

# Monte Carlo Simulation Optimisation in Imaging - HSST

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March 2023

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

# 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?

The screenshot shows the WolframAlpha search interface. The search query "what is the monte carlo method" is entered in the search bar. Below the search bar are several icons: a document, a camera, a grid, and a gear. To the right of the search bar are three buttons: "Web Apps", "Examples", and "Random".  
  
The main content area starts with "Input interpretation:" followed by "Monte Carlo method". There is a "Open code" button with a cloud icon to the right. Below this is the "Definition:" section, which contains a detailed paragraph about the Monte Carlo method. The paragraph explains that it is a problem-solving method using random numbers and observing the fraction of numbers that obey certain properties. It was named by Stanislaw Ulam in 1946, inspired by his gambling habits. Nicolas Metropolis also contributed to its development.  
  
Under the definition, there is a "More information" link with a cloud icon. At the bottom of the page, under "Related topics:", are links to "Monte Carlo integration", "quasi-Monte Carlo method", "stochastic geometry", and "uniform distribution theory". Each of these related topics has a small cloud icon to its right.

# What is Monte Carlo simulation?

The screenshot shows the WolframAlpha search interface with the query "simulation" entered in the search bar. The results are categorized into sections: Input interpretation, Definitions, American pronunciation, Hyphenation, and First known use in English.

**Input interpretation:**  
simulation (English word)

**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:**  
sim-yuh'l'eyshuhn (IPA: sɪmjəl' eɪʃən)

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

**First known use in English:**  
1340 (High Middle ages) (677 years ago)

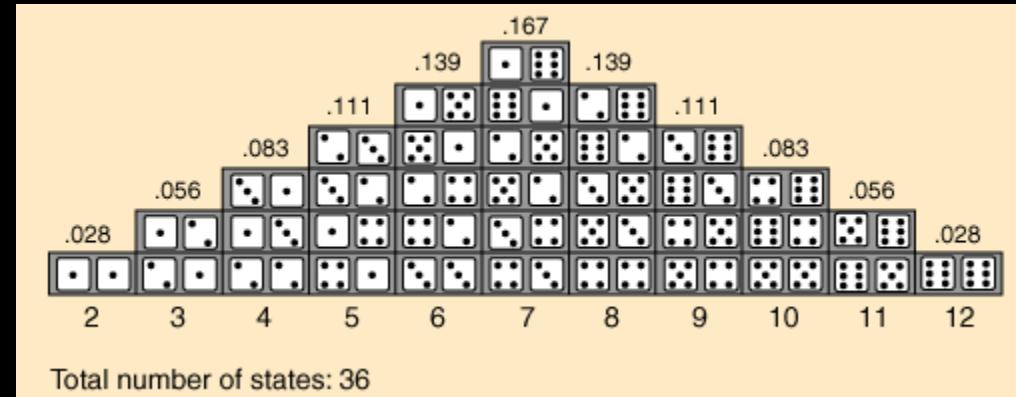
# What is Monte Carlo simulation?



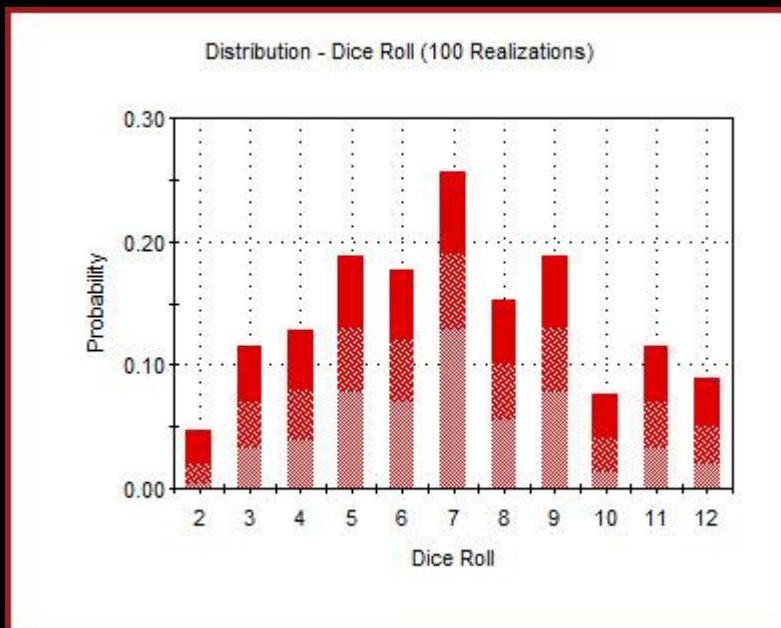
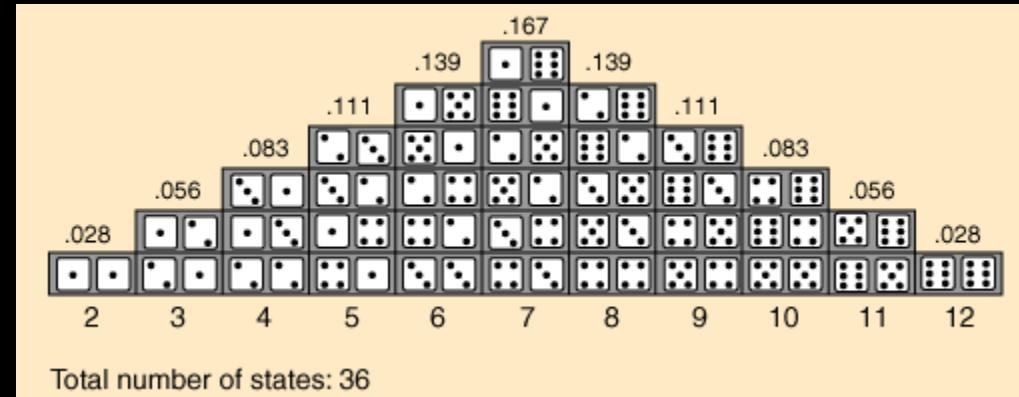
“A method which solves a problem by generating suitable random numbers and observing that fraction of the numbers obeying some property or properties. The method is useful for obtaining numerical solutions to problems which are too complicated to solve analytically.”

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

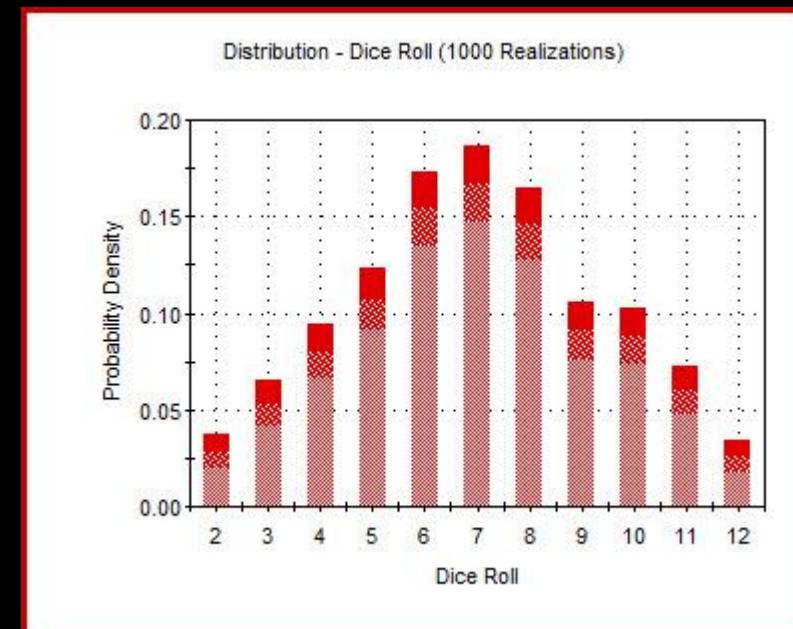
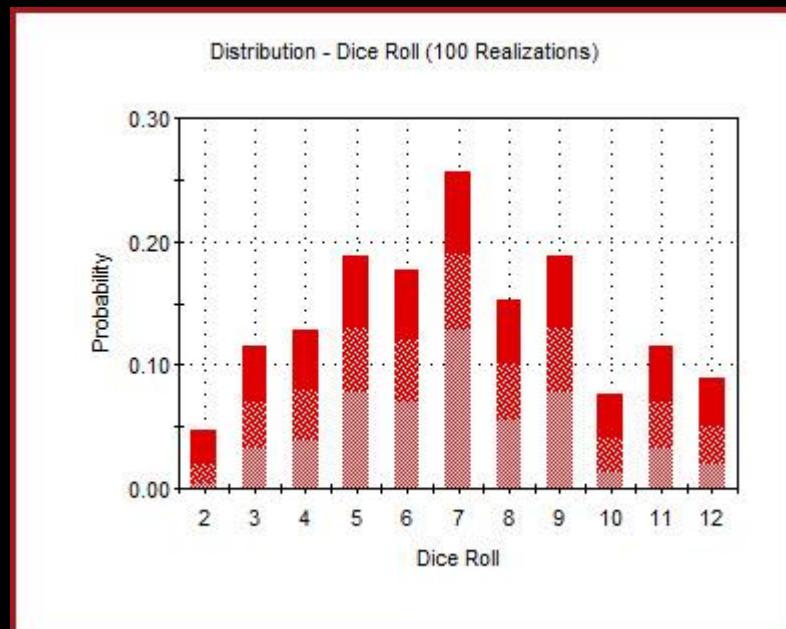
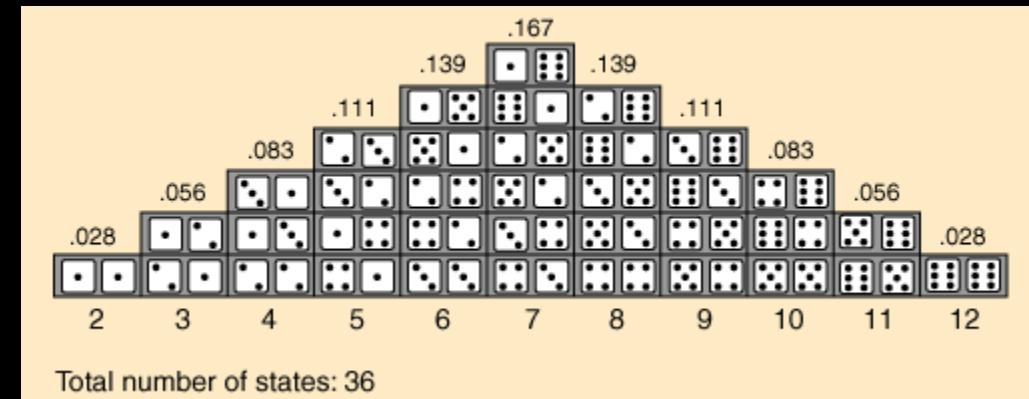
# Simple Example



# Simple Example



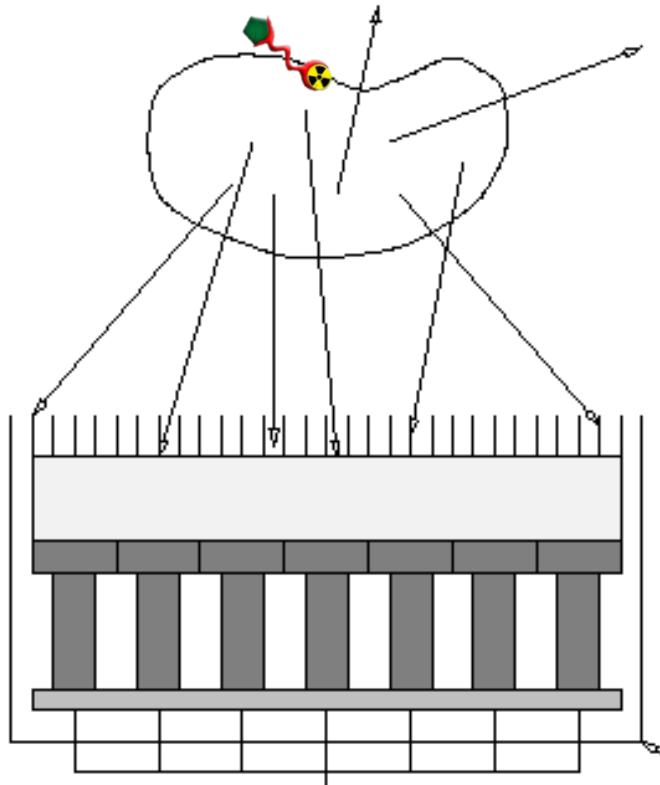
# Simple Example



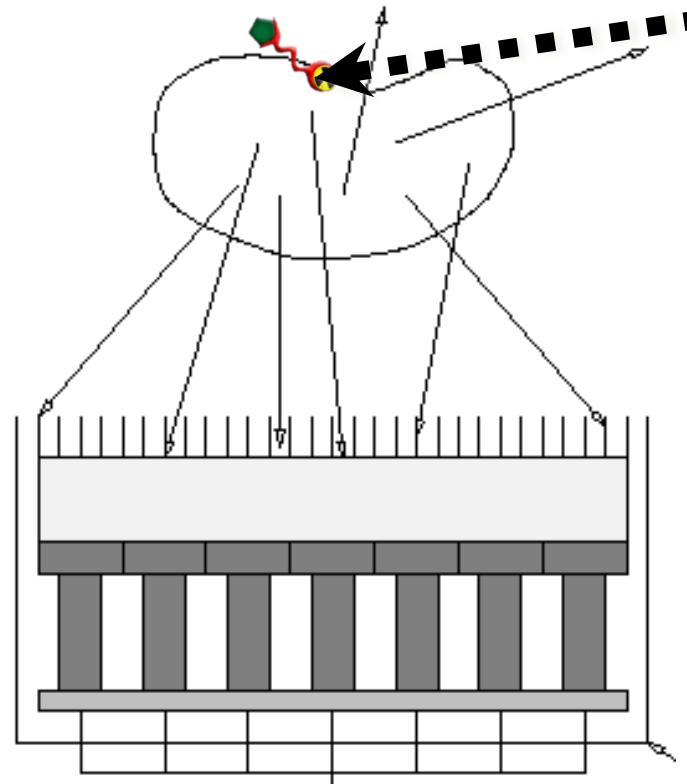
# Physics and Probability

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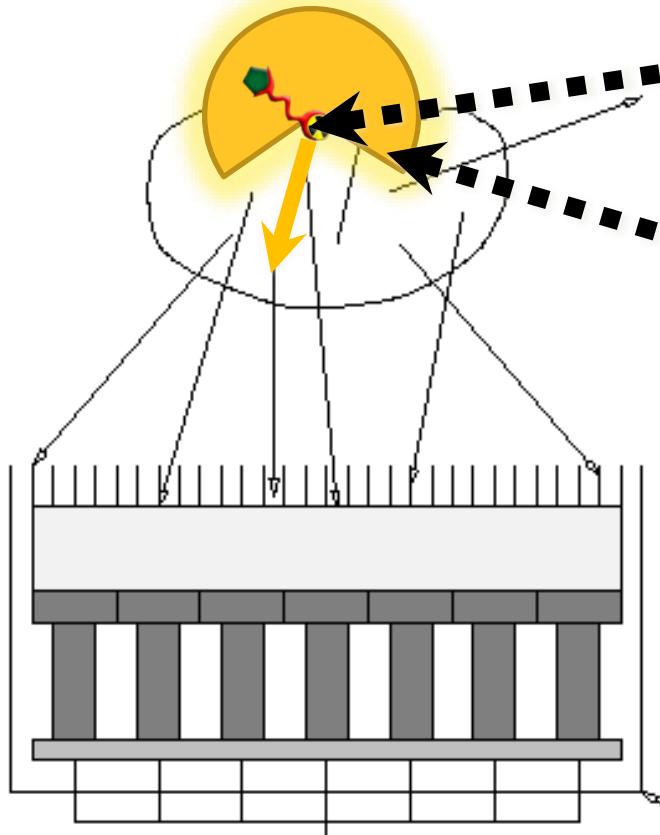


# Physics and Probability



P1 = Probability of decay  
[half-life]

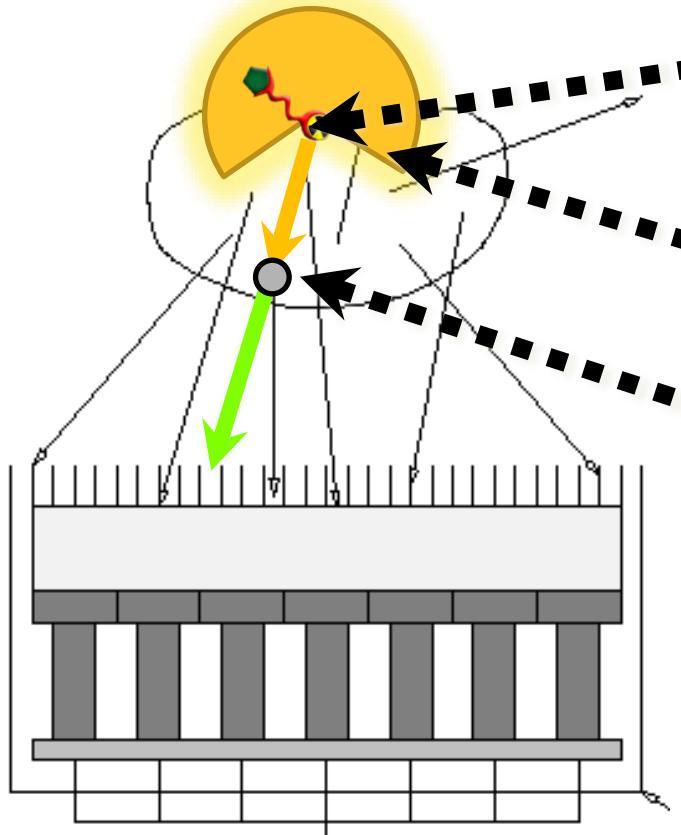
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P1 = Probability of decay  
[half-life]

P2 = Probability of emission direction  
[isotropic]

# Physics and Probability

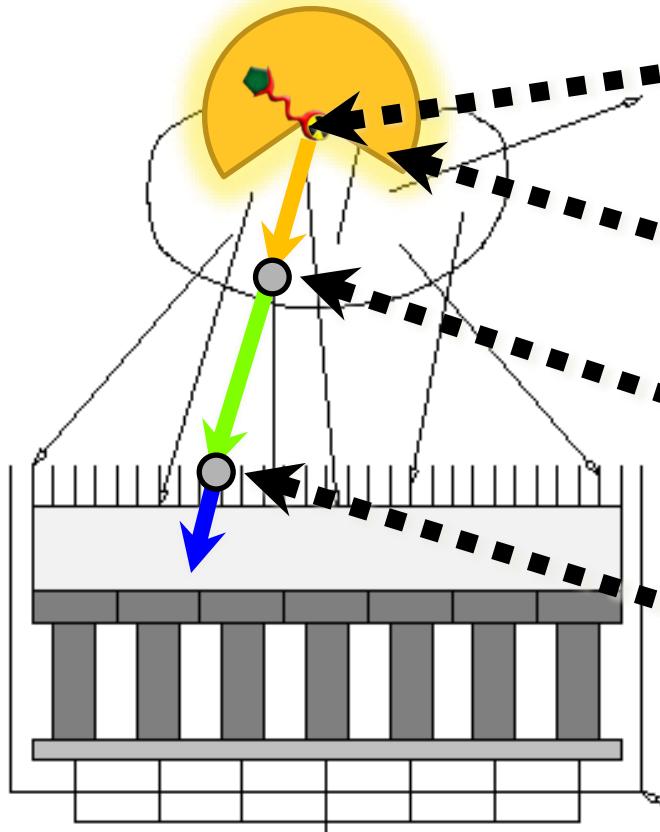


P1 = Probability of decay  
[half-life]

P2 = Probability of emission direction  
[isotropic]

P3 = Probability of interaction in body  
[cross-section, material]

# Physics and Probability



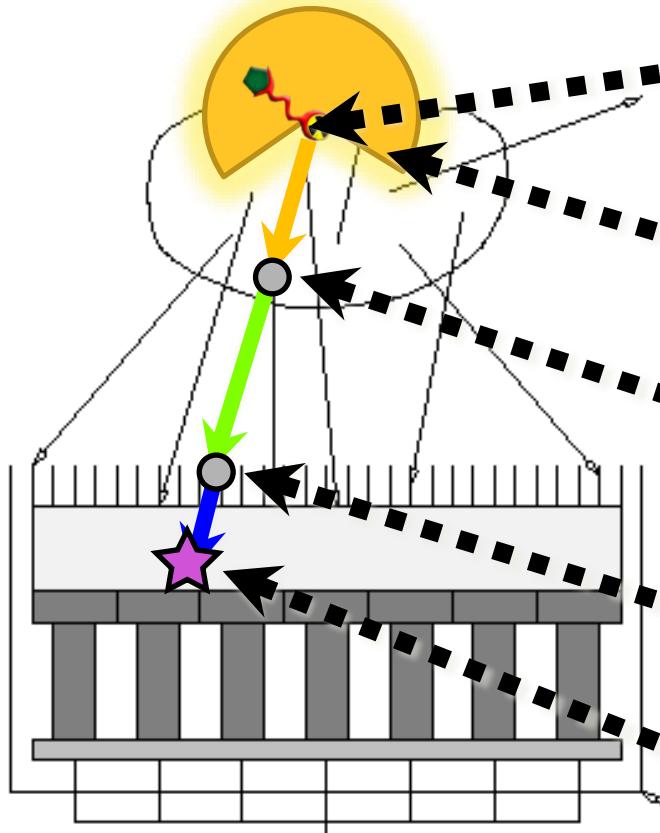
P1 = Probability of decay  
[half-life]

P2 = Probability of emission direction  
[isotropic]

P3 = Probability of interaction in body  
[cross-section, material]

P4 = Probability of interaction with collimator  
[cross-section, material]

# Physics and Probability



P1 = Probability of decay  
[half-life]

P2 = Probability of emission direction  
[isotropic]

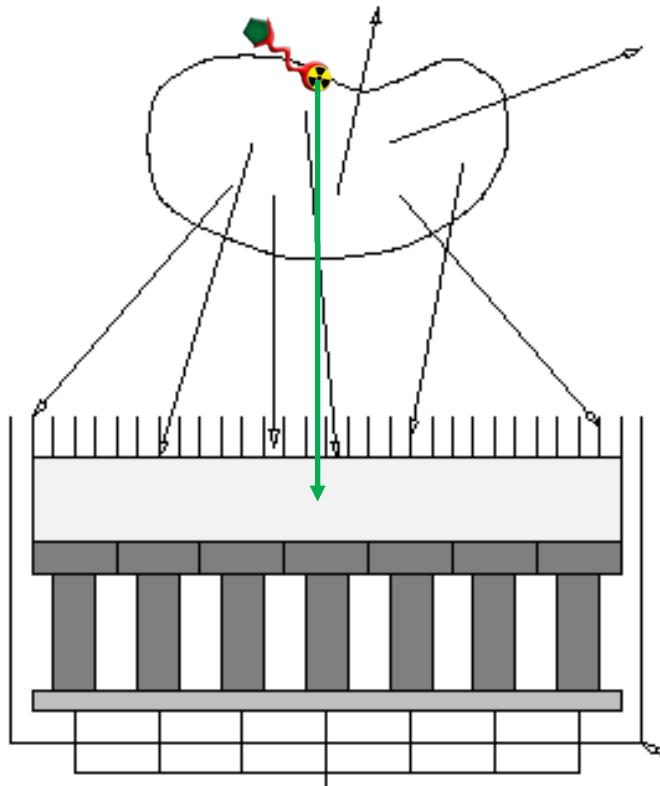
P3 = Probability of interaction in body  
[cross-section, material]

P4 = Probability of interaction with collimator  
[cross-section, material]

P5 = Probability of absorption in crystal  
[cross-section]

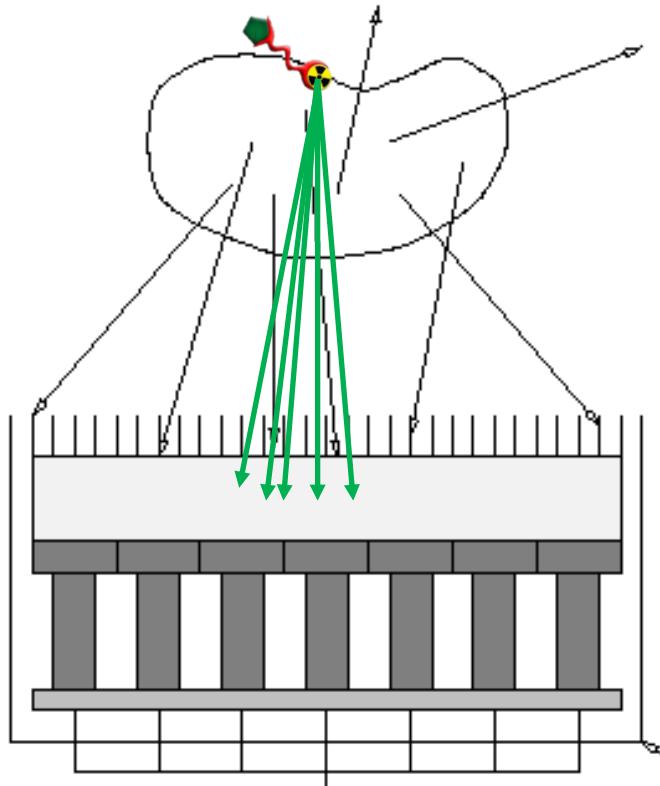
$$p(E\gamma) = p1 * p2 * p3 * p4 * p5$$

# Physics and Probability



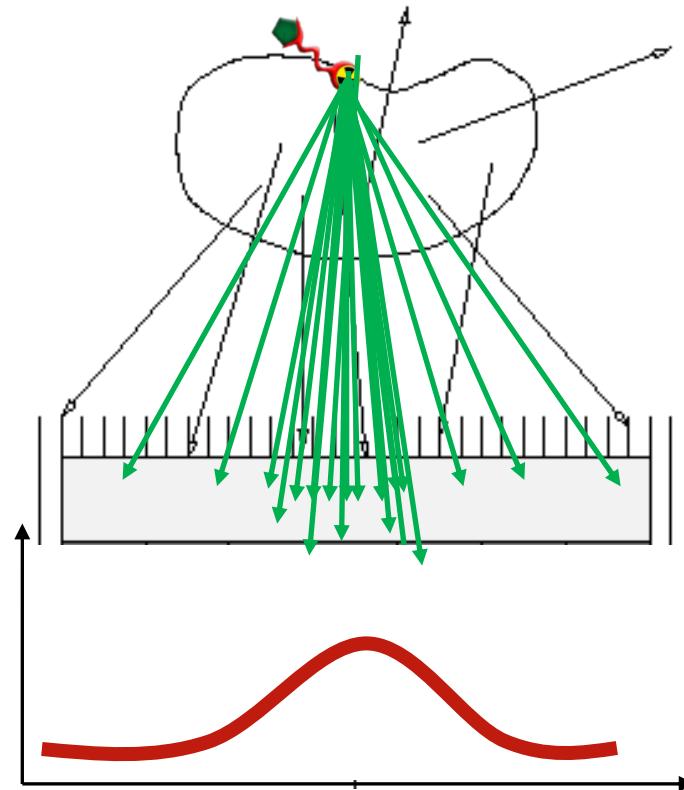
$$p(E\gamma) = p_1 * p_2 * p_3 * p_4 * p_5$$

# Physics and Probability



$$p(E\gamma) = p_1 * p_2 * p_3 * p_4 * p_5$$

# Physics and Probability



$$p(E\gamma) = p_1 * p_2 * p_3 * p_4 * p_5$$

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

# Why use it for medical imaging?

Doesn't require patients

No camera time

Easily modify the system

No radiation dose (patient or operator)

Extra information (physically non-observable)

Can provide a “ground truth”

Infinitely repeatable

Optimise imaging protocols

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Blue      = Positive Charge  
Green     = Neutral Charge  
Red       = Negative Charge



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# Optimisation of imaging windows using Monte Carlo Simulation

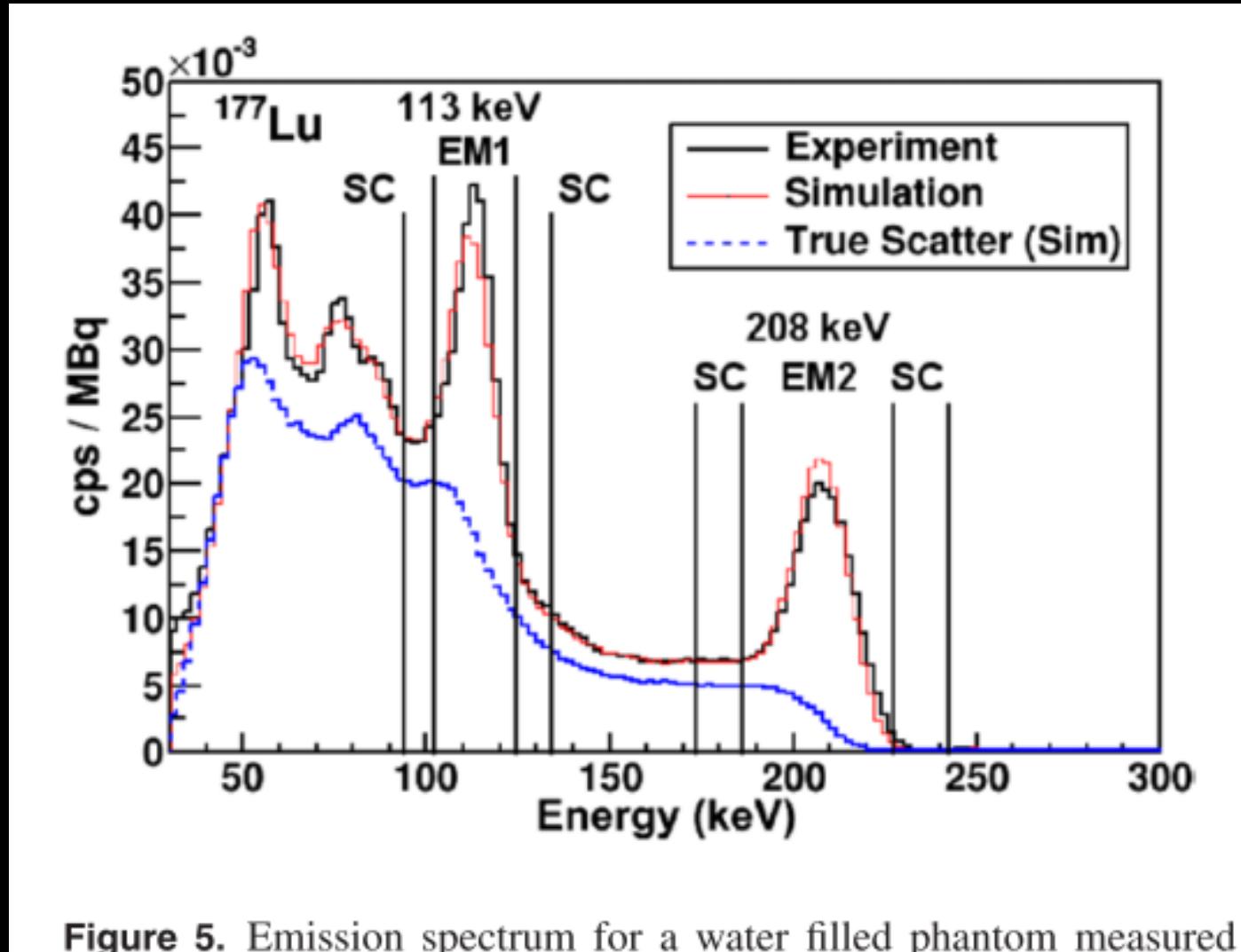


Figure 5. Emission spectrum for a water filled phantom measured

# Example: Optimisation of imaging windows

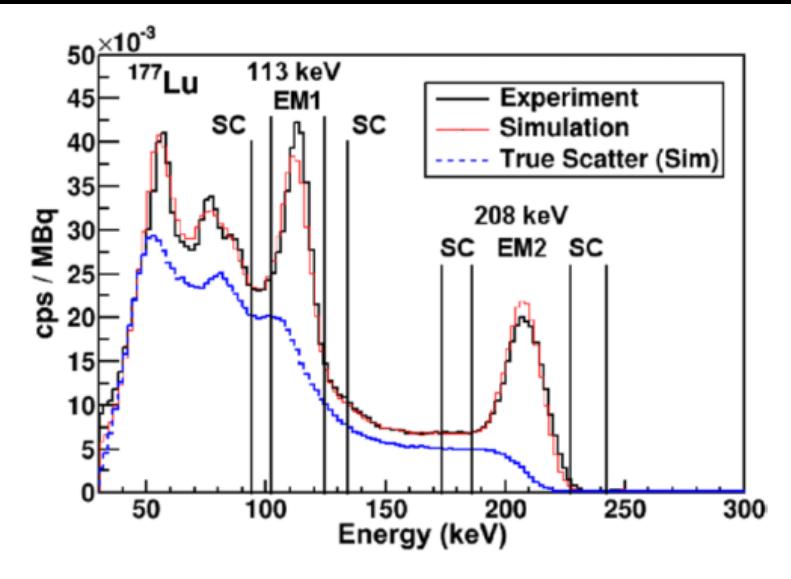
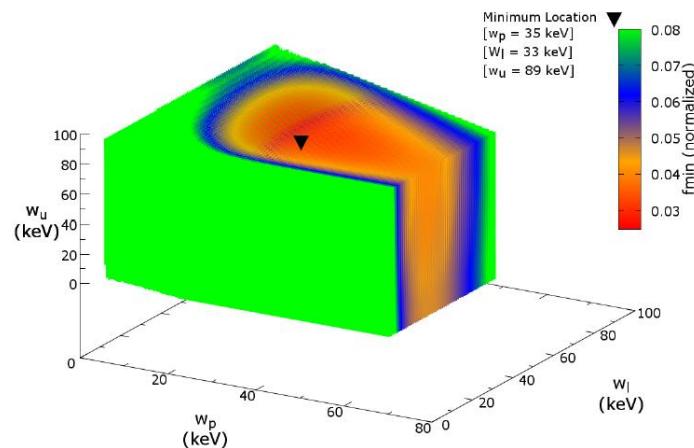


Figure 5. Emission spectrum for a water filled phantom measured



$$C_{TEW} = \left( \frac{C_l}{w_l} + \frac{C_u}{w_u} \right) \times \frac{w_p}{2}$$

$$f_{min} = \left| 1 - \frac{C_{TEW}}{TS} \right| = \left| 1 - \frac{\left( \frac{C_l}{w_l} + \frac{C_u}{w_u} \right) \times \frac{w_p}{2}}{TS} \right|$$

$$\{w_l \in \mathbb{N}^0\} \quad \{w_u \in \mathbb{N}^0\} \quad \{w_p \in \mathbb{N}^1\}$$

$$E_l + \frac{w_l}{2} > E_{min}$$

$$E_u + \frac{w_u}{2} < E_{max}.$$

Sensitive range  
Camera.

$$E_l + \frac{w_l}{2} \leq E_p - \frac{w_p}{2}$$

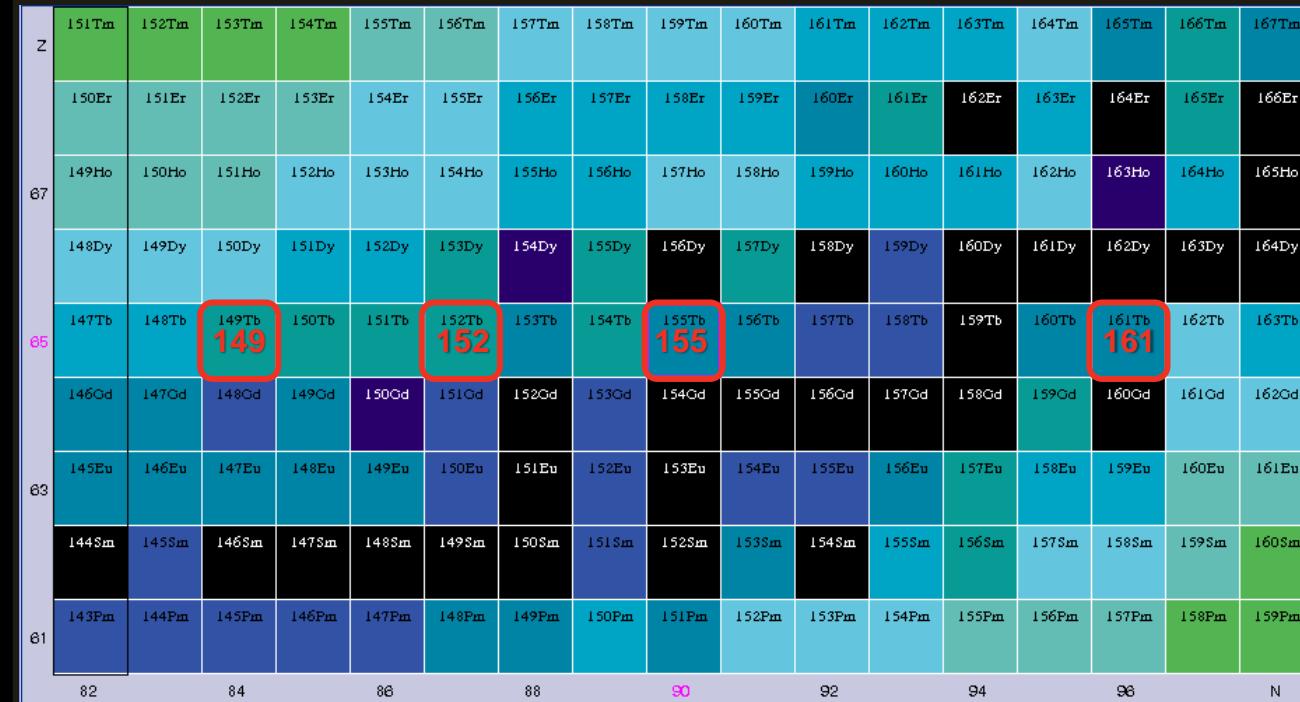
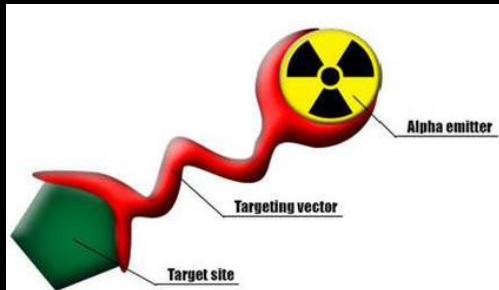
$$E_u - \frac{w_u}{2} \geq E_p + \frac{w_p}{2}.$$

Over-lapping  
windows.

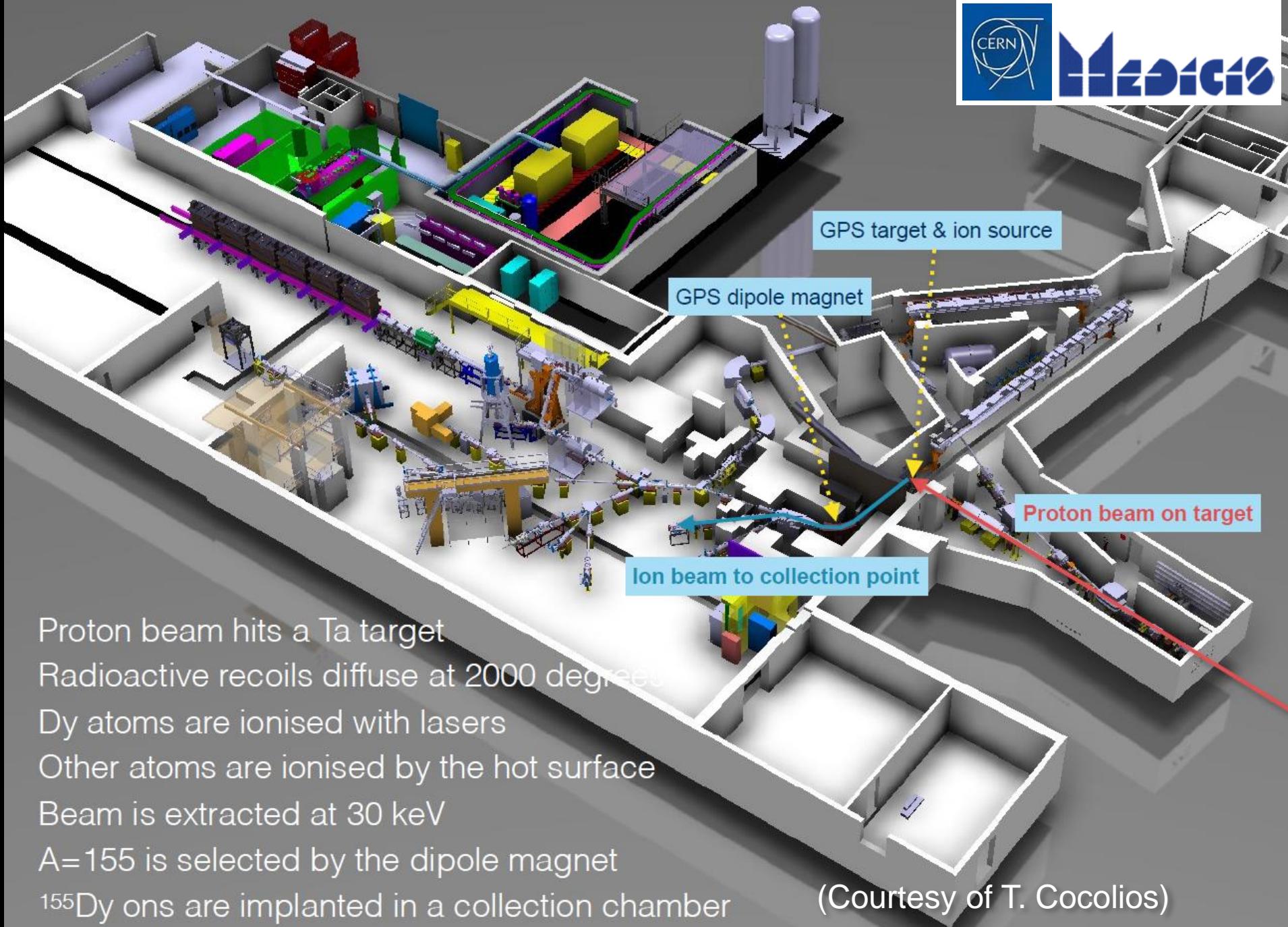
# Tb<sub>65</sub> (Theranostic Isotope Quartet)

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



# Medical physics questions for $^{155}\text{Tb}$

## How to image it?

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

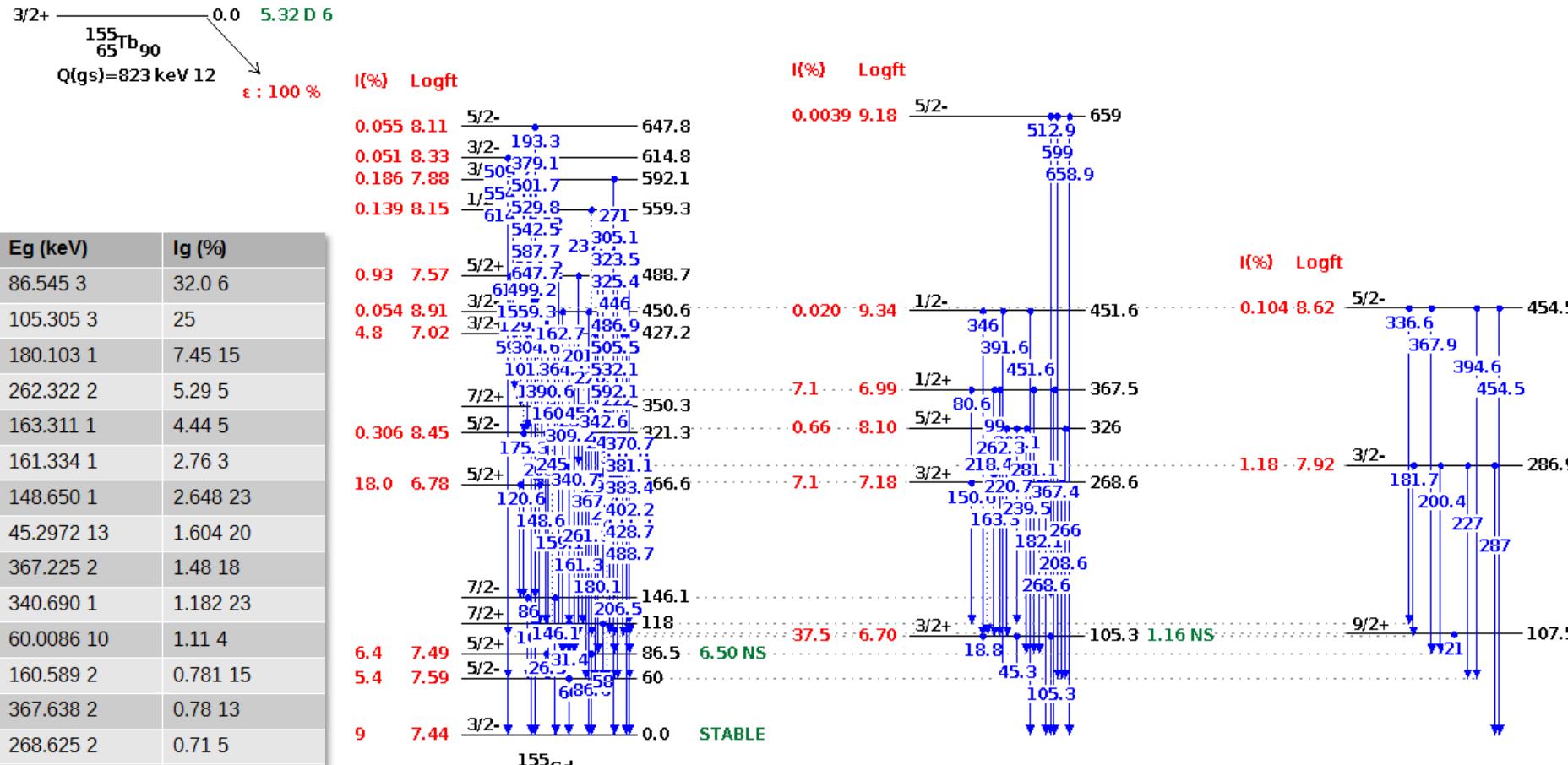


## How to measure activity?

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



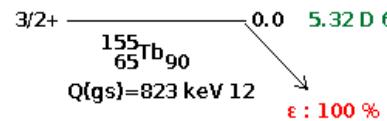
# $^{155}\text{Tb}$ (SPECT Imaging)



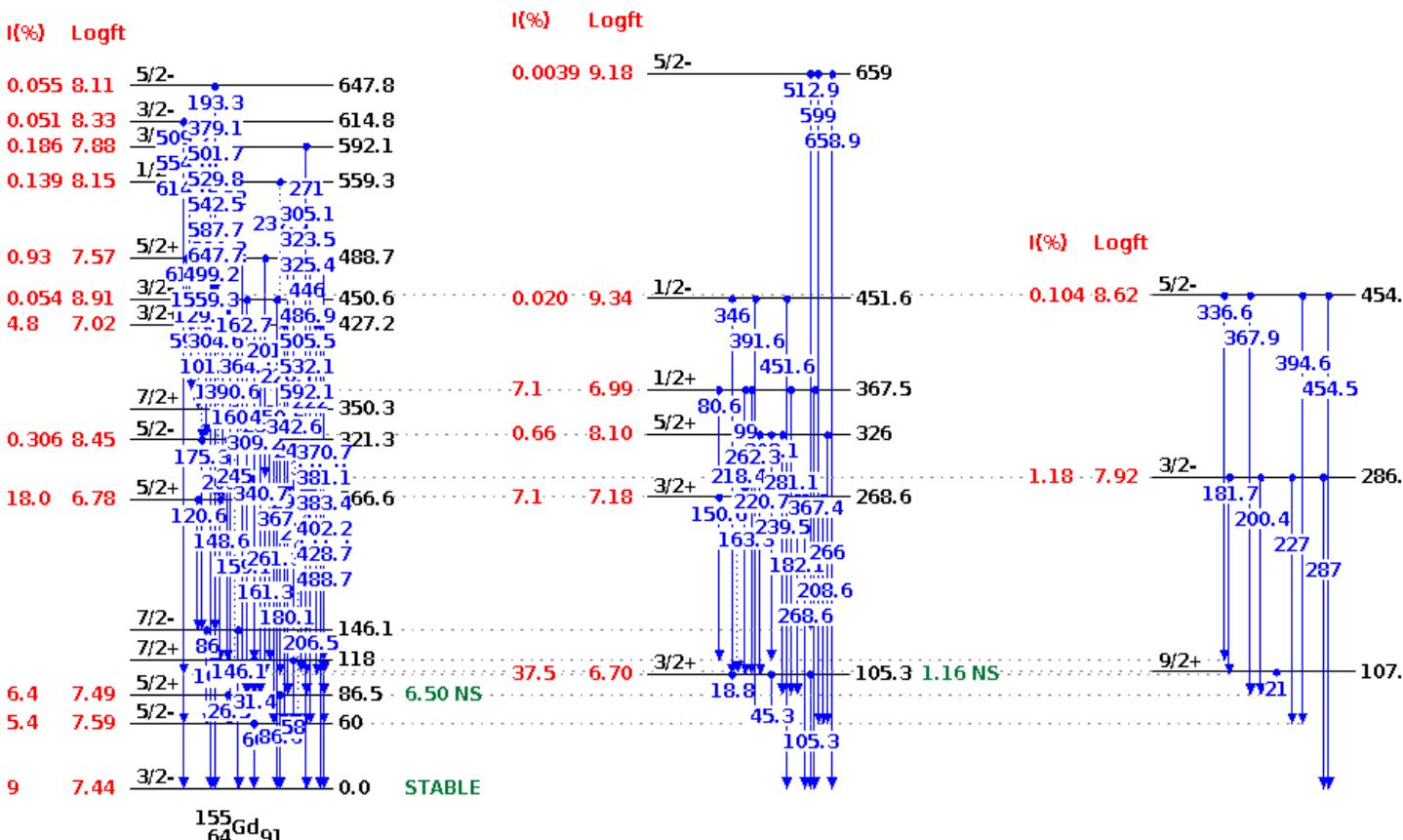
$^{155}\text{Gd}_{91}$

STABLE

# $^{155}\text{Tb}$ (SPECT Imaging)



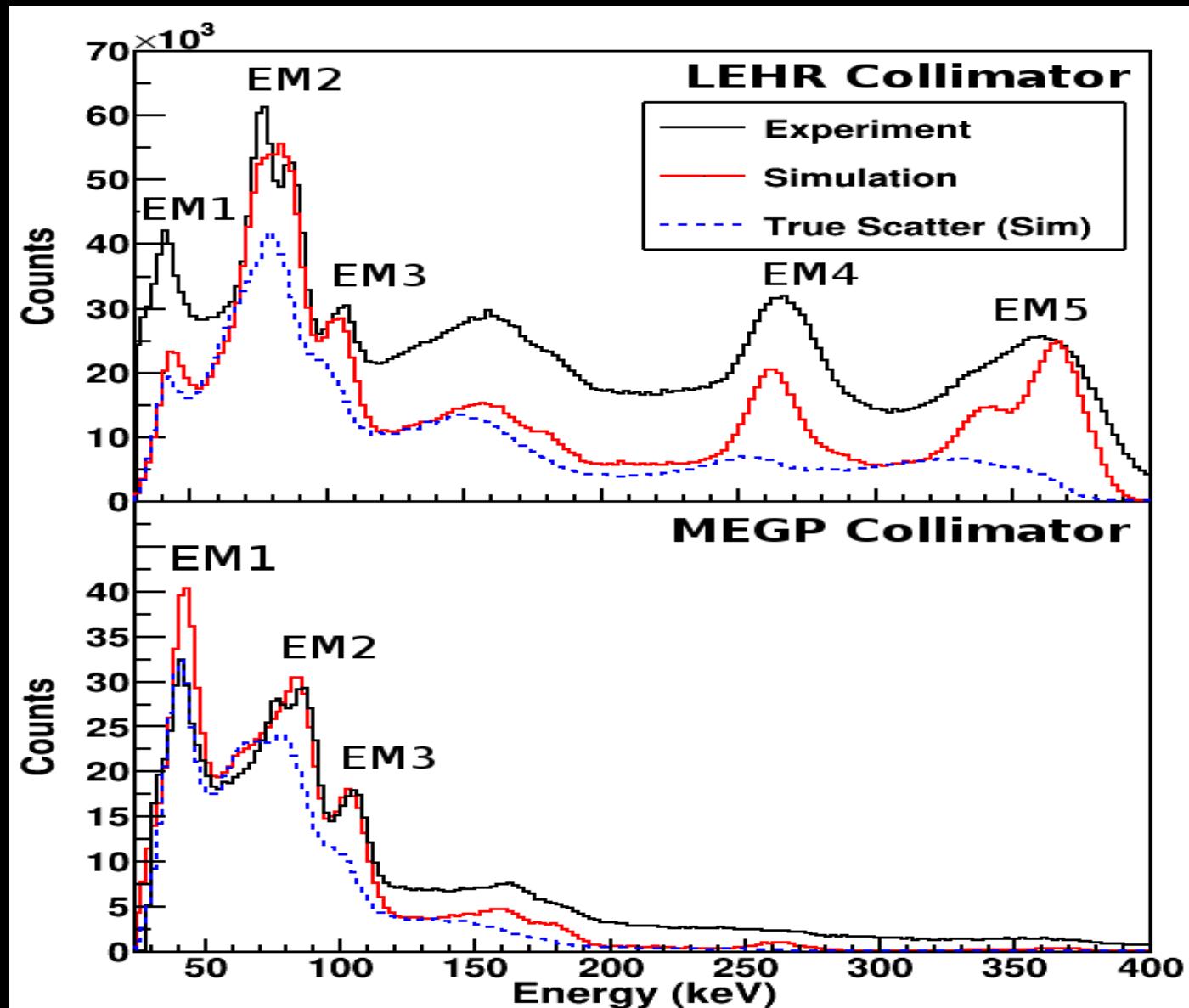
Eg (keV)	Ig (%)
86.545 3	32.0 6
105.305 3	25
180.103 1	7.45 15
262.322 2	5.29 5
163.311 1	4.44 5
161.334 1	2.76 3
148.650 1	2.648 23
45.2972 13	1.604 20
367.225 2	1.48 18
340.690 1	1.182 23
60.0086 10	1.11 4
160.589 2	0.781 15
367.638 2	0.78 13
268.625 2	0.71 5
220.778 2	0.508 5
181.694 1	0.422 5
26.533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



# Tb-155 SPECT

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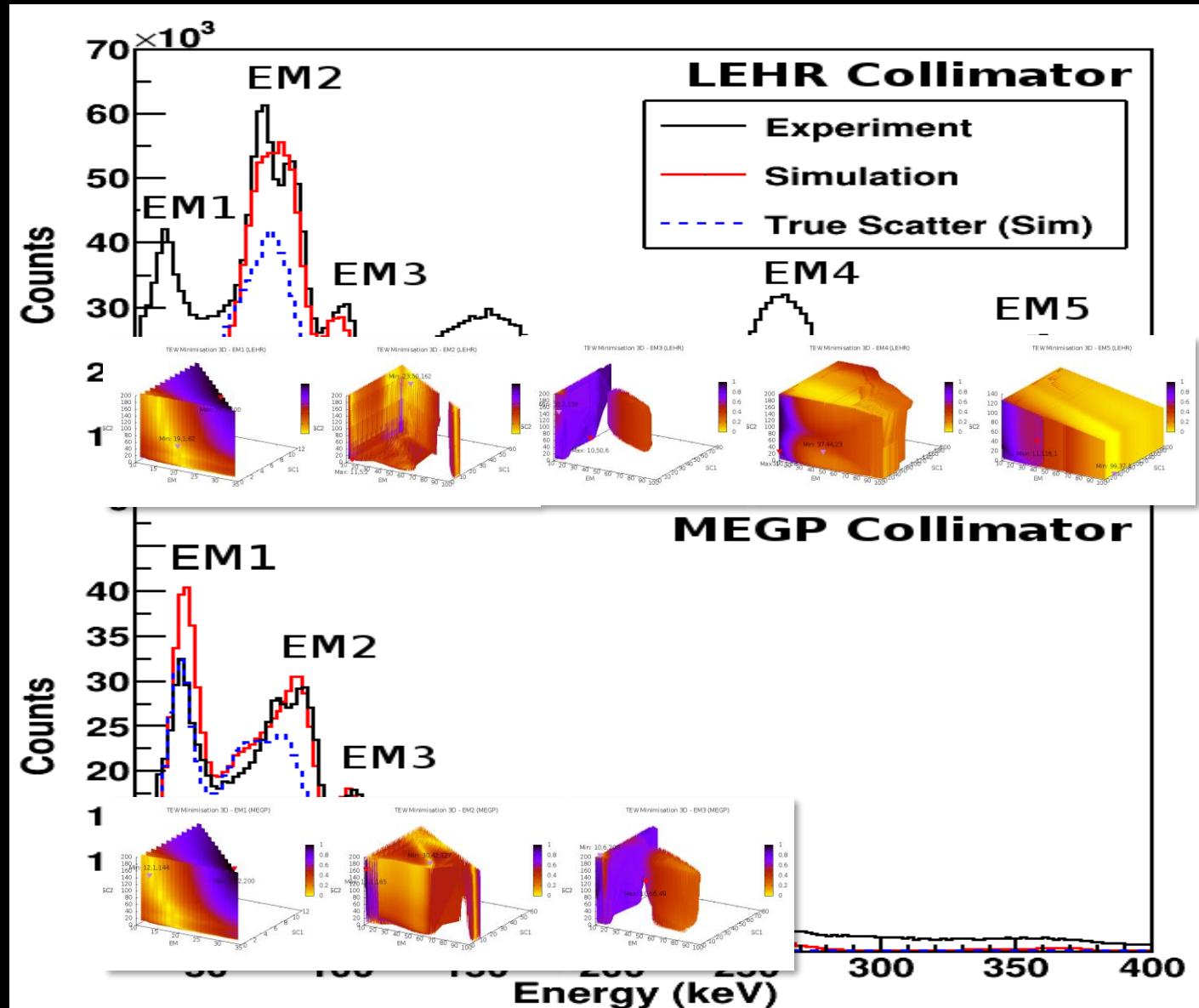
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# Tb-155 SPECT

MEMPHYS  
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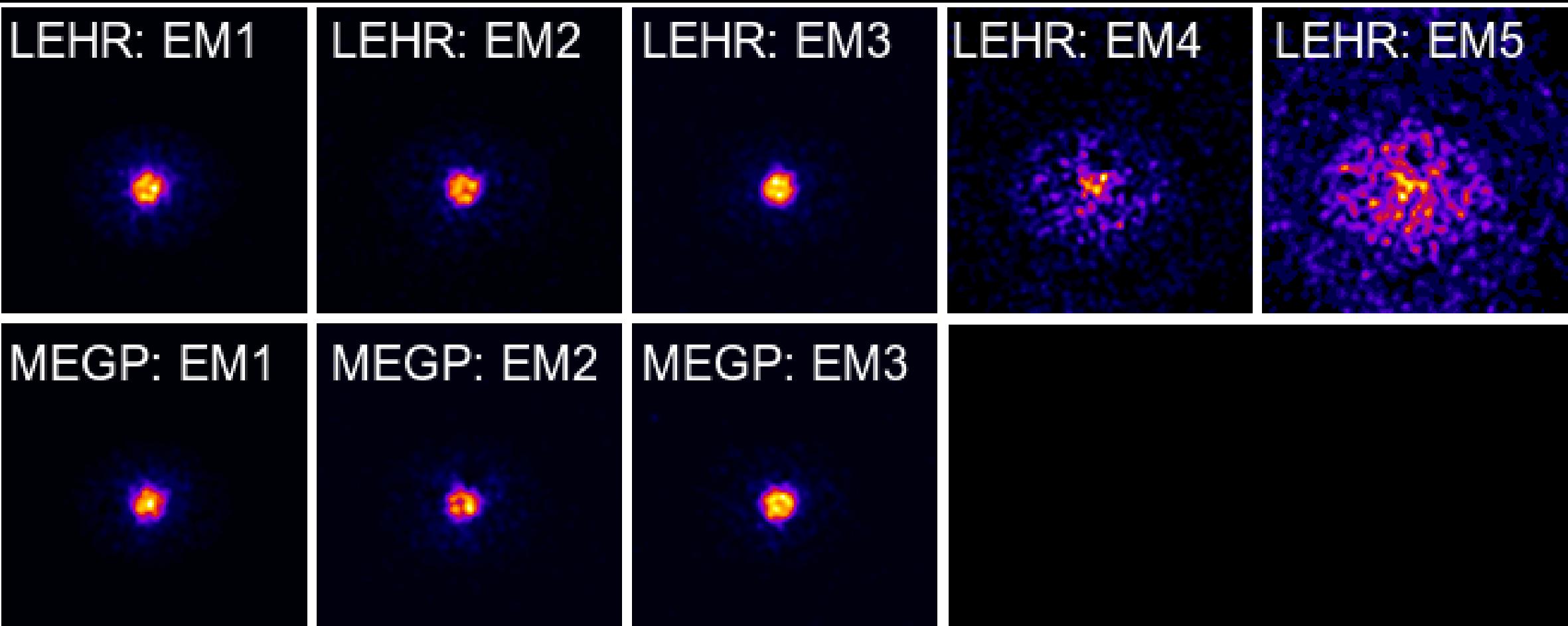
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# SPECT Imaging (List mode)

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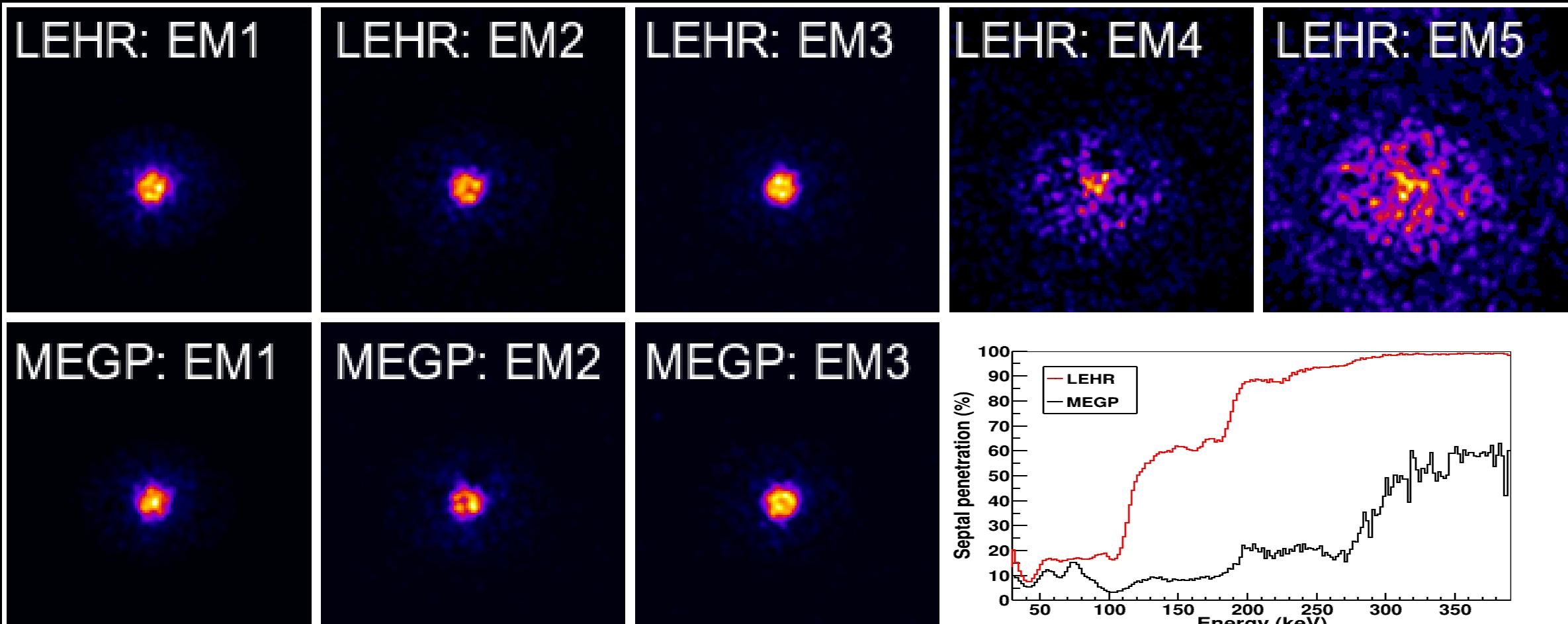
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# SPECT Imaging (List mode)

MEMPHYS  
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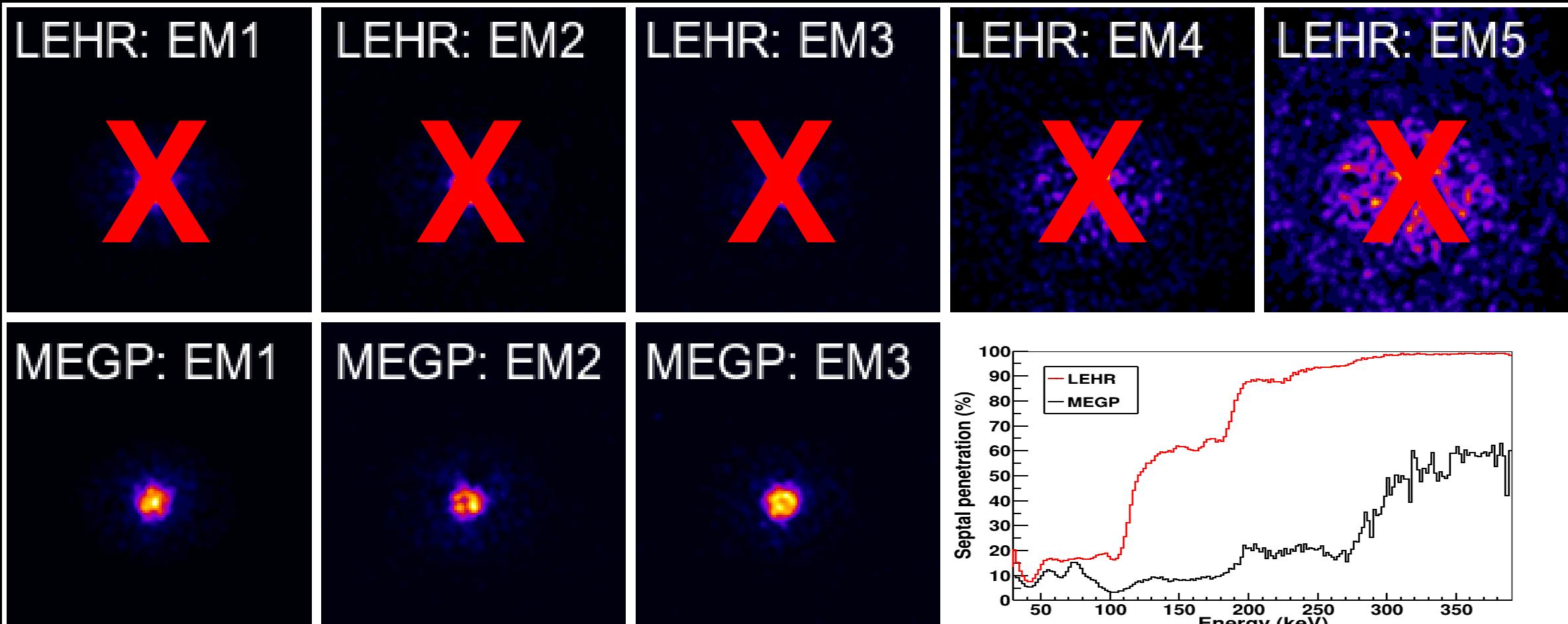
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# SPECT Imaging (List mode)

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- Can you trust the results from a simulation?

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- Yes - if the simulation has been validated

- ✓ Geometry
- ✓ Detector modelling
- ✓ Physics models (dependent on energy range)
- ✓ (Nuclear) Data

Comparison with experimental data

# Validation of simulations

- Can you trust the results from a simulation?

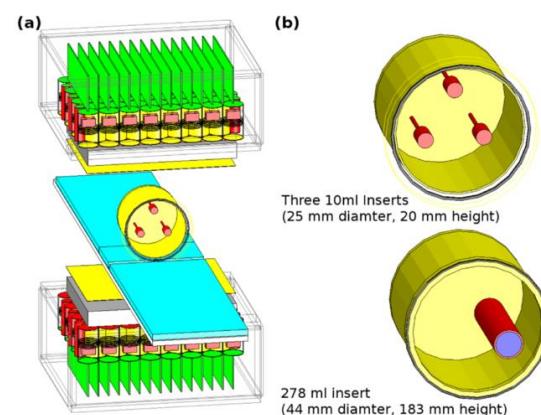
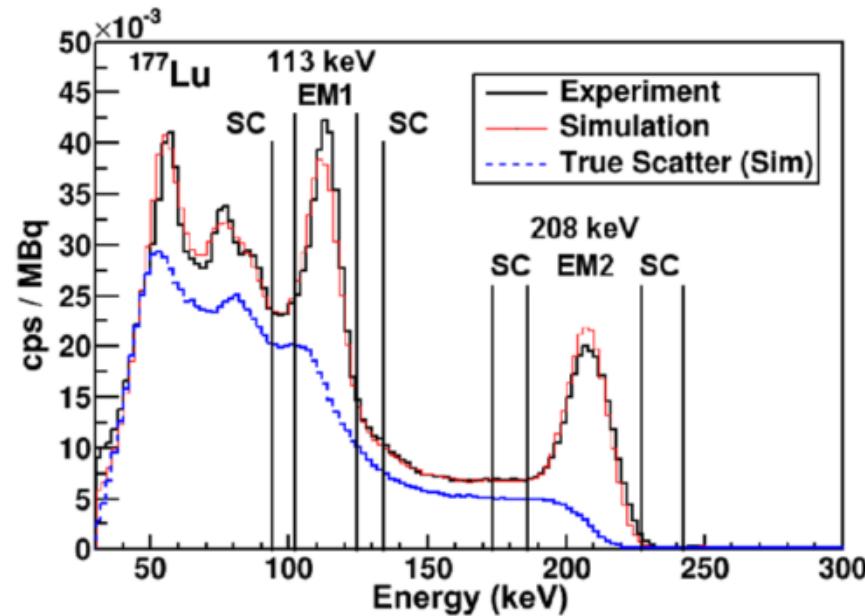
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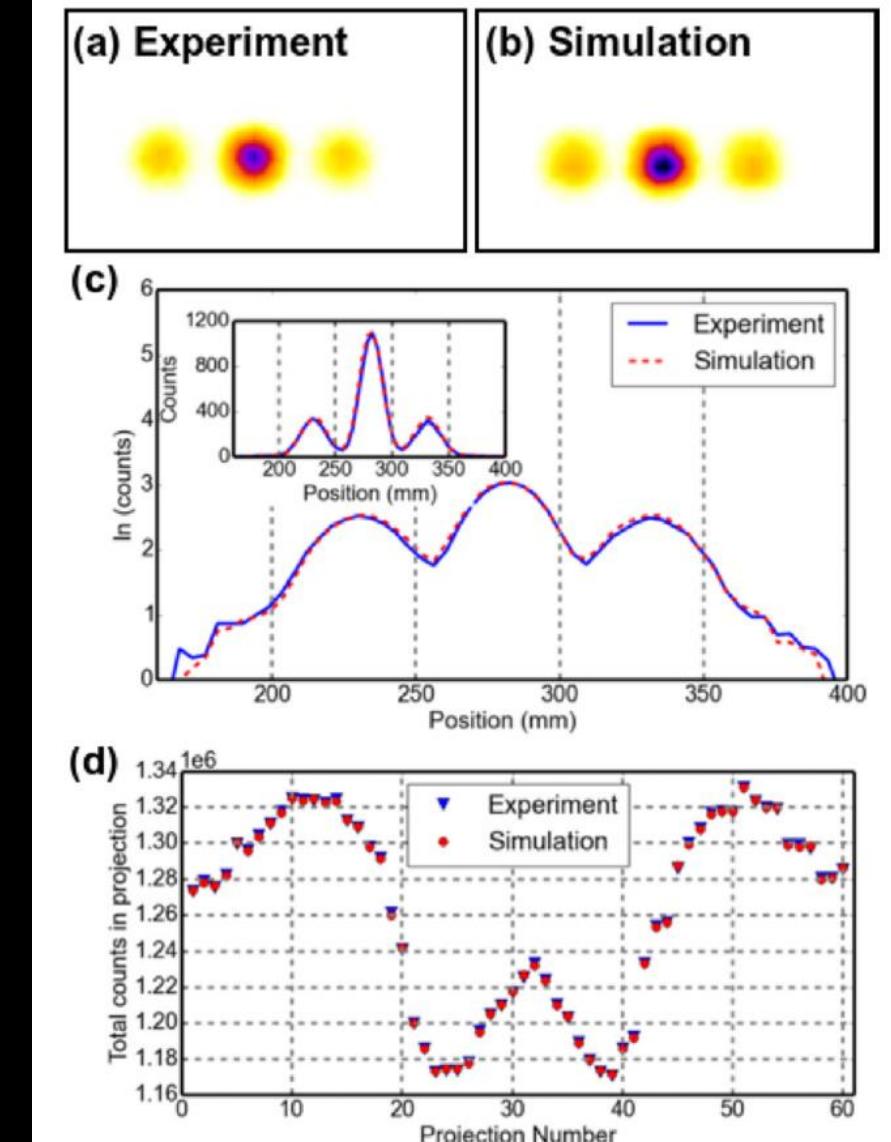
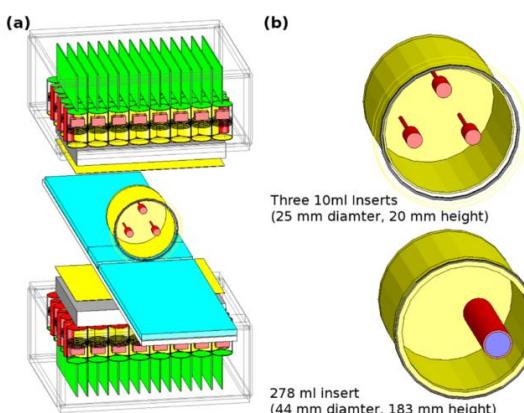
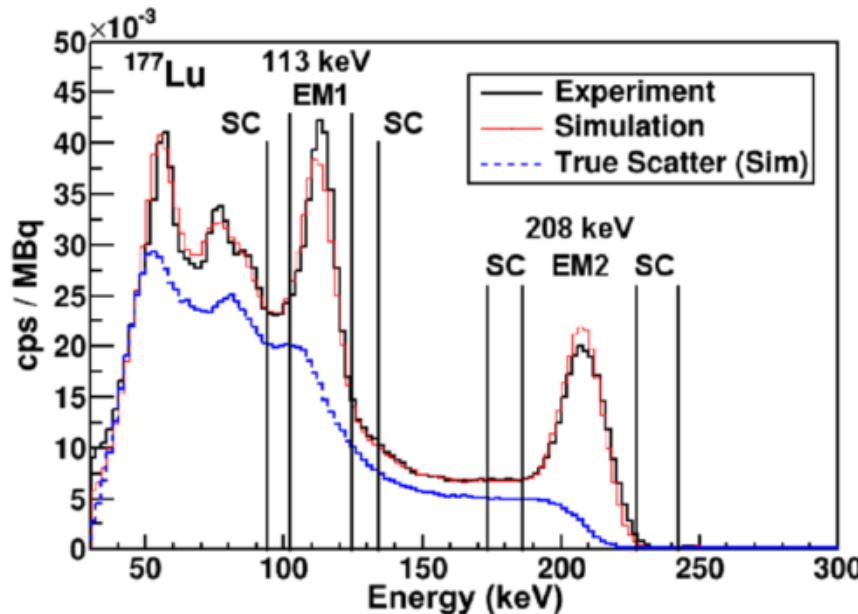
# The influence of triple energy window scatter correction on activity quantification for $^{177}\text{Lu}$ molecular radiotherapy

Andrew P Robinson<sup>1</sup>, Jill Tipping<sup>2</sup>, David M Cullen<sup>1</sup>  
and David Hamilton<sup>2</sup>



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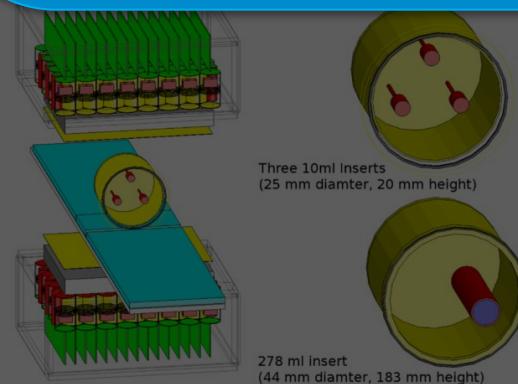
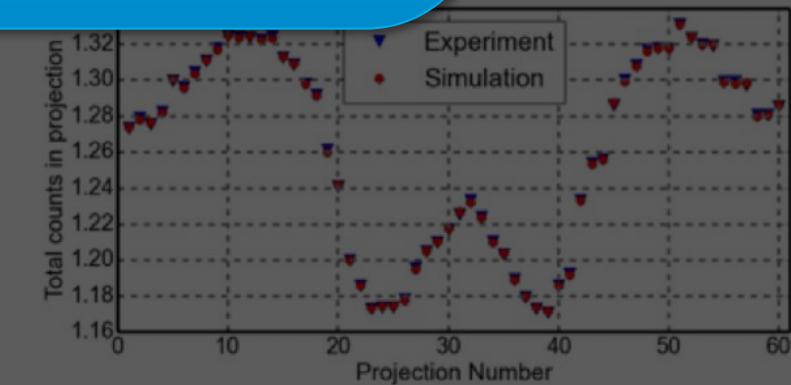
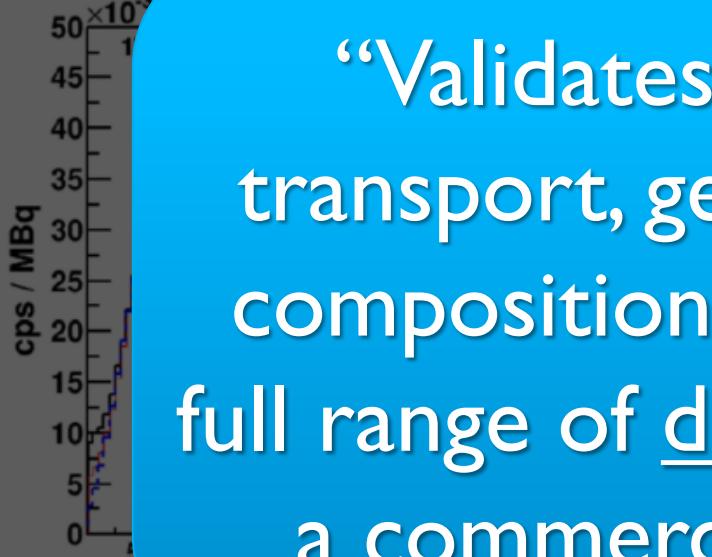
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(a) Experiment

(b) Simulation

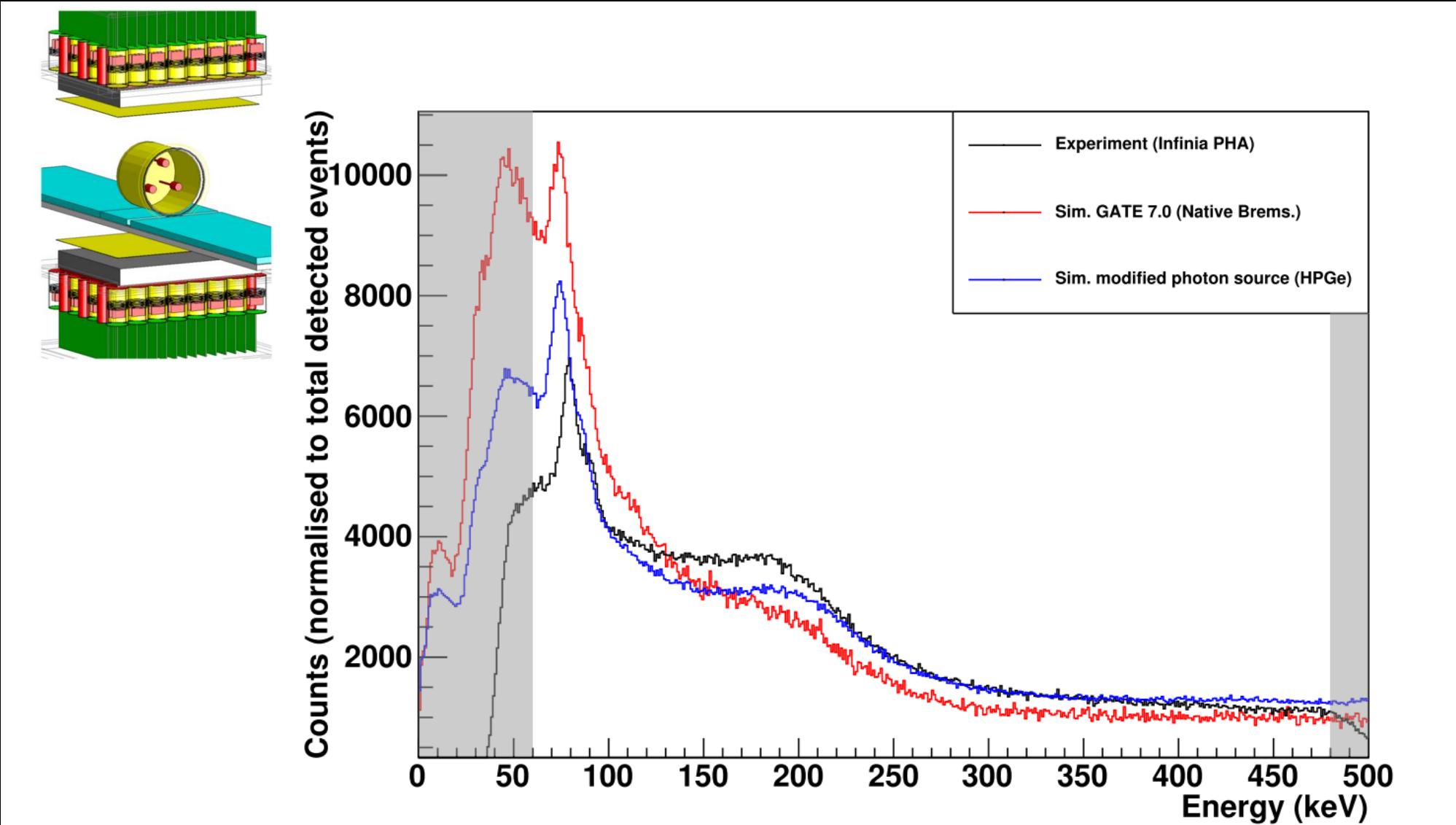
“Validates the global photon transport, geometry and material composition of the model for the full range of direct observables from a commercial SPECT camera.”



# $^{90}\text{Y}$ Bremsstrahlung Imaging

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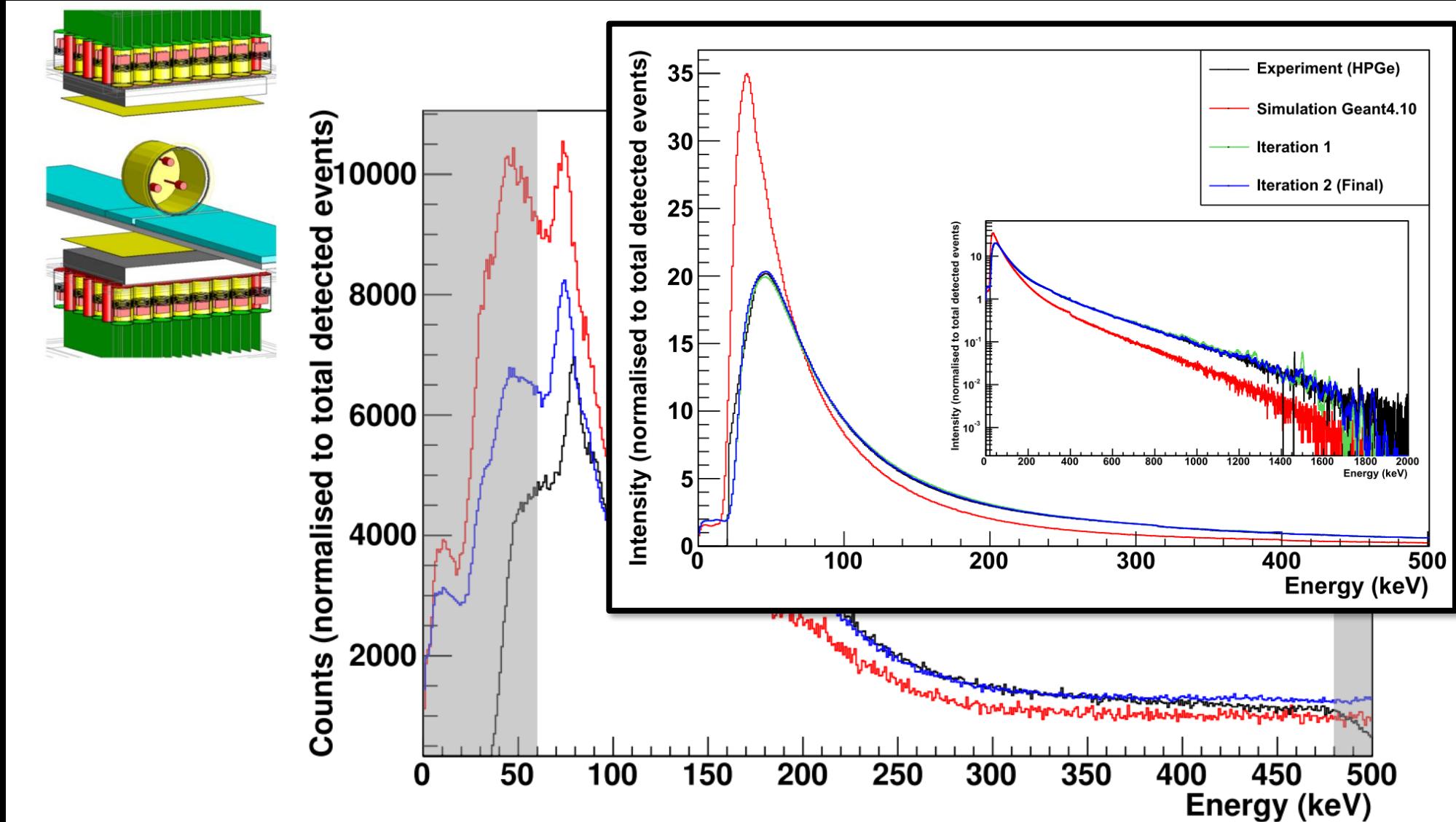
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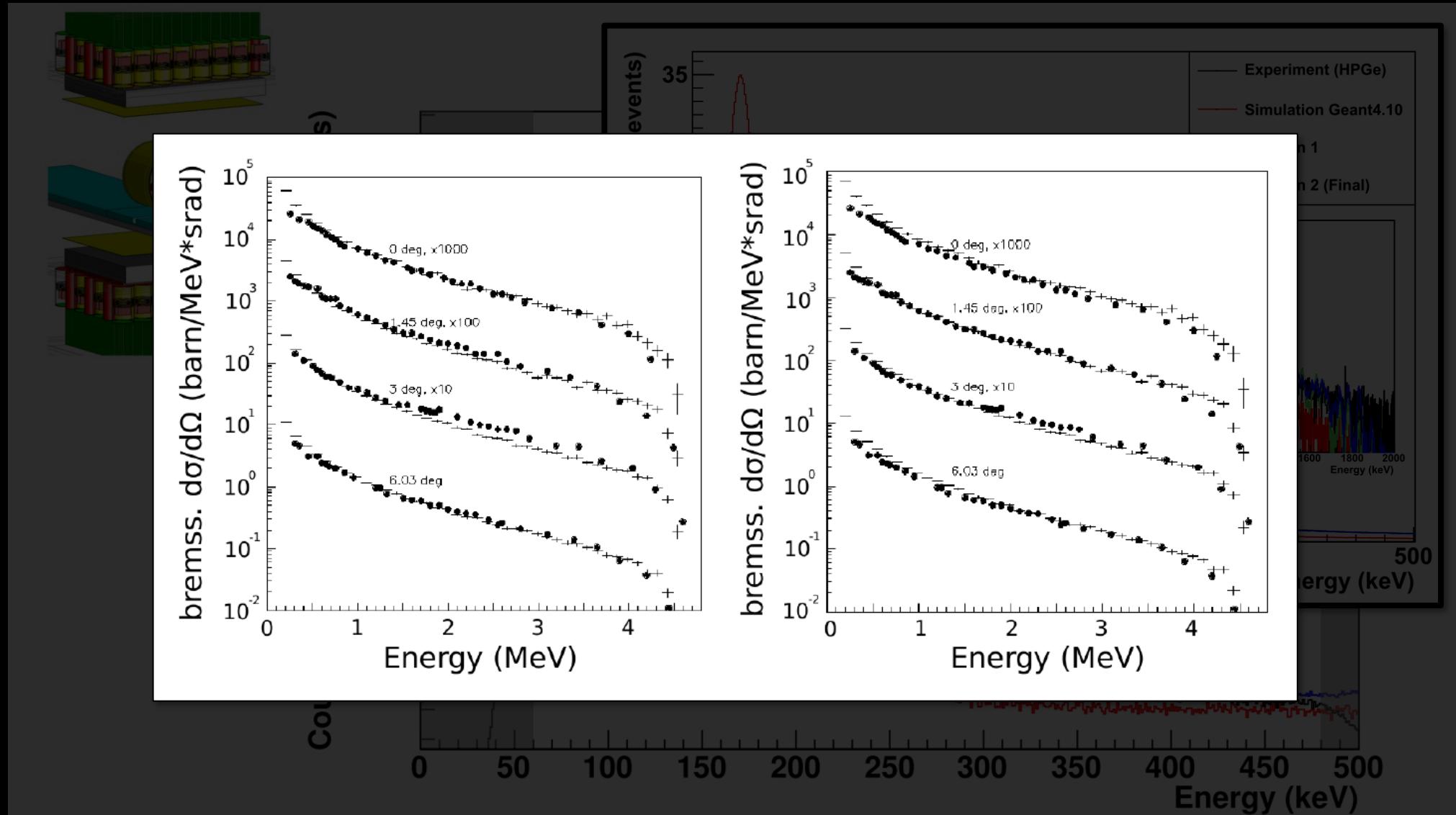
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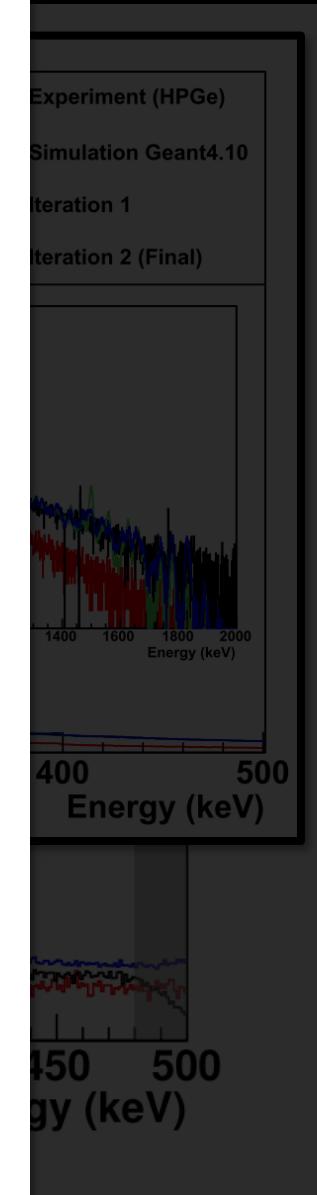
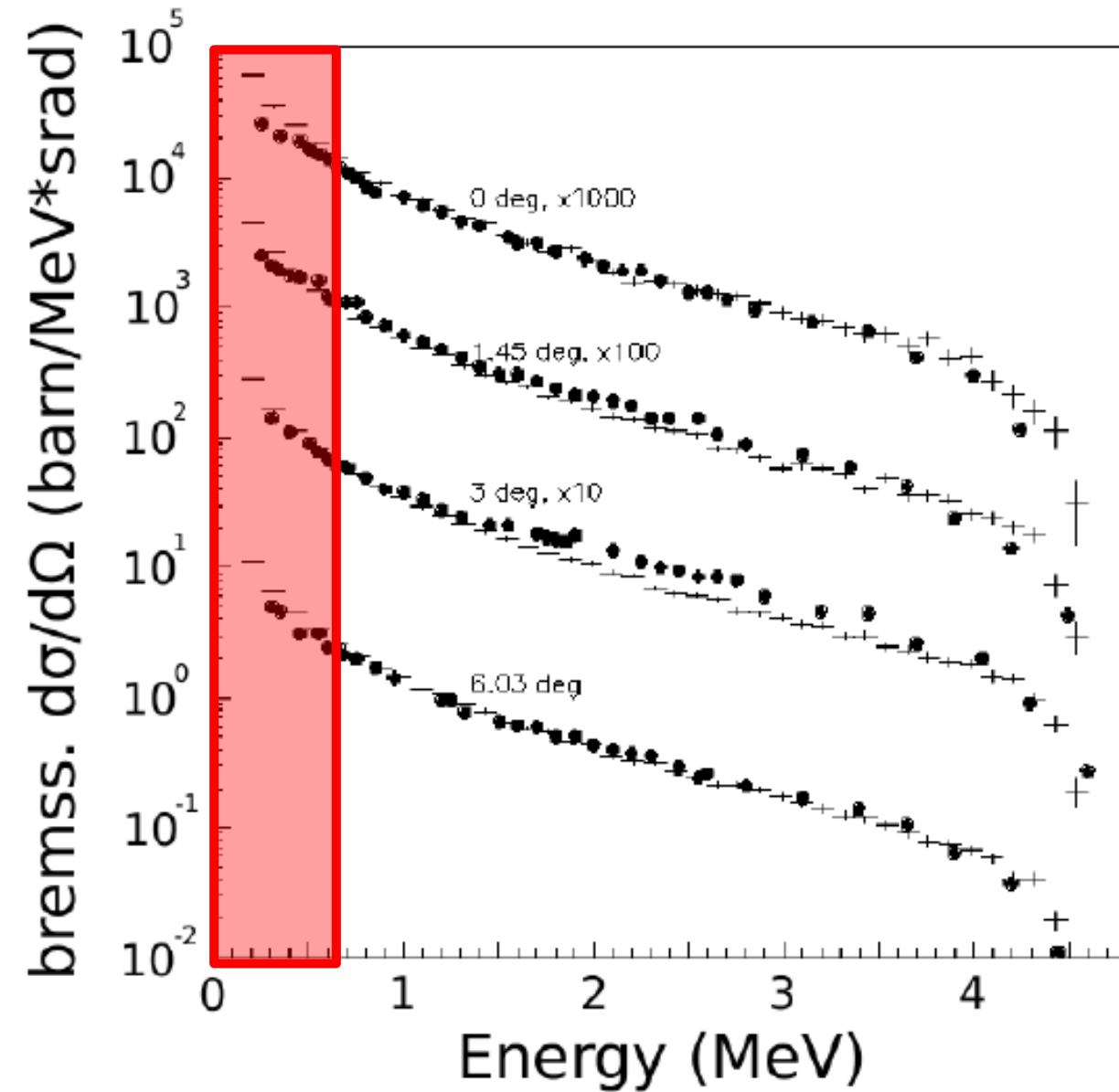
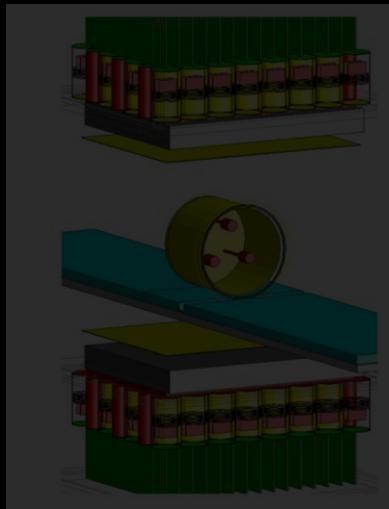
NPL  
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# $^{90}\text{Y}$ Bremsstrahlung Imaging

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# Uncertainties....

A quantitative validation methodology for Monte Carlo simulations for SPECT imaging studies

S. Pells, PhD Thesis (paper under review)

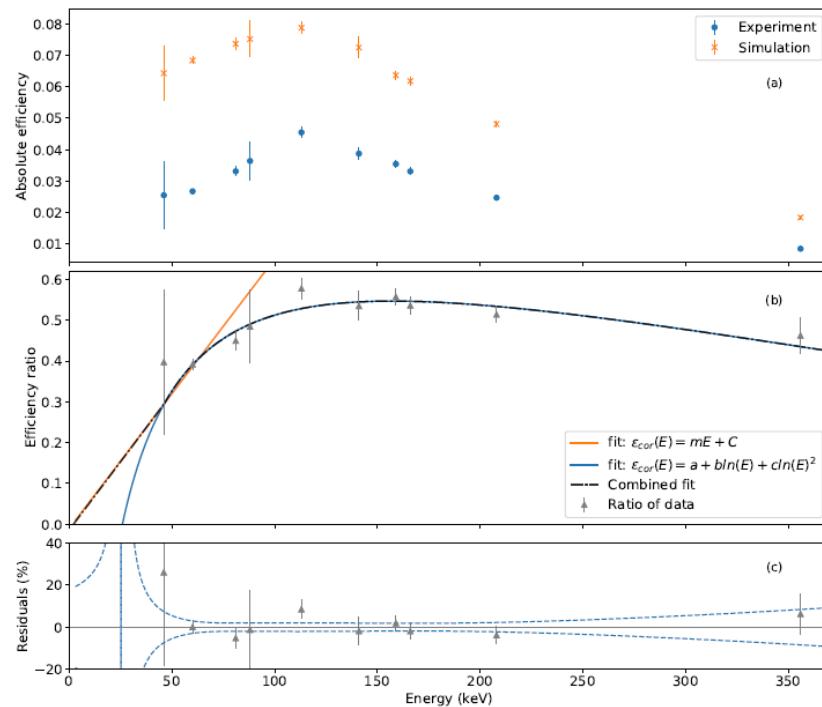


Figure 4: The data used to create the efficiency correction. (a): the absolute efficiency calculated from the experimental and simulated calibration sources. (b): the data points with the two fits as discussed in the text and the superposition of the two functions which was used for the efficiency correction. The points show the ratio of experimentally-measured and simulated efficiency for the calibration sources with their standard uncertainties. (c): the residuals of the fit to the data. The error bars on the residuals are the standard uncertainty of each data point and the dashed lines represent the uncertainty of the logarithmic fit.

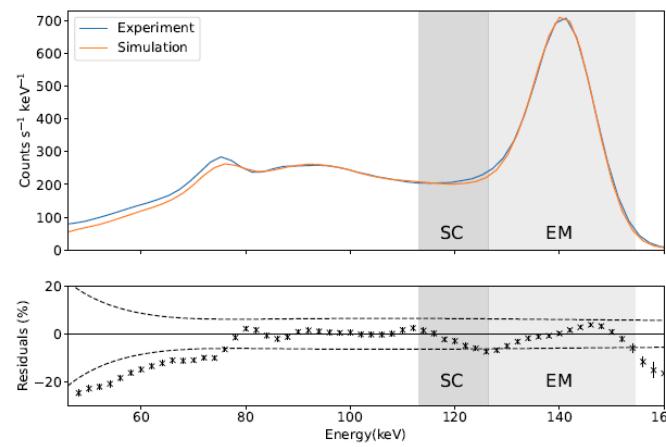


Figure 6: A comparison of the total simulated energy spectrum and the total spectrum extracted from the SPECT images for the cylindrical phantom of  $^{99m}\text{Tc}$ , plotted with 2 keV bins. The bottom plot shows the percentage residuals with standard uncertainties and the  $3\sigma$  bounds of the uncertainty on the efficiency correction shown as dashed lines. The emission (EM) and scatter (SC) windows are shaded.

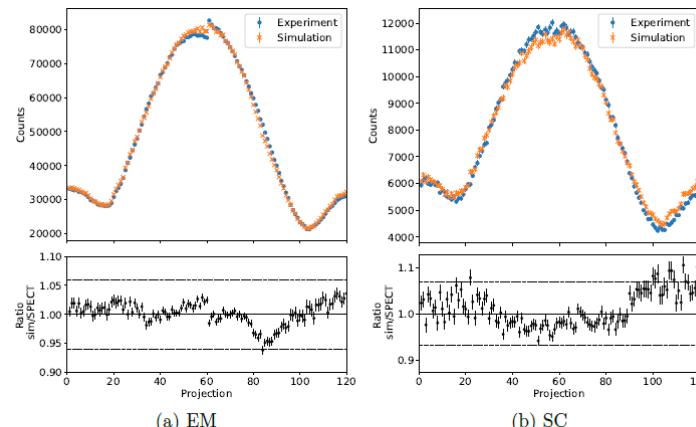
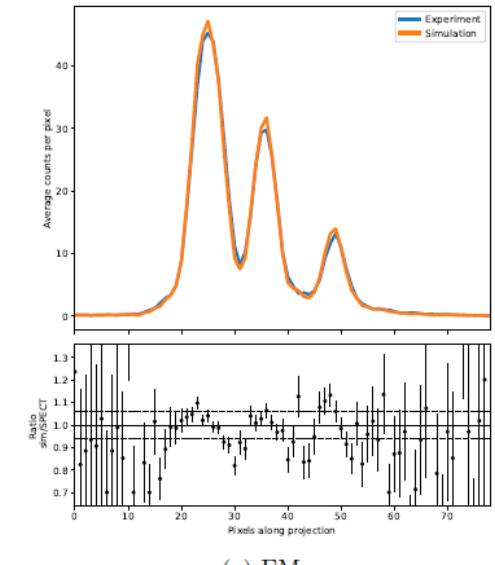
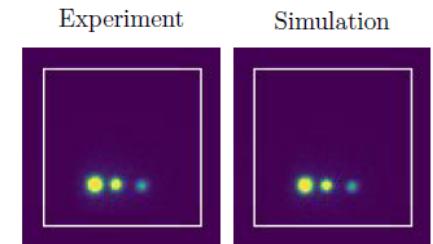


Figure 7: The counts per projection in the emission (EM) and scatter (SC) window of the simulated and experimental images of the NEMA phantom of  $^{99m}\text{Tc}$ . The simulation has been normalised using the sensitivity ratio given in Table 5. The bottom plots show the ratio of the simulated and SPECT counts for each projection and the dashed lines show the  $\pm 3\sigma$  uncertainty of the sensitivity ratio.



(a) EM

# Uncertainties....

A quantitative validation methodology for Monte Carlo simulations for SPECT imaging studies

S. Pells, PhD Thesis

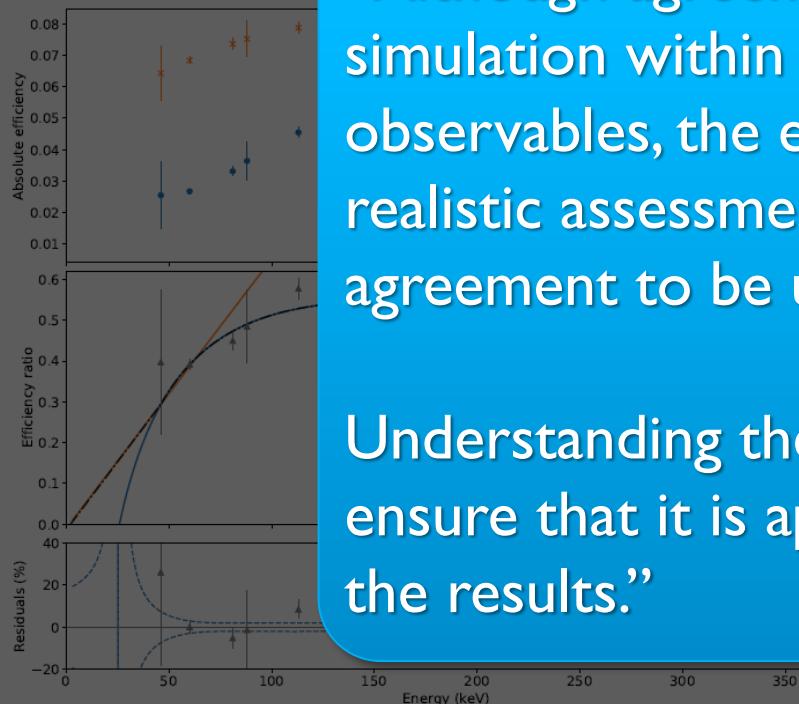


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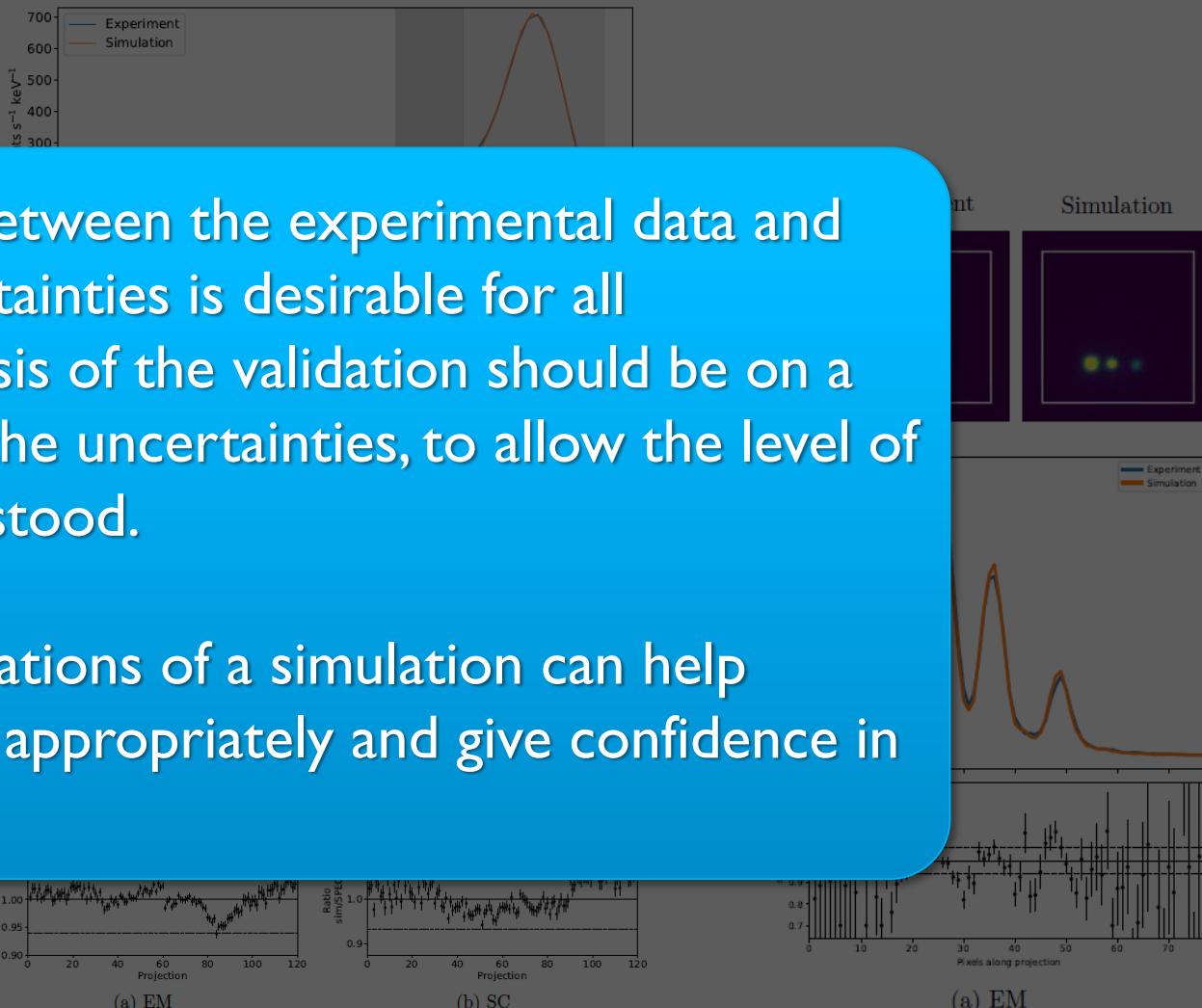


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# OpenDose: a collaborative effort to produce reference dosimetric data with Monte Carlo simulations

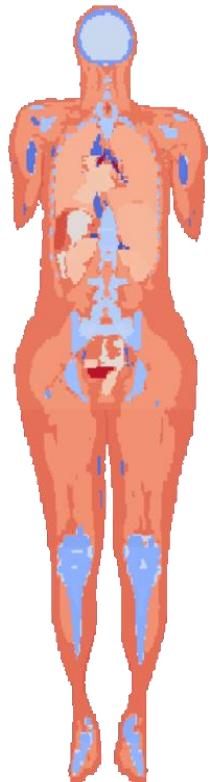
*Aims to provide a free and public resource of robust reference data to enable dosimetry calculations in nuclear medicine, using a variety of Monte Carlo codes through an international collaboration*



## 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

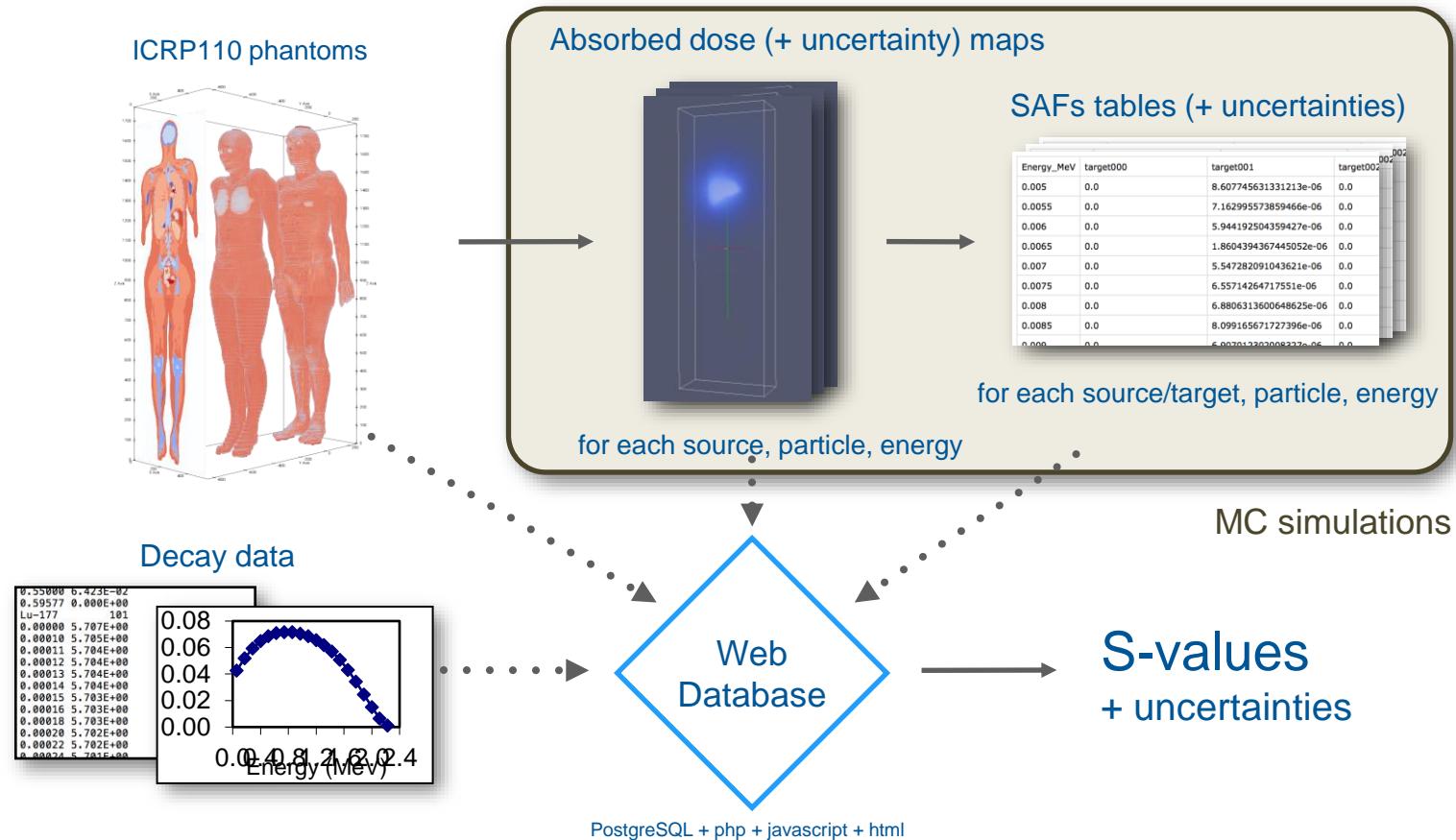
- Collaborative work, everyone is welcome!
- Create a free database
- Create an easily accessible website
- Make data available with associated uncertainties

14 research teams (18 institutes)



5 Monte Carlo codes:

Geant4/GATE - FLUKA - PENELOPE - MCNP/MCNPX - EGSnrc/EGS++

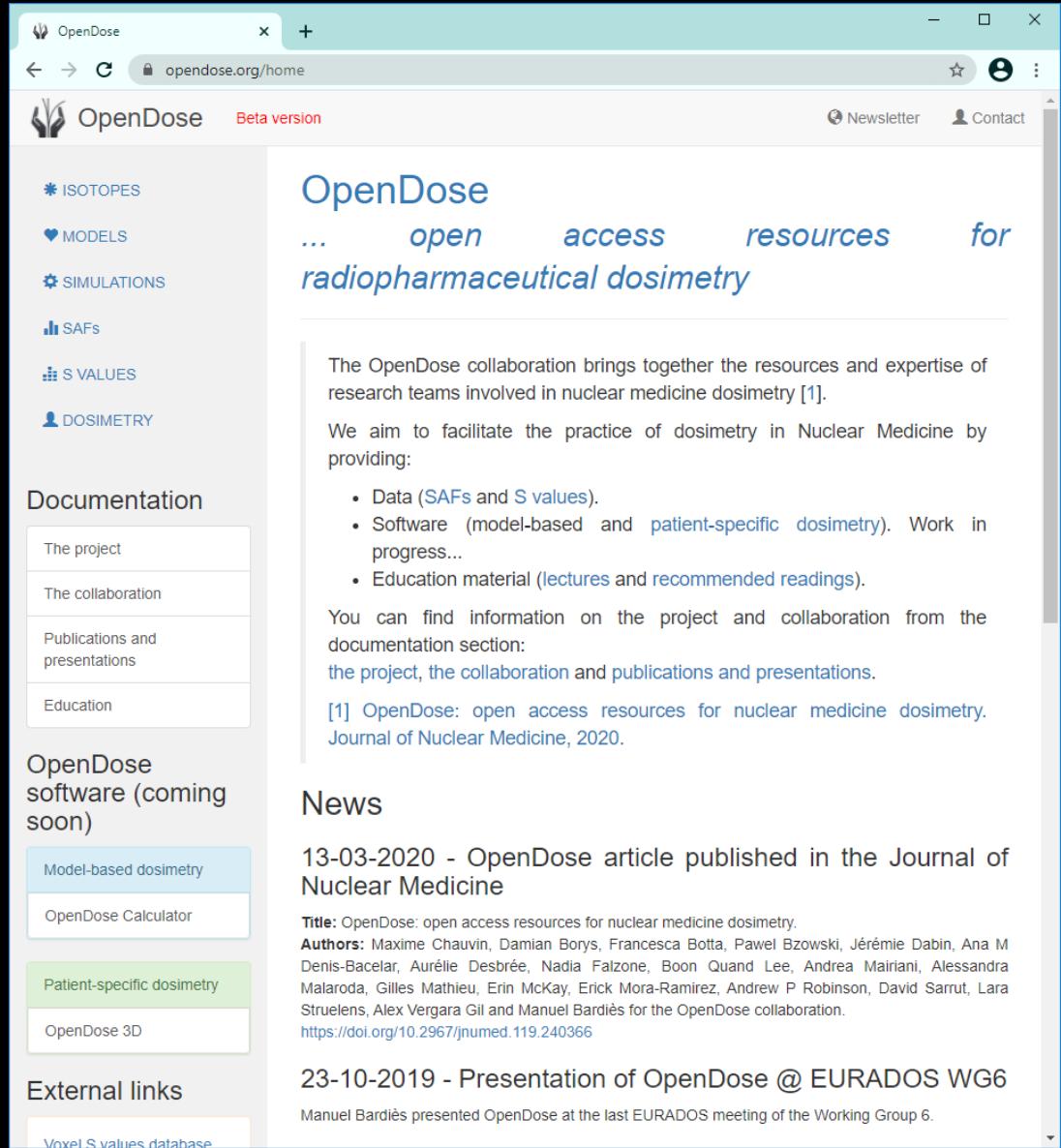


## OpenDose: Open-Access Resource for Nuclear Medicine Dosimetry

Maxime Chauvin<sup>1</sup>, Damian Borys<sup>2</sup>, Francesca Botta<sup>3</sup>, Paweł Bzowski<sup>2</sup>, Jérémie Dabin<sup>4</sup>, Ana M. Denis-Bacelar<sup>5</sup>, Aurélie Desbrée<sup>6</sup>, Nadia Falzone<sup>7,8</sup>, Boon Quan Lee<sup>7,8</sup>, Andrea Mairani<sup>9,10</sup>, Alessandra Malaroda<sup>11,12</sup>, Gilles Mathieu<sup>13</sup>, Erin McKay<sup>14</sup>, Erick Mora-Ramirez<sup>1,15</sup>, Andrew P. Robinson<sup>5,16,17</sup>, David Sarrut, Lara Struelens<sup>4</sup>, Alex Vergara Gil<sup>1</sup>, and Manuel Bardès<sup>1</sup>

<sup>1</sup>CRCT, UMR 1037, Inserm, Université Toulouse III Paul Sabatier, Toulouse, France; <sup>2</sup>Department of Systems Biology and Engineering, Silesian University of Technology Gliwice, Poland; <sup>3</sup>Medical Physics Unit, IEO, European Institute of Oncology IRCCS, Milan, Italy; <sup>4</sup>SCK-CEN, Belgian Nuclear Research Centre, Mol, Belgium; <sup>5</sup>National Physical Laboratory, Teddington, United Kingdom; <sup>6</sup>Institut de Radioprotection et de Sécurité Nucléaire (IRSN), Fontenay-aux-Roses, France; <sup>7</sup>MRC Oxford Institute for Radiation Oncology, University of Oxford, Oxford, United Kingdom; <sup>8</sup>GenesisCare, Sydney, New South Wales, Australia; <sup>9</sup>Heidelberg Ion-Beam Therapy Center (HIT), Department of Radiation Oncology, Heidelberg University Hospital, Heidelberg, Germany; <sup>10</sup>Medical Physics, National Centre of Oncological Hadrontherapy (CNAO), Pavia, Italy; <sup>11</sup>School of Physics and CMRP, University of Wollongong, Wollongong, New South Wales, Australia; <sup>12</sup>Theranostics and Nuclear Medicine Department, St. Vincent's Public Hospital, Sydney, New South Wales, Australia; <sup>13</sup>Département du Système d'Information, Inserm, Paris, France; <sup>14</sup>St. George Hospital, Sydney, New South Wales, Australia; <sup>15</sup>CICANUM, Escuela de Física, Universidad de Costa Rica, San José, Costa Rica; <sup>16</sup>Schuster Laboratory, School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom; and <sup>17</sup>The Christie NHS Foundation Trust, Manchester, United Kingdom

1514 THE JOURNAL OF NUCLEAR MEDICINE • Vol. 61 • No. 10 • October 2020



The screenshot shows the OpenDose website homepage. The header includes the OpenDose logo, a beta version notice, and links for newsletter and contact. The main content area features a large banner with the text "OpenDose ... open access resources for radiopharmaceutical dosimetry". Below the banner, a paragraph explains the collaboration's goal: "The OpenDose collaboration brings together the resources and expertise of research teams involved in nuclear medicine dosimetry [1]. We aim to facilitate the practice of dosimetry in Nuclear Medicine by providing: Data (SAFs and S values), Software (model-based and patient-specific dosimetry). Work in progress... Education material (lectures and recommended readings)." A "Documentation" sidebar lists links to "The project", "The collaboration", "Publications and presentations", and "Education". Another sidebar for "OpenDose software (coming soon)" lists "Model-based dosimetry" (selected), "OpenDose Calculator", "Patient-specific dosimetry" (selected), "OpenDose 3D", and "External links" (selected). At the bottom, a link to "Voxel S values database" is visible.

**OpenDose** ... open access resources for radiopharmaceutical dosimetry

The OpenDose collaboration brings together the resources and expertise of research teams involved in nuclear medicine dosimetry [1]. We aim to facilitate the practice of dosimetry in Nuclear Medicine by providing:

- Data (SAFs and S values).
- Software (model-based and patient-specific dosimetry). Work in progress...
- Education material (lectures and recommended readings).

You can find information on the project and collaboration from the documentation section: the project, the collaboration and publications and presentations.

[1] OpenDose: open access resources for nuclear medicine dosimetry. Journal of Nuclear Medicine, 2020.

## News

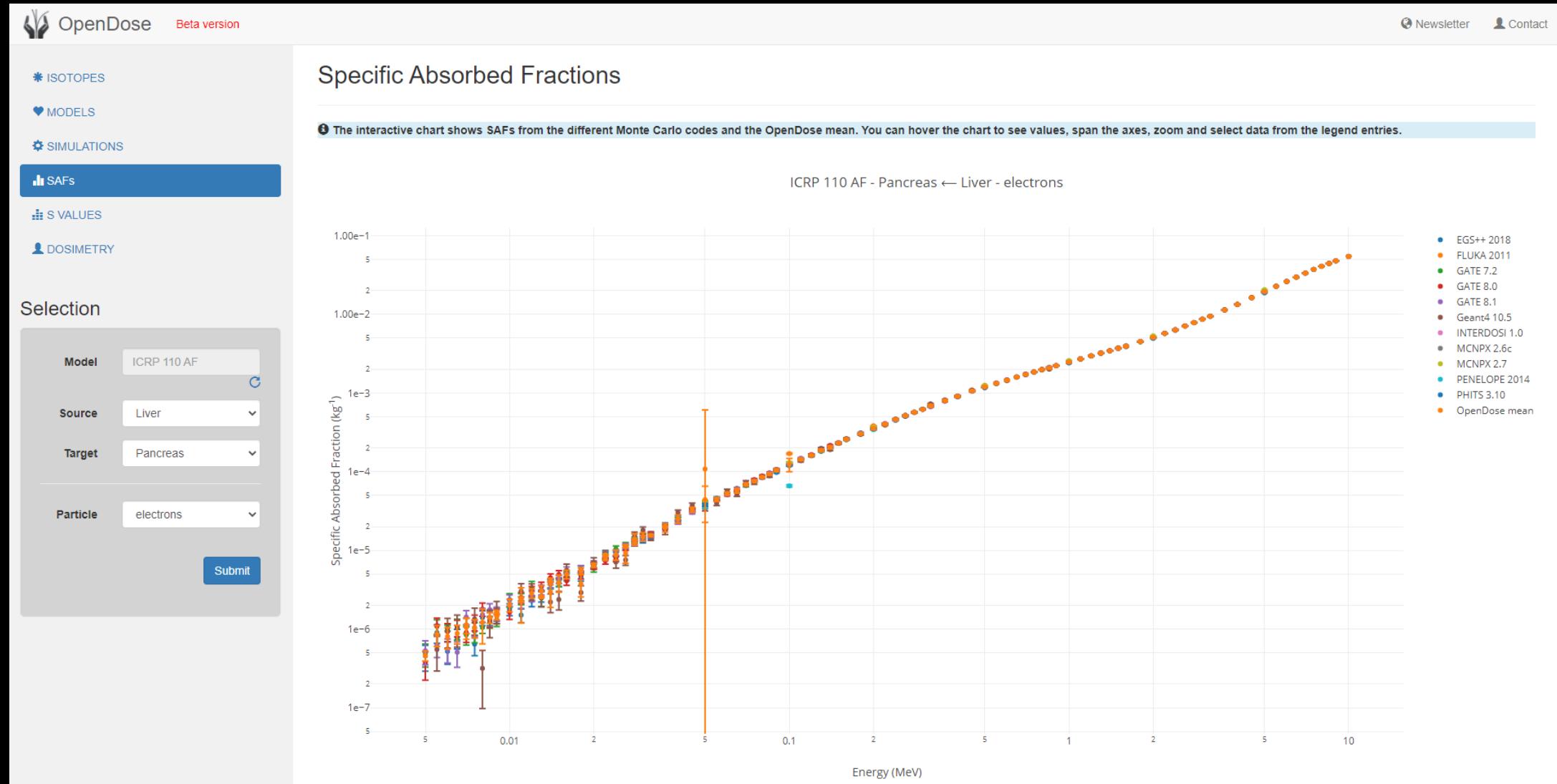
13-03-2020 - OpenDose article published in the Journal of Nuclear Medicine

**Title:** OpenDose: open access resources for nuclear medicine dosimetry.  
**Authors:** Maxime Chauvin, Damian Borys, Francesca Botta, Paweł Bzowski, Jérémie Dabin, Ana M. Denis-Bacelar, Aurélie Desbrée, Nadia Falzone, Boon Quan Lee, Andrea Mairani, Alessandra Malaroda, Gilles Mathieu, Erin McKay, Erick Mora-Ramirez, Andrew P. Robinson, David Sarrut, Lara Struelens, Alex Vergara Gil and Manuel Bardès for the OpenDose collaboration.  
<https://doi.org/10.2967/jnumed.119.240366>

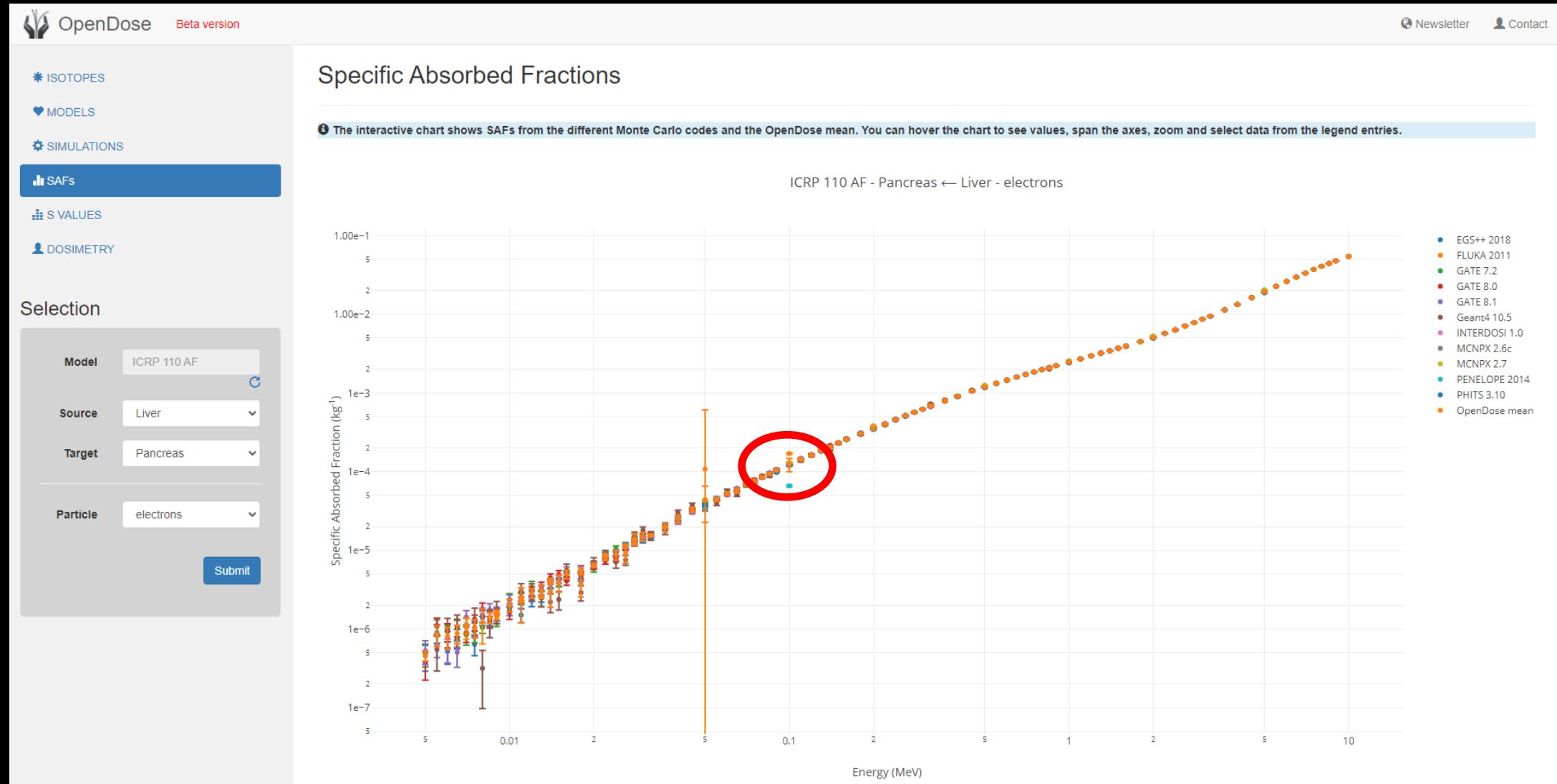
23-10-2019 - Presentation of OpenDose @ EURADOS WG6

Manuel Bardès presented OpenDose at the last EURADOS meeting of the Working Group 6.

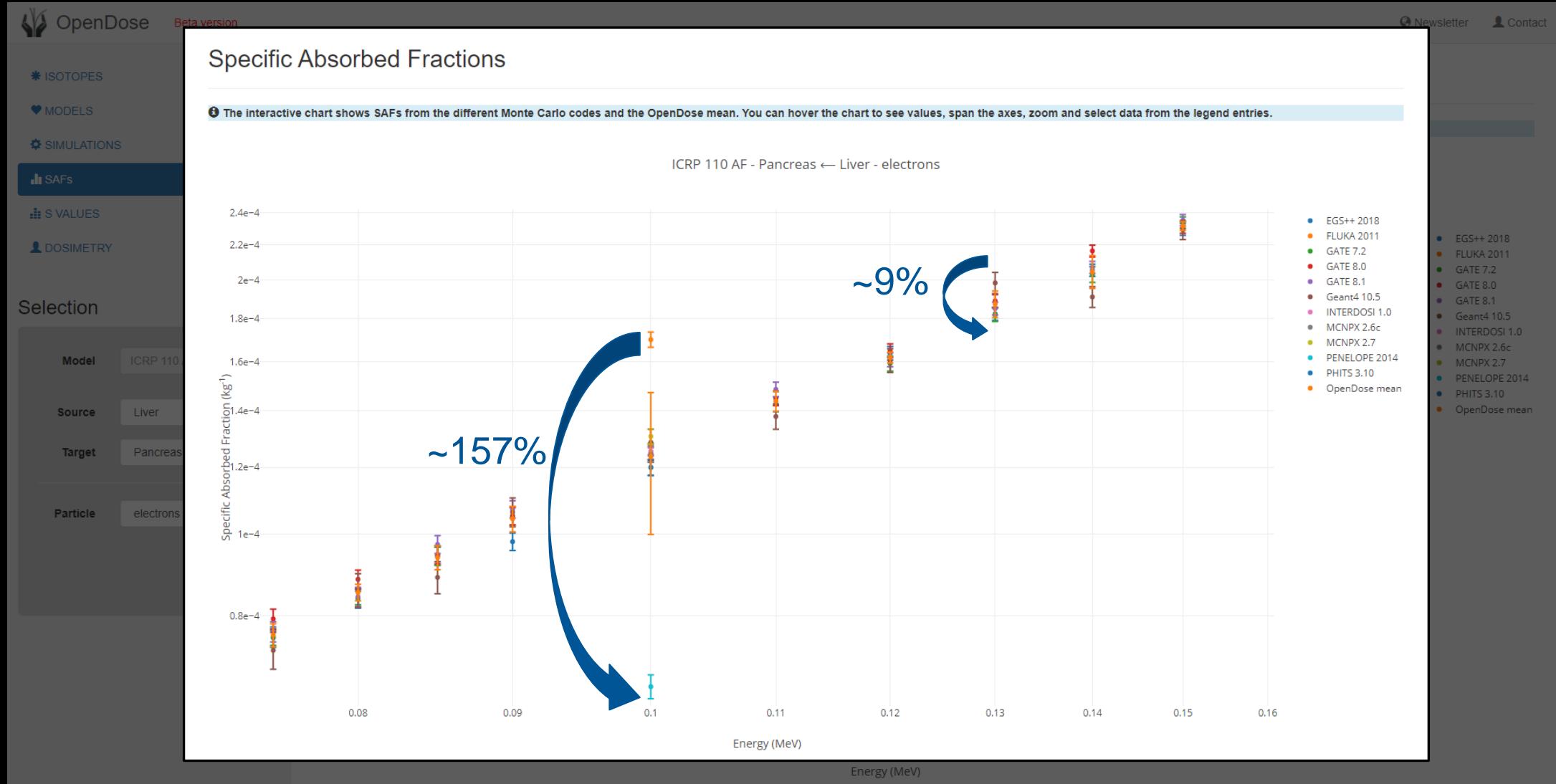
# SAF results: Pancreas ← Liver (electrons)



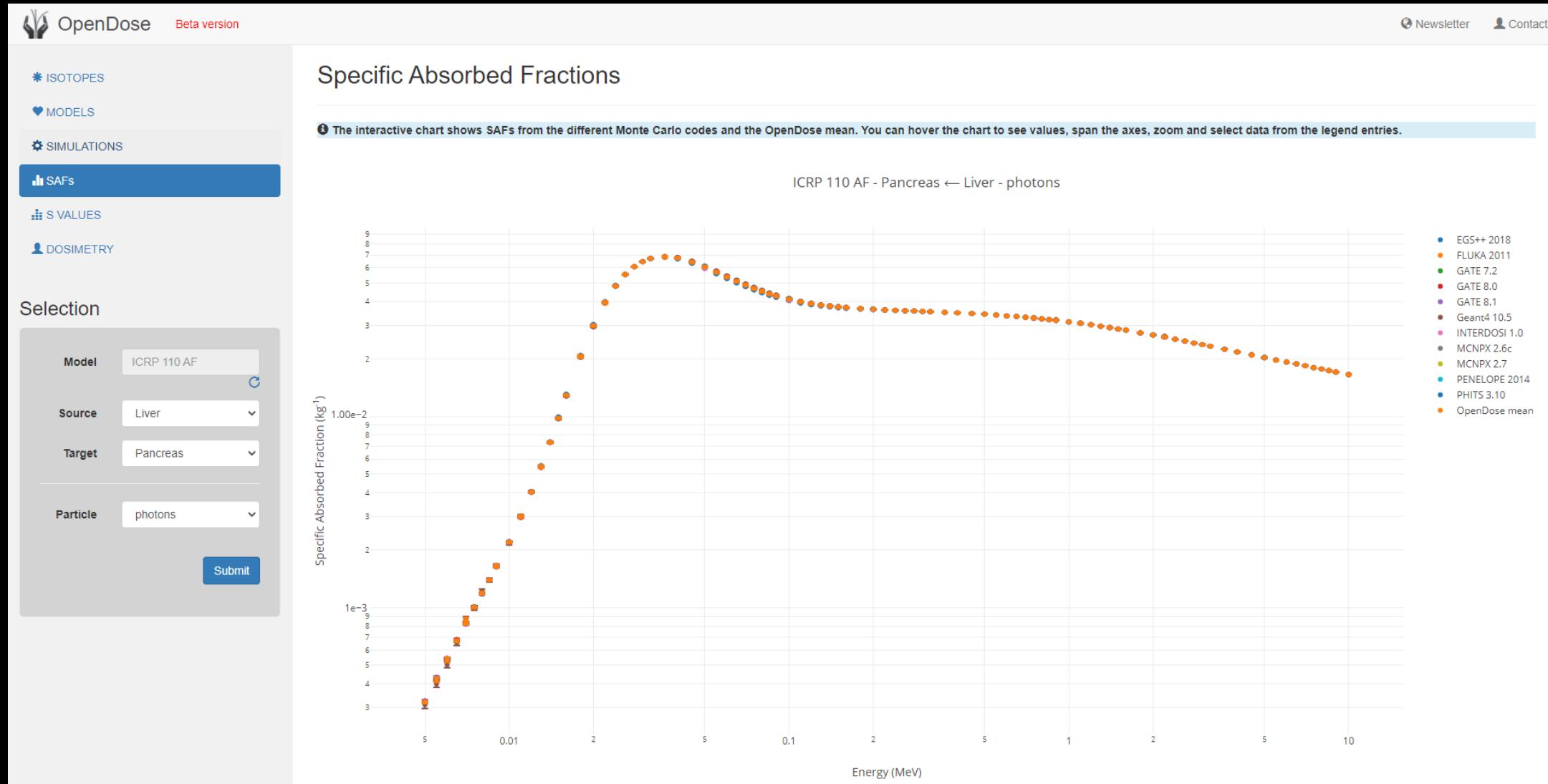
# SAF results: Pancreas ← Liver (electrons)



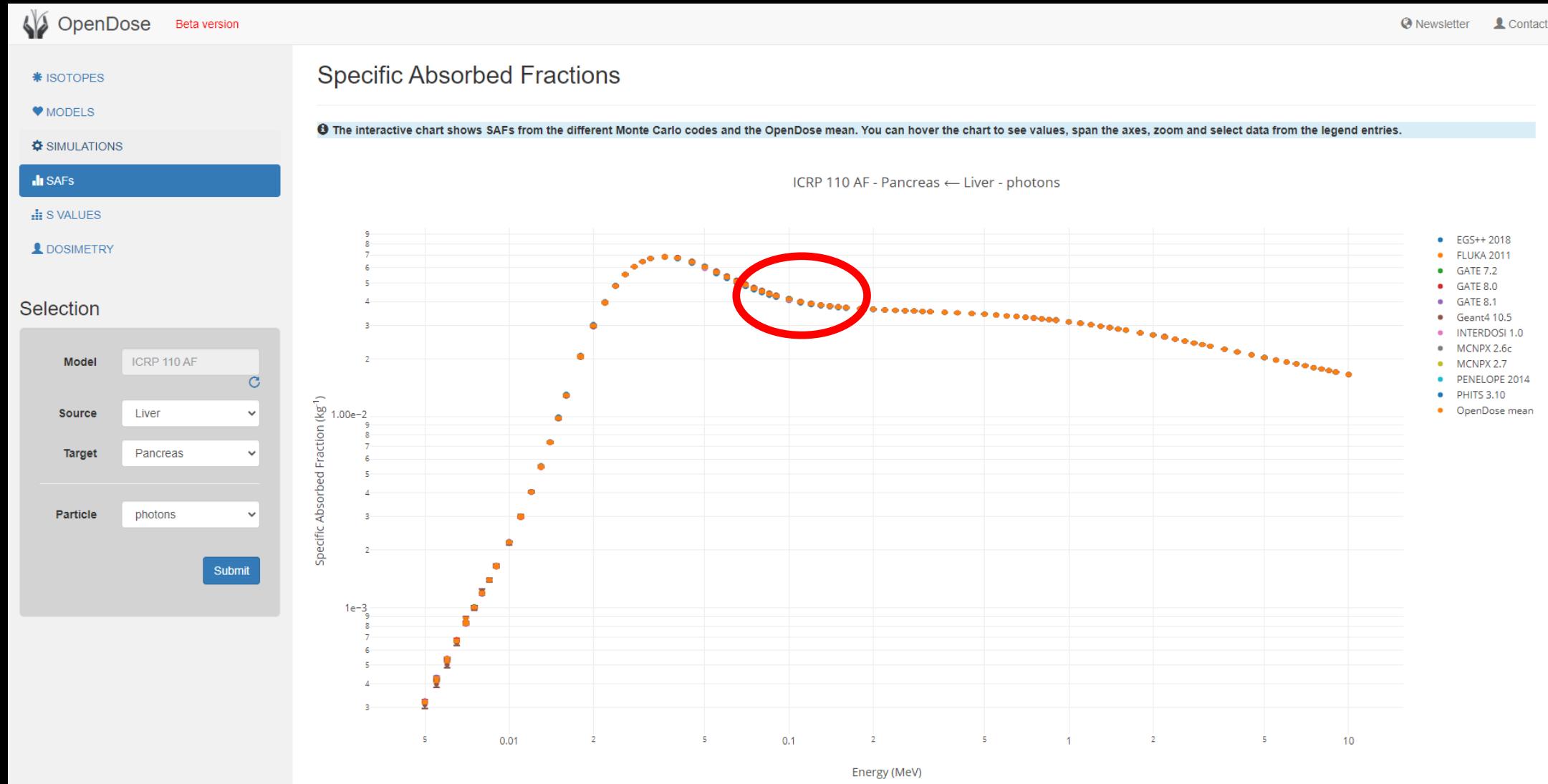
# SAF results: Pancreas ← Liver (electrons)



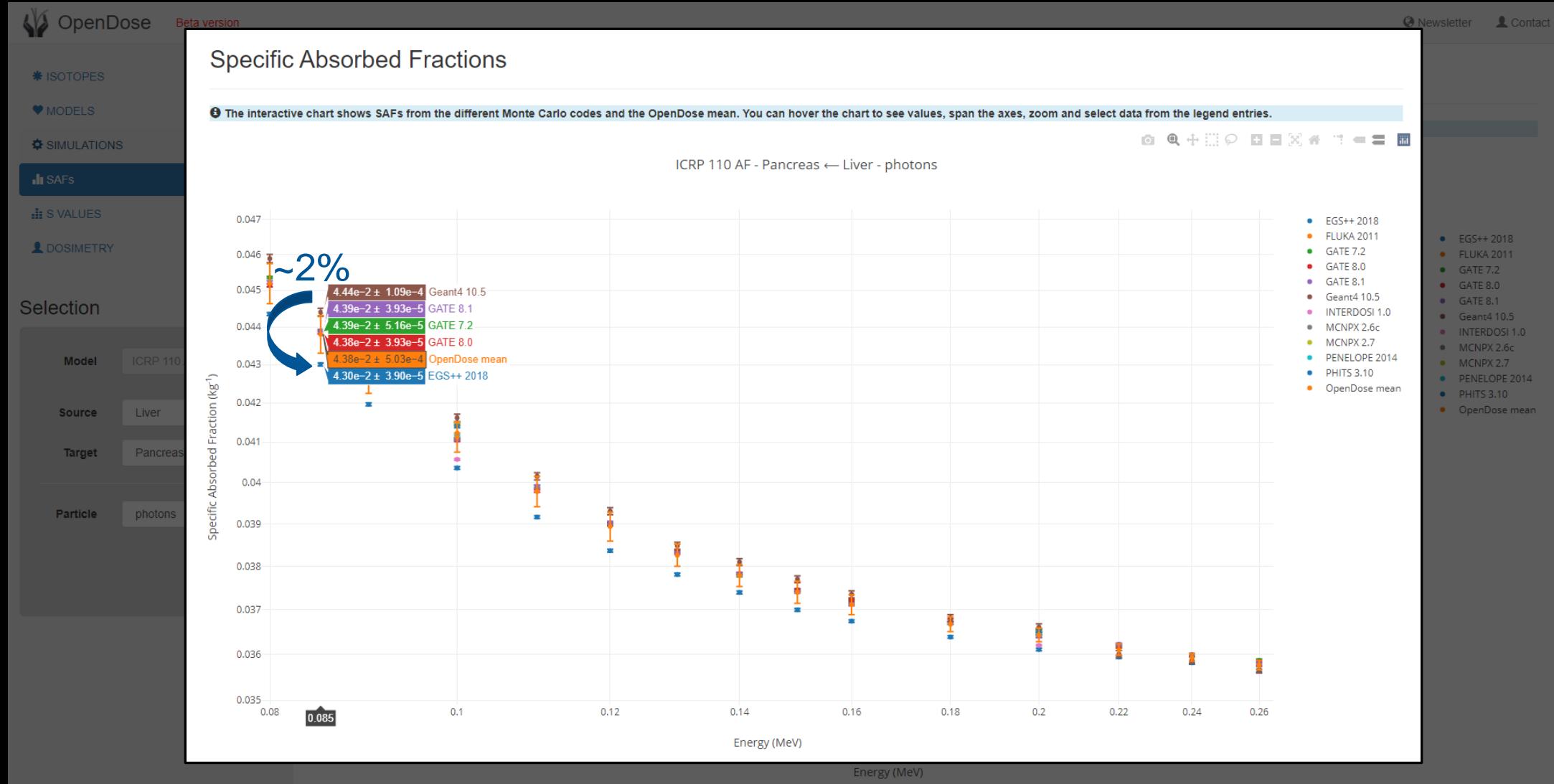
# SAF results: Pancreas ← Liver (photons)



# SAF results: Pancreas ← Liver (photons)



# SAF results: Pancreas ← Liver (photons)



# Validation of simulations

- Can you trust the results from a simulation?

- Yes - if the simulation has been validated

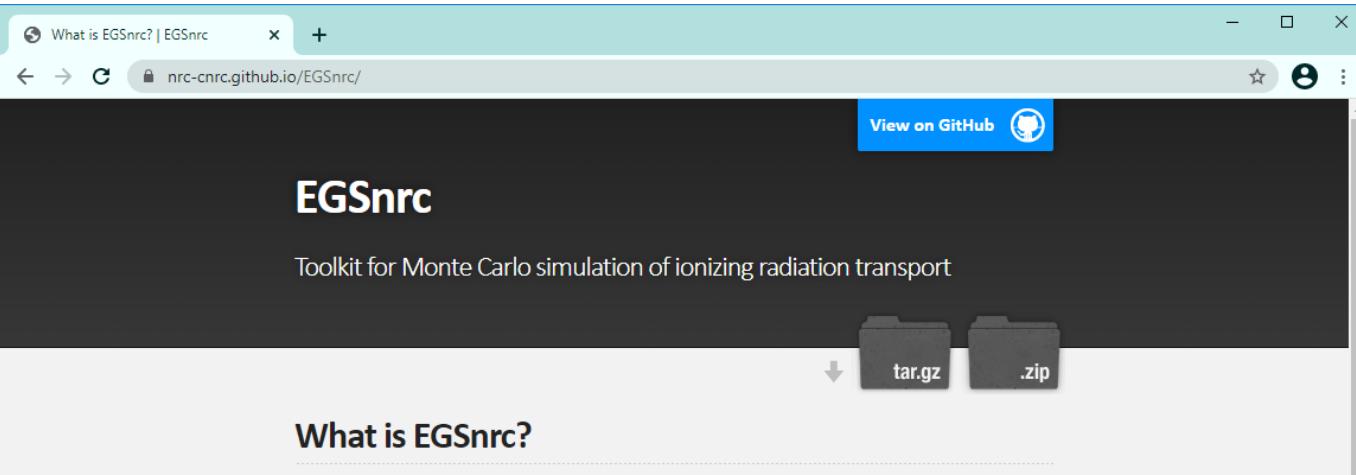
- ✓ Geometry
- ✓ Detector modelling
- ✓ Physics models (dependent on energy range)
- ✓ (Nuclear) Data

Comparison with experimental data

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

# Tools you can use

## EGSnrc (<https://nrc-cnrc.github.io/EGSnrc/>)



The screenshot shows the GitHub page for the EGSnrc project. At the top, there's a header with the project name and a 'View on GitHub' button. Below the header, the title 'EGSnrc' is displayed, followed by a subtitle 'Toolkit for Monte Carlo simulation of ionizing radiation transport'. Underneath, there are two download links: 'tar.gz' and '.zip'. The main content area is titled 'What is EGSnrc?' and contains a detailed description of the software, mentioning its history as a complete overhaul of the Electron Gamma Shower (EGS) package developed at SLAC in the 1970s, and its features like photon, electron, and positron propagation with kinetic energies between 1 keV and 10 GeV. It also notes the incorporation of crucial refinements in charged particle transport, better low energy cross sections, and the egs++ class library for geometry modeling.

EGSnrc is a software toolkit to perform Monte Carlo simulation of ionizing radiation transport through matter. It models the propagation of photons, electrons and positrons with kinetic energies between 1 keV and 10 GeV, in homogeneous materials. EGSnrc was originally released in 2000, as a complete overhaul of the Electron Gamma Shower (EGS) software package originally developed at the Stanford Linear Accelerator Center (SLAC) in the 1970s. Most notably, EGSnrc incorporates crucial refinements in charged particle transport, better low energy cross sections, and the egs++ class library to model elaborate geometries and particle sources.

DOI: [10.4224/40001303](https://doi.org/10.4224/40001303)

### Documentation

- [Getting Started](#) with guided tutorials
- [EGSnrc core manual \(PIRS-701\)](#)
- [BEAMnrc accelerators \(PIRS-509a\)](#)
- [DOSXYZnrc voxel dose \(PIRS-794\)](#)
- [egs++ geometries, sources and applications \(PIRS-898\)](#)
- [g application reference manual \(PIRS-3100\)](#)
- [RZ and SPH apps user manual \(PIRS-702\)](#)
- [RZ GUI egs\\_inprz \(PIRS-801\)](#)
- [BEAMDP basic manual \(PIRS-509e\)](#)
- [BEAMDP advanced manual \(PIRS-509c\)](#)
- [STATDOSE 3D dose processor \(PIRS-509f\)](#)

# Tools you can use

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

The screenshot shows the official website for MCNP, a Monte Carlo N-particle transport code. The page is hosted by Los Alamos National Laboratory. The header features the Los Alamos logo and the title "A General Monte Carlo N-Particle (MCNP) Transport Code". The main content area includes the MCNP6 logo, the text "Monte Carlo Methods, Codes, & Applications Group" and "Los Alamos National Laboratory", and a detailed "ABSTRACT" section describing the code's capabilities. A sidebar on the left provides links to various MCNP resources like news, FAQ, and user manuals. A "CONTACTS" section at the bottom lists the MCNP Team and Web Admin. A "SECURED BY SSL" badge is visible near the bottom left.

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

**mcnp** HOME

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

**CONTACTS**

MCNP Team  
MCNP Web Admin

SECURED BY SSL

**MCNP Highlights**

Additions to MCNP Reference Collection (2020-09-13)  
MCNP6 SQA Plan & Requirements, LA-UR-20-26666  
Additions to MCNP Reference Collection (2019-11-07)

# Tools you can use

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

The screenshot shows the official Geant4 website at <https://geant4.web.cern.ch/>. The page has a light blue header with the CERN Accelerating science logo and a search bar. Below the header is the large GEANT4 logo with the tagline "A SIMULATION TOOLKIT". The main content area starts with an "Overview" section, which describes Geant4 as a toolkit for particle simulation. It features four main navigation boxes: "Applications" (with an image of a satellite), "User Support" (with an image of a globe and various components), "Publications" (with an image of a detector), and "Collaboration" (with an image of a group of people). To the right, there is a "News" sidebar with a list of recent updates. At the bottom, there is an "Events" section and a "Past events" link.

Geant4 (https://geant4.web.cern.ch/)

G4 Overview | geant4.web.cern.ch +

CERN Accelerating science

Sign in Directory

GEANT4 A SIMULATION TOOLKIT

Download | User Forum Contact Us | Bug Reports

Geant4

### Overview

Geant4 is a toolkit for the simulation of the passage of particles through matter. Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science. The three main reference papers for Geant4 are published in Nuclear Instruments and Methods in Physics Research A 506 (2003) 250-303, IEEE Transactions on Nuclear Science 53 No. 1 (2006) 270-278 and Nuclear Instruments and Methods in Physics Research A 835 (2016) 186-225.

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

**User Support** Getting started, guides and information for users and developers

**Publications** Validation of Geant4, results from experiments and publications

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

### Events

26<sup>th</sup> Geant4 Collaboration Meeting, at IRISA Laboratories, Rennes (France), 20-24 September 2021.

Past events

News

2021-03-10  
2021 planned developments.

2021-02-05  
Patch-01 to release 10.7 is available from the [Download area](#).

2020-11-06  
Patch-03 to release 10.6 is available from the [Download archive area](#).

# Tools you can use

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

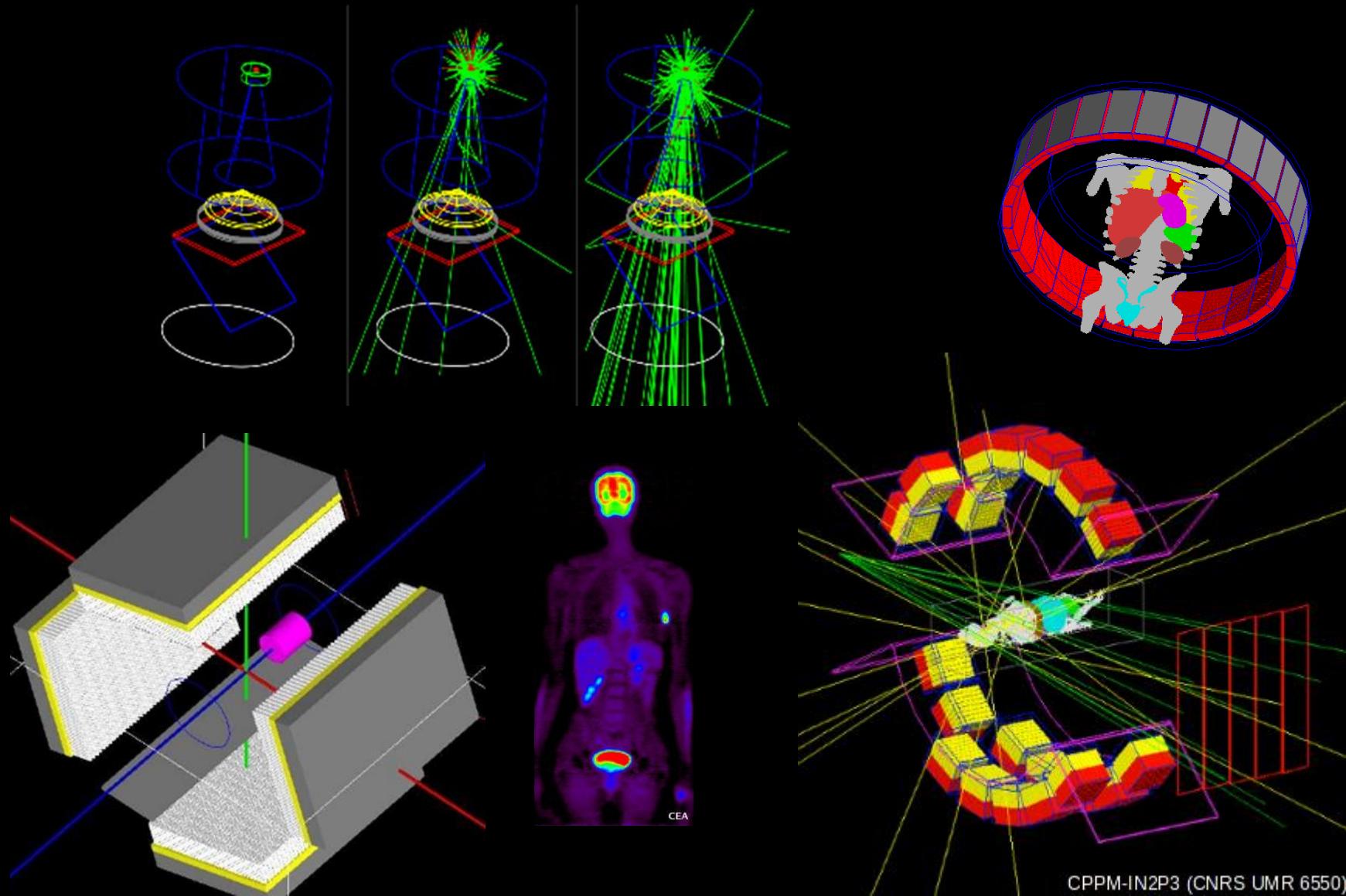
The screenshot shows a web browser displaying the GATE website at [www.opengatecollaboration.org](http://www.opengatecollaboration.org). The page features the GATE logo at the top center. Below the logo is a navigation bar with links for MAILING-LIST, DOWNLOAD, DOCUMENTATION, EVENTS, PUBLICATIONS, OPPORTUNITIES, COLLABORATION, and a search icon. The main content area contains a large image of a 3D simulation visualization. The visualization depicts a cylindrical object, likely a phantom, with various internal structures colored in green, red, and blue. Numerous thin lines, representing particle tracks or rays, originate from the left side of the cylinder and fan out towards the right. A coordinate system is overlaid on the simulation, with axes labeled 'X 20 cm', 'Y 20 cm', and 'Z 80 cm'. To the left of the simulation, there is a white callout box containing the text: "GATE is an advanced opensource software developed by the international OpenGATE collaboration". At the bottom of the page, a footer text states: "GATE is an advanced opensource software developed by the international OpenGATE collaboration and dedicated to numerical simulations in medical imaging and radiotherapy. GATE is based on the Geant4 toolkit."

# GATE

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

MEMPHYS   
Metrology for Medical Physics

NPL   
National Physical Laboratory



```
. └── 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
- ✗ User developed data analysis tools

# Monte Carlo Training

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



## TRAININGS

*The OpenGATE collaboration in partnership with CNRS Formation Entreprises are proposing two annual trainings organized in France: one dedicated to beginner users and one dedicated to Python data analysis. Those trainings are provided in english, they are open to 20 users maximum with 3 teachers.*

*Further, the collaboration can propose special trainings for companies (on site) wishing to use GATE, don't hesitate [to contact us for](#) more information.*

**2022:**

- 

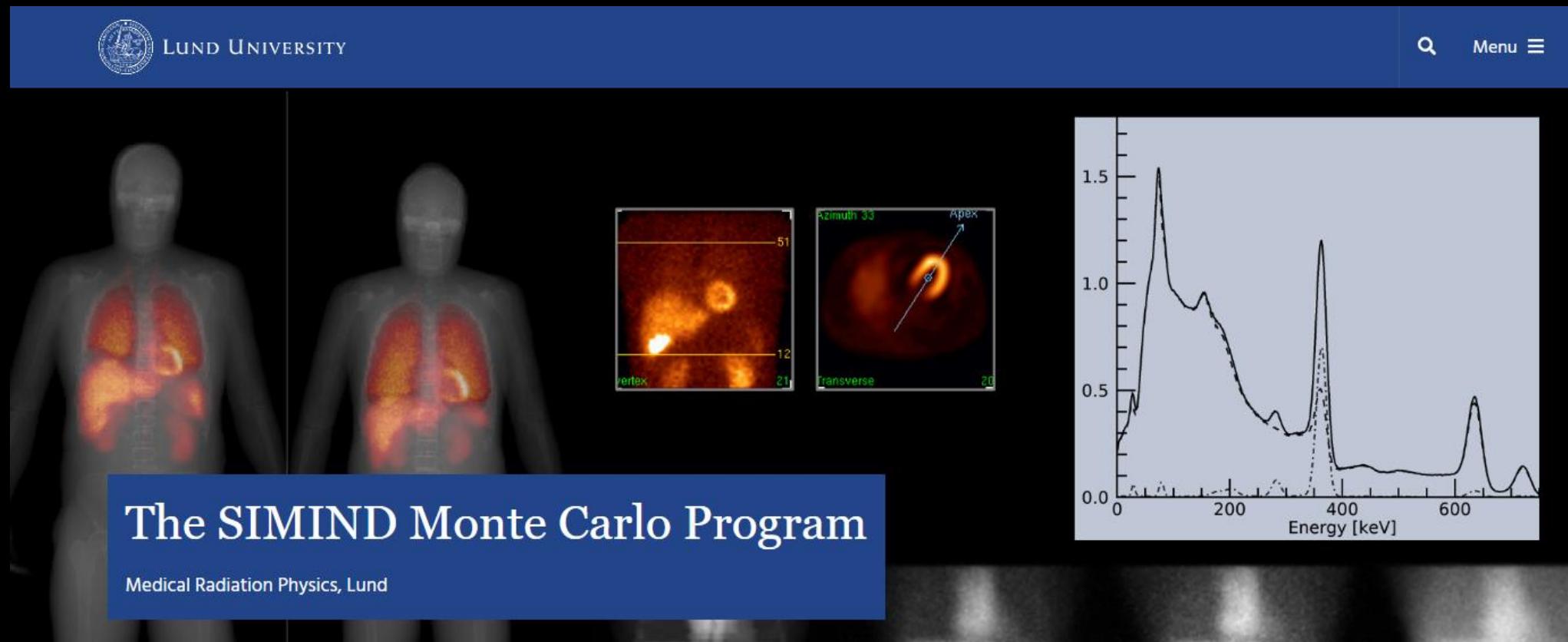
8-10 March: Python data analysis for GATE simulations, [Registration open](#)

# SIMIND (SPECT)

MEMPHYS  
Metrology for Medical Physics

NPL  
National Physical Laboratory

<https://simind.blogg.lu.se/>



<http://camino.cs.ucl.ac.uk/>

**UCL MICROSTRUCTURE IMAGING GROUP**



[UCL](#) » [CMIC](#) » [MIG](#) » [CAMINO](#) » [UCL Camino Diffusion MRI Toolkit](#)



## UCL Camino Diffusion MRI Toolkit

Camino is an open-source software toolkit for diffusion MRI processing. The toolkit implements standard techniques, such as diffusion tensor fitting, mapping fractional anisotropy and mean diffusivity, deterministic and probabilistic tractography. It also contains more specialized and cutting-edge techniques, such as Monte-Carlo diffusion simulation, multi-fibre and HARDI reconstruction techniques, multi-fibre PICO, compartment models, and axon density and diameter estimation.

**Home** | Camino has a modular design to enable construction of processing pipelines that include modules from other software packages. The toolkit is primarily designed for unix platforms and structured to enable simple scripting of processing pipelines for batch processing. Most users use linux, MacOS or a unix emulator like cygwin running under windows. However, the core code is written in Java and thus is simple to call from other platforms and programming environments, such as matlab running under unix or windows.

**Download** | The microstructure imaging group at UCL lead development and maintenance of the toolkit. The [PICSL](#) group at the University of Pennsylvania also contribute heavily, as have Geoff Parker and colleagues at the University of Manchester.

**Tutorials** | Many of the specialist modules arise from the research of the MIG and collaborating groups. However, the toolkit also includes implementations of many other techniques in the literature that we have found useful.

**Command Lists** | We hope you find Camino useful. We welcome any feedback, contributions or suggestions for additions to the toolkit.

**Technical Documentation** | Camino is distributed under the Artistic License 2.0. The full text of the license is [here](#).

**Citations** | If you use Camino in your research, please include the appropriate citations from the [citations page](#).

**Support** |

**Related Links** |

Page last modified on November 12, 2013, at 08:44 PM

Microstructure Imaging Group - University College London - Gower Street - London - WC1E 6BT -  +44 (0)20 7679 0221 - Copyright © 1999-2009 UCL. [Disclaimer](#) | [Accessibility](#) | [Privacy](#) | [UCL Search](#) | [UCL-CS Help](#) | [Edit](#) | [History](#) | [Print](#) | [Recent Changes](#) | [Search](#)

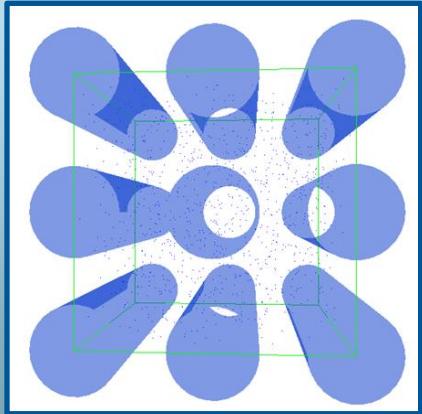
# MRI?

MEMPHYS  
Metrology for Medical Physics

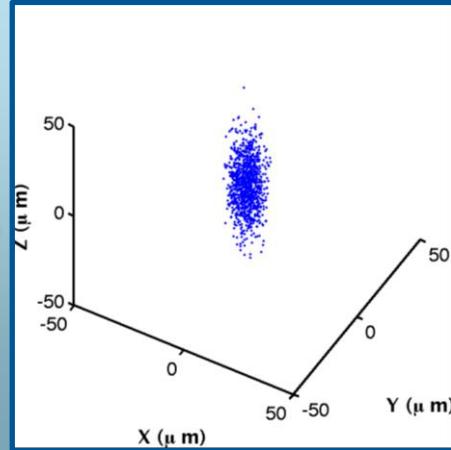
NPL  
National Physical Laboratory

## Simulation Pipeline

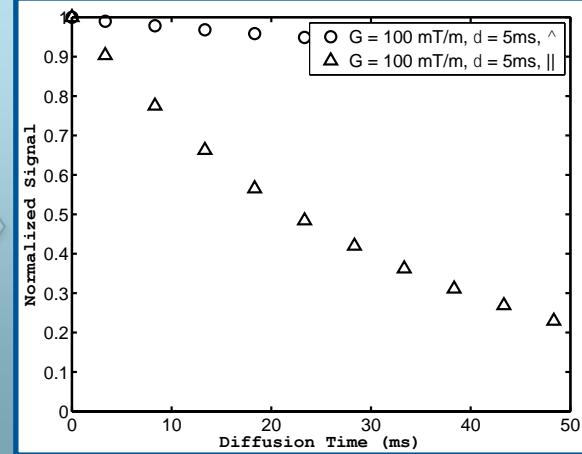
### Diffusion Substrate



### Displacement PDF



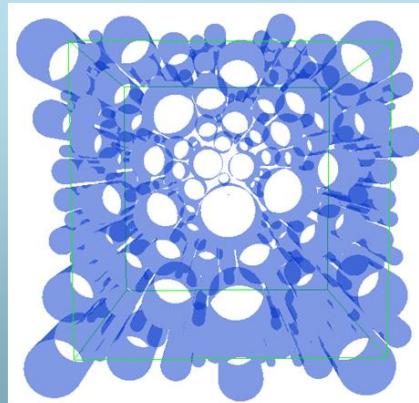
### Diffusion MR Signal



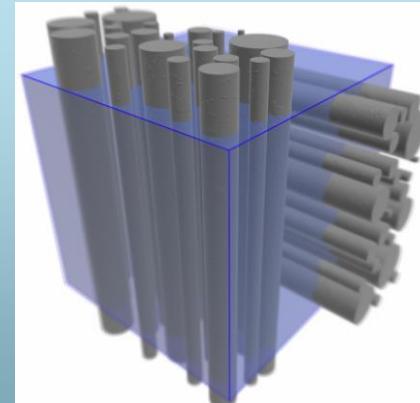
**Camino**  
Simulation and analysis for  
Diffusion MRI

Hall and Alexander  
IEEE TMI 2009

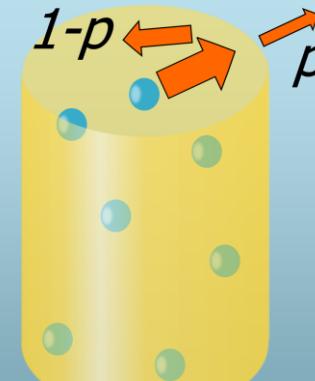
## Available Substrates



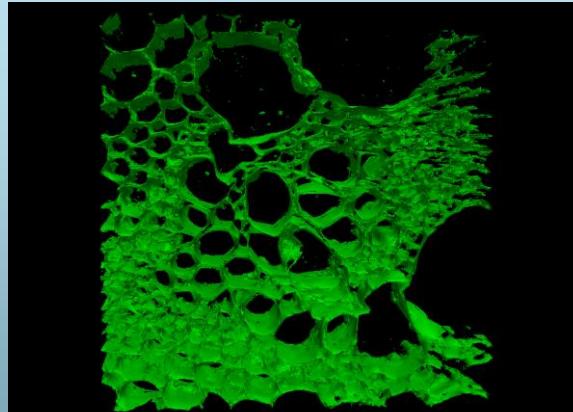
Gamma-Distributed Radii



Crossing Cylinders



Permeable Cylinders



Mesh-based substrates

# 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)
- ✓ (Nuclear) Data

Comparison with experimental data

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

# Getting Started with GATE



The screenshot shows a GitHub repository page for 'a-p-robinson / HSST-MonteCarlo-Lecture'. The repository is public and contains several files and folders:

- Commits:** a-p-robinson Added 2022 lecture slides (18 seconds ago), Lecture\_Demos (Adding files from 2018, 3 years ago), Getting\_Started\_wi... (Adding 2109 presentations, 3 years ago), HSST\_MonteCarlo\_... (Added 2022 lecture slides, 18 seconds ago), LICENSE (Initial commit, 3 years ago).
- About:** No description, website, or topics provided.
- Licenses:** MIT License.
- Statistics:** 0 stars, 2 watching, 0 forks.
- Releases:** No releases published. Create a new release.
- Packages:** No packages published. Publish your first package.
- Languages:** C 59.9% (represented by a green bar), Shell 40.1% (represented by a blue bar).

A message at the bottom encourages adding a README: "Help people interested in this repository understand your project by adding a README." A "Add a README" button is also present.

<https://github.com/a-p-robinson/HSST-MonteCarlo-Lecture/>

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

<https://opengate.readthedocs.io/en/latest/>

<https://gate.uca.fr/download/vgate>

<https://www.virtualbox.org/>



# Getting Started with GATE



## Navigation

- Introduction
- Getting started
- General concept
- Imaging application
- Radiotherapy and dosimetry applications
- Thermal therapy application
- Parallel computing
- GateTools
- vGate (virtual Gate)
- GATE using Docker

## Quick search

Go

## Welcome to GATE's documentation!

- Introduction
  - Authors
  - Forewords
  - Overview
  - The GATE mailing list
  - The GATE project on GitHub
  - GateRT
- Getting started
  - 1. Installation Guide V9.2
  - 2. Compiling GATE V9.2
  - 3. Validating Installation
  - 4. Enabling LUT Davis Model
- General concept
  - 1. Getting Started
  - 2. Defining a geometry
  - 3. Materials
  - 4. Setting up the physics
  - 5. Cut and Variance Reduction Techniques
  - 6. Source
  - 7. Voxelized source and phantom
  - 8. Tools to Interact with the Simulation : Actors
  - 9. How to run Gate
  - 10. Visualization
- Imaging application
  - 1. Defining a system
  - 2. Attaching the sensitive detectors
  - 3. Digitizer and readout parameters
  - 4. Data output
  - 5. Generating and tracking optical photons
  - 6. Compton camera imaging simulations: CCMod (TO BE ADDED SOON IN GATE 9.3)
  - 7. Third-party reconstruction software
- Radiotherapy and dosimetry applications
  - 1. Radiotherapy General Concept
  - 2. Beam modelling
- Thermal therapy application
  - 1. Nanoparticle mediated hyperthermia
- Parallel computing
  - 1. How to use Gate on a Cluster
  - 2. How to use Gate on a GPU
- GateTools
- vGate (virtual Gate)
  - Generalities
  - Miscellaneous
- GATE using Docker
  - GATE 9.2 on docker
  - Example to run GATE with Docker on your computer (unix-system):
  - Example to install GATE with Docker on Amazon Web Services (AWS) (Amazon Linux machine):
  - Example to install GATE with Docker on Amazon Web Services (AWS) (Ubuntu Linux machine):