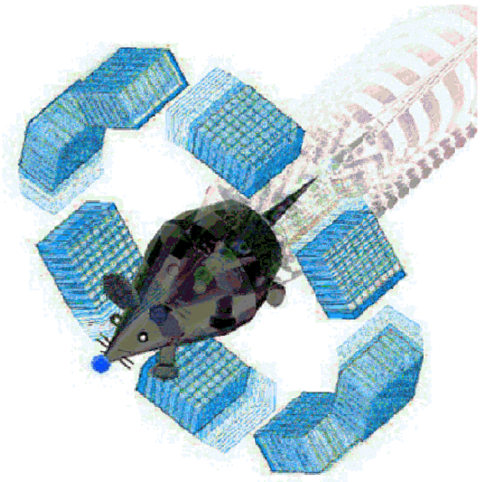
Importance sampling in GATE

Jan De Beenhouwer, Steven Staelens



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Overview

1. Importance sampling
2. Geometrical importance sampling (GIS)
3. GIS Integration in GATE
4. GIS Energy spectra / spatial resolution
5. Forced detection principle (FD)
6. FD weight corrections
7. FD energy spectra
8. GIS & FD efficiency

Importance sampling

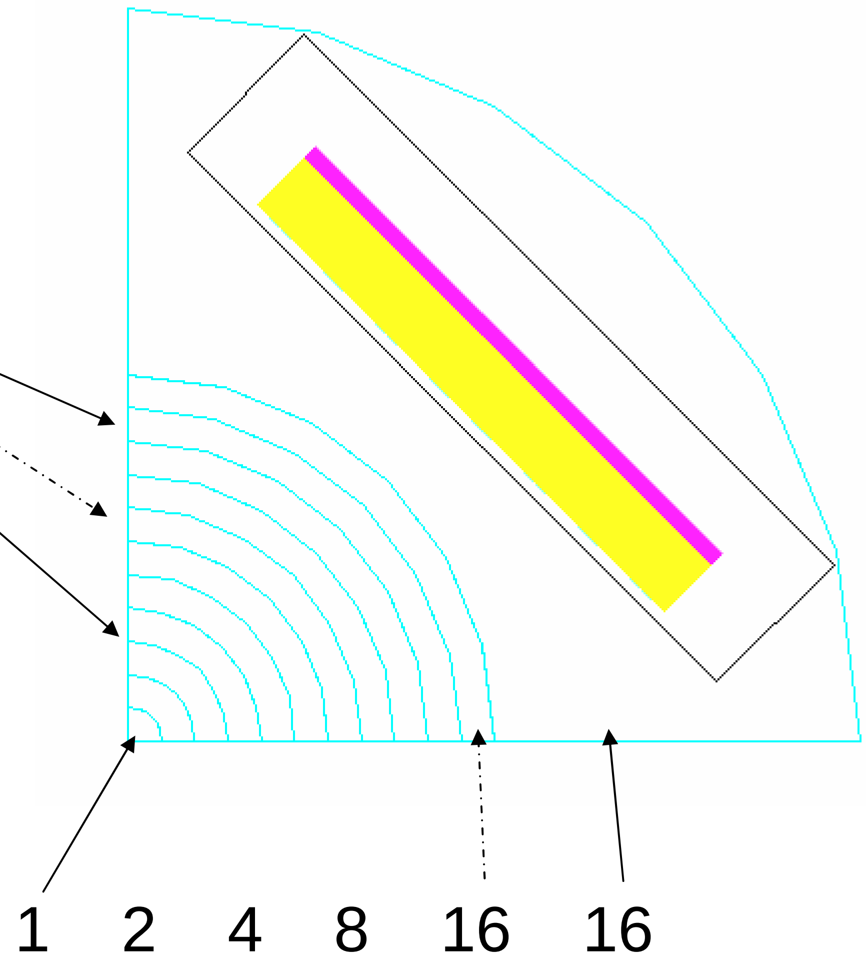
- Goal: to reduce computing time
- Idea: augmented sampling of interesting events : source biasing, leading particle biasing, geometry splitting, weight windows, forced detection
- Introduces bias, which is corrected for by introducing statistical weights
- Result : Equal mean value; reduced variance of mean value

Geometrical importance sampling

Divide a parallel world geometry up into importance cells

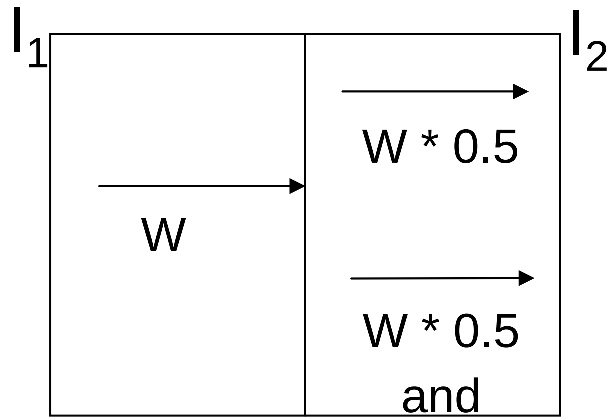
Assign an importance value to each cell

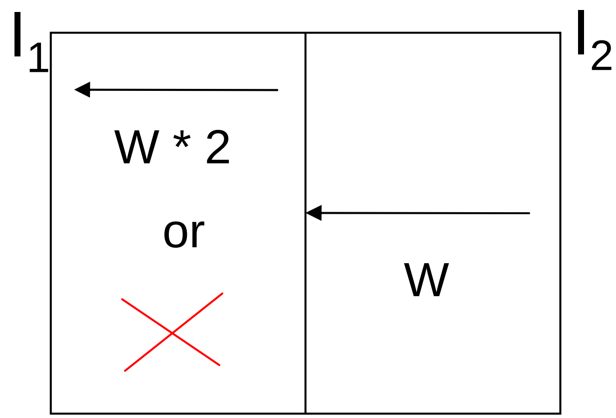
Apply splitting and Russian Roulette at cell borders according to an importance algorithm



Geometrical importance sampling

- For ex.: two cells with $I_2 = 2 * I_1$
- A particle is tracked through the parallel world
- when crossing from cell m to cell n: $r = I_n / I_m$
  1. if r = 1: continue transport
  2. if r < 1: play Russian roulette
  3. if r > 1: split into r tracks with $W_{new} = W / r$

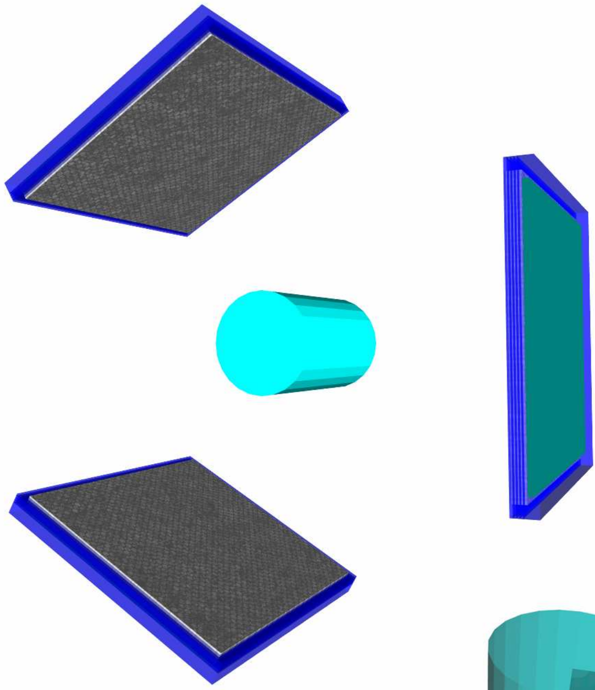


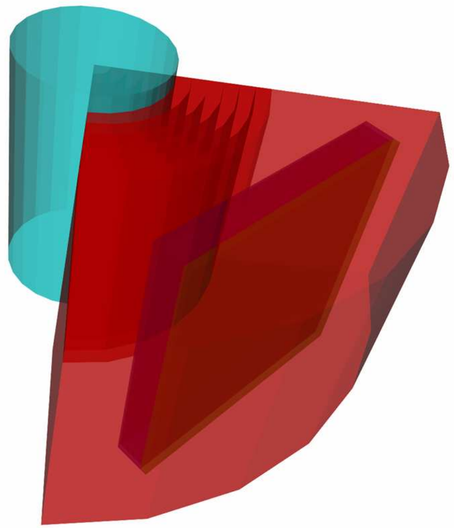


GIS integration in GATE

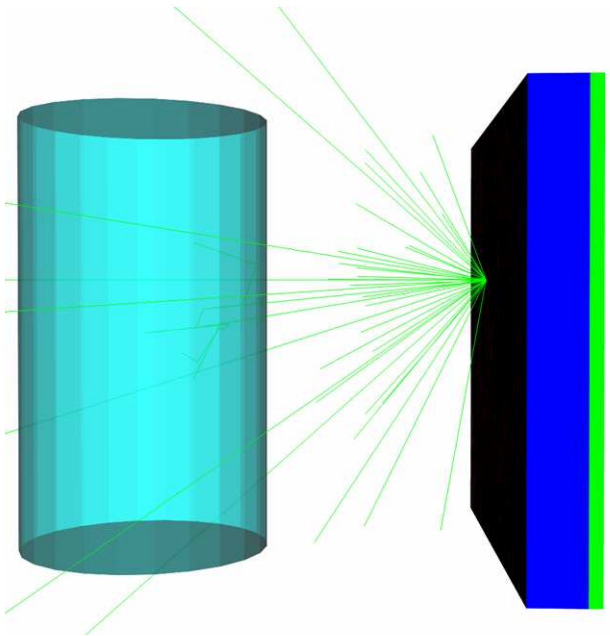
Rotational Importance Maps

- Necessary for multiheaded SPECT
- Synchronised with geometry movement of detector setup through the virtual clock in OpenGate
- Easy setup using the OpenGate script macros
- To be extended with automatic importance value generation

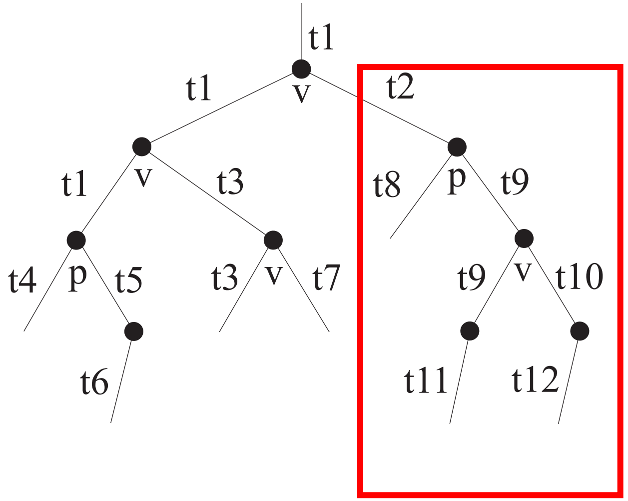




GIS integration in GATE

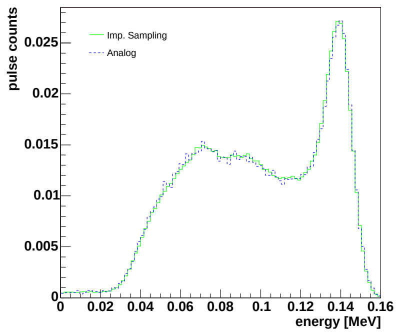


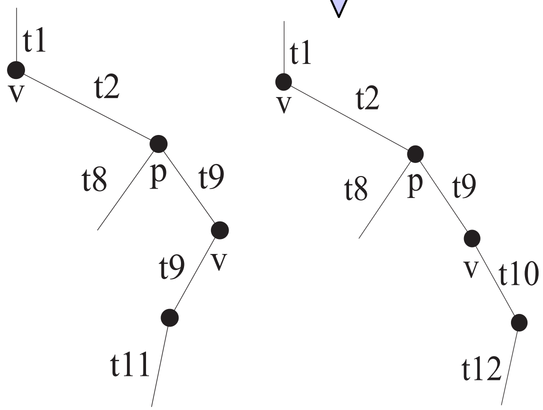
Record history



Analyse : GatePulseAdder

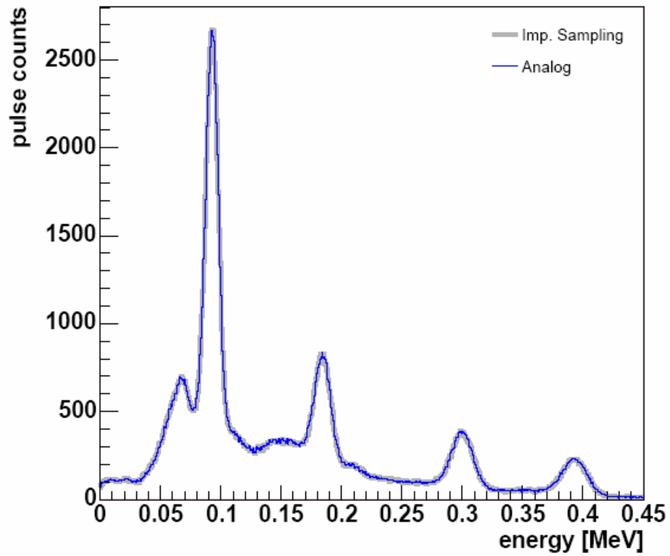
Weighted ROOT output

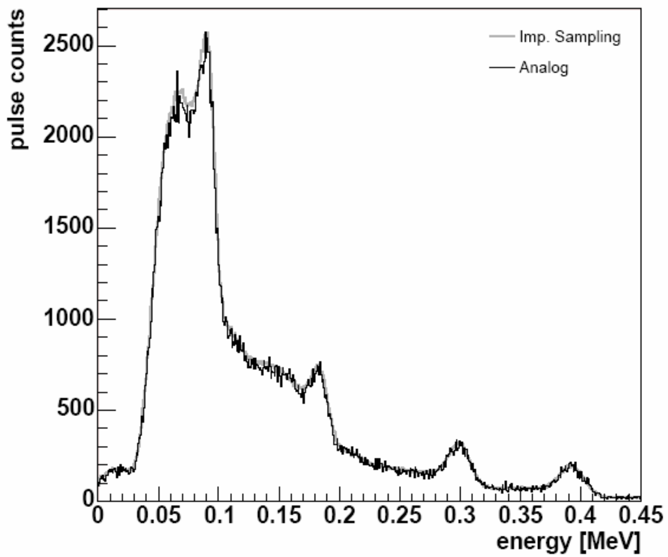




Weighted Interfile output

GIS energy spectra





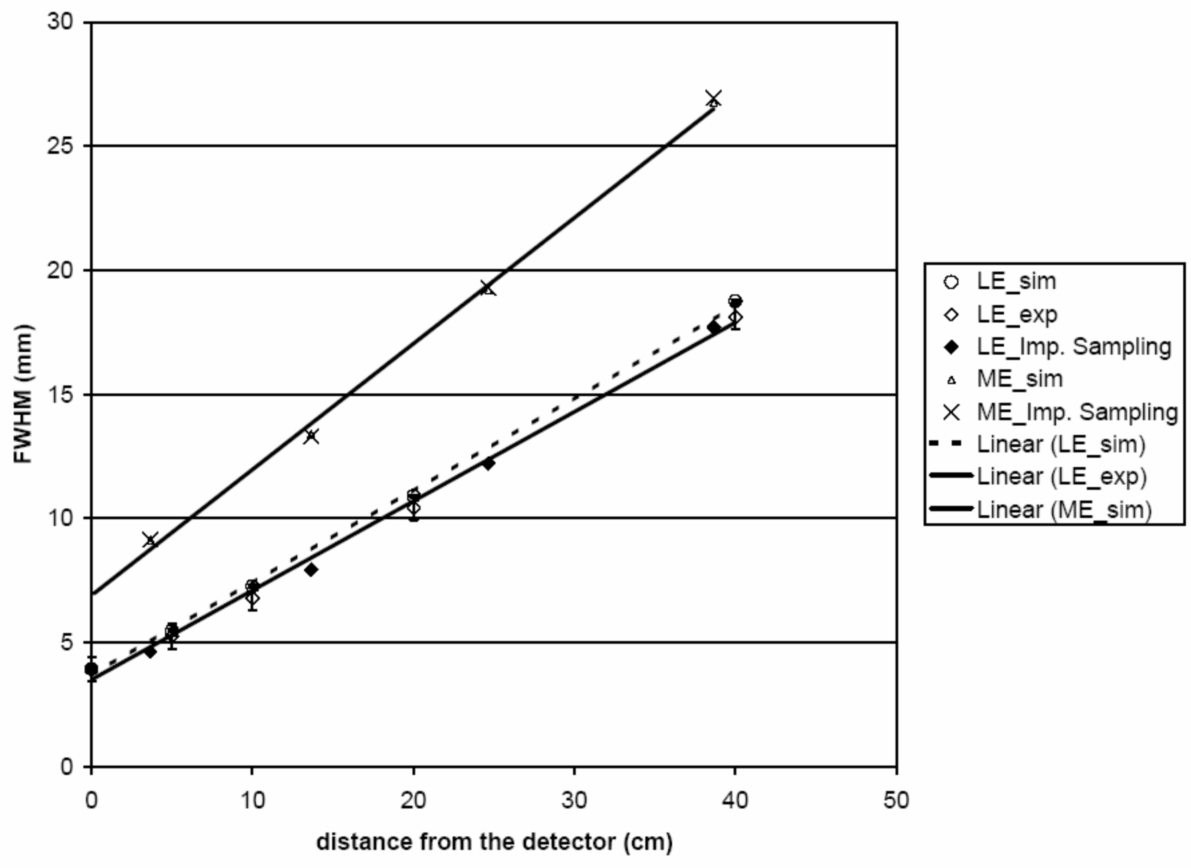
- Energy spectra are a first indication of validity of the particle history detangling

- A Ga67 point source with a radius of 1.5mm was used at a distance of 25cm from a realistic detector with a MEGP collimator.

- The source activity was 36 MBq for importance sampling and 250 MBq for the analog simulation, with an acquisition time of 30 seconds.

- As a final verification, the Ga67 point source was placed in the middle of a water phantom made of a cylinder with radius 12 cm and height 34.56 cm. An equal activity of 100 MBq for both cases was used over an acquisition time of 30 seconds.

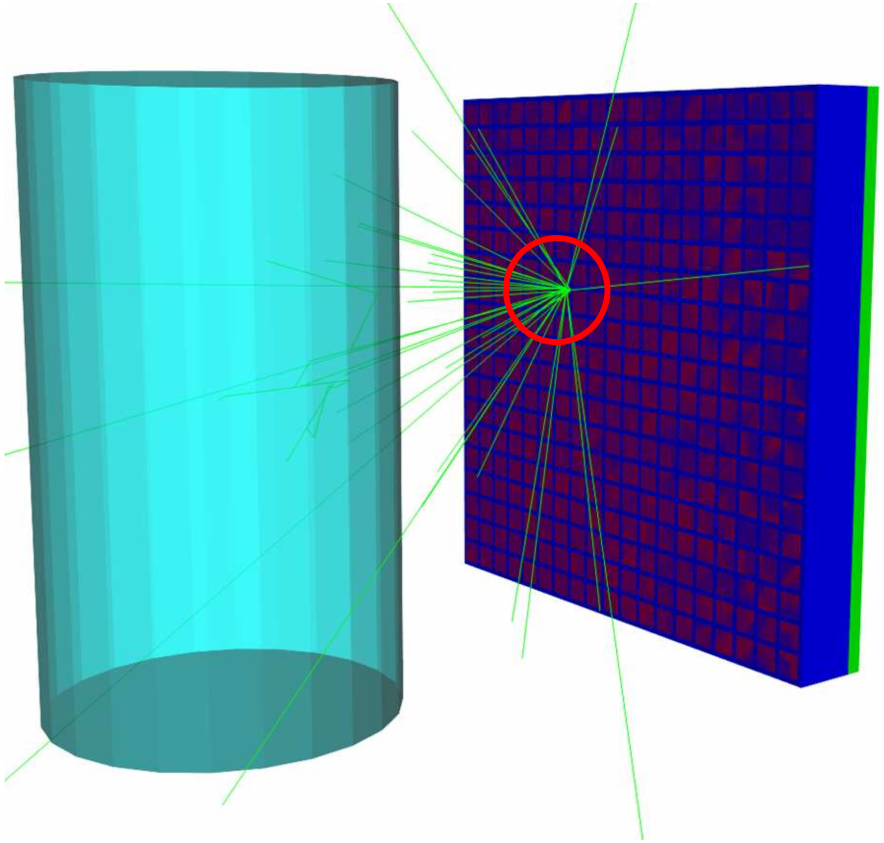
GIS spatial resolution



- Both a 99mTc and a Ga67 point source with a radius of 0.5 mm were placed at increasing distances from the detector

- For the 99*m*Tc simulations a photopeak window at 129-151 keV was used, while for 67Ga two photopeak windows were used : at 83.7-102.3 keV and at 171.1-198.8 keV.

Forced detection principle (FD)



Geometrical importance sampling generates multiple tracks to increase detection possibility

•The collimator still stops most photons

•Geometrical importance sampling cannot avoid this, unless by using an inefficient, fine importance map, on the level of collimator holes sizes.

Fast Simulation of Realistic SPECT Projections using Forced Detection in Geant4 (Embec 2005)

A. Goedicke, B. Schweizer, S. Staelens, J. De Beenhouwer

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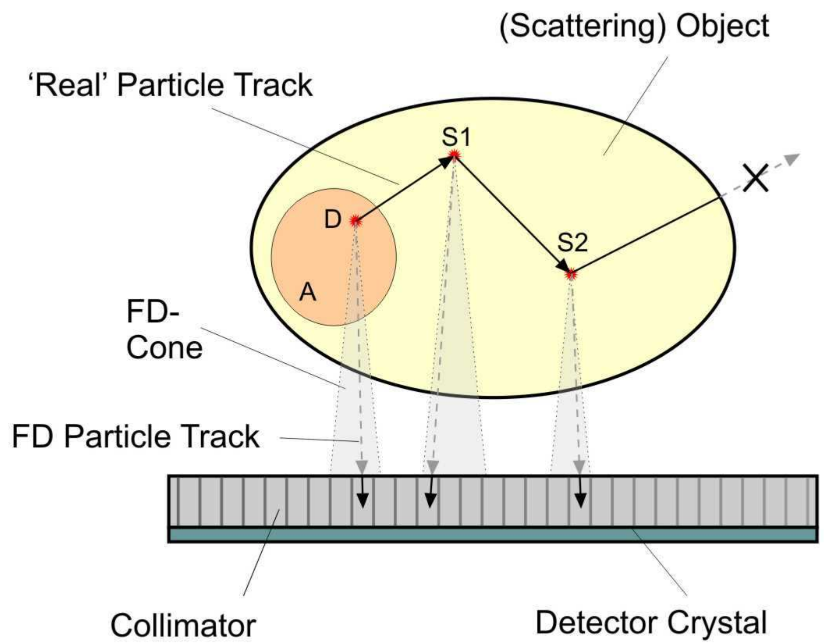
Forced detection principle (FD)

1. Photon generation is as usual
2. At each interaction point a copy of the photon is created
3. The copy is forced to escape the object in a direction within a cone around the detector normal
4. When the original photon leaves the object, it is destroyed
5. Within the FD cone, the daughter particle is projected onto the entry plane of the collimator, in order to be tracked from there by the analogue MC code again to simulate the collimator including septal penetration or scatter.



FD weight corrections

The daughter particle's weight is simply computed as the product of the three factors:

- the track probability of the mother before the interaction,
- the probability that the mother particle will be redirected to a path within the pre-defined FD cone, and
- the probability that no further interaction occurs until the particle reaches the collimator surface.

Interaction sites → Nuclear decay, Compton interaction

FD weight corrections

For a nuclear decay event, a virtual daughter is created with weight :

$$p^{(v)}{}_{d} = \boxed{\frac{\Omega_{Cone}}{4\pi}} \cdot p_T$$

propagation towards the detector within the pre-selected emission cone (solid angle Ω)

Probability that the particle reaches the detector without further interaction

$$p^{(m)}{}_{d} = 1 - p^{(v)}{}_{d}$$

Substract this from the weight of the mother

FD weight corrections

For a Compton interaction a virtual daughter that propagates towards the detector within the pre-selected cone is created with a weight :

$$p^{(v)}{}_{c} = p^{(m)}{}_{i} \cdot p_T \cdot \sigma_C^{-1} \cdot \int_{\Omega_{Cone}} \left(\frac{d\sigma_C}{d\Omega} \right) d\Omega$$

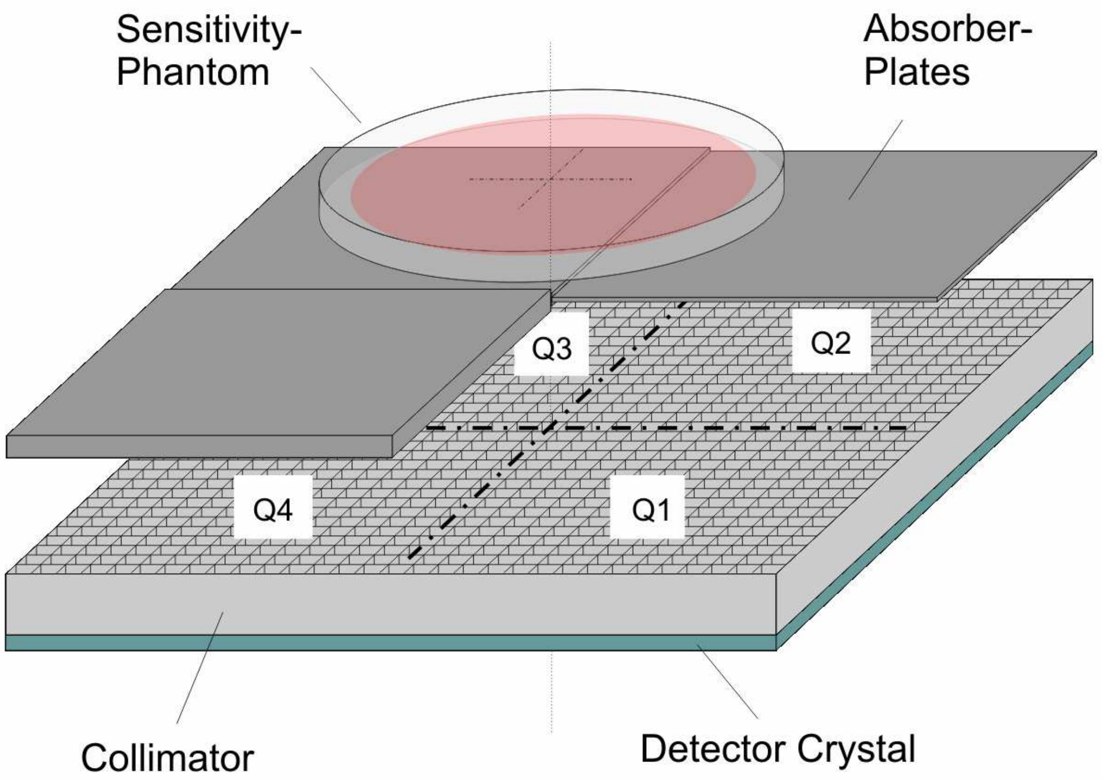
normalized to the total Compton cross-section to represent the probability that the mother is scattered into the cone.

Differential Compton cross section.

$$p^{(m)}{}_{i+1} = p^{(m)}{}_{i} - p^{(v)}{}_{c}$$

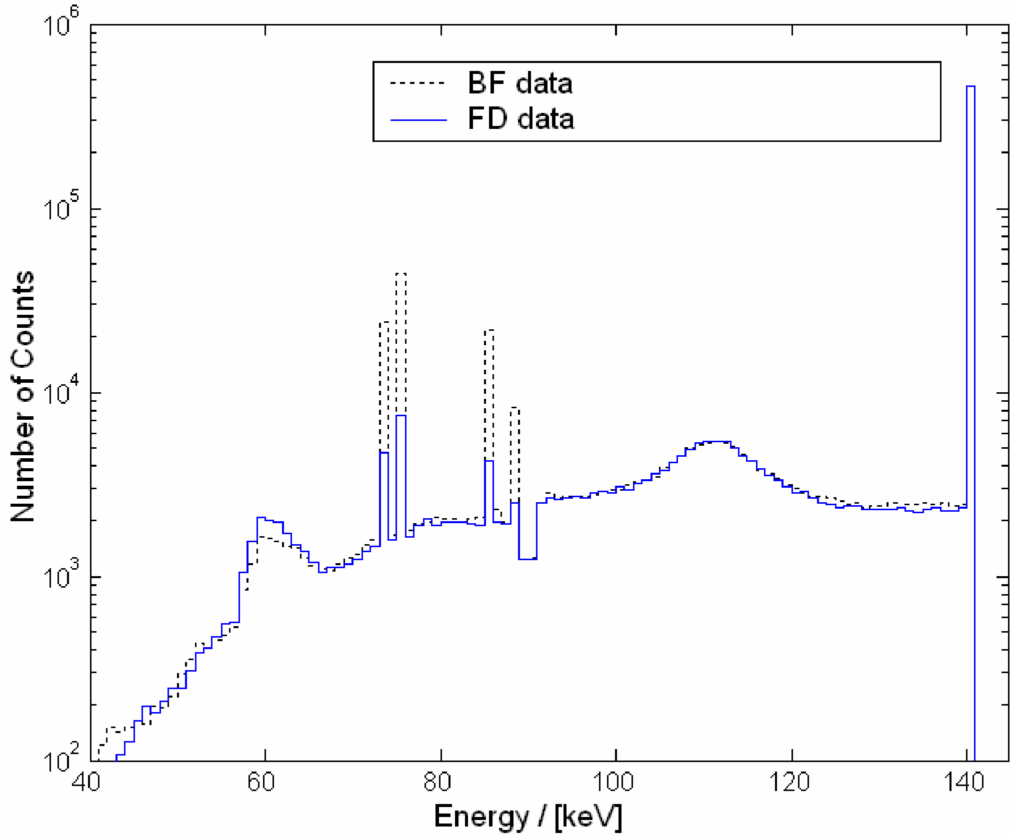
Substract this from the weight of the mother

FD results in Geant4



- Disk like phantom with a thin layer of Tc-99m solution in a cylinder (20 mm thickness, 300 mm diameter)
- Located above a pixellated solid state detector
- Lead absorber plates with one, two and three times a thickness of 0.52 mm, centrally located in the gap between the bottom face of the phantom and the collimator,

FD results in Geant4



- Due to the chosen FD cone angle the lead fluorescence is quantitatively underestimated by the FD approach, since the out-of-cone areas of the collimator, which also contribute to that part of the spectrum, are not hit by virtual particles.

solution → Enlarge FD cone but ... diminished performance

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Efficiency

- The efficiency of these techniques is inversely related to the sensitivity of the detector
- The acceleration compared to an analogue simulation is between 5 and 15 for GIS and between 105 and 159 for FD
- The FD code currently only covers the effects of nuclear decay and Compton scattering. An extension to include Rayleigh scattering and / or the photoelectric effect is considered. Especially lead fluorescence is not yet dealt with correctly
- FD is being integrated into GATE without modifications to GEANT4