Optical simulation for the Temporal project: study of scintillation photon detection time and SiPM modelisation

M, Dupont, C. Morel

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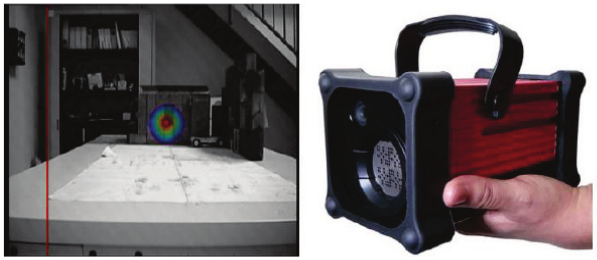
Outline

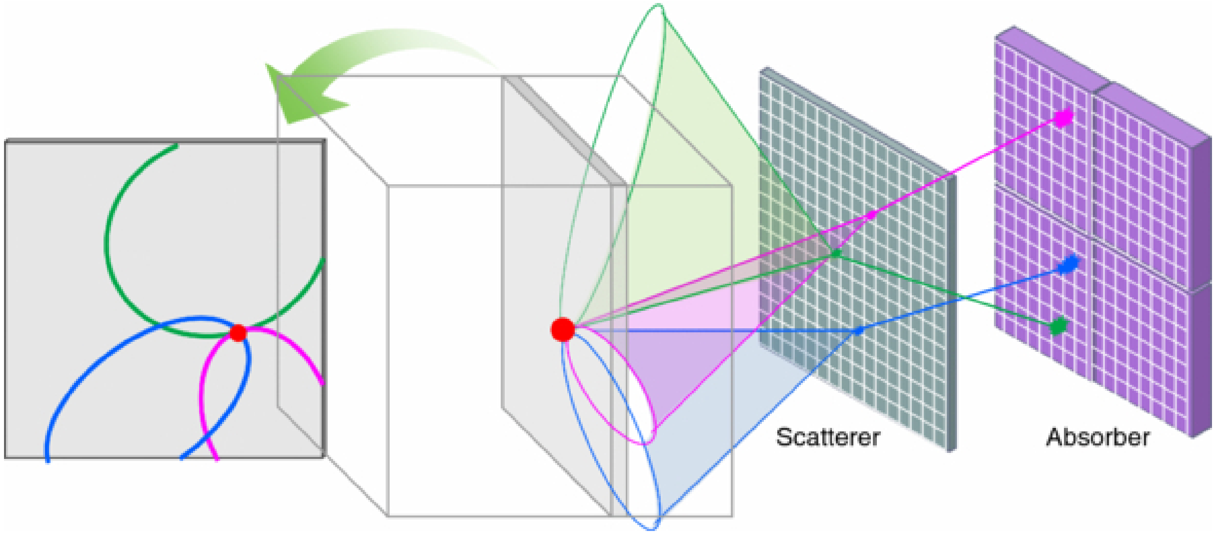
1) Presentation of Temporal project
2) Time study with GATE
3) SiPM modeling

Context: the **Temporal** Project

Aim: Development of a **Compton Camera** to help nuclear dismantling operations



Typical example of a camera

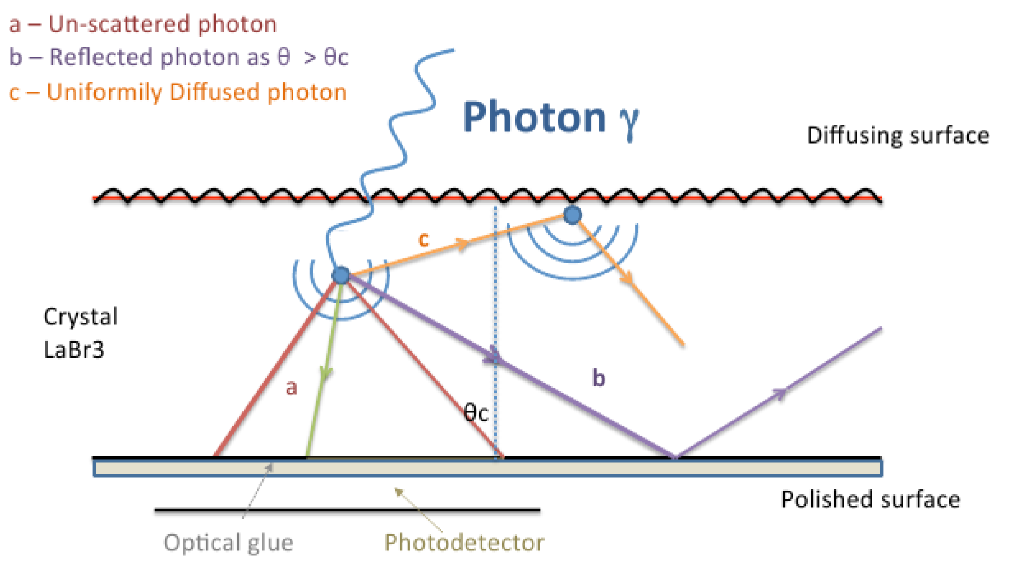


In temporal, each detector = Scintillation Crystal + SiPM

Problem : retrieve (x,y,z,E) of each interaction

Temporal Project: Position of scintillation

- After scintillation, optical photons emitted towards the detection surface will form a disc



- Using arrival time of optical photons in order to estimate the center and diameter of the disc of unscattered photons
- Need a good time resolution → Use SiPM

Goals with GATE on this problematic

- Implement a macro model (fully analytical without optical simulation) of the pair “Crystal/SiPM” like for the pair “Crystal/PMT” for fast simulation
- In the context of the Temporal project: perform a time accurate simulation of the pair “Crystal/SiPM”

  For this, we need to:

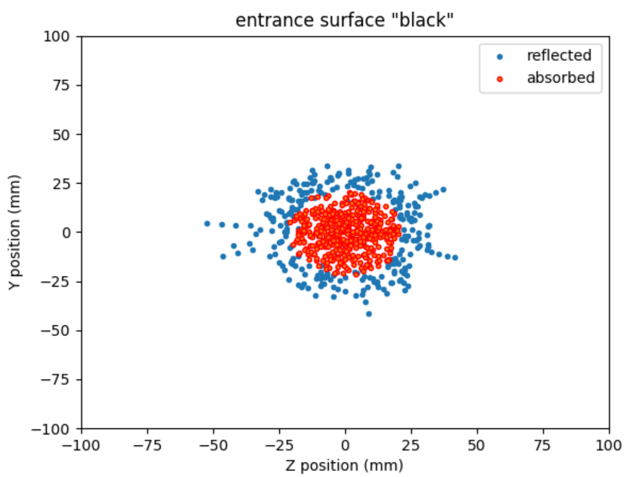
  - Fully simulate scintillation and follow each photon in the crystal
  - Treat each photoelectron in SiPM

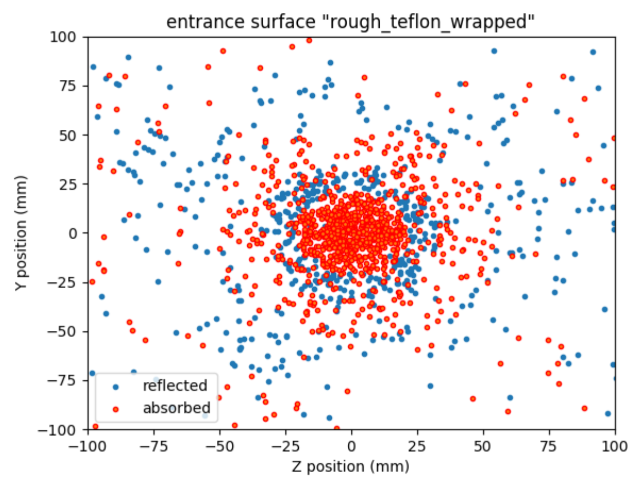
  This can be checked experimentally and used to calibrate the macro model implementation

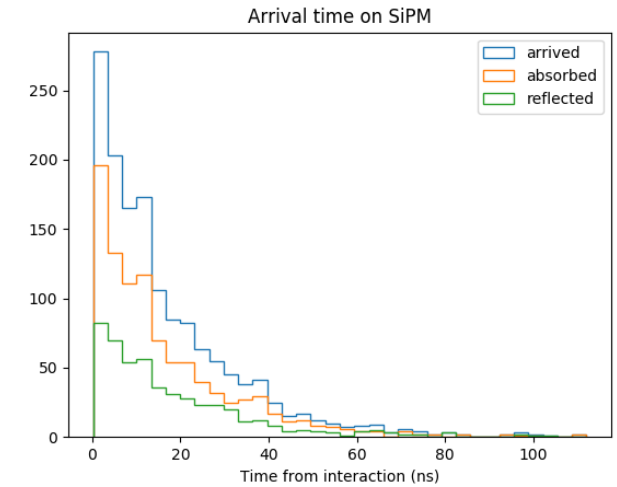
Study of Scintillation Photon Detection Time (1/2)

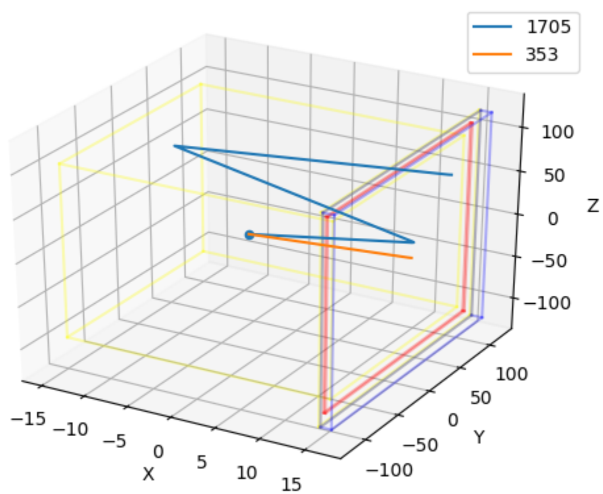
- Aim: understand and quantify parameters on time detection like:
  - optical indexes
  - scintillation parameters (rise time, scintillation decay)
  - coupling material
  - surfaces (as a source of noise)
- For these, I develop a special actor to record every step of scintillation photon in the crystal (implementation of `UserSteppingAction`)
- Simulation of an interaction of a Gamma ray (511 keV) in a crystal of $LaBr_3$*:Ce(5%)* : 200 x 200 x 30 mm^3 coupled to SiPM (same size)

Study of Scintillation Photon Detection Time (2/2)



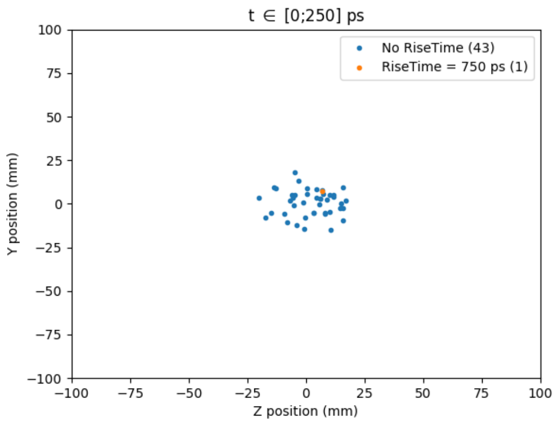


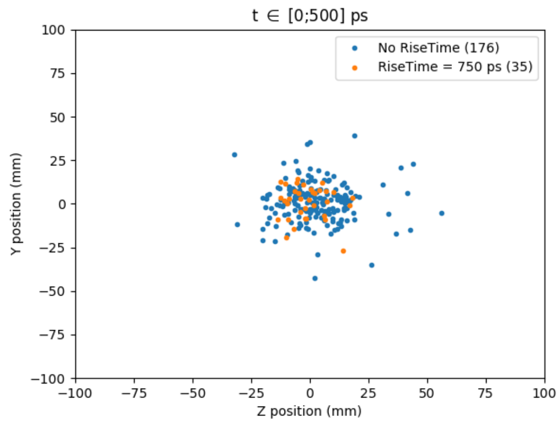


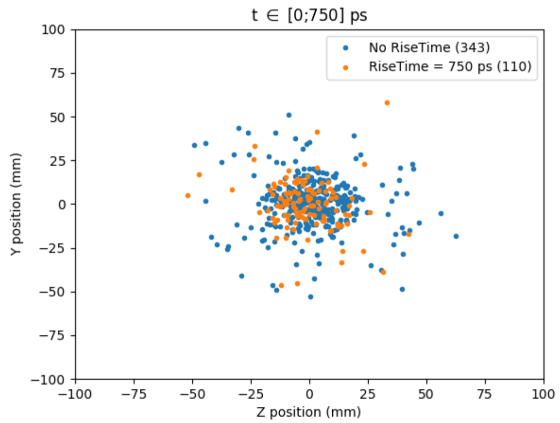


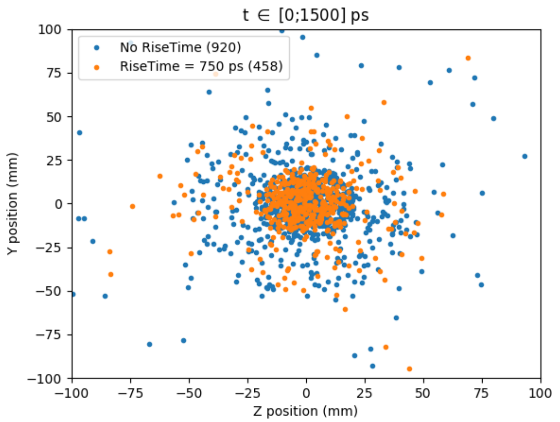
- Top left and middle: effect of the type of the entrance surface on the image of interaction; all reflected photons are a source of noise in the determination of the disc
- Top right: histogram of arrival time on the SiPM
- Bottom left: trajectory of a reflected photon before its detection

Formation of the Detection Disc









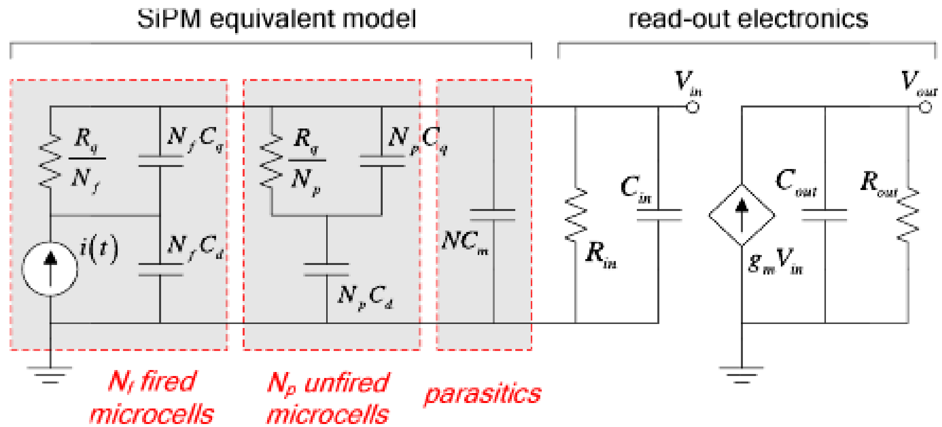
Effect of *FASTSCINTILLATIONRISETIME* on images at different time shots from 250 ps to 1500 ps (time since gamma interaction). We see only absorbed photons generated by one photoelectric event at the depth X=13 mm.

- Usefull to determine time resolution needed of electronic-readout and of course the impact of the scintillator material
- After 500 ps, the disc is clearly apparent and can be used to determine the position of interaction

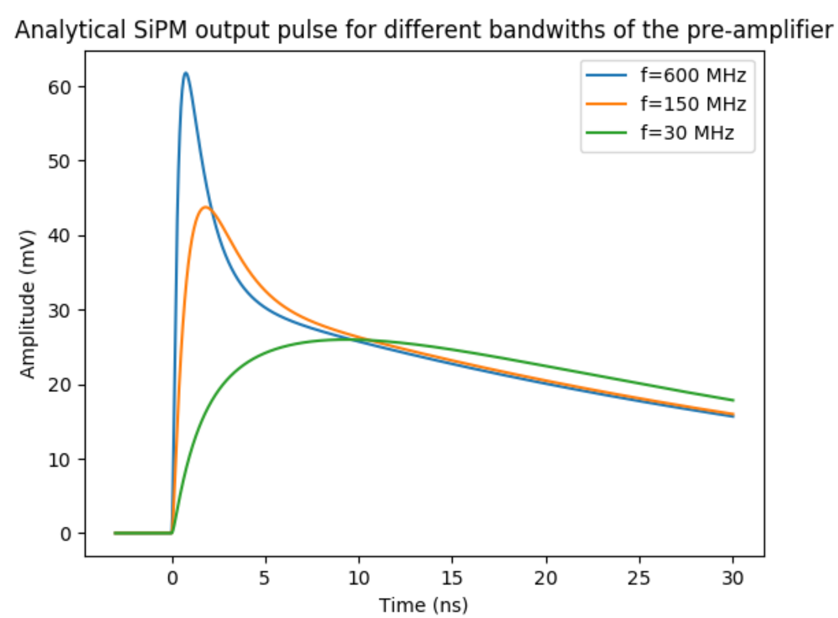
Model of SiPM

- *New Improved Model and Accurate Analytical Response of SiPMs Coupled to Read-Out Electronics*, Marano 2016*.

$$v_{out}(t) = k\left(A_d e^{\frac{-t}{\tau_d}} + A_{p1} e^{\frac{-t}{\tau_{p1}}} + A_{p2} e^{\frac{-t}{\tau_{p2}}} + A_{out} e^{\frac{-t}{\tau_{out}}}\right)$$



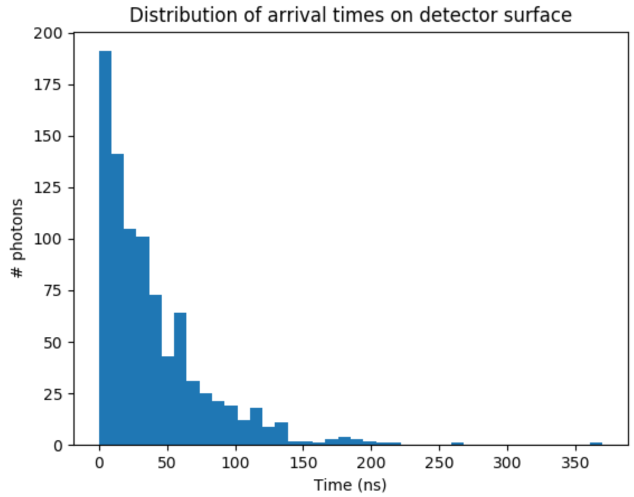
- Depends on rising time, quenching time, recovery time and pre-amplifier bandwidth
- Times are computed from electrical parameters of SiPM (number of cells, internal resistances and capacitances, …)
- Fully parametric model
- Quite difficult to determine all the electrical parameters



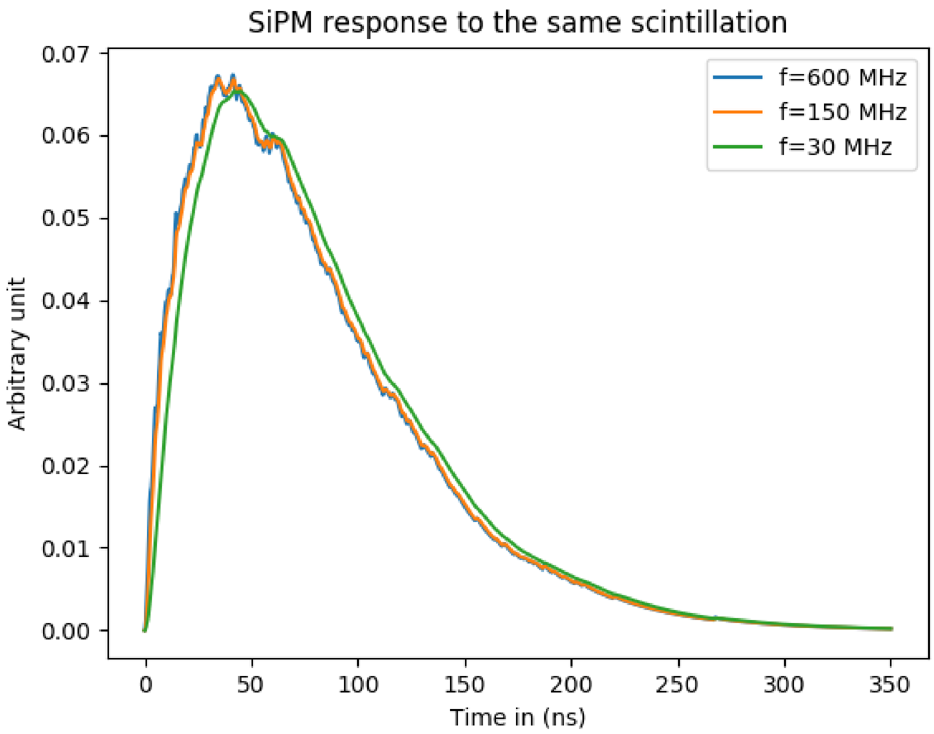
*D. Marano et al in IEEE Sensors Journal, vol. 16, no. 1, pp. 19-21, Jan.1, 2016.

GATE simulation and SiPM

- Example of a simulation of a LSO crystal 3x3x3 mm³ coupled to 3x3 mm² SiPM
- Tracking of each optical photon in the crystal



- Summation of signals induced by photoelectrons in every µCell of the SiPM



Conclusion & To Do list

- Mastering optical simulation is not easy
- Basic simulation of “crystal/SiPM” available
- Add :
  - crosstalk
  - afterpulse
  - µCell recovery time
  - dark noise (DCR)
- Compare simulations to experimental data