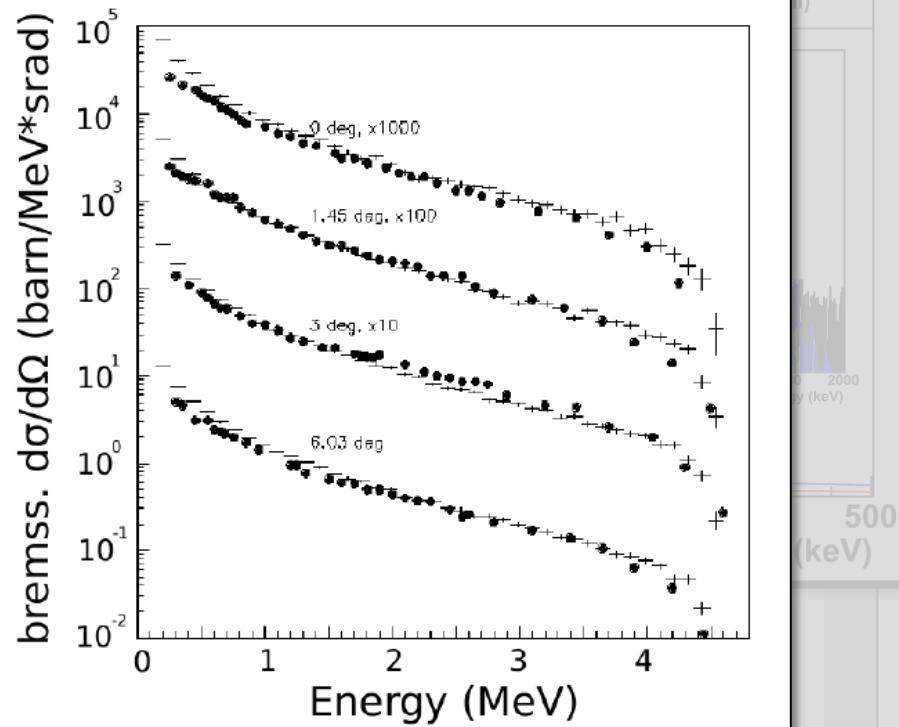
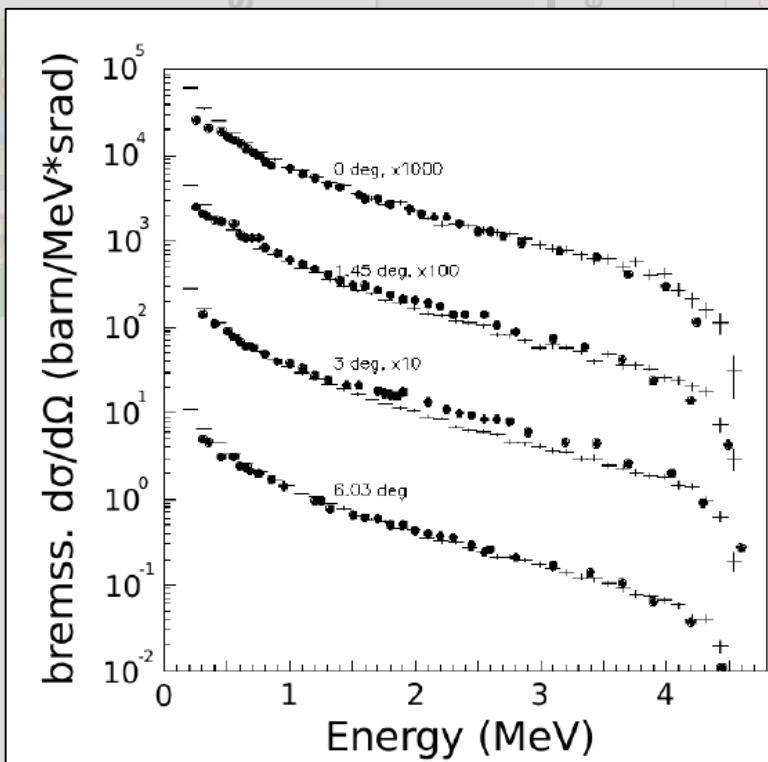
^{90}Y Bremsstrahlung Imaging



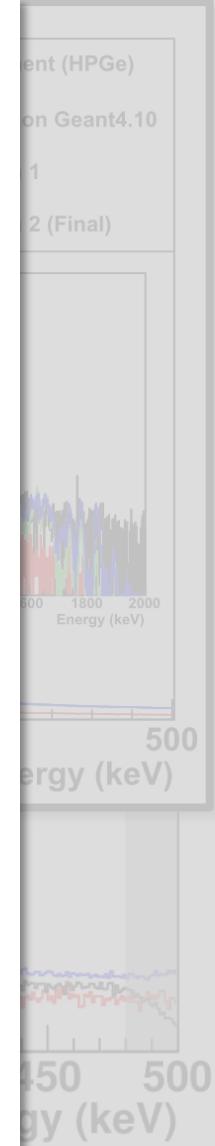
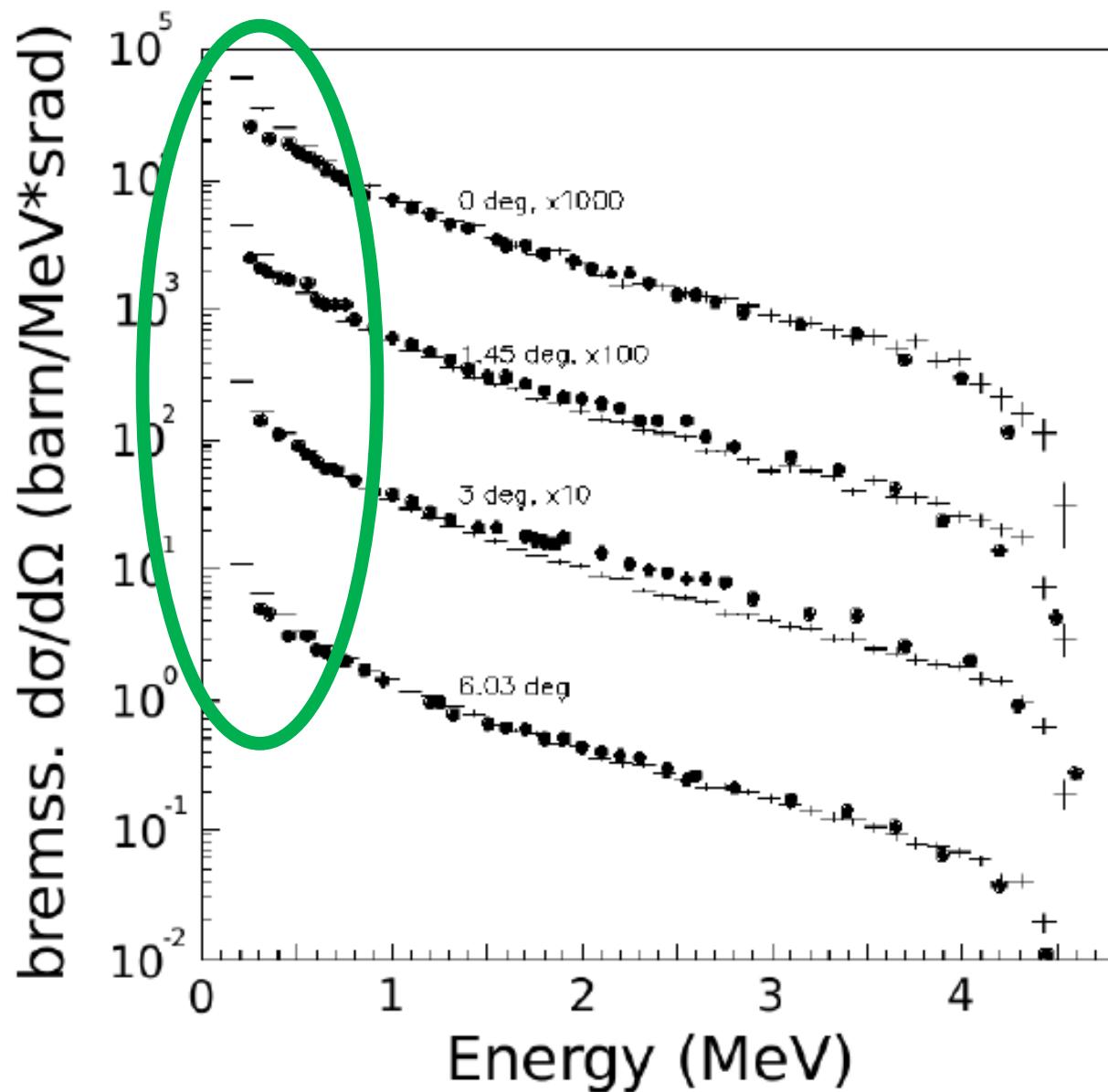
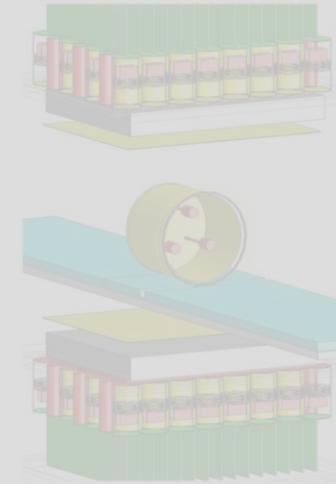
^{90}Y Bremsstrahlung Imaging



^{90}Y Bremsstrahlung Imaging



^{90}Y Bremsstrahlung Imaging





About this project

Objectives:

The project addresses the following scientific and technical objectives:

1. To improve modern measurement techniques for silicon detectors (Si(Li)), solid scintillator crystals (LaBr₃/CeBr₃) and magnetic spectrometers for measurements of beta spectra. (WP3)
2. To optimise beta spectrometers, based on Metallic Magnetic Calorimeters (MMCs), and measure new high resolution beta spectra for low (< 100 keV) and intermediate (< 1 MeV) end-point energy pure beta emitters Sm-151, C-14, Tc-99 and Cl-36. (WP2), D5, D6
3. To improve theoretical computation methods and compare the measured and calculated beta spectra. (WP1 and WP4)
4. To investigate the effect of improved beta spectra on absolute activity measurements and measure Bremsstrahlung cross-sections to quantify their effect. (WP4)
5. To facilitate the take up of the technology and measurement infrastructure developed by the project by the measurement supply chain (accredited laboratories, instrumentation manufacturers) and end users (the nuclear medicine community and the nuclear power industry). (WP5)

⁹⁰Y Bremsstrahlung Imaging

- MC codes **do not reproduce correctly** the bremsstrahlung production
 - Study presented at the last ICRM LS WG (**simulation of dose calibrator**)
 - Med. Phys. 37 (2010) 2943, NIM B 350 (2015) 41-48
- There is a need **to measure the cross-section** for bremsstrahlung production in order to improve the accuracy of the **simulation**
 - Use to calculate the correction for energy loss through the escape of bremsstrahlung photons in LSC and in MMCs for beta spectra measurement
- New experiments are proposed using:
 - an **electron gun** (up to 2 MeV)
 - A set-up for **gamma measurement**

5. To facilitate the take up of the technology and measurement infrastructure developed by the project by the measurement supply chain (accredited laboratories, instrumentation manufacturers) and end users (the nuclear medicine community and the nuclear power industry). (WP5)

OpenDose: a collaborative effort to produce reference dosimetric data with Monte Carlo simulations

Aims to provide a free and public resource of robust reference data to enable dosimetry calculations in nuclear medicine, using a variety of Monte Carlo codes through an international collaboration



Challenges

- 2 ICRP 110 reference adult phantoms (male and female)
- 140 organs (19600 target/source combinations!)
- ICRP 107: ~1200 radionuclides
- MIRD RADTABS source of decay data: ~300 radionuclides

Too big for a single institution!!!



Proposal

- Collaborative work, everyone is welcome!
- Create a free database
- Create an easily accessible website
- Make data available with associated uncertainties
- First meeting took place at the EANM 2016, Barcelona.

14 research teams (18 institutes)

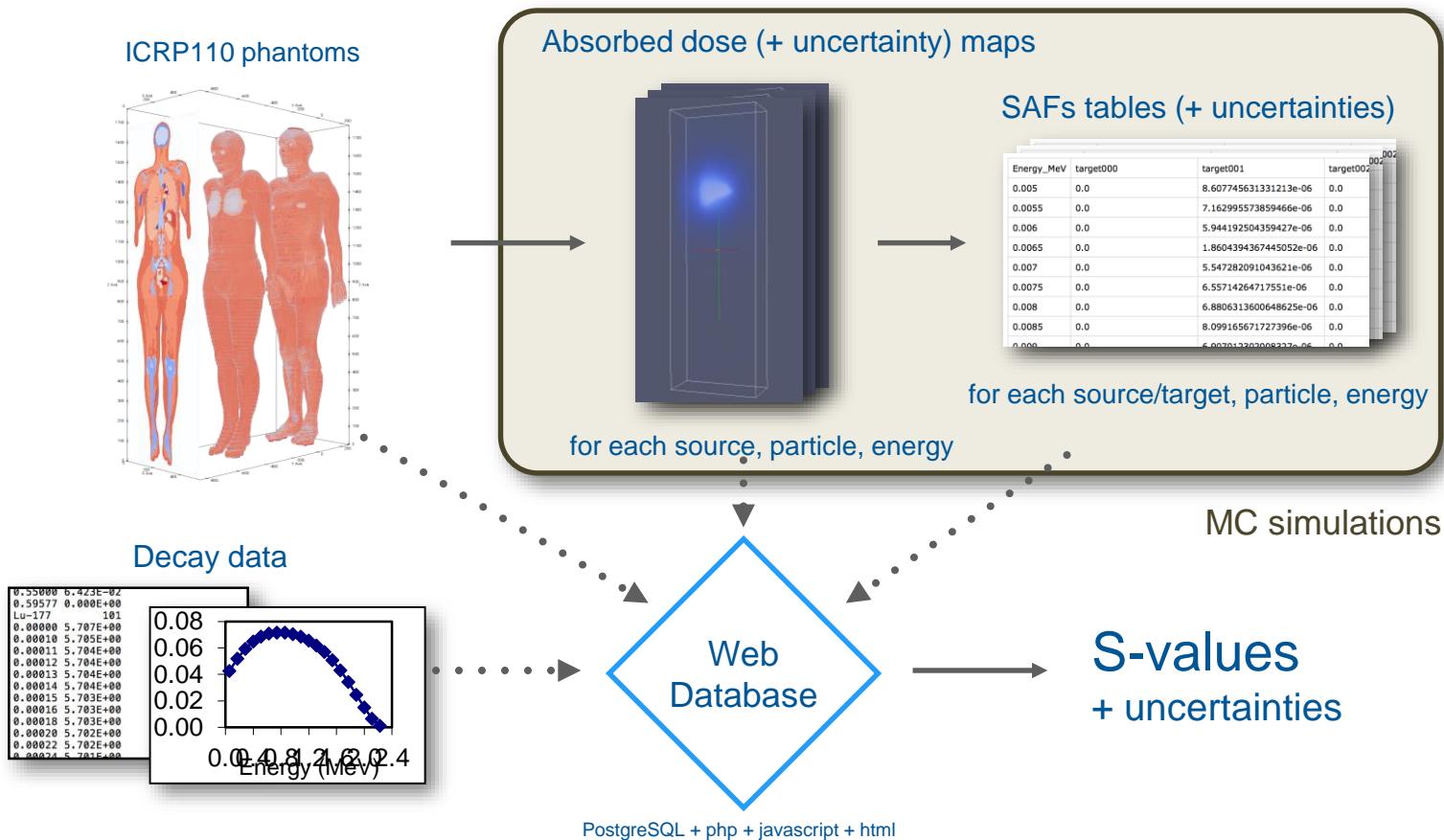


OpenDose: initial comparisons

- Compute mono-energetic specific absorbed fractions (SAF, ϕ/m)
$$S(r_t \leftarrow r_s) = \sum_i \frac{\Delta_i \Phi_i(r_t \leftarrow r_s)}{m_t}$$
- Generate S-values by integrating over the decay spectra
- Check-point simulations:
 - Adult female phantom
 - Sources: liver, blood (trunk)
 - Targets: 140
 - Seven energies: 0.05, 0.1, 0.2, 0.5, 1, 2 and 5 MeV
 - Electrons and photons
 - 10^8 histories, cut-off energies of 10 keV
 - $2 \text{ (sources)} \times 2 \text{ (e}^-/\text{g}) \times 7 \text{ (energies)} = 28 \text{ simulations / } \sim 1 \text{ week (1 core)}$
- But... $2 \text{ (female/male models)} \times 140 \text{ (sources)} \times 2 \text{ (e}^-/\text{p}) \times 91 \text{ (energies)} = 50960 !$



OpenDose: Framework



Validation of simulations

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- Yes - if the simulation has been validated
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Comparison with experimental data

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- Examples (demos)
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- **Tools you can use**

Tools you can use

EGSnrc

(http://www.nrc-cnrc.gc.ca/eng/solutions/advisory/egsnrc_index.html)

The screenshot shows the official NRC website for the EGSnrc software. The header includes the Canadian flag, "Government of Canada / Gouvernement du Canada", and links for "Canada.ca | Services | Departments | Français". The main navigation bar features "Programs and services", "Areas of R&D", "Research facilities", "Publications", "Careers", and "About NRC". Below this, a breadcrumb trail shows the current page: "Home > Programs and services > Technical and advisory services > EGSnrc: software tool to model radiation transport". The main content area has a blue header "EGSnrc: software tool to model radiation transport". It includes a "Download EGSnrc from github" button. A sidebar on the left lists "Programs and services" such as "Research programs and collaboration opportunities", "Technical and advisory services" (with "EGSnrc: software tool to model radiation transport" highlighted), "Licensing opportunities", and "Industrial Research Assistance Program (IRAP)". The main text discusses the software's purpose in modeling radiation transport through matter, its Monte Carlo method, and its applications in medical physics like radiotherapy. It also mentions training and international use. The footer contains a "Targeted audience" section with a bulleted list of users and a "Description of the software" section.

EGSnrc: software tool to model radiation transport

[Download EGSnrc from github](#)

Overview of the software

NRC's electron gamma shower (EGS) software toolkit can meet your specific requirements relating to modelling the passage of electrons and photons through matter. EGSnrc relies on Monte Carlo, which is the most accurate method to model the transport of radiation. The included BEAMnrc software component can meet your requirements relating to modelling beams travelling through consecutive material components, ranging from a simple slab to the full treatment head of a radiotherapy linear particle accelerator (linac).

EGSnrc is used to address a broad range of questions about the propagation of radiation in materials. It is particularly well-suited for medical physics purposes, such as the research and development of devices that allow medical professionals to detect radiation, image a patient's anatomy using x-rays, or deliver a prescribed radiation dose to a tumour while sparing healthy tissue. But given its flexible, modular design and companion utilities, EGSnrc can also be used for a vast range of applications, including the simulation of research and industrial linac beams, x-ray emitters, radiation shielding, and more.

NRC also trains Canadian and international physicists on use of the software.

NRC contributes to the development and application of the Monte Carlo method in the modelling of radiation transport since the early 1980s. The EGSnrc software is now downloaded more than 5,000 times per year by academic, medical and industrial researchers worldwide.

Targeted audience

- Medical physicists, universities and hospitals.
- Companies that develop radiotherapy equipment and software.
- Universities and industries working with radiation, including radiation measurement, radiotherapy, radiation protection, radiation processing, medical imaging, and other electron and photon radiation applications.

Description of the software

Tools you can use

MCNP (<https://mcnp.lanl.gov/>)

The screenshot shows the homepage of the MCNP website. At the top left is the Los Alamos National Laboratory logo. A banner across the top center reads "A General Monte Carlo N-Particle (MCNP) Transport Code". Below the banner, the title "Monte Carlo Code Group" and subtitle "Los Alamos National Laboratory" are displayed. To the left is a sidebar with links for MCNP5, MCNP6, MCNP FAQ, MCNP Bugs, Upcoming Classes, Related Efforts, Monte Carlo Team Personnel, User Manual, Reference Collection, Forum For Users, and How to get MCNP. Below this is a "CONTACTS" section with links for MCNP Team and MCNP Web Admin. A circular "ENTRUST" seal is also present. The main content area includes sections for ABSTRACT, which describes MCNP as a general-purpose Monte Carlo N-Particle code; CROSS-SECTION DATA, which discusses pointwise and group-wise cross-section data; STANDARD FEATURES, which lists powerful general source, criticality source, and surface source features; and TALLIES, which details various flexible tally types. A "MCNP Highlights" box at the bottom contains news items about the MCNP6.2 release, reference collection updates, and production releases. The footer at the very bottom states that MCNP® and Monte Carlo N-Particle® are registered trademarks owned by Los Alamos National Security, LLC.

A General Monte Carlo N-Particle (MCNP) Transport Code

mcnp

MCNP5
MCNP6
MCNP FAQ
MCNP Bugs
Upcoming Classes
Related Efforts
Monte Carlo Team Personnel
User Manual
Reference Collection
Forum For Users
How to get MCNP

CONTACTS

MCNP Team
MCNP Web Admin

MCNP Highlights

The MCNP6.2 release from RSICC is expected in Spring 2017.
The MCNP Reference Collection was updated on 2017-01-31.
There are new reference reports on fission neutron multiplicity and Whisper sensitivity-uncertainty methods.
The MCNP6.1.1 update (2014) is available from RSICC.
The MCNP6.1 production release (2013) is available from RSICC.

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Tools you can use

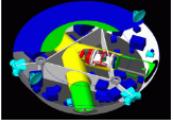
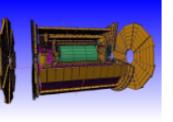
Geant4 (<http://geant4.web.cern.ch/geant4/>)

Geant 4

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Applications **User Support** **Publications** **Collaboration**

A sampling of applications, technology transfer and other uses of Geant4

Getting started, guides and information for users and developers

Validation of Geant4, results from experiments and publications

Who we are: collaborating institutions, members, organization and legal information

News

- 8 March 2017 - 2017 planned developments.
- 28 February 2017 - Patch-01 to release 10.3 is available from the [Download](#) area.
- 27 January 2017 - Patch-03 to release 10.2 is available from the [source archive](#) area.
- 17 February 2016 - Patch-03 to release 10.1 is available from the [source archive](#) area.

Events

- [45th Geant4 Technical Forum](#), CERN, Geneva (Switzerland), 23 March 2017.
- [12th Geant4 Space Users Workshop](#), Guildford (UK), 10-12 April 2017.
- Geant4 Course at the 14th Seminar on Software for Nuclear, Sub-nuclear and Applied Physics, Porto Conte, Alghero (Italy), 4-9 June 2017.
- Geant4 Tutorial and International Multidisciplinary User Workshop, Ton Duc Thang University, Ho Chi Minh City (Vietnam), 15-16 June 2017.
- Geant4 User Workshop, Sage Hotel, Wollongong (Australia), 19-22 September 2017.
- [22nd Geant4 Collaboration Meeting](#), UOW Campus, Wollongong (Australia), 25-29 September 2017.
- [Past events](#)

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Last updated: 08 Mar 2017

Tools you can use

GATE (<http://www.opengatecollaboration.org/>)

The screenshot shows the GATE website homepage. On the left, there's a 'User login' form with fields for 'Username' and 'Password', and links for 'Create new account' and 'Request new password'. Below it is a section titled 'PMB Citations Prize' featuring a thumbnail of a journal cover and a brief description. The main content area has a heading 'Forewords' followed by a detailed text about the software's purpose and capabilities. To the right, there's a 'Shortcuts' sidebar with icons for 'Subscribe to GATE-users mailing-list', 'Wiki' (Request account on GATE collaborative wiki), 'GitHub' (Access to GATE project on GitHub), 'SurveyMonkey' (GATE users survey), and a 'Download' link. At the bottom, there's a 'PMB 60th anniversary collection' section and a 'GATE: sample results' image.

GATE
Simulations of Preclinical and Clinical Scans in Emission Tomography, Transmission Tomography and Radiation Therapy

Home Download Documentation Collaborative Wiki Mailing-list Training Publications Meetings Opportunities Awards About GATE

User login

Username *

Password *

Create new account Request new password

Log in

PMB Citations Prize

Members of the OpenGATE collaboration have won the Physics in Medicine & Biology Citations Prize twice, in 2009 for their paper 'GATE: a simulation toolkit for PET and SPECT' and in 2015 for their paper 'GATE V6: a major enhancement of the GATE simulation platform enabling modelling of CT and radiotherapy'.

PMB citations prize

Forewords

GATE is an advanced opensource software developed by the international OpenGATE collaboration and dedicated to numerical simulations in medical imaging and radiotherapy. It currently supports simulations of Emission Tomography (Positron Emission Tomography - PET and Single Photon Emission Computed Tomography - SPECT), Computed Tomography (CT), Optical Imaging (Bioluminescence and Fluorescence) and Radiotherapy experiments. Using an easy-to-learn macro mechanism to configure simple or highly sophisticated experimental settings, GATE now plays a key role in the design of new medical imaging devices, in the optimization of acquisition protocols and in the development and assessment of image reconstruction algorithms and correction techniques. It can also be used for dose calculation in radiotherapy experiments.

If you are interested in contributing to GATE, here are a few tips regarding what you can do to be part of this collaborative effort:

- Reply to the mailing list
- Contribute to the documentation: ask for a login/password and then modify the documentation on the wiki
- Report bugs

GATE project is now publicly available on GitHub. So, any people identified as a GATE contributor on GitHub can create, assign and close an issue

- Add/modify the source code or fix bugs
- Start by copying the GATE public repository from GitHub
`git clone https://github.com/OpenGATE/Gate.git`
- Create a specific branch on your repository copy and commit your modifications in that branch
- Create your own copy (fork) of GATE public repository inside your GitHub account so as to be able to push your branch onto this copy
- Once your code is ok,

 1. Create a pull-request from your Gate repository to the official Gate repository
 2. Provide an example that tests your new feature
 3. If you implemented a new feature, have the associated documentation ready
 4. Inform these three people from the collaboration (S. Jan, D.Sarrut and A. Dubois) who will then get in touch with you to integrate your changes in the official repository.

- Interested in a long term participation? Why not join the collaboration? Read some documentation about the collaboration and contact us

Shortcuts

Subscribe to GATE-users mailing-list

Request account on GATE collaborative wiki

GitHub
Access to GATE project on GitHub

SurveyMonkey®
GATE users survey

Download

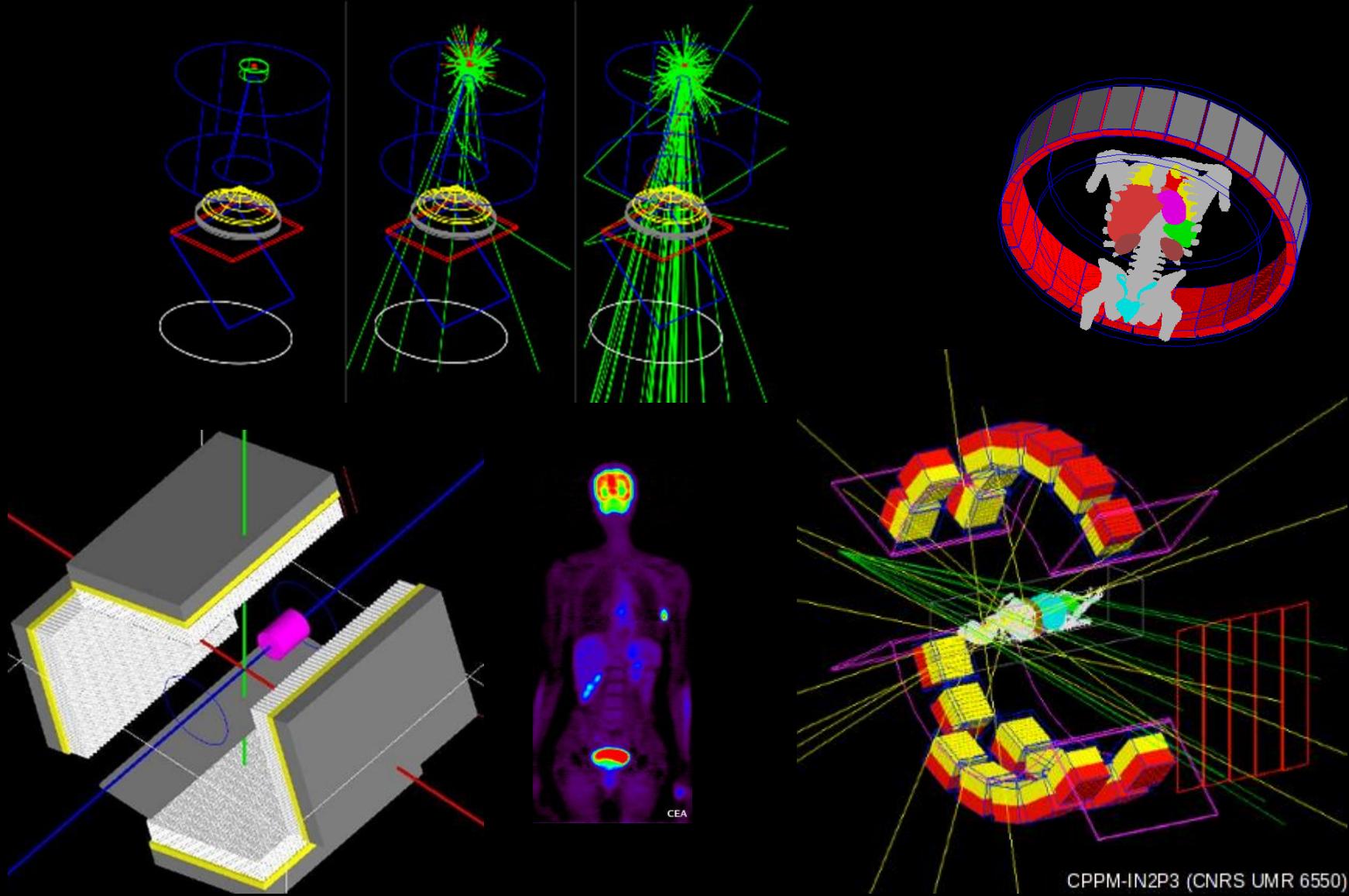
PMB 60th anniversary collection

To commemorate 60 years of PMB, the Editorial Board and International Advisory Boards of the journal have selected just 25 of the thousands of important works published in PMB that they felt have had a particular impact on the development of the field. 'GATE: a simulation toolkit for PET and SPECT' paper is one of them !

GATE: sample results

GATE

<http://www.opengatecollaboration.org/>



CPPM-IN2P3 (CNRS UMR 6550)

```
├── AddExternalData.sh
└── CMakeLists.txt
├── example_ARF
├── example_CT
├── example_DNA
├── example_doseactor
├── example_dosimetry/
│   ├── brachytherapy
│   ├── electron_radiotherapy
│   ├── external-beam-therapy-photon
│   ├── molecular-therapy-I131
│   └── protontherapy
├── example_fluorescence
├── example_OPTICAL
├── example_PET
├── example_PHANTOM_SOURCE
├── example_PhysicsLists
├── example_Radiotherapy
├── example_ROOT_Analyse
├── example_SPECT
├── example_SPECT_GPU
├── example_TimeActivityCurve
├── example_TrackerDetector
├── example_UserFluenceSource
├── example_UserSpectrum
├── example_vpgtle
└── gpumacros
```

- ✓ Wide variety of examples
 - ✓ Multiple modalities
 - ✓ Doesn't require C++
 - ✓ Large user base
 - ✓ Actively developed
 - ✓ Increasingly well referenced
-
- ✗ Still requires validation
 - ✗ Develop data analysis tools
 - ✗ Undocumented bugs

Monte Carlo Training

- NPL: Planning a GATE course (from developers) also EGS course (magnetic fields).
If this would be of interest,
andrew.robinson@npl.co.uk



- Potential “Introduction to Geant4” course for HSST
libby.osborn@manchester.ac.uk
- GATE Training sessions are available
<http://www.opengatecollaboration.org/TrainingSessions>

Summary

- Monte Carlo simulation can be a powerful tool for modelling imaging systems.
- There are a number of benefits to using MC:
 - Extra non-observable information
 - “Ground truth”
 - Optimisation of protocols
- Importance of validation – comparison to experimental data
- A number of packages available
(GATE is a good starting point for many modalities).

Validation of simulations

- Can you trust the results from a simulation?
- Yes - if the simulation has been validated
 - ✓ Geometry
 - ✓ Detector modelling
 - ✓ Physics models (dependent on energy range)

Comparison with experimental data

