Réduction de variance pour le calcul Monte-Carlo des doses hors-champs en radiothérapie

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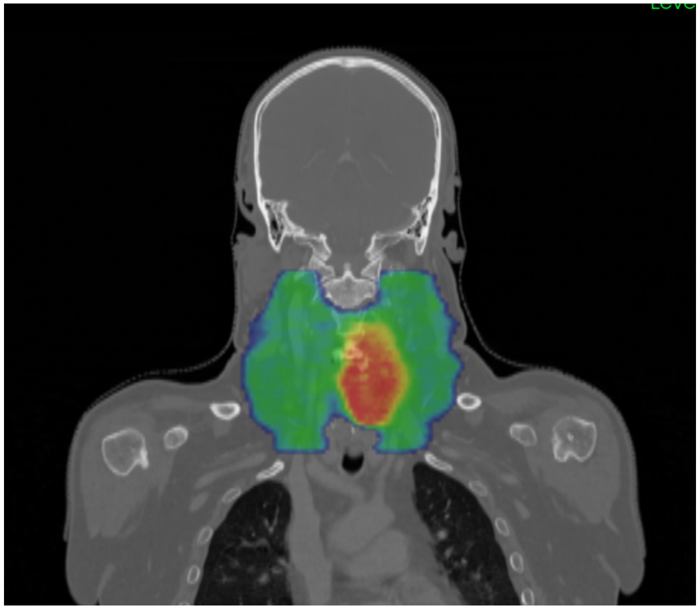
Out-Of-Field (OOF) dose for the Volume Modulated Arc Therapy (VMAT)



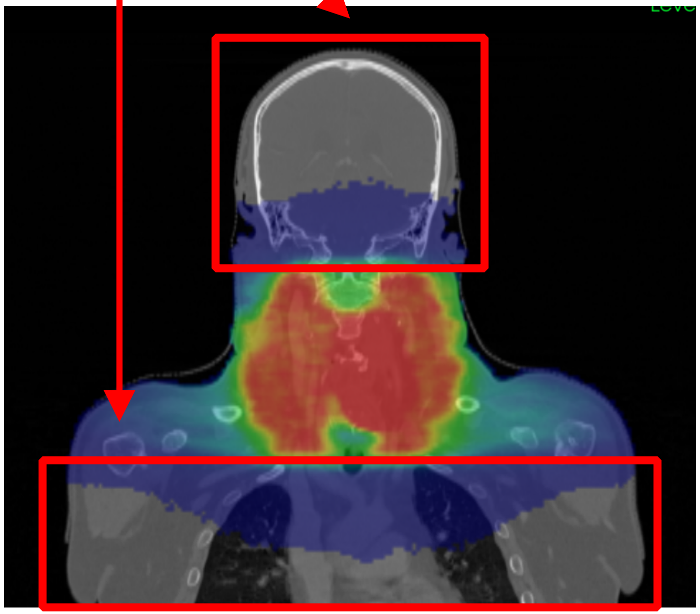
TPS calculation of a VMAT modality

TPS calculation

- Accurate (in-field)
- Fast

Out-Of-Field (OOF) dose for the Volume Modulated Arc Therapy (VMAT)

Potential immune effects to investigate



TPS calculation of a VMAT modality

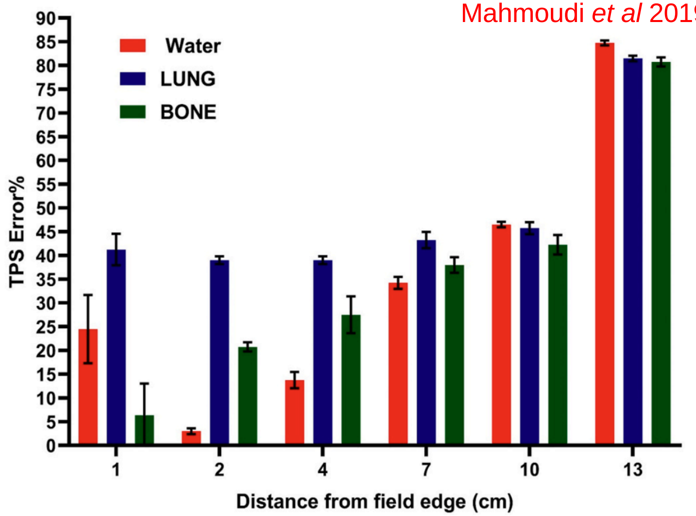
TPS calculation

- Accurate (in-field)
- Fast
- Less precise (OOF)
  - ~ 100 % of error

MC simulations

- Accurate
- Time consuming

Mahmoudi *et al* 2019



Difference between dose measurements and Monaco TPS predictions

Radiotherapy immune-effect

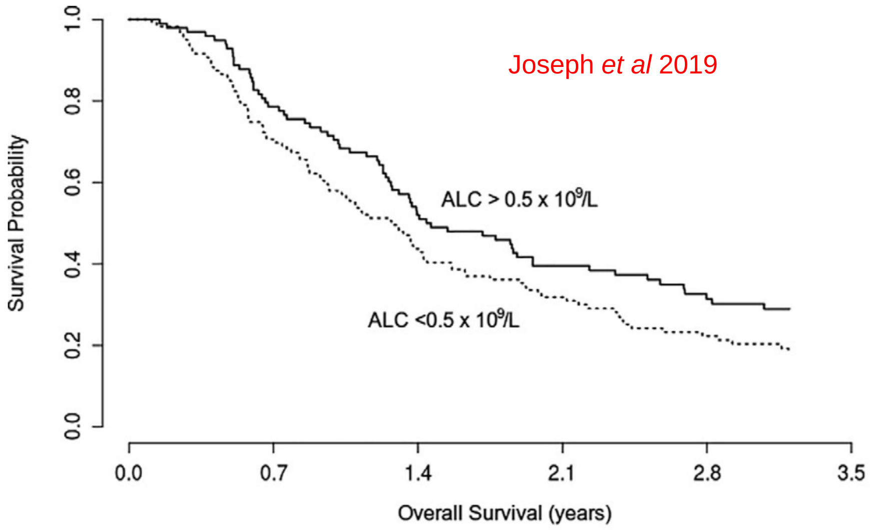
In-field: double-edged sword

- Immune system stimulation
- Circulating lymphocyte killing
  - DL50 ~ 2Gy

Out-of-field

- Low dose in the immunological organ at risk
  - Potential effect on lymphocyte production

▶ Lymphopenia



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

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

Collaboration:

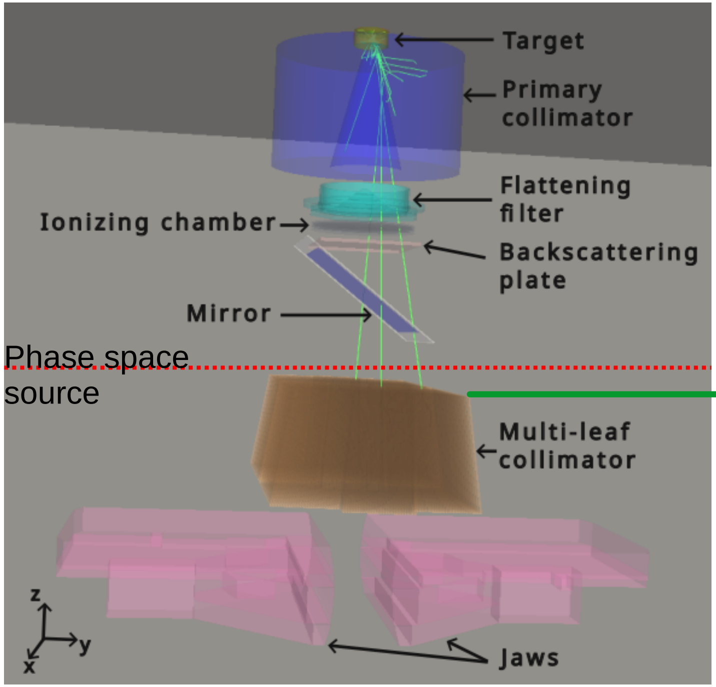
- CLB (Centre Léon Bérard)
- IGR (Institut Gustave Roussy)
- CREATIS
- UMR 1030

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

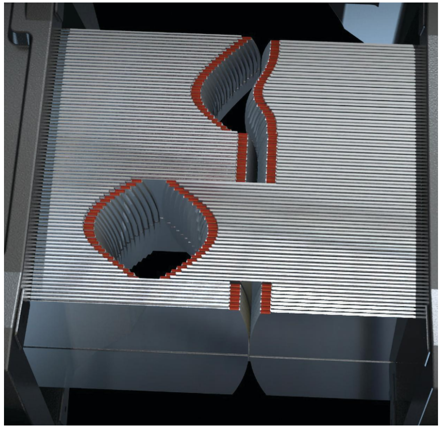
- Deep learning tools to quantify the OOF dose
    - Trained on MC simulations

Elekta Versa HD in GATE 10

Elekta Versa HD

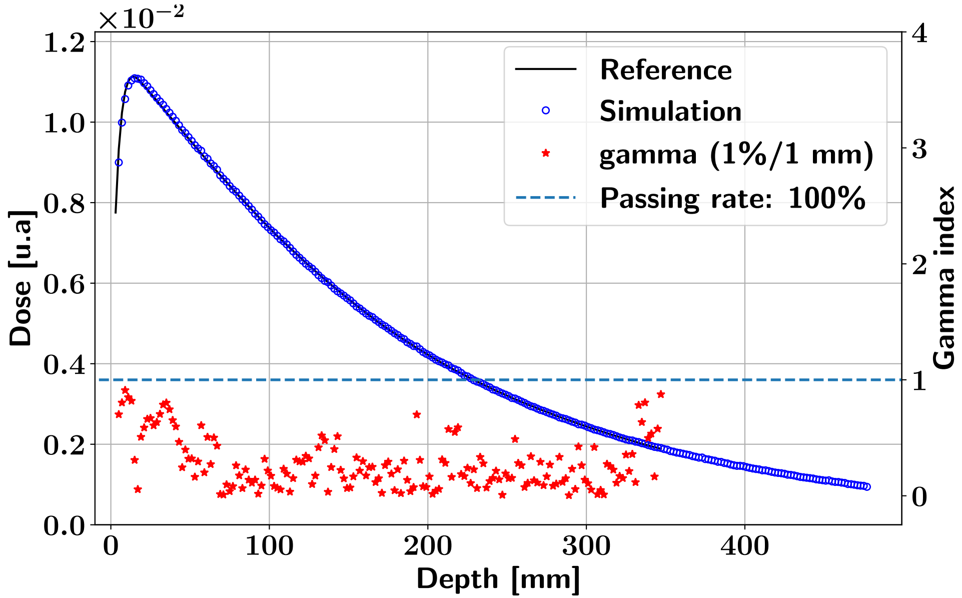


Elekta LINAC VERSA HD 6 MV simulation

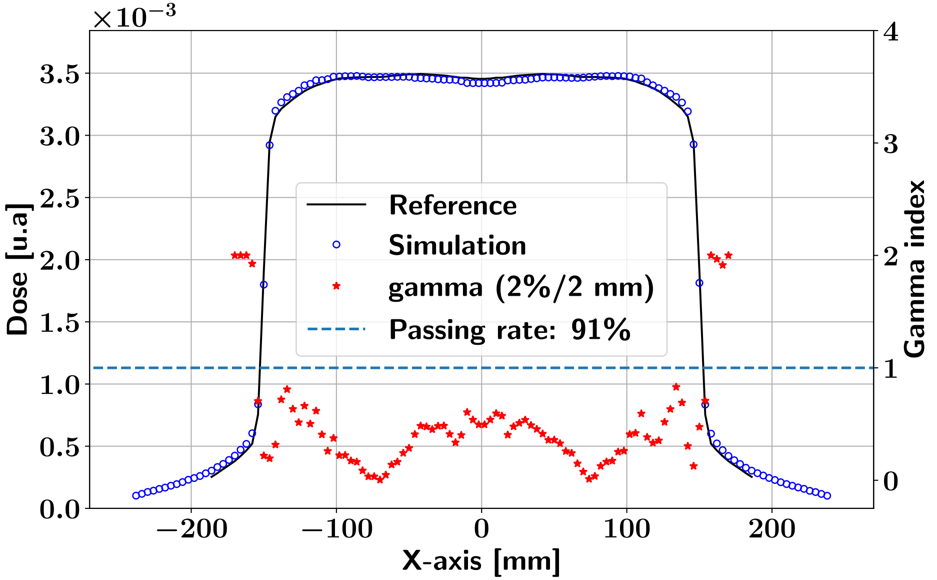


Agility MLC

In-field validation

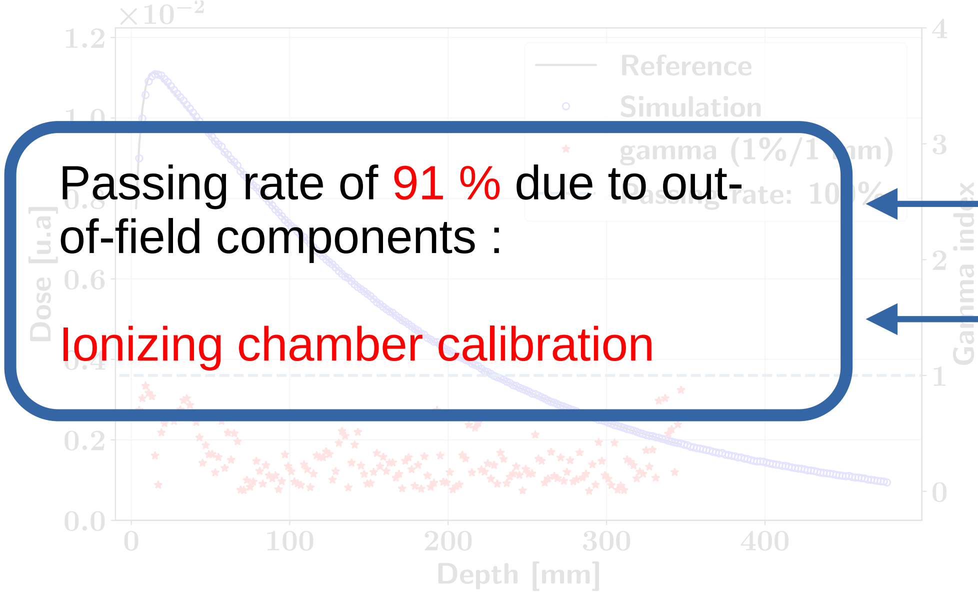


Percentage depth dose profile (PDD) 1 %/1 mm comparison between experiments and simulation for a 10×10 cm² field



X-axis profile 2 %/2 mm comparison between experiments and simulation for a 30×30 cm² field

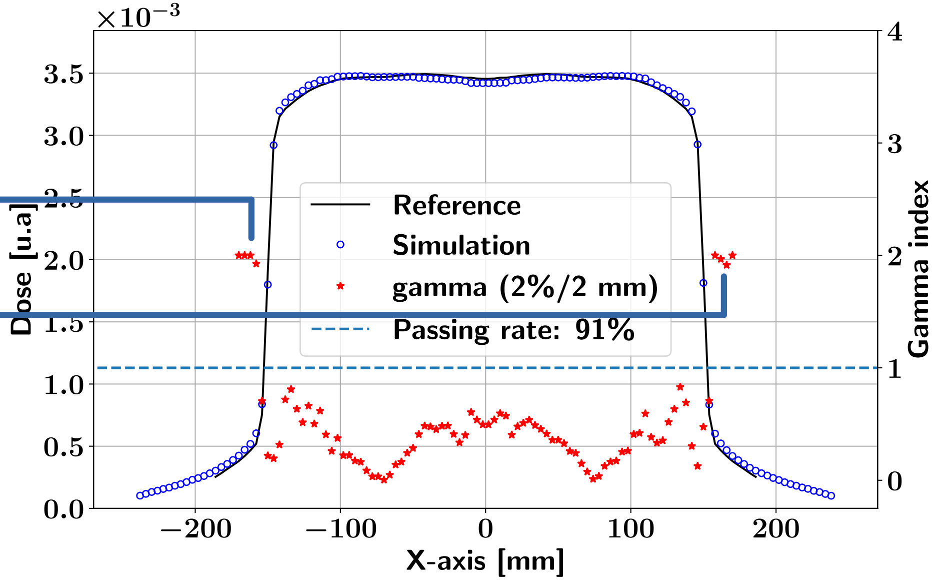
In-field validation



Passing rate of 91 % due to out-of-field components :

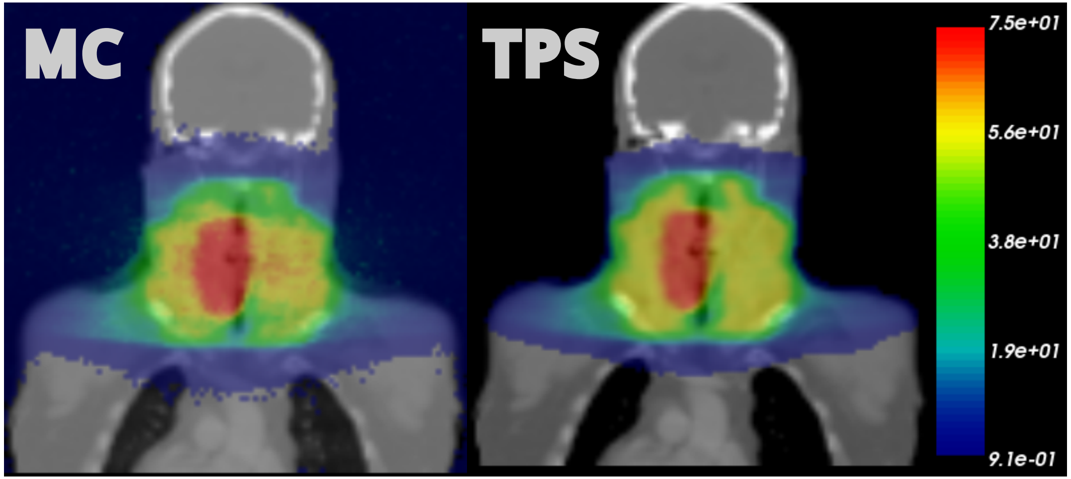
Ionizing chamber calibration

Percentage depth dose profile (PDD) 1 %/1 mm comparison between experiments and simulation for a 10×10 cm² field

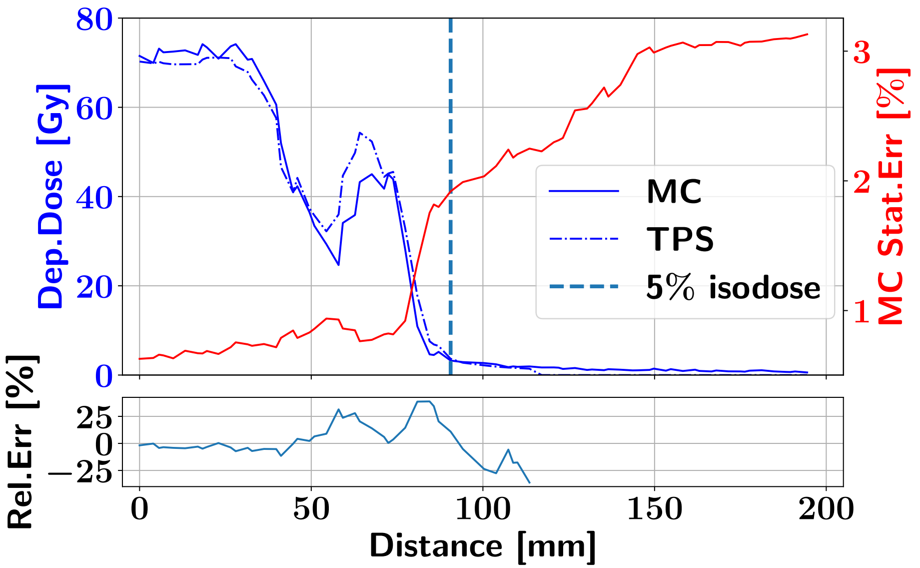


X-axis profile 2 %/2 mm comparison between experiments and simulation for a 30×30 cm² field

VMAT simulation

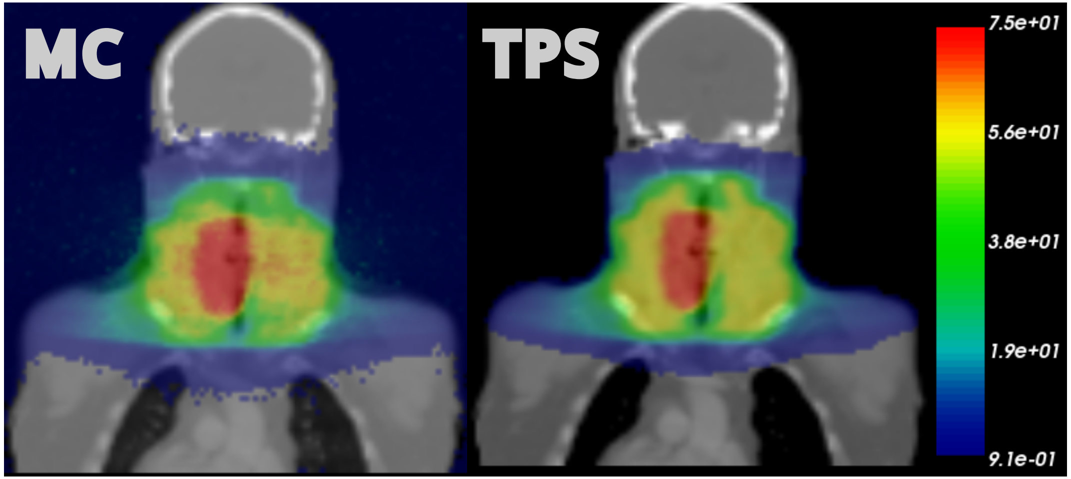


VMAT modality comparison between MC simulation and Monaco calculation



Dose along Isocenter-minimal deposited-dose axis

VMAT simulation



VMAT modality comparison between MC simulation and Monaco calculation

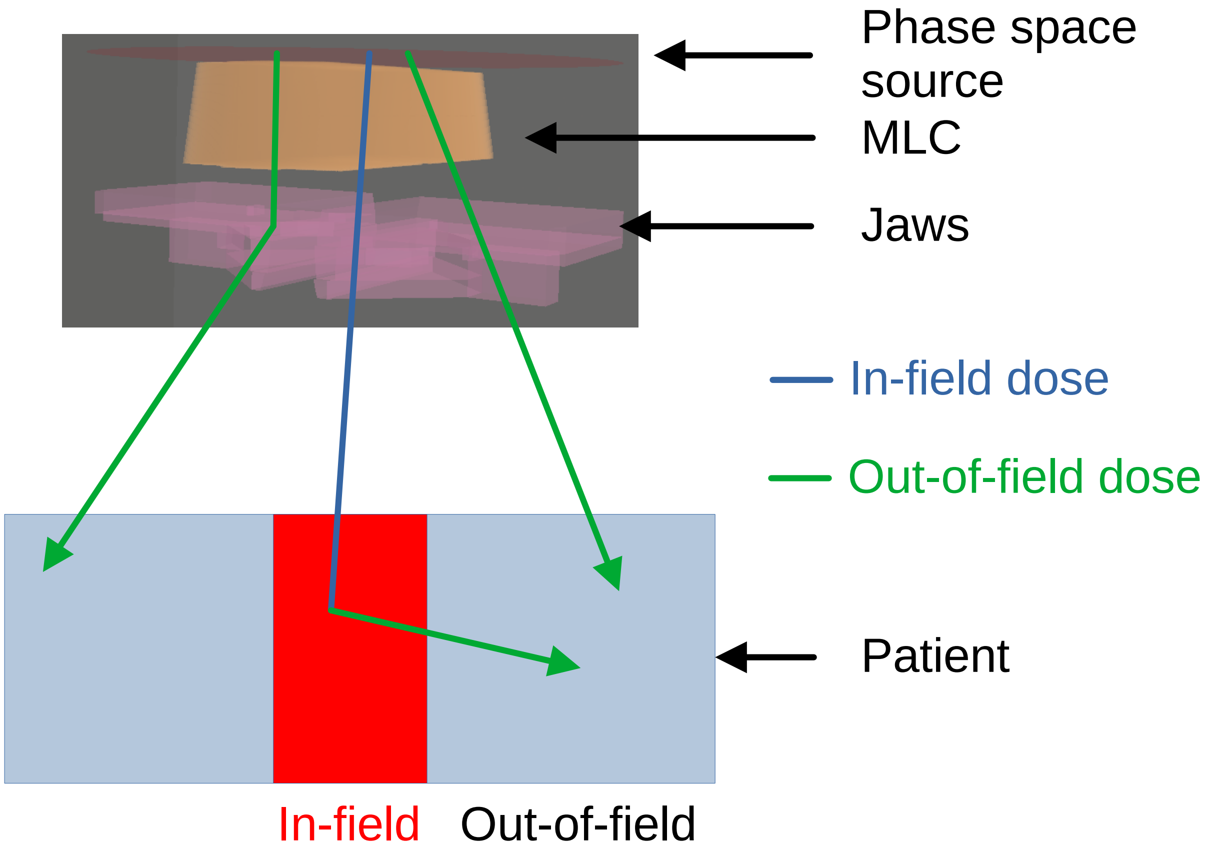
Reproduction of the TPS

- Inaccuracy coming from :
  - HU to material conversion
  - LINAC model inaccuracy

Simulation running time :

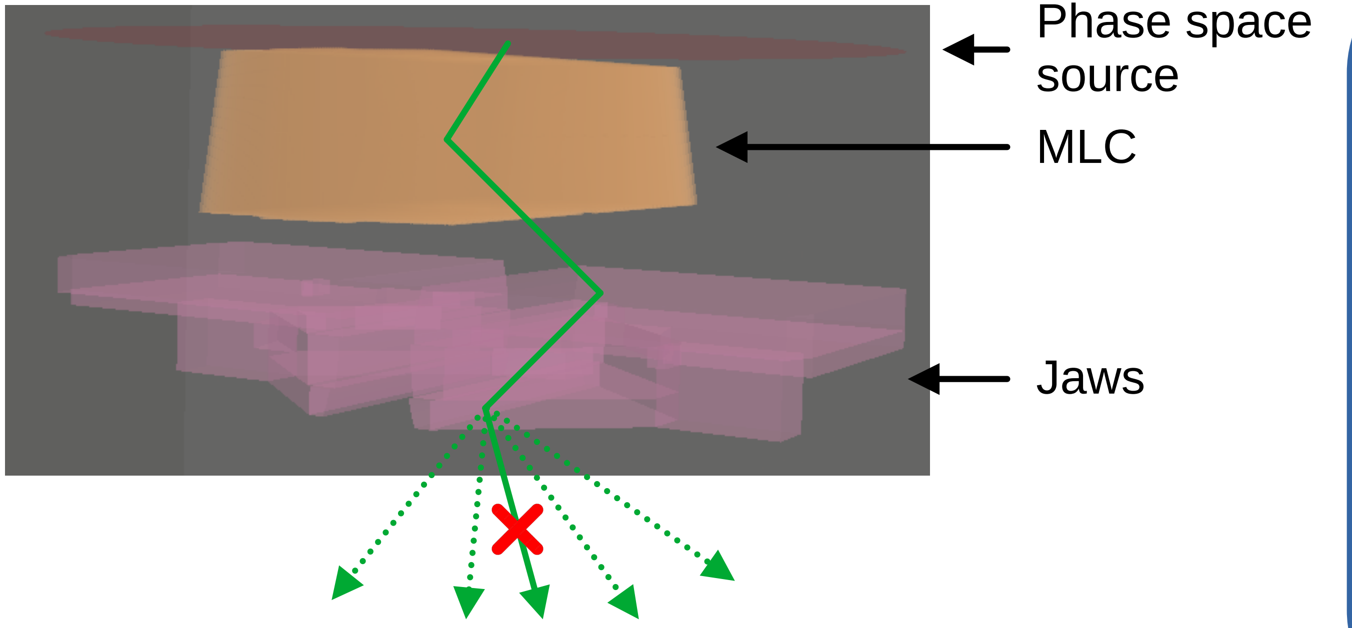
- One patient : ~ 10 kh of simulation
  - 100 patient database: several months on the cluster
  - Variance Reduction Methods (VRM)

Variance reduction for secondary photons :



- OOF components sources :
  - Patient scatter
  - Head scatter/leakage
- Two VRM applied to :
  - Patient
    - SeTLE (Smekens 2014)
  - LINAC head
- Last vertex splitting method

Last vertex splitting method

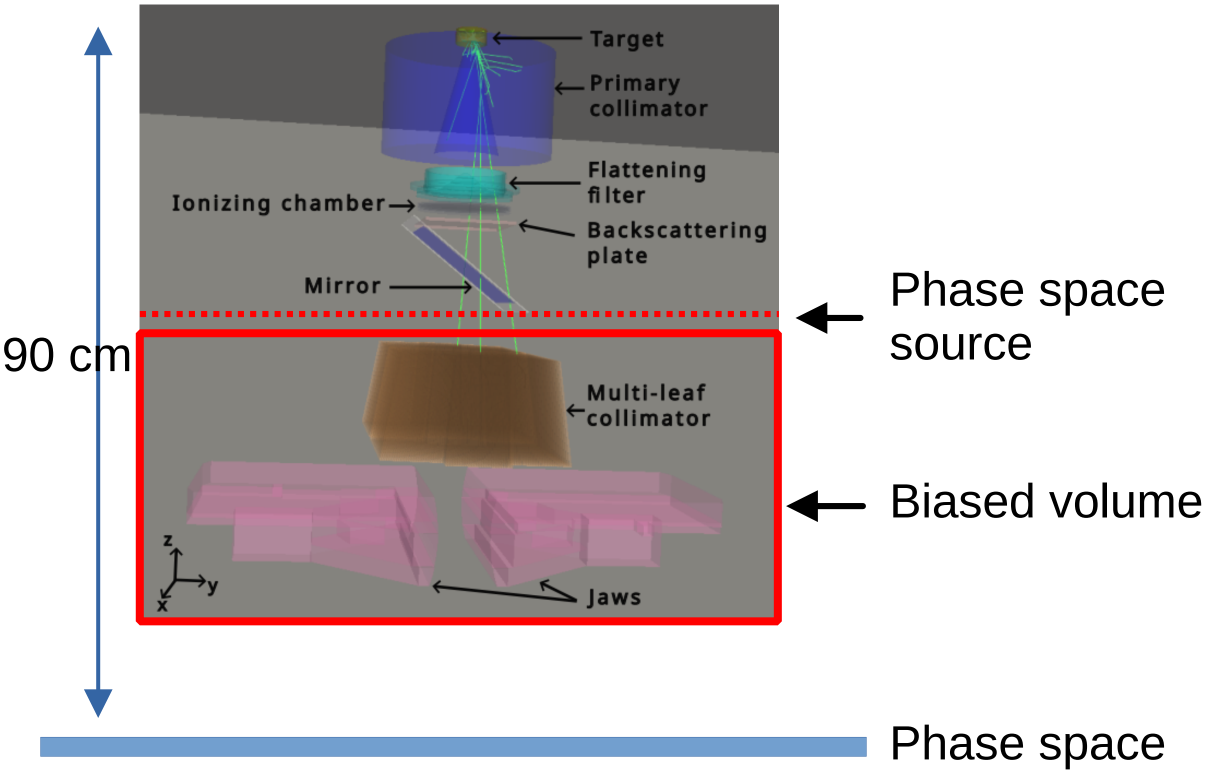


Sketch of the last vertex splitting applied to a triple Compton scattering

Last vertex splitting

- Interesting photons :
  - Rare events
  - ~ 1/50 photons exit the collimation
  - Collimation system diffusion
- Split :
  - According to its last process
  - At its last vertex

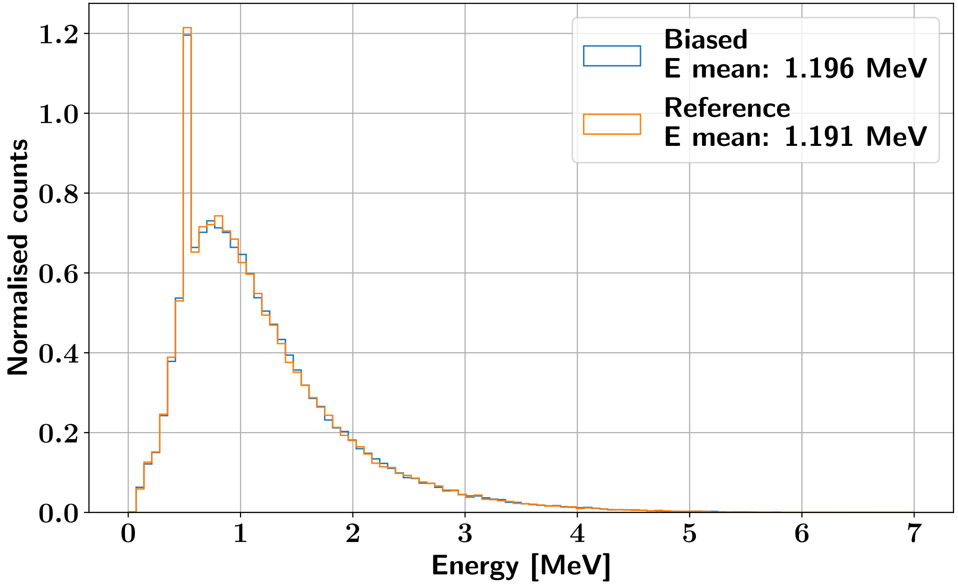
Assessment of last vertex splitting method



Simulation set-up to assess the method

- Method applied to the LINAC head
  - Em standard 3
  - High cut on e-
- Phase space to retrieve
  - Energy
  - Position
  - Direction
  - Particle name

Bias method evaluation



Photon energy spectrum obtained at the exit of the LINAC head

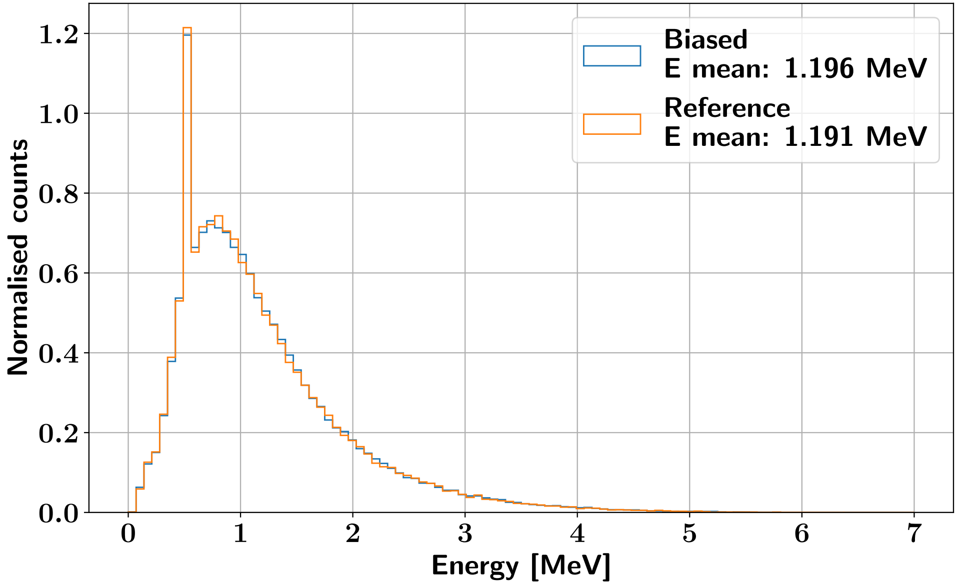
Comparison between :

- Normal simulation
- Biased simulation
  - Splitting of 1

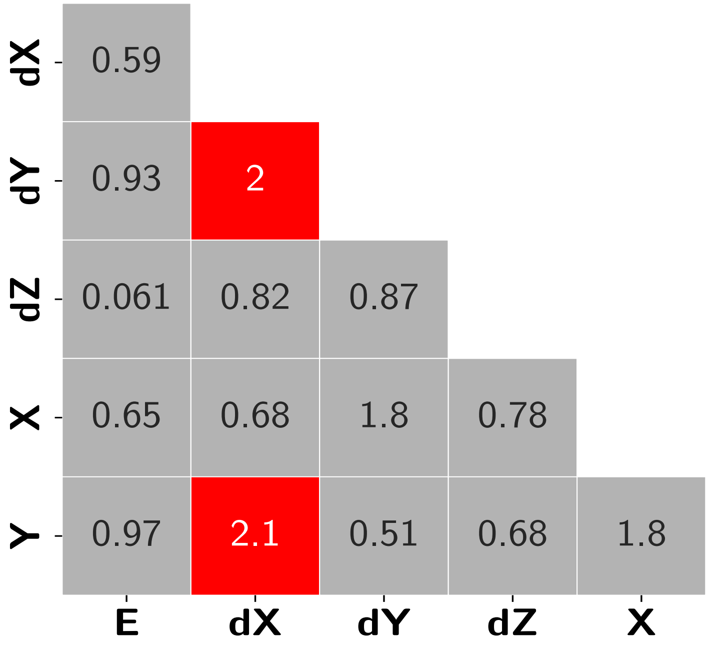
E	dX	dY	dZ	X	Y
1.7	0.088	0.6	1.5	0.064	0.82

Marginal distribution Z-score of biased simulation

Bias method evaluation



Photon energy spectrum obtained at the exit of the LINAC head



Correlation matrix Z-score of biased simulation with the respect to the analog simulation

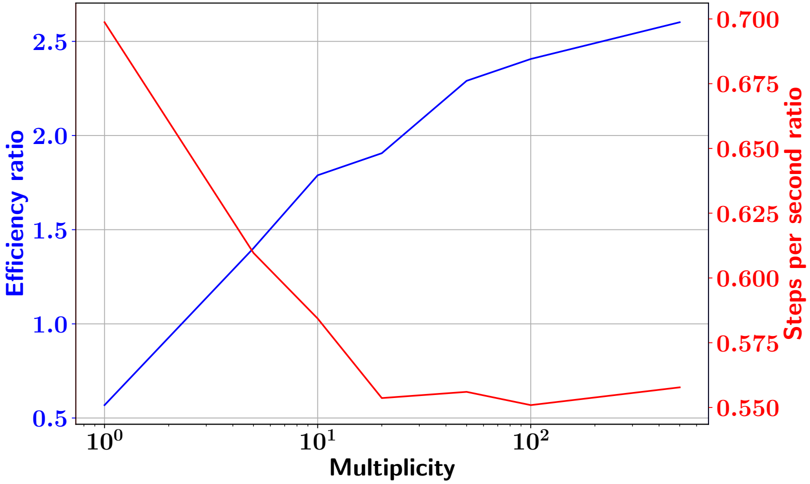
Biasing method efficiency

Simulation efficiency

$$\epsilon = \frac{1}{\mathbb{V}[\hat{E}] \times t}$$

- V[Ê]: mean energy variance
- t: simulation running time

- Efficiency ratio:
  - Biased/Analog simulation
  - Precision increase for a same running time



Efficiency ratio according to the multiplicity.

Preliminary efficiency ratio of about 2.5, but :

- GEANT4 method to be optimized

Biasing method efficiency

Simulation efficiency

$$\epsilon = \frac{1}{\mathbb{V}[\hat{E}] \times t}$$

- V[Ê]: mean energy variance
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- Efficiency ratio:
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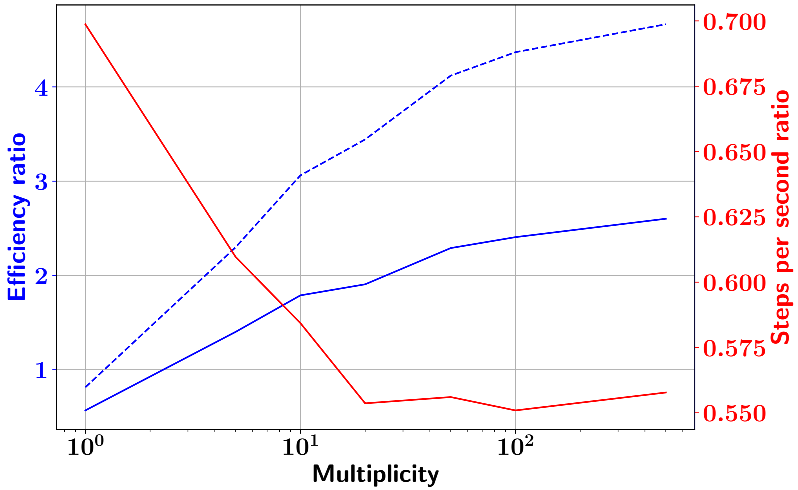

Efficiency ratio according to the multiplicity.

Upper bound on the efficiency ratio about ~ 5

Conclusion and discussion

- Development of a LINAC model using GATE10
  - In-field dose: Validated
  - Out-of-field dose: work in progress
- Dynamic simulation able to reproduce a RT plan
- New VRM: Last vertex splitting
  - Preliminary speed-up: × 2.5
  - Applied to LINAC head but generic
- Next steps :
  - Combine with TLE
  - Generate the patient database