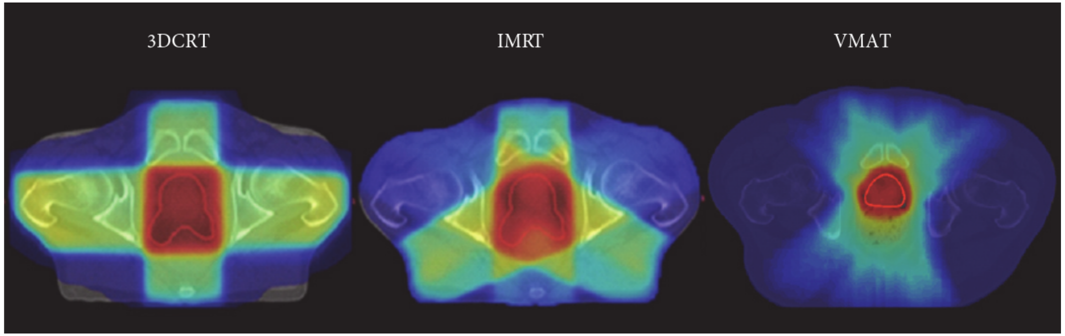
ESTIMATING OUT-OF-FIELD DOSE DISTRIBUTION BASED ON MONTE CARLO TRAINING DATASET

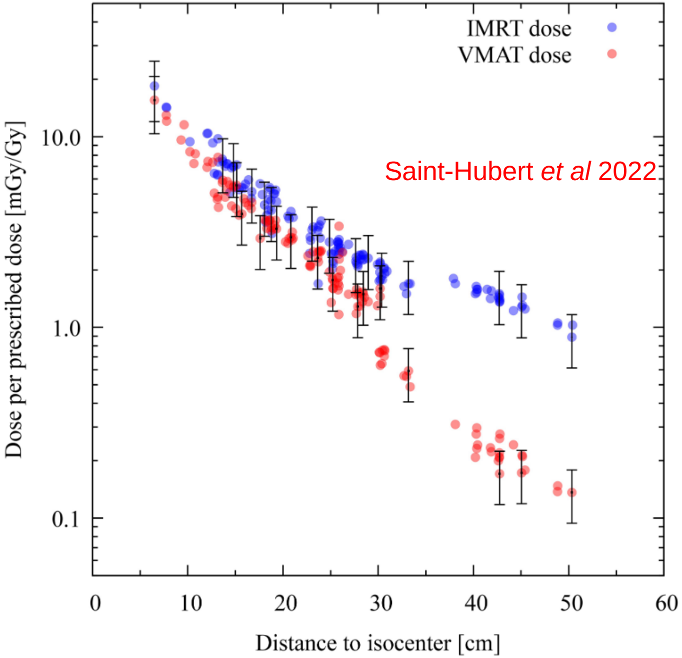
Maxime Jacquet
CREATIS Lyon

Out-Of-Field dose



Comparison of the deposited dose according to treatment modality

Vanneste *et al* 2016



Experimental measurements of Out-Of-Field dose for IMRT and VMAT in an anthropormorphic phantom

Recent photon radiotherapy methods:

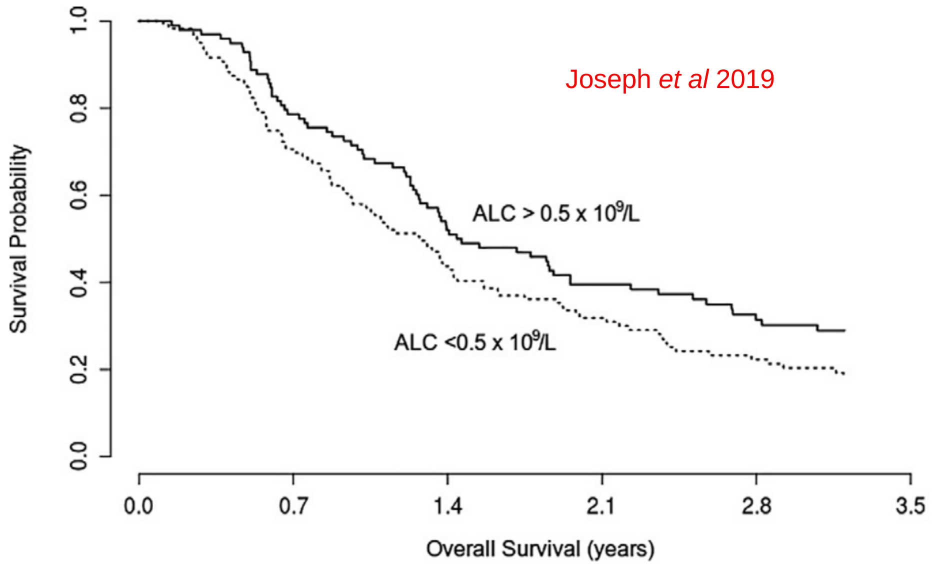
- Diminution of the high dose deposited outside of the tumour volume
- Higher peripherical dose deposited

Out-Of-Field dose

- Out-Of-Field (OOF) dose consequences:
  - Increased risk of radiation-induced cancers
  - Lymphopenia: negative correlation with patient overall survival

- Immuno-radiotherapy implementation
  - Precise estimation of OOF dose

⇒ New dose constraints on lymphocyte-rich structures (thymus, bone marrow, spleen ...)



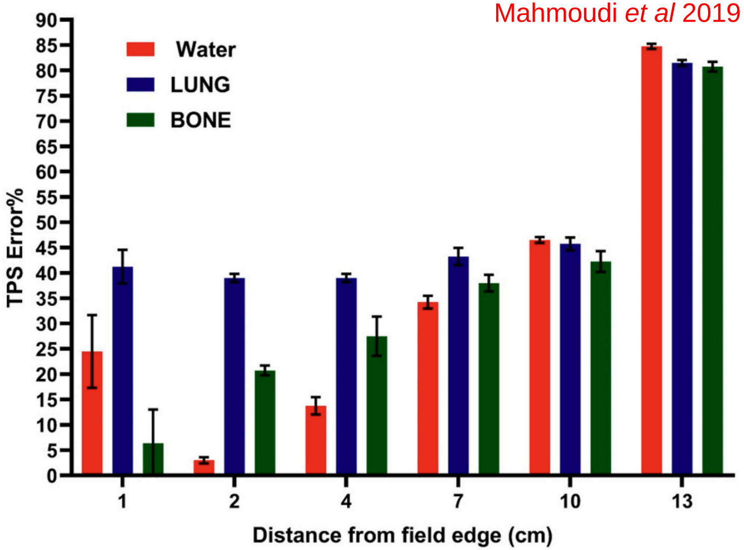
Overall survival with post-treatment absolute lymphocyte count (ALC)

OOF dose estimation

- OOF dose = below 5 % isodose
- Treatment Planning systems (TPS) strongly underestimates the deposited dose
- To accurately estimate OOF dose:
  - Analytical models
  - Monte-Carlo (MC) simulations

	Analytical models	MC simulations
Calculation time	++ ~ minutes	- ~ days
Accelerator design	++ Simple models	- Accurate models
Precision	+	++
Empirical adjustement	- Derive parameters from experiments	++ Matching experiments
Adaptability	-	+

Mahmoudi *et al* 2019



Difference between dose measurements and Monaco TPS predictions

Lymphocyte-Sparing Artificial Intelligence-guided Radio-Immunotherapy (LySAIRI) RHU project

Collaboration:

- CLB (Centre Léon Bérard)
- CREATIS
- IGR (Institut Gustave Roussy)

Deliver novel solutions toward the first effective implementation of immuno-radiotherapy

- Deep learning tools to quantify the OOF dose

OOF dose estimation

Deep learning models trained by MC simulations

	Analytical models	MC simulations	Deep learning models
Calculation time	++ ~ minutes	- ~ weeks	++
Accelerator design	++ Simple models	- Accurate models	-
Precision	+	++	+(+)
Empirical adjustement	- Derive parameters from experiments	++ Matching experiments	++
Adaptability	-	+	++

Training datasets

Proof of concept:

- Images of patients with a head and neck cancers
- Dataset training: pair of corresponding dose distributions
  - TPS calculations (Monaco)
  - MC simulations of an Elekta versa HD: GATE

⇒Generation of the OOF dose directly from the TPS information

GATE

GEANT4 wrapping:

- Easy access to GEANT4 functionnalities
- Additionnal features
- Collaborative development

Medical physics applications

Dosimetry studies

- External and internal therapy
- Hadrontherapy

Imaging systems

- PET
- SPECT
- Compton camera
- X-ray

However:

Old code

- 15 years of development

Hundreds of contributors

- Maintenance issues

→ New release of Gate:
GATE 10

GATE 10

- Based on new C++ technologies
- Python wrapping:
  - Easy to use
  - Combination with numpy/scipy libraries
- Open access collaborative work

Windows compatibility

Multithreading available

```python
waterbox = sim.add_volume("Box", "Waterbox")
waterbox.size = [40 * cm, 40 * cm, 40 * cm]
waterbox.translation = [0 * cm, 0 * cm, 25 * cm]
waterbox.material = "G4_WATER"
rot = (scipy.spatial.transform.
       Rotation.from_euler("XYZ", [45,90,90], degrees=True).as_matrix())
waterbox.rotation = rot
```

Python list

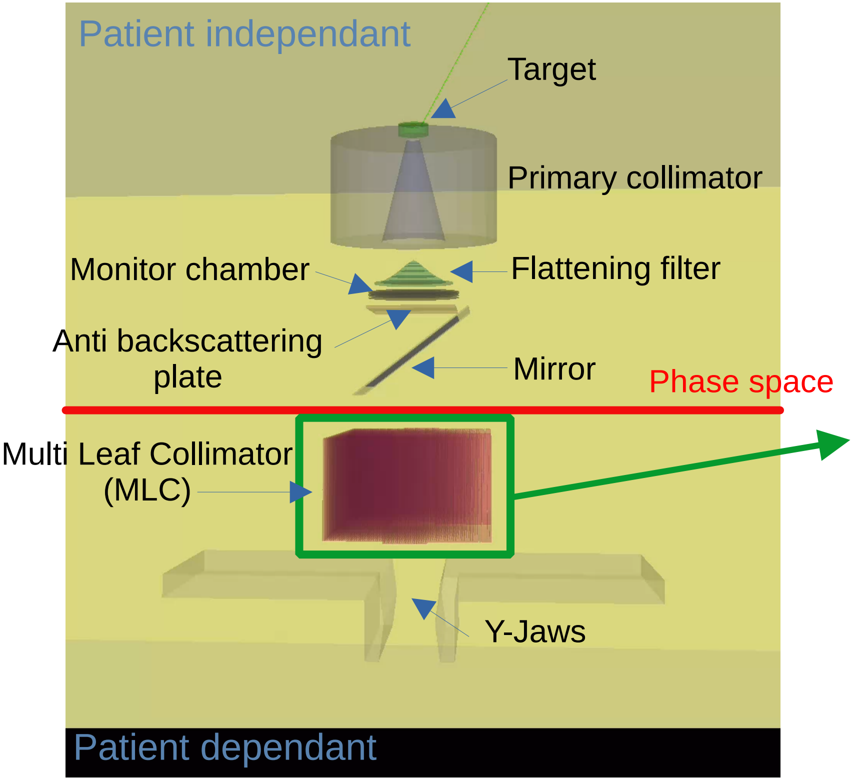
Scipy function

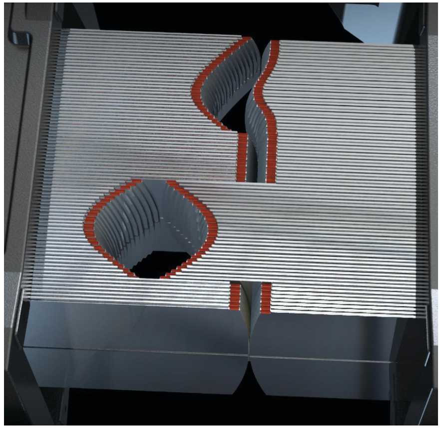
- Still in development
- Beta version available at the end of the year

Waiting for your contributions ☺

Simulation of the Elekta Versa HD

Elekta Versa HD





Agility MLC

Elekta LINAC VERSA HD 6 MV simulated with GATE 10

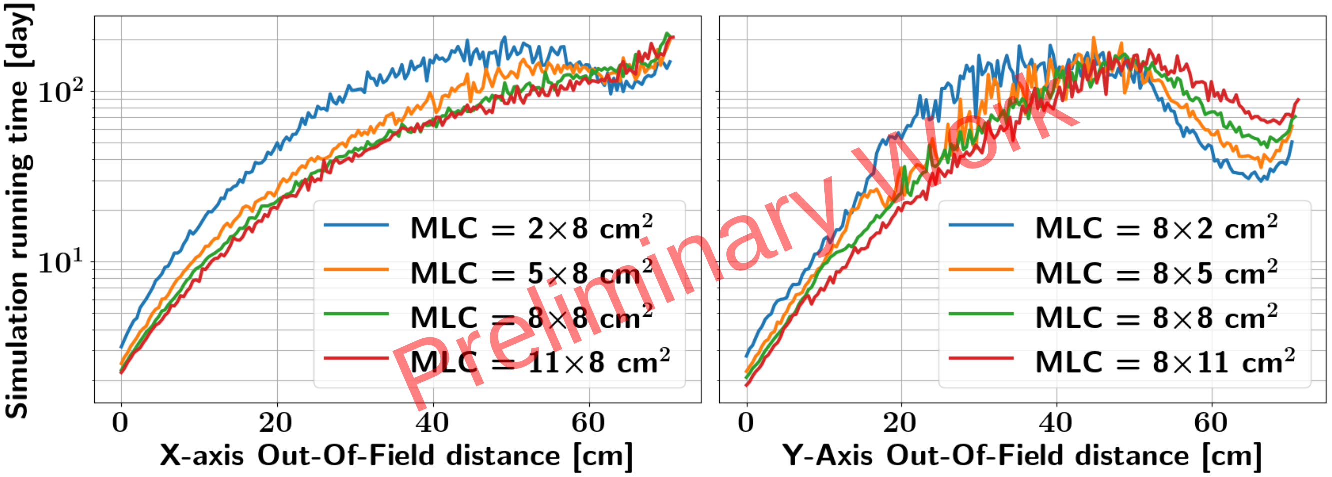
Estimation of OOF calculation times

Simulation settings

- Phase Space
- Ideal MLC

Targeted error on OOF dose distribution: 5 %

- Number of photon to simulate
- Simulation running time on a voxelized image



Day number to achieve 5 % of statistical uncertainties as a function of the axis-distance for differents MLC apertures

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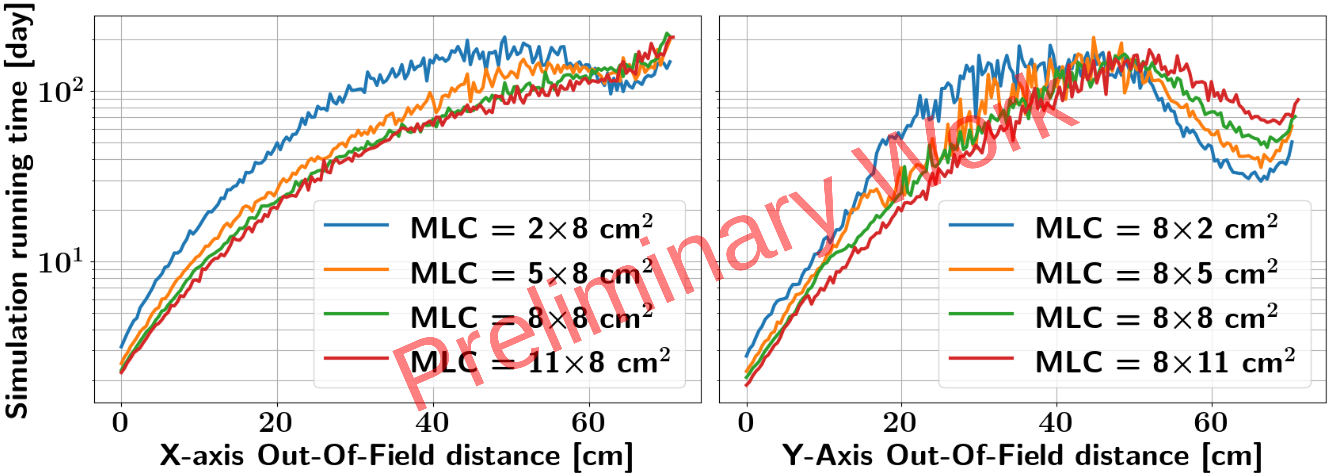

Day number to achieve 5 % of statistical uncertainties as a function of the axis-distance for differents MLC apertures

For far OOF (~40 cm):

- ~ 10^{11} photons to simulate
- 50 - 200 simulation days on one thread (i9-13950HX)

If targeted precision = 1 %

- Running time ~ 25 times higher

MC simulations acceleration

Perspective: strategies for MC simulation acceleration

« Full » MC approach

- Phase space before the MLC
- Precise but time consuming

Particle generation

Virtual Source Model approach

- Several virtual sources:
  - Primary photons
  - Secondary photons
- Faster but less precise

Chetty *et al* 2000
Chabert *et al* 2016

Generative Adversarial Network (GAN) approach

- Particle generation with GAN
  - Trained on phase space data
- Faster but precision on low dose ?

Sarrut *et al* 2019

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Sarrut *et al* 2019

Particle transportation

Biasing approach:

- Most of OOF events: Compton scattering
  - « Smart » suppresion of p.e. processes
  - Weighting by the event probability of occurence
- Variance reduction but edge-effect ?

Selective Tracking Lenght Estimator (TLE) approach

- « Low » energy photons in the OOF regions:
  - Local photon energy deposition
- Variance reduction but realistic approximation ?

Smekens *et al* 2012

CONCLUSION

LySAIRI project:

- Deep learning models development
- Accurate MC datasets training

Development of MC simulations

- Elekta Versa HD in GATE 10
- Running time estimation for one image:
  - 50 – 200 days on one thread
  - Daily scale with the cc-in2p3

Acceleration strategies of MC simulations