Light Distribution Models for Compact γ-Camera

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Gate Technical Meeting
11/05/207

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Context

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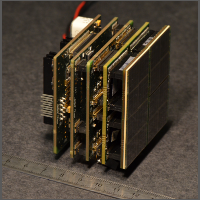
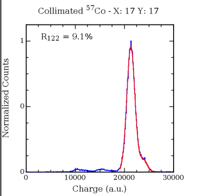
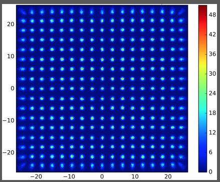
- Compact γ-camera have interest in addition to counting probe for radio-guided tumor surgery (eg. SNOLL)
- Need of compact devices for use in contact with tissues for improved resolution, sensitivity and ergonomics

- We developed 2 light hand-held γ
  - 256 pixels dedicated photodetection module[1]
  - 5×5 cm^2 continuous $LaBr_3$:Ce (5, 6 mm)
  - 15 mm Pb collimator + lateral Pb shielding
  - High performances with submilimetric intrinsic spatial resolution
    $\rightarrow$ iterative fit of light distribution model
  - light weight (1.2 kg, 1.8 kg)

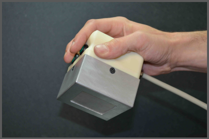






TReCam: PS-PMT

Magics: SiPM



[1] N. Dinu *et al.* NIMA 2015

- Need to fully understand our cameras and in particular how is the light distributed, to improve capabilities at low activities and short acquisition time.
  - Improve energy and spatial performances
  - Improve background rejection

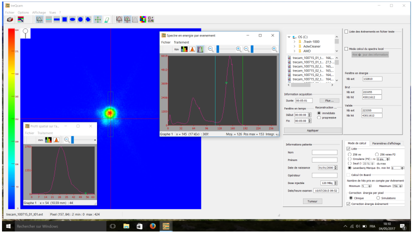
- TReCam is currently under clinical evaluation at Hospital Jean Verdier (Bondy) by surgeon Alexandre Bricou
  - He's using the camera in a SNOLL clinical protocol (breast cancer)
  - He's simulating realistic clinical cases and detector response with Gate

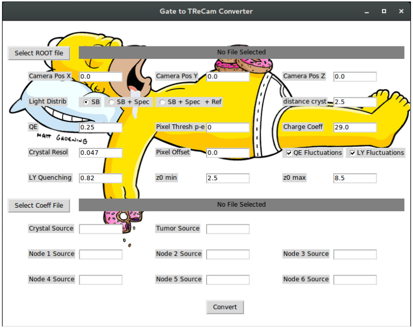
$\Rightarrow$ How to ease Gate simulation analysis and detector response simulation ?

Gate To TReCam

- gate_to_trecam is a small python GUI to convert Gate simulation (no optics) to our standard “clinical” tool format with detector parameter tuning
    - LY and intrinsic resolution of the crystal
    - Photodetector QE and fluctuations
    - Light distribution model

$\Rightarrow$ How is the light distributed on the photo-detector ?





- The Scrimger-Baker model[2] is the standard mode use to describe the distribution of light in a continuous scintillator.
  - x_0, y_0, z_0 are the coordinates of the position of interaction of the γ-rays in the scintillator
  - N_0 is the total number of photons emitted.

Scrimger-Baker Équation

$$\frac{dN(x_0, y_0, z_0)}{ds} = \frac{N_0}{2\pi z_0^2 \left(1 + \left(\frac{r}{z_0}\right)^2\right)^{\frac{3}{2}}}, \text{ with } r = \sqrt{(x - x_0)^2 + (y - y_0)^2} \quad (1)$$

- In our cameras it works quite well as a fitting model for spatial reconstructions (x_0, y_0) but not for DoI (z_0) and energy (N_0).

[2] JW Scrimger, RG Baker, Physics in medicine and biology 12.1 (1967)

- As this equation can be integrated, one can use it to generate a Monte Carlo set of "photons" positions (x, y) following a probability density of SB:

Scrimger-Baker random distribution

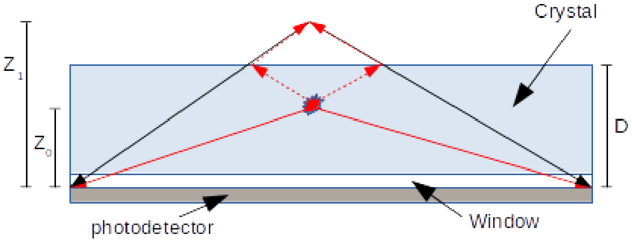
$$\begin{cases} x = x_0 + r \times cos(\theta) \\ y = y_0 + r \times sin(\theta) \end{cases} \quad \begin{cases} r = \sqrt{\frac{1}{(1-U)^2} - 1} \\ U \text{ random number on } [0, 1[\\ \theta \text{ random number on } [0, 2\pi[\end{cases} \tag{2}$$

- This model only represent the light emitted directly towards the photodetector: ie modeling very large crystals or with absorbing coating all around

Double Scrimger-Baker Model (1)

⇒ Can we upgrade this model to a more adapted to our cameras ?

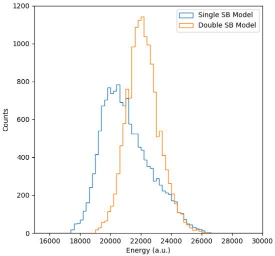
- Our crystals have absorbing coatings on the sides and reflective coating (diffusive) on the top (opposite to the photodetector)
  - Light is spread in two components (top and bottom)
    - Assuming specular reflection on top
    - Assuming no refraction/reflection on the bottom window
  - Each component is composed by a fraction light given by a solid angle



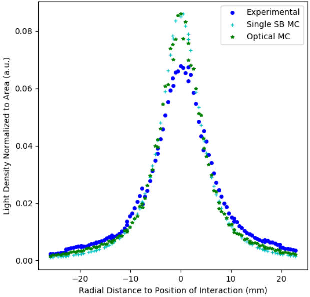
Double Scrimger-Baker Model

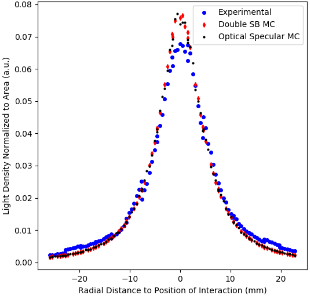
$$\begin{cases} \frac{dN(r,z_0)}{ds} = \frac{N}{2\pi\Omega}\left(\frac{\Omega_0(r,z_0)}{z_0^2\left(1+\left(\frac{r}{z_0}\right)^2\right)^{\frac{3}{2}}}\frac{\Omega_1(r,z_1)}{z_1^2\left(1+\left(\frac{r}{z_1}\right)^2\right)^{\frac{3}{2}}}\right) \\ r = \sqrt{(x-x_0)^2+(y-y_0)^2} \\ z_1 = 2D - z_0 \end{cases} \quad (3)$$

- Gate Simulation ^{57}Co 122 keV γ with these models
  - Single SB Spectrum asymmetric because of the term in $1/z_0^2$
  - Double SB Number of photons roughly independent of z_0



Light Density Profiles





- Comparison between experimental data, these 2 models and Gate (Optic)
  - Realistic Gate optics simu far from experimental data
    $\Rightarrow$ hard to get optical parameters with hygroscopic crystal
  - Better agreement between exp data , double SB model and specular Gate simu.

$\Rightarrow$ Need more work to fully understand our experimental behavior.

Summary

- We developed light hand held γ-cameras
- We need to have a better understanding of how light is distributed in our devices
  - To improve fitting model for position of interaction reconstruction
  - Perform better MC simulation of our detector for realistic clinical cases.
- We used a double Scrimger-Baker
  - Better agreement to our exp data than realistic optical simulation and standard SB model.
  - Need better evaluation of the optical parameter of our scintillator (use LUT Davis).

$\Rightarrow$ Current work on a range of non hygroscopic scintillator to test various reflective/absorbing coating to improve our models.
$\Rightarrow$ Also testing of neural network algorithm based on experimental data for position reconstruction.

Thanks for your attention !