

CREATIS activities about GATE development

Maxime Jacquet

CREATIS



Monte Carlo detection system simulation

Aim : Detector prototyping & Reconstruction improvement

- SPECT imaging systems :
 - Veriton
A.Etxebeste, D. Sarrut
 - Compton Camera MACACO
Z. Hurani, D. Sarrut, **A. Etxebeste**
- Hadrontherapy online monitoring : Compact Compton Camera
M.Jacquet, J. Létang, A. Etxebeste, **D. Sarrut**

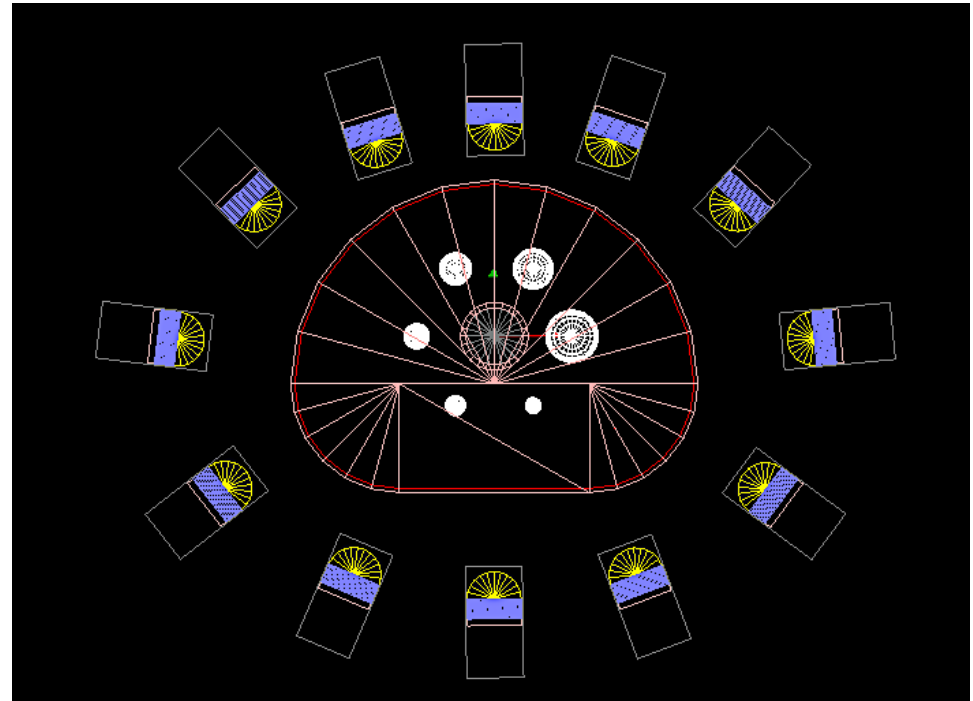
Monte Carlo Model of Veriton CT

MC model encompasses :

- Geometrical description
- Dynamic acquisition
- Digitizer chain

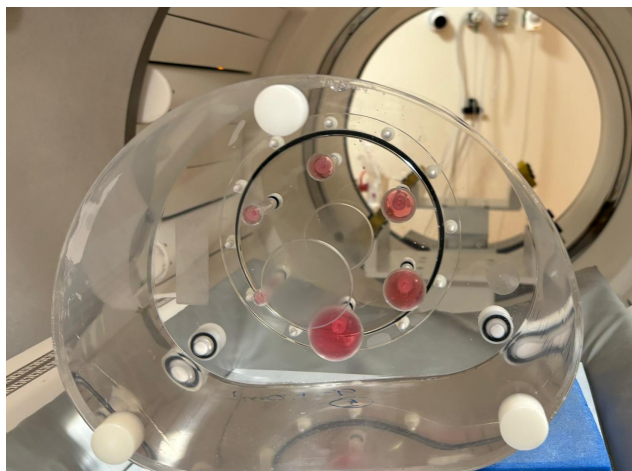
Output

- Images
- Detected counts



Veriton system simulation

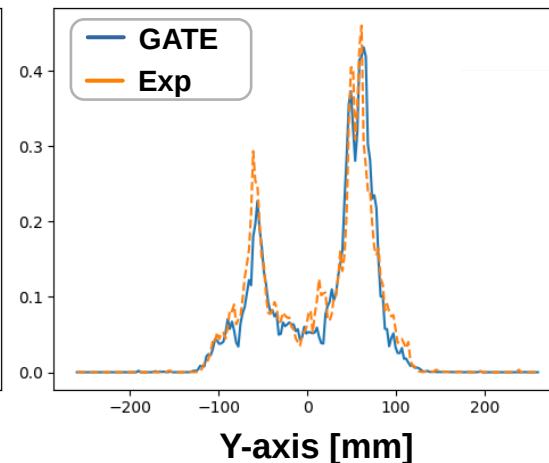
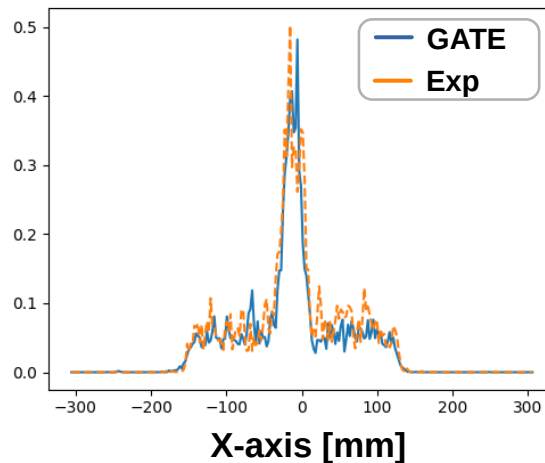
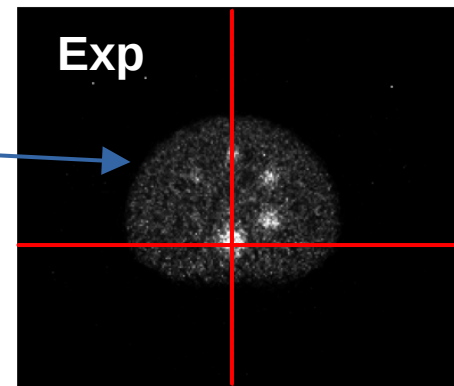
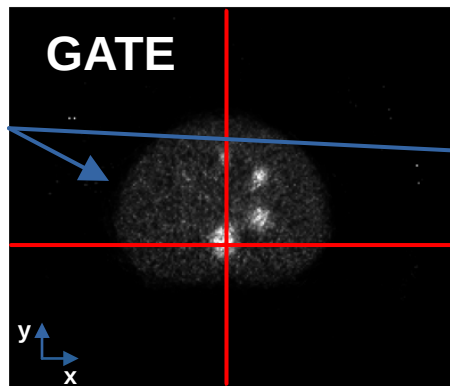
Monte-Carlo model of Veriton CT



IEC phantom experiment

- ^{99m}Tc
 - 146 kBq/mL in spheres
 - 13.3 kBq/mL in background
- Primary windows acquisition [129.8, 150.8] keV

RTK OSEM reconstruction
Rit et al 2014



Comparison between exp and MC Veriton model

Monte Carlo model of MACACO Compton Camera

GATE 10 online

GATE 10 offline

CoReSi

Lequertier et al 2025

[Github project](#)

MC simulation

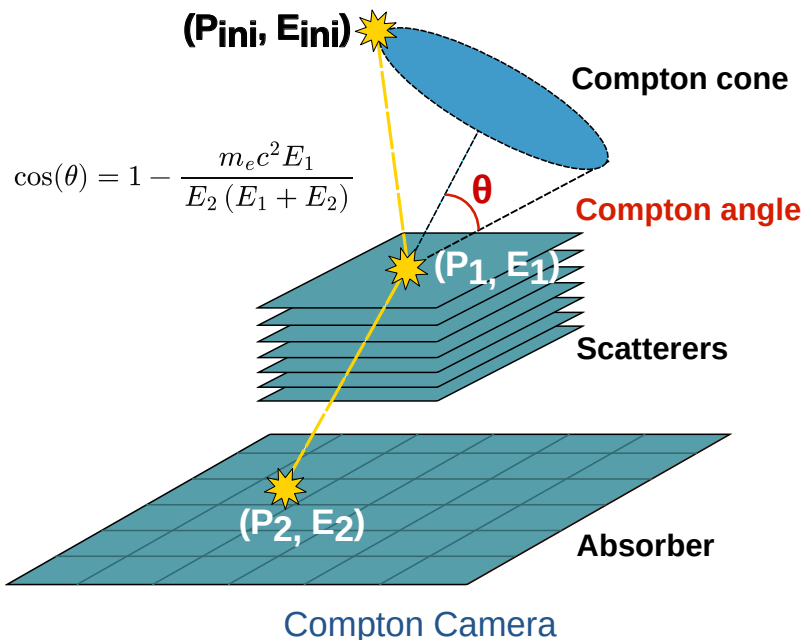
Singles

Post-processing

$(\bar{X}_1, E_{\text{dep}1})$
 $(\bar{X}_2, E_{\text{dep}2})$

Cone reconstruction

Reconstructed images



Monte Carlo model of MACACO Compton Camera

GATE 10 online

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CoReSi

Lequertier *et al* 2025

[Github project](#)

MC simulation

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$(\bar{X}_1, E_{\text{dep}1})$
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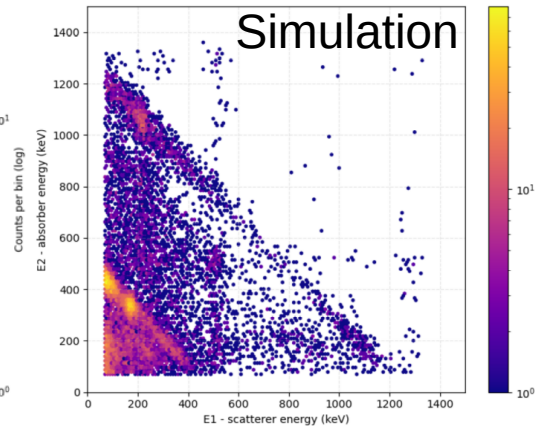
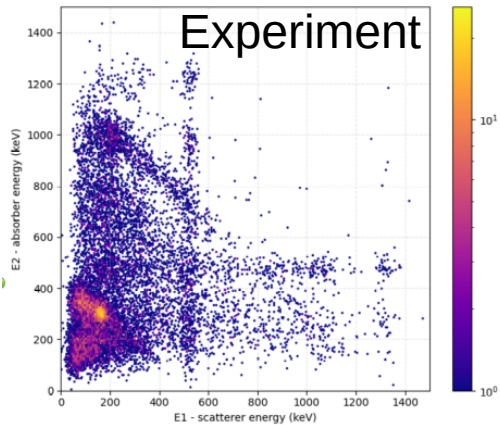
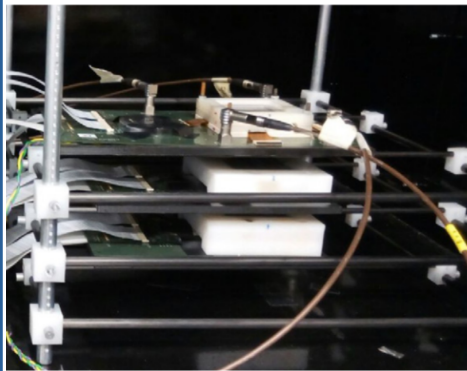
Cone reconstruction

Reconstructed images

On going interoperability !

[Pull request 852](#)

Munoz *et al* 2017

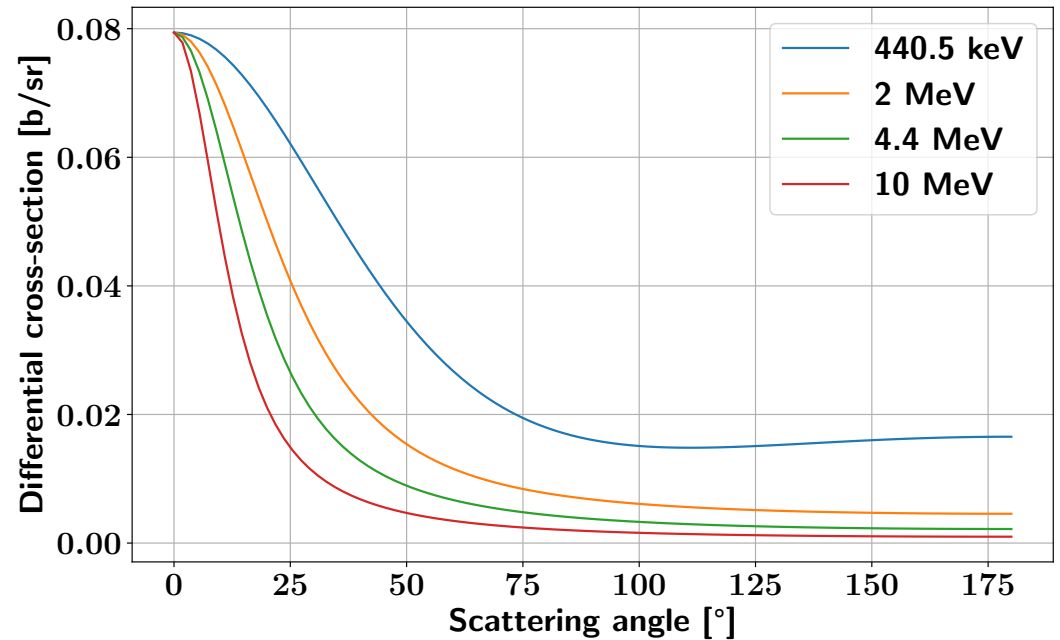


Compton Camera MACACO

Deposited energy in the scatterer vs absorber

Monte Carlo model of Compact Compton Camera

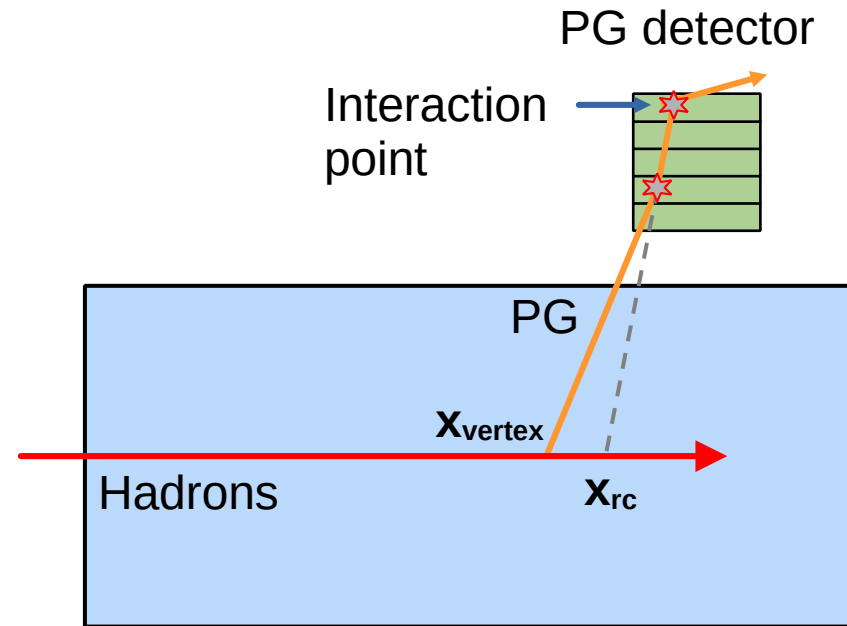
- In hadrontherapy, PG imaging:
 - $1 < E_{PG} < 10 \text{ MeV}$
 - **Low scattering angle**



Klein-Nishina differential cross-sections

Monte Carlo model of Compact Compton Camera

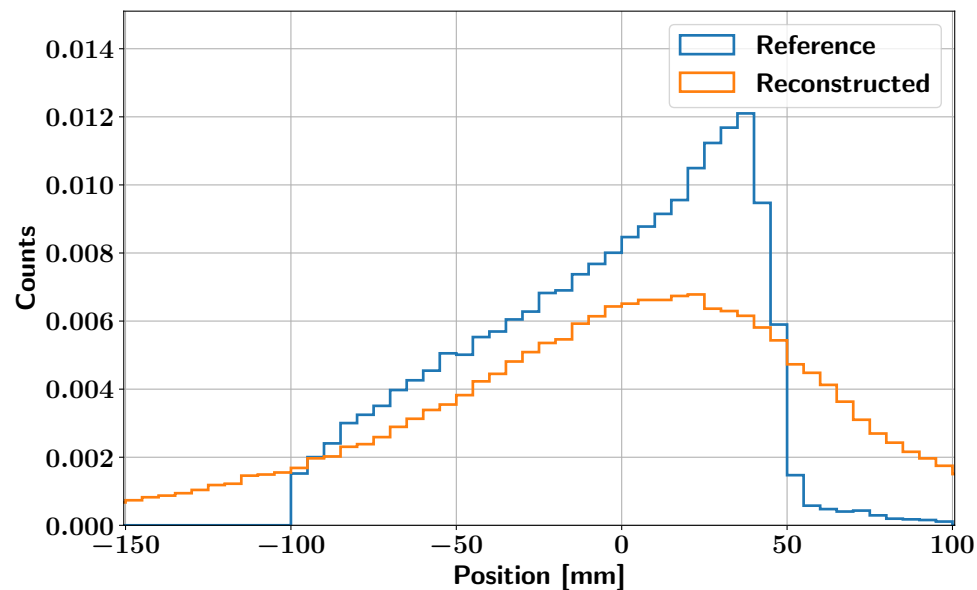
- In hadrontherapy, PG imaging:
 - $1 < E_{PG} < 10$ MeV
 - **Low scattering angle**
- Hypothesis :
 - Scattering angle negligible
 - Vertex reconstruction :
line-beam intersection
- E_y knowledge not needed
- **Loss of spatial resolution**



Compact Compton Camera sketch

Monte Carlo model of Compact Compton Camera

- In hadrontherapy, PG imaging:
 - $1 < E_{PG} < 10$ MeV
 - **Low scattering angle**
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line-beam intersection
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1D PG vertex reconstruction with the CCC

- ~ 5 cm (FWHM) of spatial resolution
- ~ 4 mm on Bragg Peak position measurement

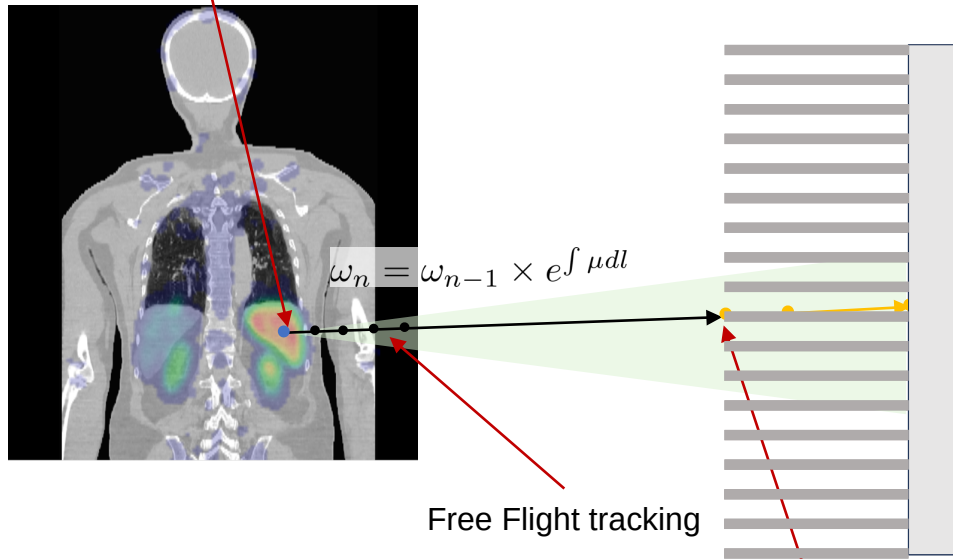
Aim : Speed-up of Monte Carlo simulation

- Free-Flight Angular Acceptance
D. Sarrut, A. Etxebeste, M. Jacquet, J. Létang
- Last Vertex Splitting + hybrid Tracking Length Estimator
M. Jacquet, J. Létang, **D. Sarrut**
- vpgTLE
J. Létang, D. Sarrut

Free-Flight Angular Acceptance

Generic speed-up of SPECT simulations

Primary emission point sampled



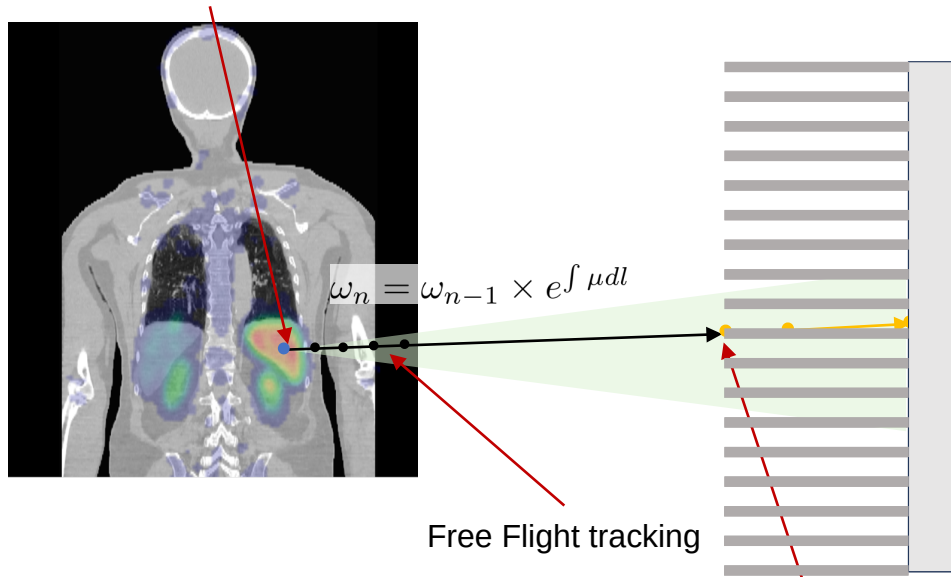
$$\omega_0 = 1 \quad \omega_1 = \omega_0 \times \frac{1 - \cos(\theta_{max})}{2}$$

Step 1 : Primary photons simulation

Free-Flight Angular Acceptance

Generic speed-up of SPECT simulations

Primary emission point sampled

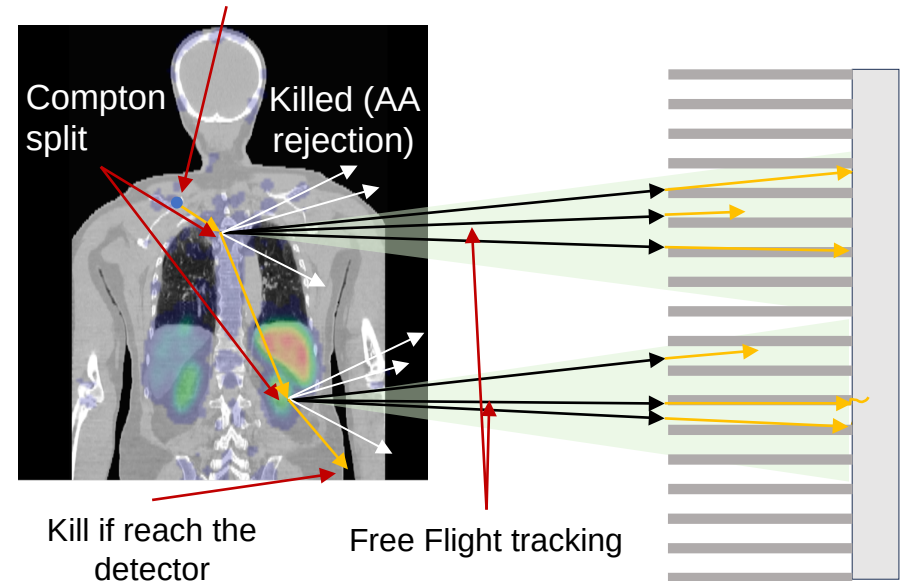


Conventional tracking

$$\omega_0 = 1 \quad \omega_1 = \omega_0 \times \frac{1 - \cos(\theta_{max})}{2}$$

Step 1 : Primary photons simulation

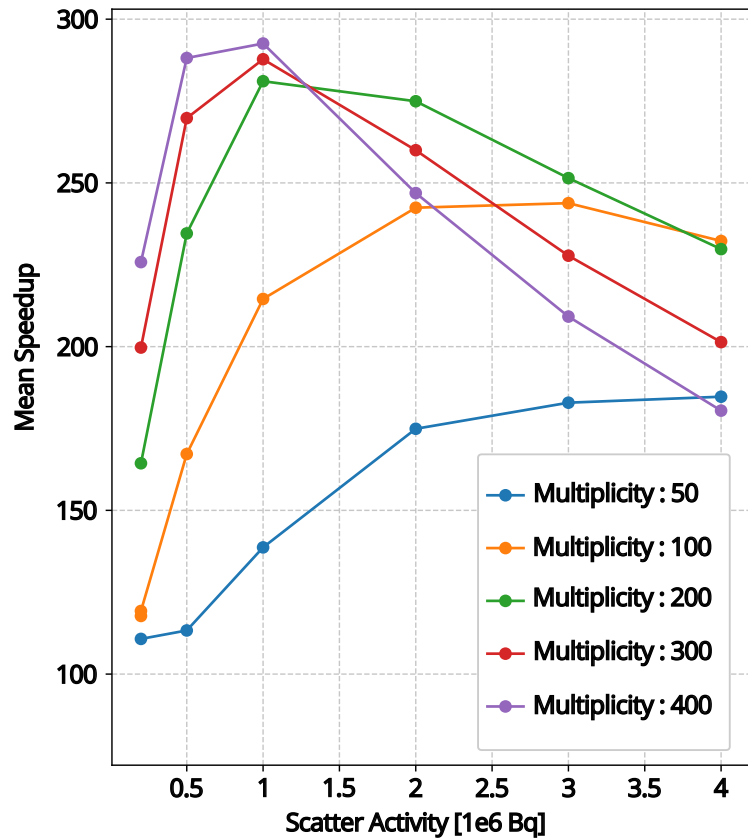
Primary emission point sampled



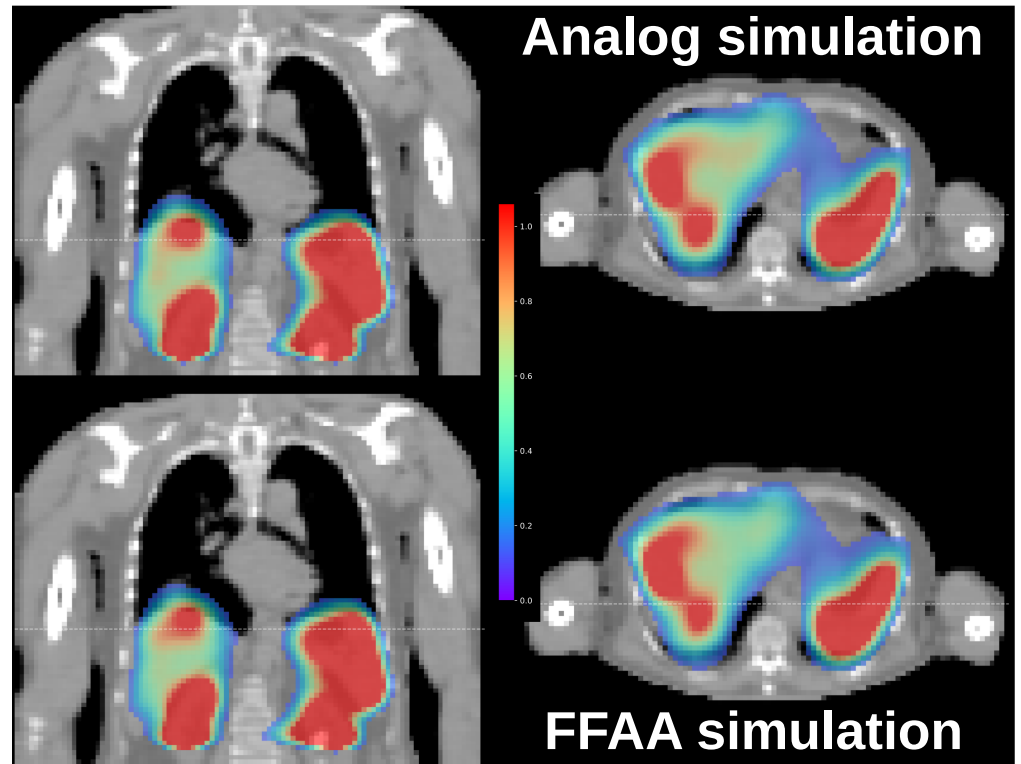
$$\omega_1 = \omega_0 / N_{split}$$

Step 2 : Scattered photons simulation

Free-Flight Angular Acceptance



Mean speedup compared to an analog simulation



Comparison of SPECT reconstruction between an analog and a FFAA simulation

Last Vertex Splitting + hybrid Tracking Length Estimator

Jacquet et al 2025

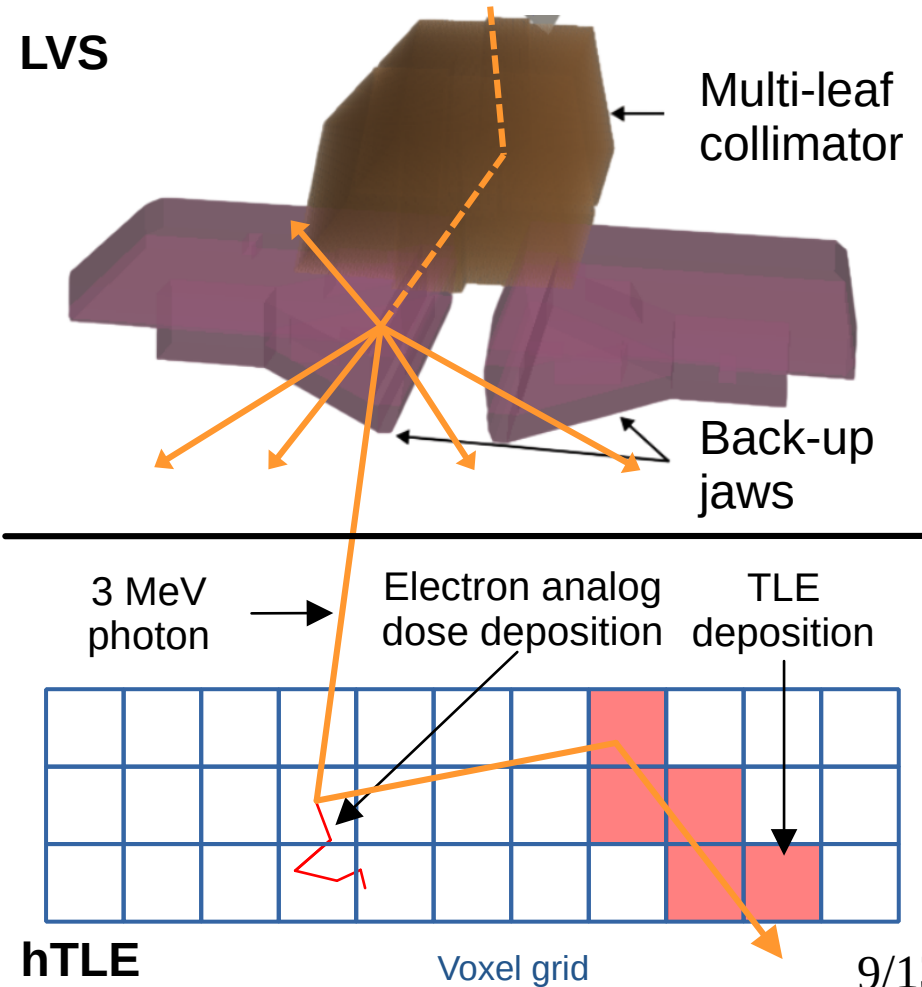
photon Last Vertex Splitting (LVS) :

- **Better sampling** for scattered events from the collimation system
- **Out-of-field dose** estimation

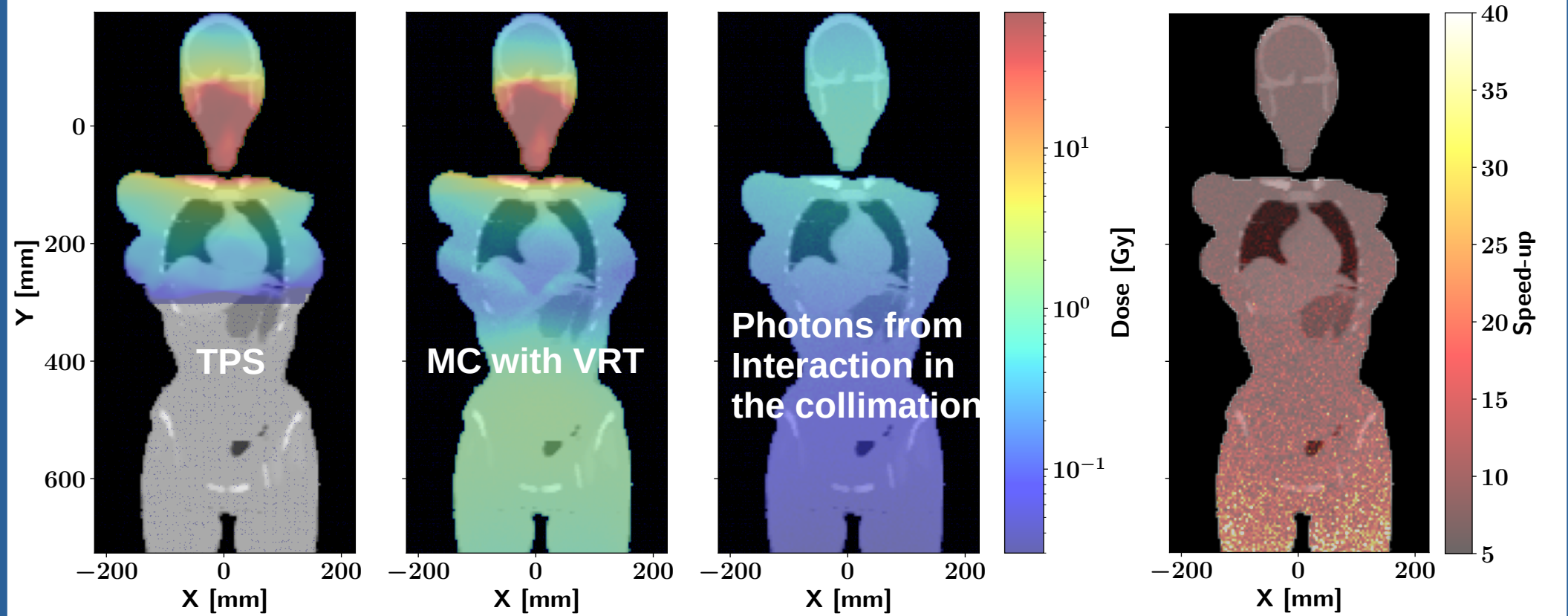
hybrid Tracking Length Estimator (hTLE) :

- Increase amount of information provided by tracked photons.

$$D_i^{\text{TLE}} = \frac{E \times \mu_{\text{en}}(E, m_i) \times L_i}{\rho_i \times V}$$



Last Vertex Splitting + hybrid Tracking Length Estimator

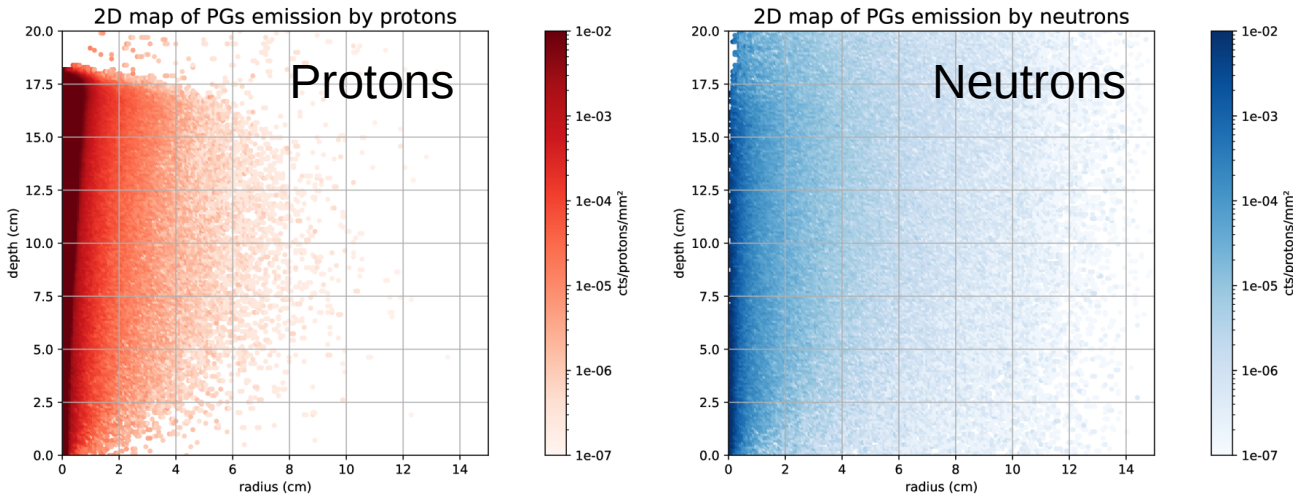


Dose deposition comparison between
TPS estimated dose and LVS + hTLE dose

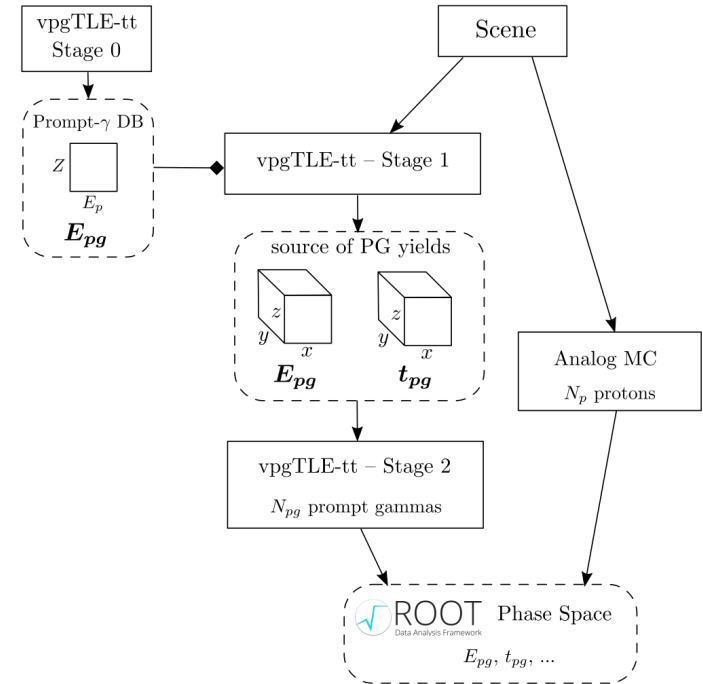
Speedup of interacted
photons simulation 10/13

Voxellized prompt-gamma TLE (vpgTLE)

Fast MC simulation for PG imaging devices prototyping



PG radial distribution from proton and neutron with 160MeV proton in water

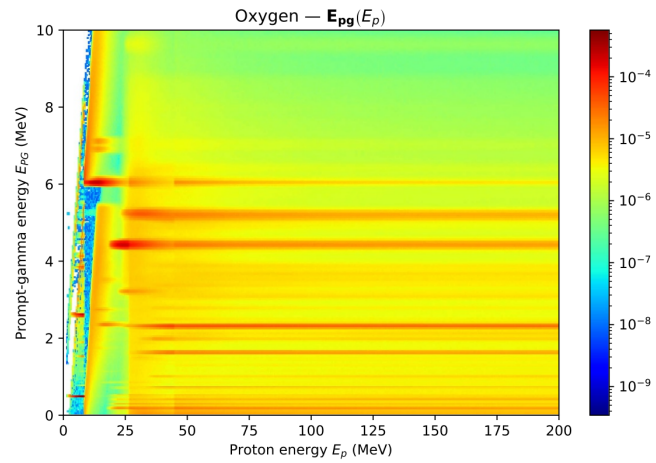


VpgTLE flowchart

Voxellized prompt-gamma TLE (vpgTLE)

Stage 0 : database

- PG vs proton energy
- Per element
- To recompute for each change in physics list

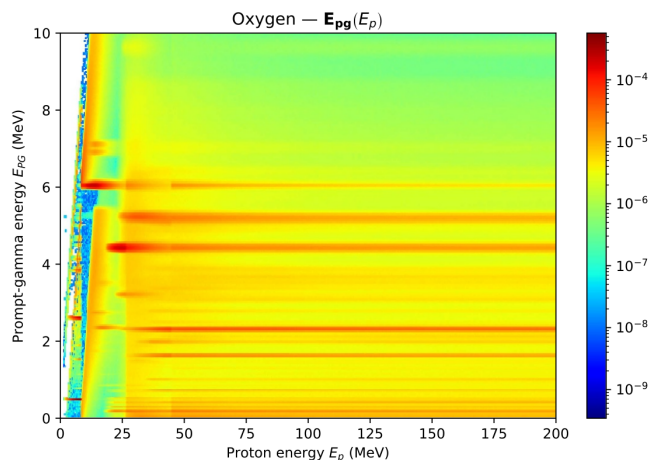


Gate 9 Database for Oxygen

Voxellized prompt-gamma TLE (vpgTLE)

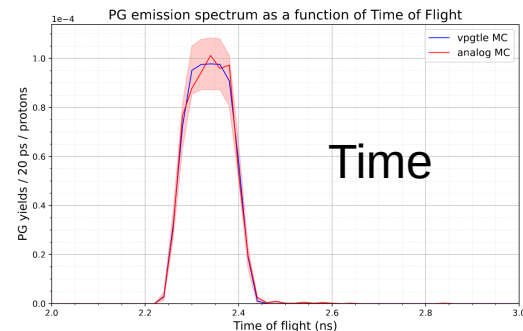
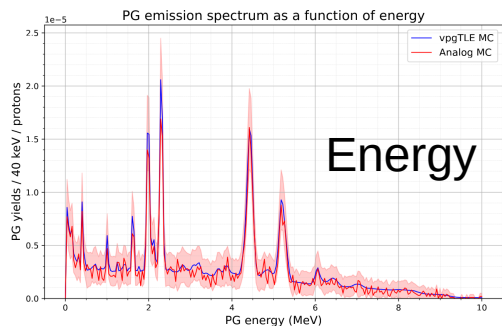
Stage 0 : database

- PG vs proton energy
- Per element
- To recompute for each change in physics list



Gate 9 Database for Oxygen

Stage 1 : independent proton energy and time voxel distributions



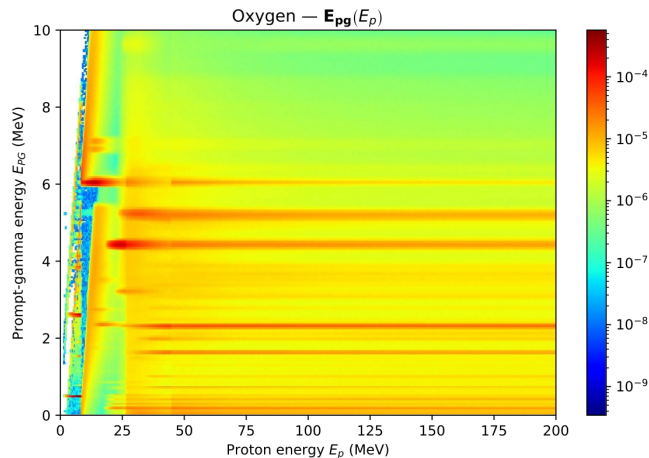
PG energy and time distributions

Gate 9 and 10

Voxellized prompt-gamma TLE (vpgTLE)

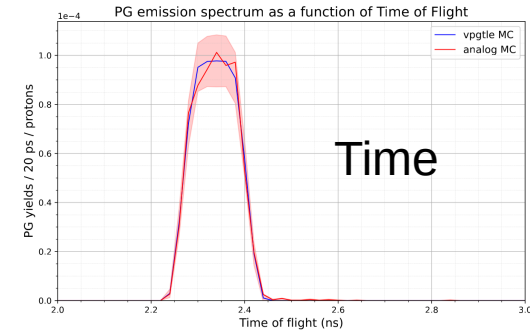
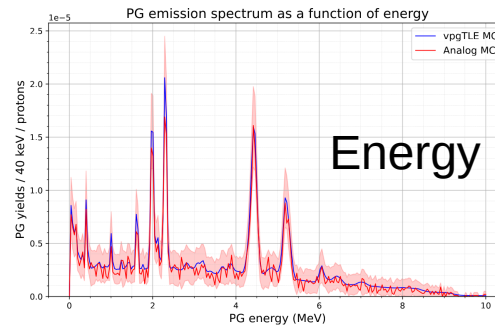
Stage 0 : database

- PG vs proton energy
- Per element
- To recompute for each change in physics list



Gate 9 Database for Oxygen

Stage 1 : independent proton energy and time voxel distributions



PG energy and time distributions

Gate 9 and 10

Stage 2 : 4D energy and time PG sources (Gate 9)

- Efficiency : ~ **around 50**
- Stage 0 and 2 to Gate 10
- Extend to He and C ions

Conclusion and on-going works

- Modeling of clinical systems
 - SPECT (Veriton, ...)
 - LINAC (Elekta versa HD, ...)
- Novel detectors prototyping :
 - Compton Camera for SPECT
 - Compact Compton Camera for hadrontherapy
- Generic VRT applicable to these systems :
 - SPECT : FFAA
 - Photon radiation therapy : LVS + hTLE (on-going work)
 - Proton therapy : vpgTLE (on going work)