CREATIS (team 4) research activities at Léon Bérard cancer center (CLB)

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On behalf of **Tomoradio** team @ CLB
(*tomographic imaging and therapy with radiation*)

Outline

- Dosimetry in Targeted Radionuclide Therapy (TRT)
- Alpha source model for MC photon imaging in RIV
- Proton imaging
- Spectral CT
- Data consistency conditions: SPECT-DCC
- VRT: prompt-gamma TLE with time tagging
- *VRT: out-of-field dose in RT (➡ talk of Maxime Jacquet)*

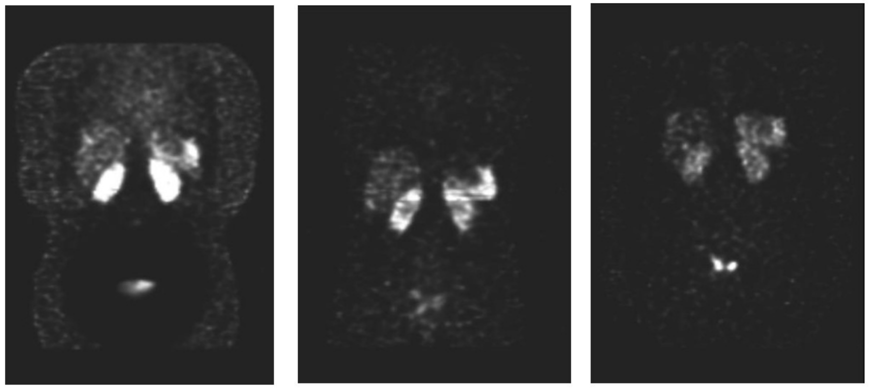
Targeted Radionuclide Therapies

Radionuclide therapy dosimetry

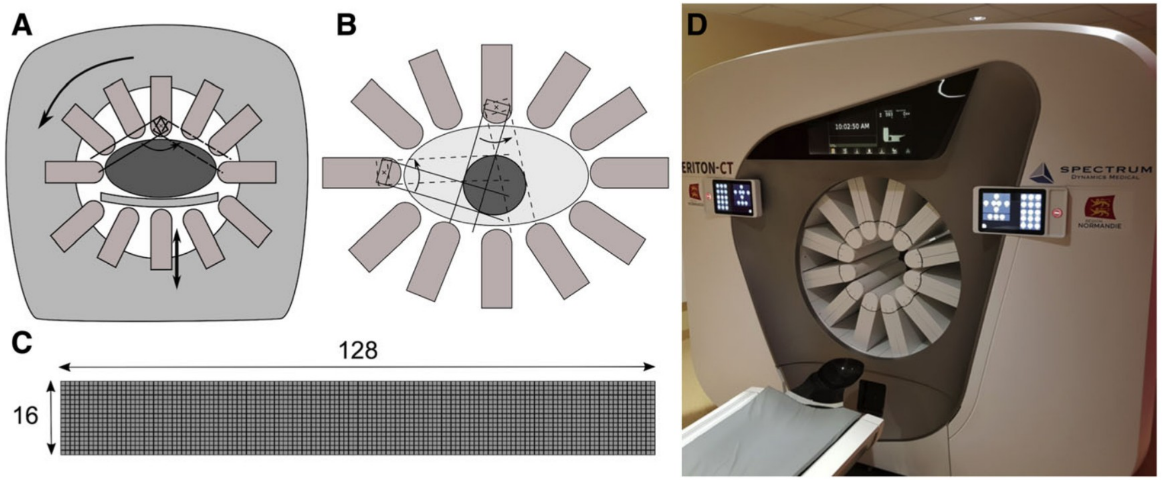
- ^{177}Lu for Neuroendocrine (NETs) and prostate (PSMA) tumors
- ^{90}Y selective internal radiation therapy (SIRT liver)
- ^{225}Ac clinical study in progress
- Patients from Léon Bérard cancer center
  DB of around 100 patients (PSMA)
- Collaboration: Siemens, Spectrum Dynamics (Veriton)

VERITON-CT

- W //-hole collimators
- CZT detectors



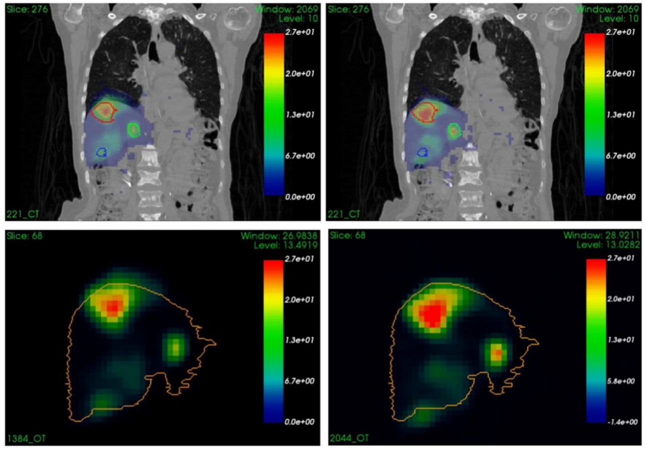
SPECT images at 4h, 24h, 96h



Dosimetry and outcome prediction

- **Response varies** from patient to patient
- **Dosimetry personalizes treatment** but requires **multiple post-injection images** to monitor the biodistribution over time
- Additional **imaging burden** on centers with limited resources
- Dose computation (GATE) / SPECT motion compensation
- Collaboration with IRSN (AAP Conjoint CNRS-IRSN 2025)

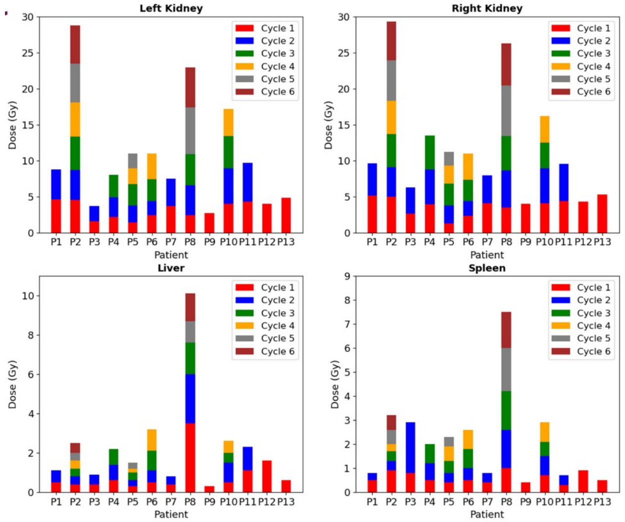
[Vergnaud 2022, EJNMMI Physics 9:37]
[Vergnaud 2023, EJNMMI Physics 10:8]
[Vergnaud 2023, EJNMMI Physics 10:58]
[Vergnaud 2024, EJNMMI Physics 11:65]



Respiratory motion impacts lung and tumor doses

Motion compensated SPECT reconstruction for radioembolization ^{99m}Tc (29 patients)

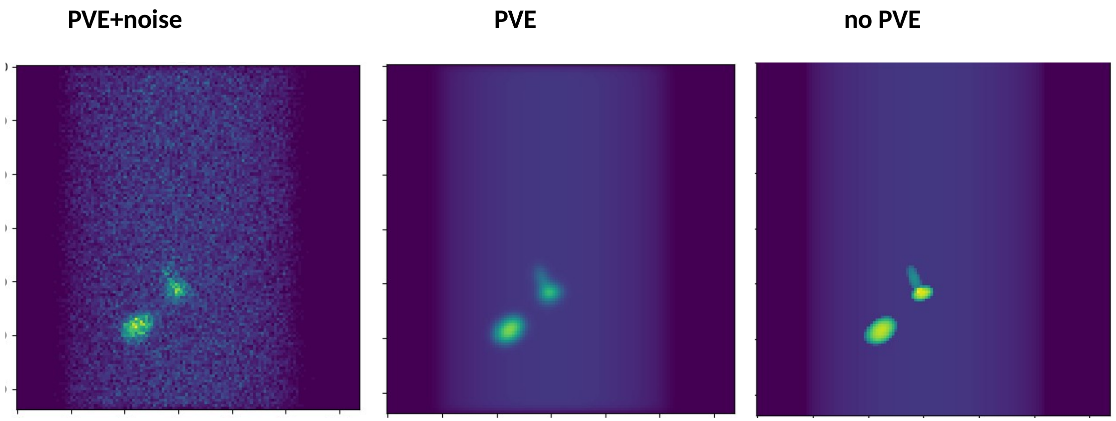
Organ dose variability
- High *inter-patient*
- Low *intra-patient*

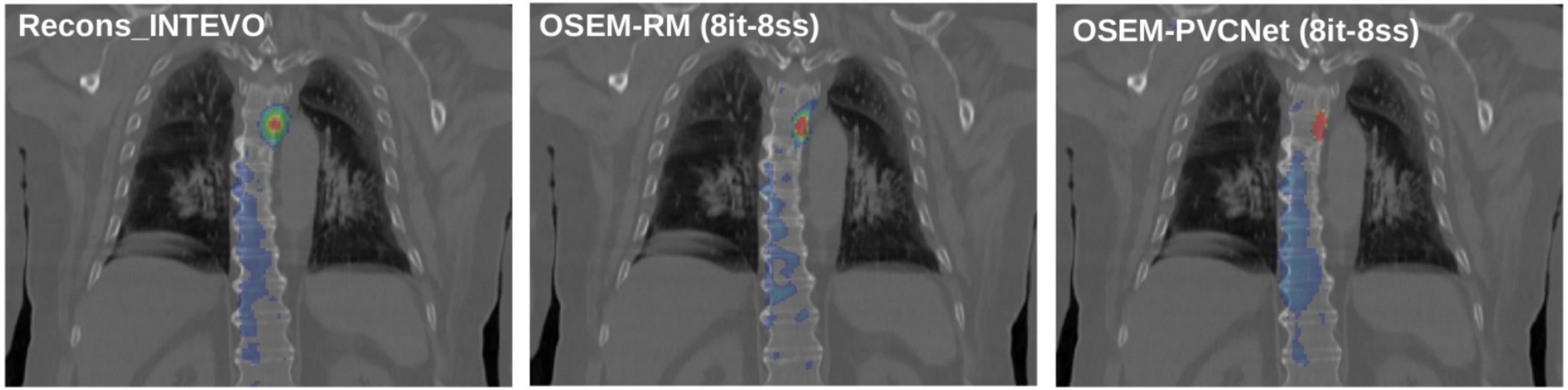


Estimated dose for some organs ^{177}Lu-PSMA (13 patients)

SPECT Partial Volume Correction

- Simulated database of SPECT images (^{99m}Tc) with and without Partial Volume Effect
- Train neural network to reduce PVE
- PVE compensation on projections + Denoiser network (prior to reconstruction)
- RTK toolkit for reconstruction





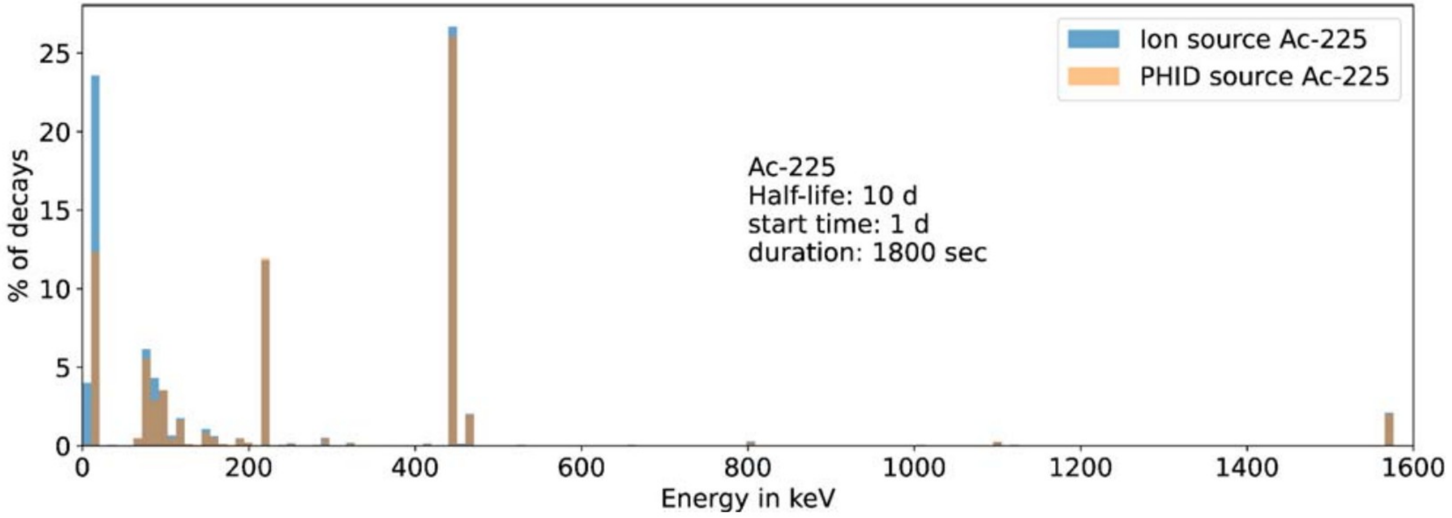
[Kaprelian 2023, Fully3D]
[Kaprelian 2024, NSS-MIC]

PHID: PHoton from Ion Decay

A photon source model for **alpha-emitter radionuclides**

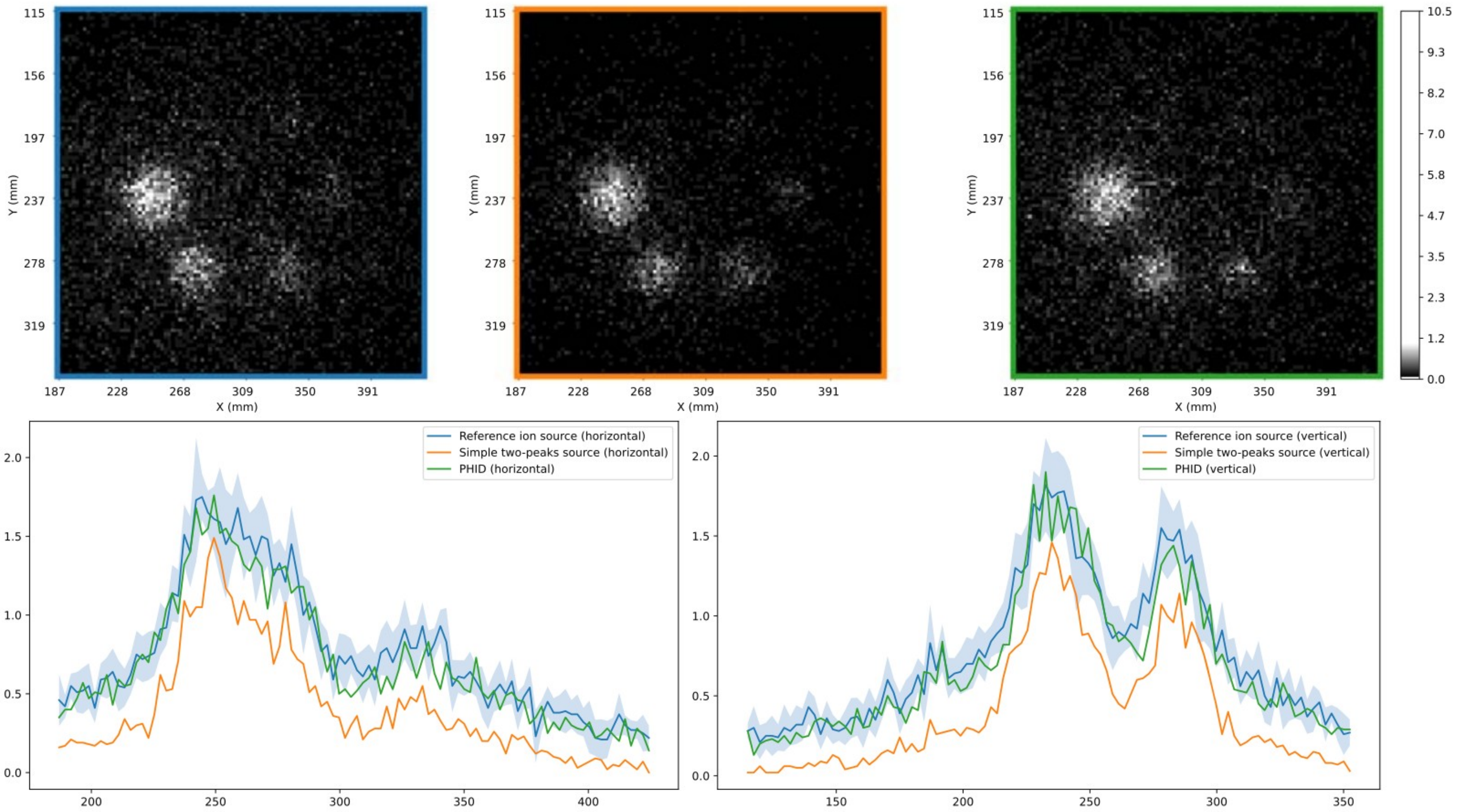
- **Photon emission** for *in-vivo* imaging (^{225}Ac, ^{212}Pb...)
- Both isometric transition and atomic relaxation (no Bremsstrahlung and annihilation)
- Extracted from Geant4 + IAEA
- Avoid long full Geant4 simulation (only photons) : x30 faster
- Integration in GATE v10

[Sarrut 2024, PMB 69]



PHID: 225Ac SPECT example

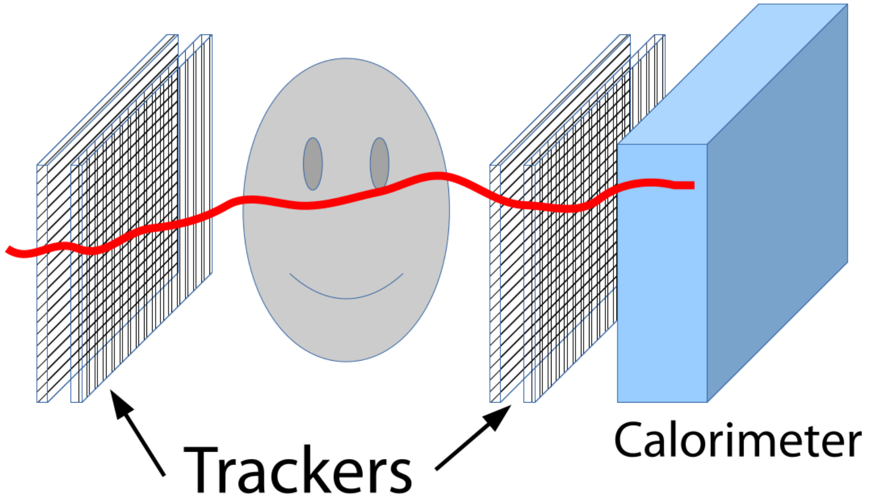
- Two main energy peaks: 218 keV and 440 keV
- 60% more counts with the complete model



Ion CT reconstruction

Pioneer work: [Rit 2013, Med Phys 40]

“Filtered backprojection proton CT reconstruction along most likely paths”

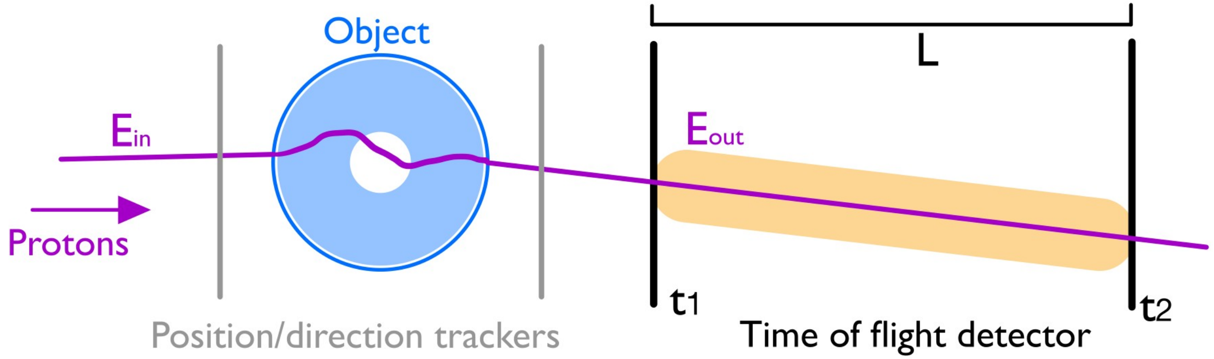


International collaborators using the open source

pCT software (https://github.com/SimonRit/PCT):

- LMU Munich (Georges Dedes, Guillaume Landry)
- INFN Florence (Monica Scaringella, Carlo Civinini, Mara Bruzzi)
- IEM Madrid (Maria José García Borge, Jose Antonio Briz)

Time-of-Flight ion imaging



Measure the **residual energy** after the scanned object via the **time-of-flight**: [Krah 2022, PMB 67]

Novel approach: **Sandwich ToF** ion CT (STOFICT):
[Ulrich-Pur 2023, JINST 18][Ulrich-Pur 2024, PMB 69]

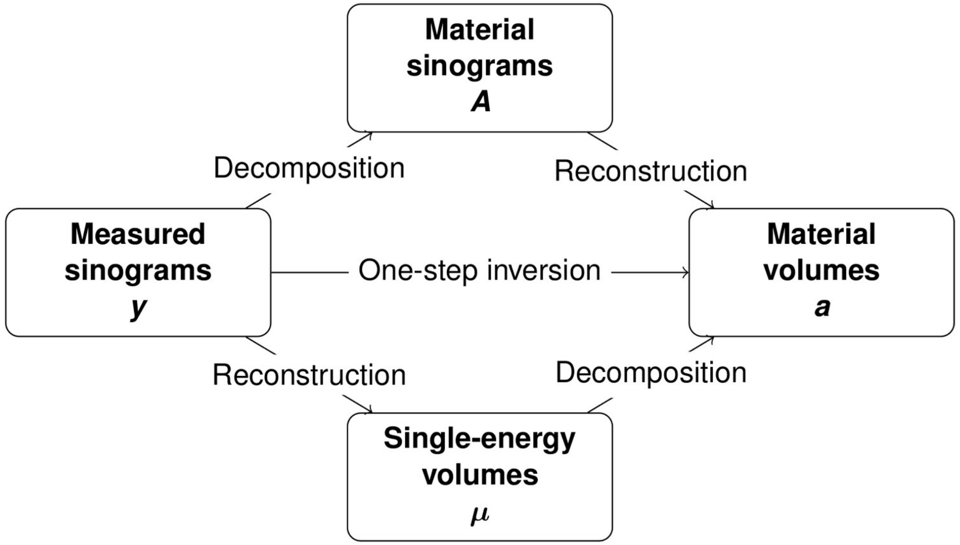
- Time-of-flight depends on the stopping power of the material only
- But the energy dependency yields a non linear inverse problem
- INSERM PCSI project 2024, collaboration CREATIS / CLB / TU Wien

Spectral CT decomposition and reconstruction

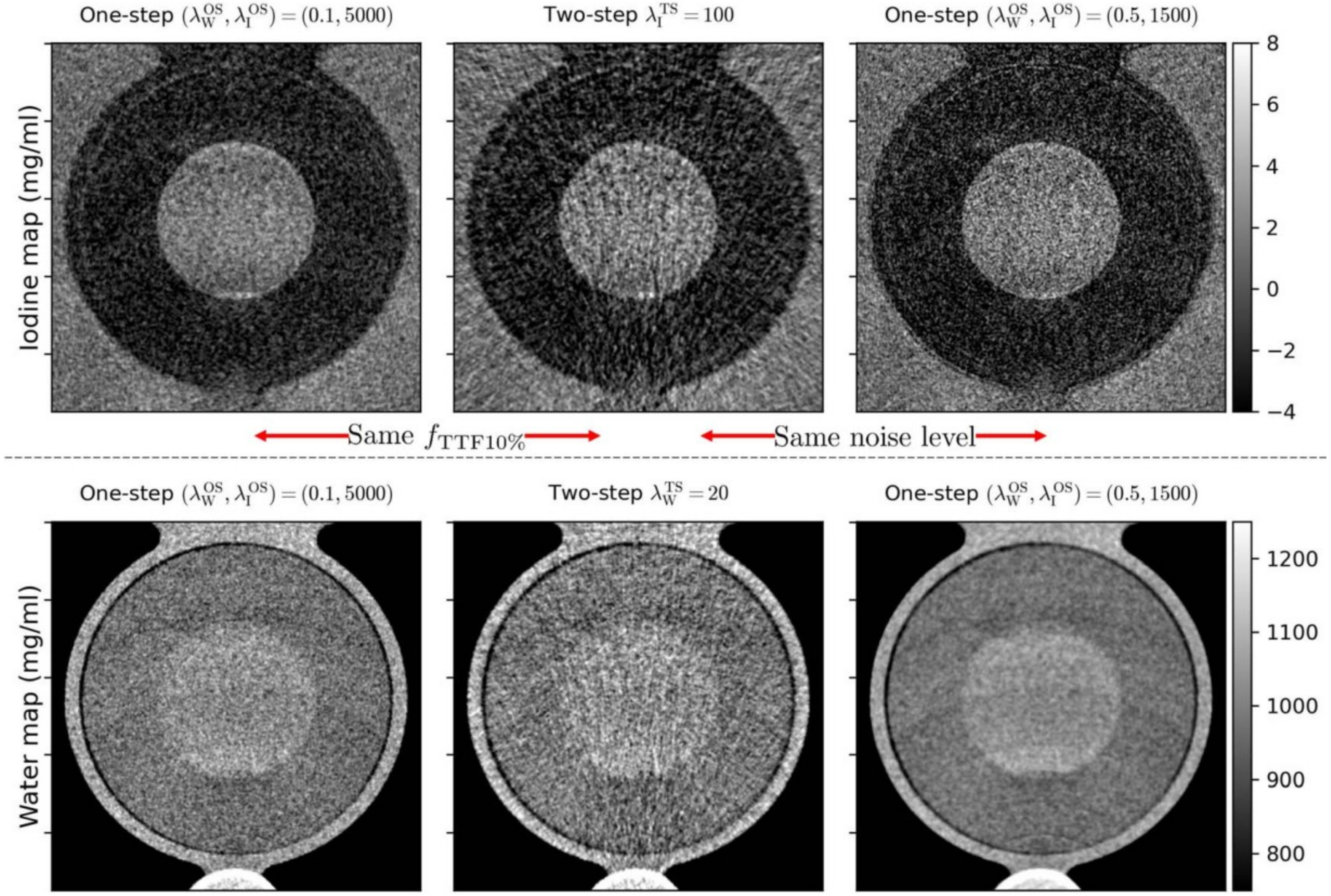
- Founding paper:
  [Alvarez and Macovski 1976, PMB 21]

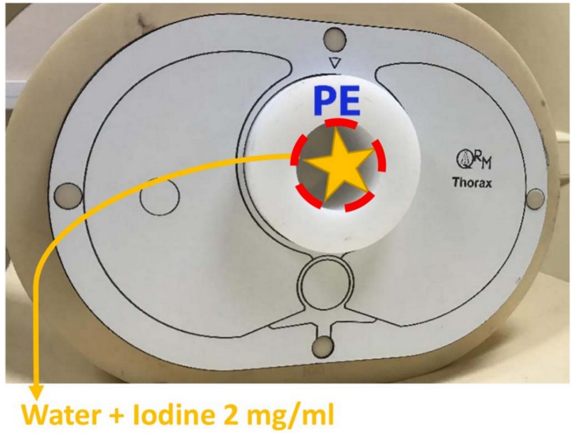
$$\mu(\boldsymbol{x}, \epsilon) \approx \sum_{m=1}^{M} a_m(\boldsymbol{x}) f_m(\epsilon)$$

- **One step** spectral CT reconstruction in RTK
  - [Mory 2018, PMB 63]
  - [Rodesch 2024, PMB 69]



Spectral CT decomposition and reconstruction





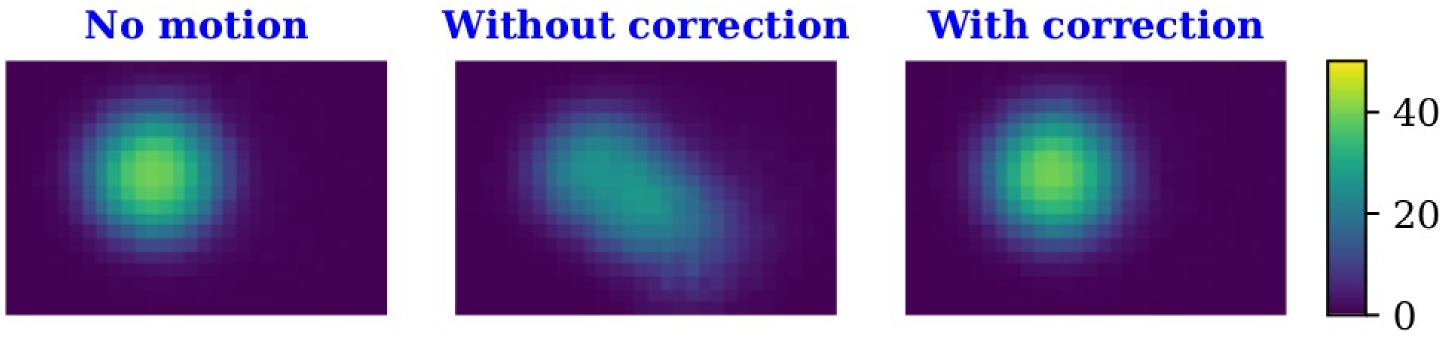
One-step method: **Improve IQ**

- Better SR or
- Lower noise

Data consistency conditions for motion detection and estimation during SPECT

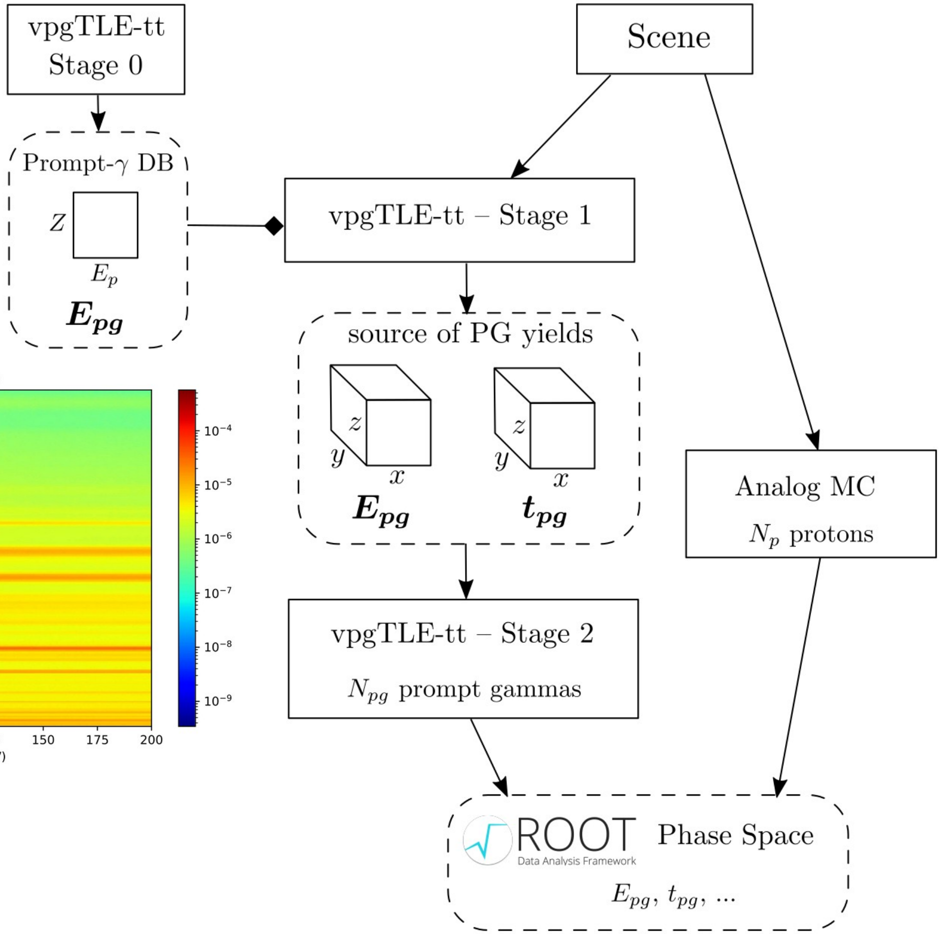
- DCC (or range conditions) are **equations that should be verified** if the projection data follow the model underlying the reconstruction (e.g., the Radon transform for 2D parallel x-ray CT)
- In **SPECT**, the underlying transform is the **attenuated Radon transform** which can be converted to exponential Radon transform under some conditions (constant attenuation in the convex region of emission).
- We have used DCCs for estimating and correcting motion before reconstruction in SPECT

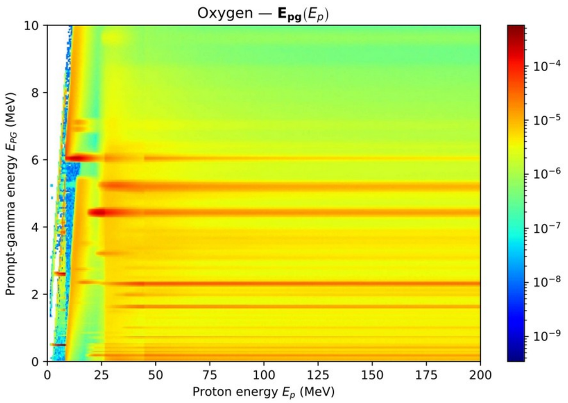
[Bui 2024, ICCR]

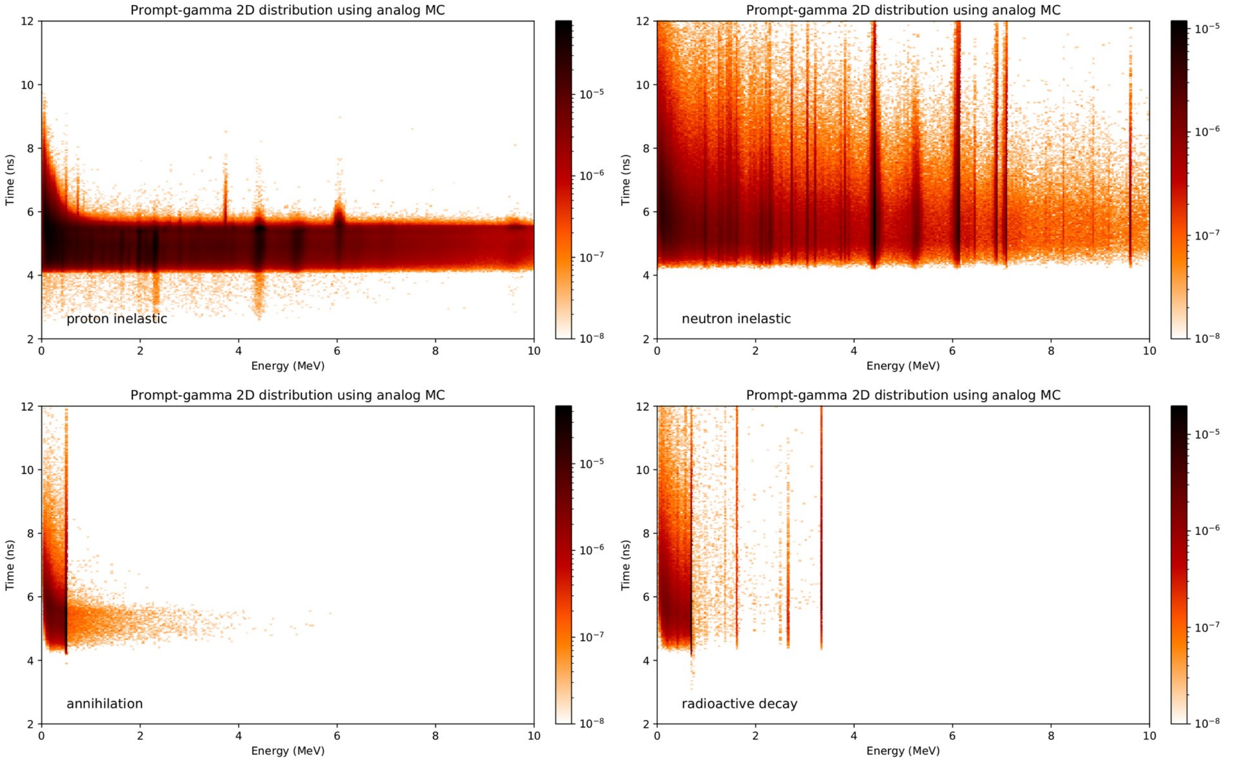


- 150 Mbq ^{99m}Tc
- Ø20mm
- 60 proj (15s)
- Rigid motion

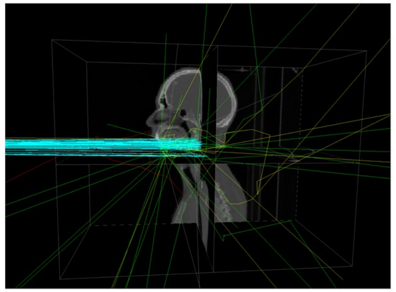
Prompt-γ TLE with time tagging



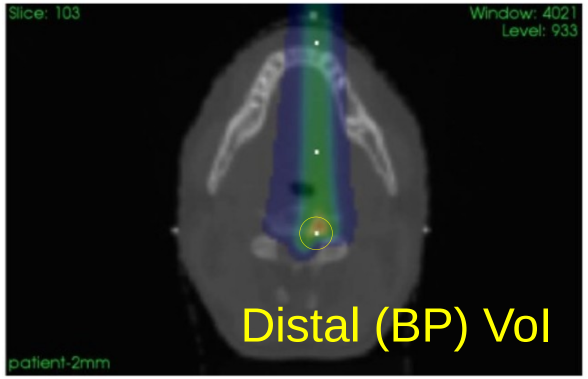


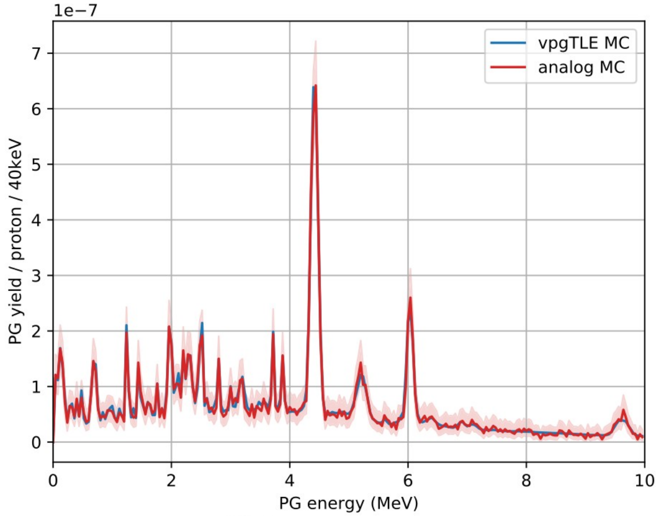


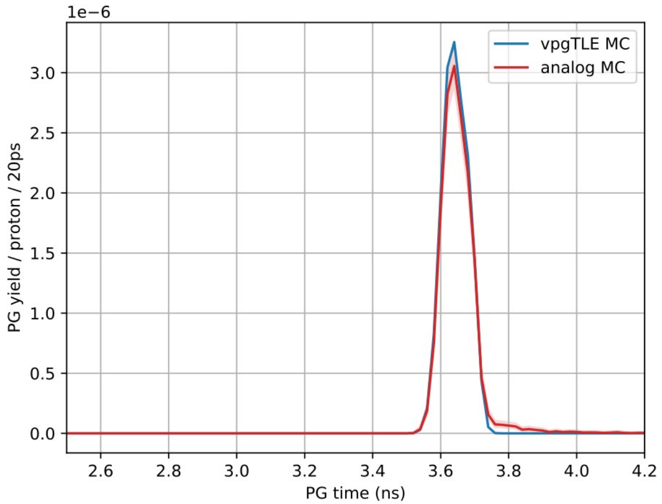
process	counts	%
proton inelastic	1.17×10^7	53%
annihilation	7.14×10^6	32%
neutron inelastic	1.57×10^6	7.1%
neutron capture	7.94×10^5	3.6%
radioactive decay	6.96×10^5	3.2%
e-/e+ bremsstrahlung	8.96×10^4	0.4%

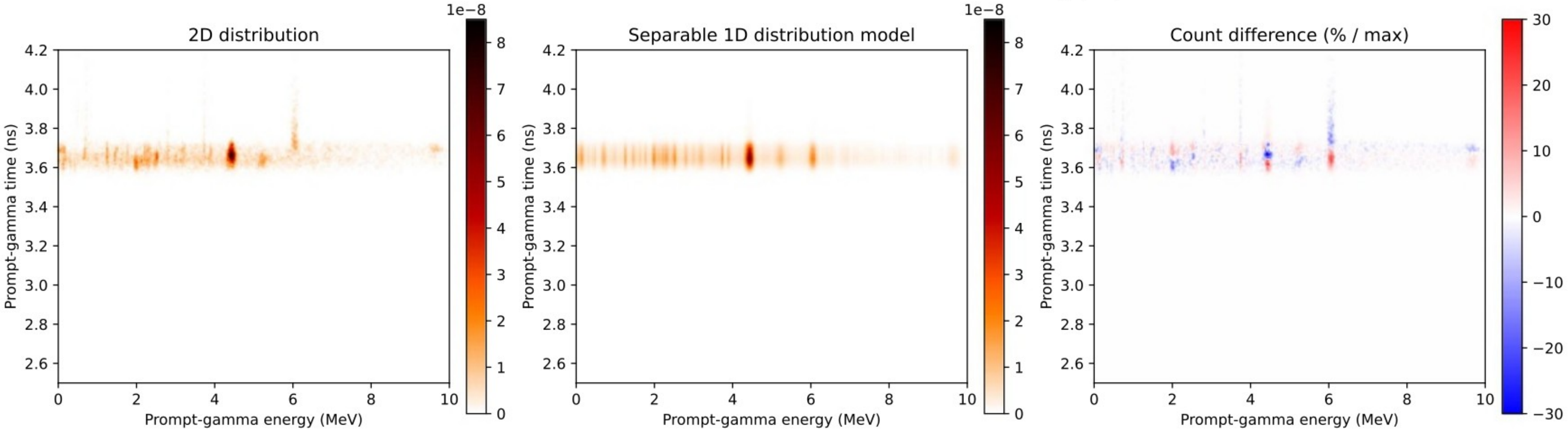


Prompt-ɣ TLE with time tagging









- Gain 50 wrt analog MC
- Negligible temporal bias

GATE 10

- GATE is an open-source GEANT4 application for Monte Carlo simulations
- Dedicated to medical physics:
  - PET, SPECT, Compton Camera, etc
  - Radiation-, proton-, radionuclides-, brachy- therapies
- Community-based, Opengate collaboration

… on the shoulders of

- Create simulations via Python instead of macros
- Improved multithreading and multi-processing (split & merge)
- Robust tests-based development
- Easy installation: `pip install --pre opengate`

  First official release in ~~May~~, ~~July~~, end of 2024

8 - 11 July 2024
Lyon - France
20th edition

420 attendees !

Treatment Planning
Imaging
Dose Delivery
Quality Assurance
Artificial Intelligence
...

using Computers
for Radiation Therapy

Merci pour votre attention !

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