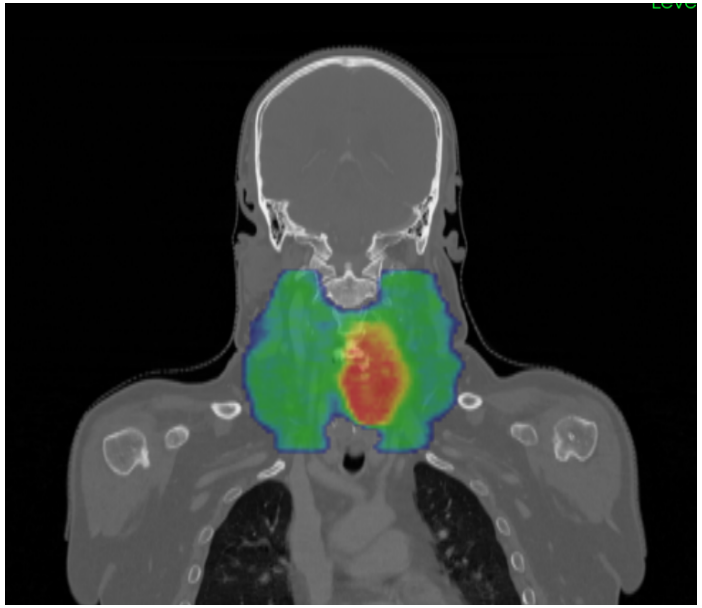
Variance Reduction Technique to Optimize LINAC Head Modeling

Maxime Jacquet
CREATIS Lyon

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



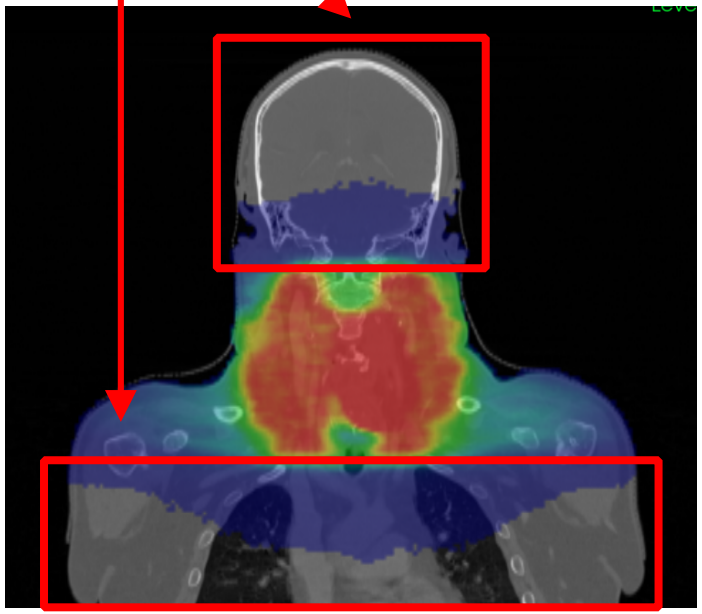
TPS calculation of a VMAT modality

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

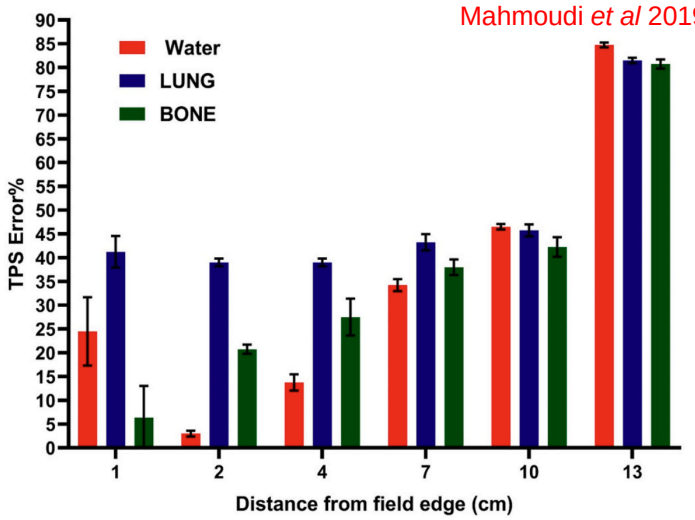
TPS calculation

- 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

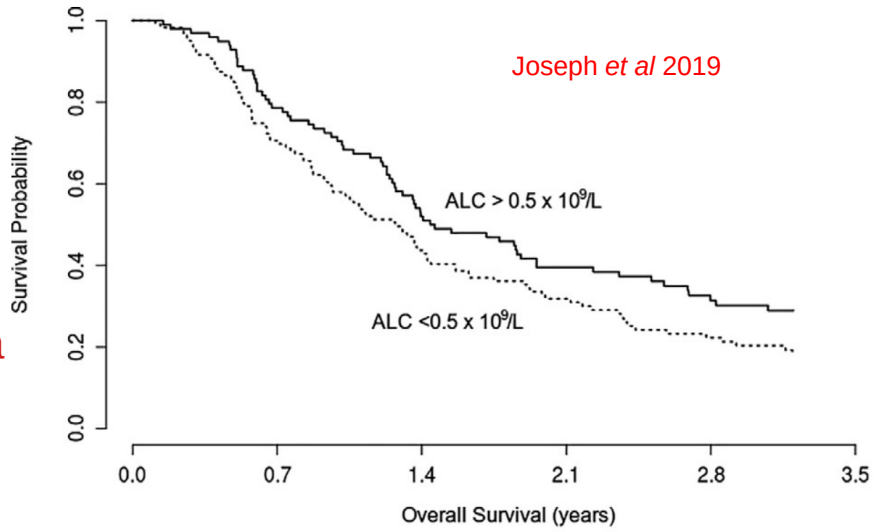
In-field: double-edged sword

- 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



Joseph *et al* 2019

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

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

Collaboration:

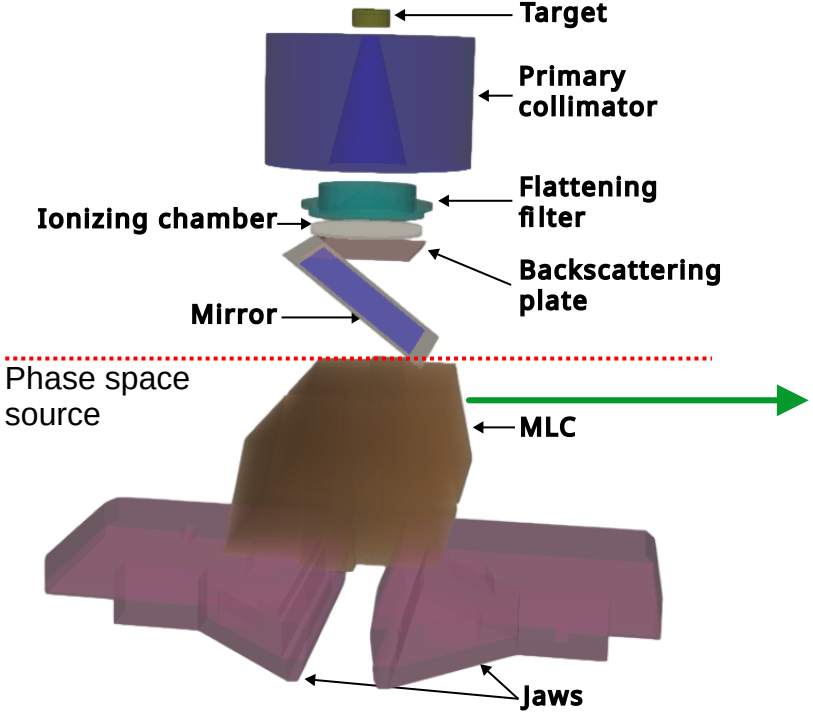
- CLB (Centre Léon Bérard)
- IGR (Institut Gustave Roussy)
- CREATIS
- UMR 1030

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

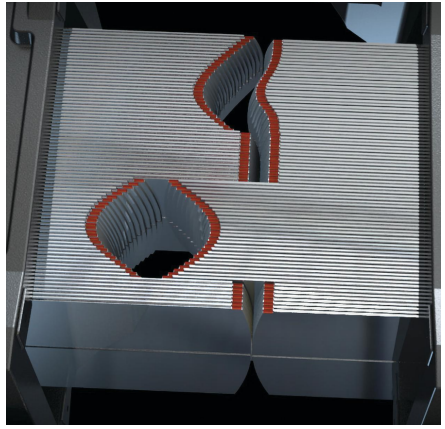
- Deep learning tools to quantify the OOF dose
  - Trained on MC simulations

Elekta Versa HD in GATE 10

Elekta Versa HD

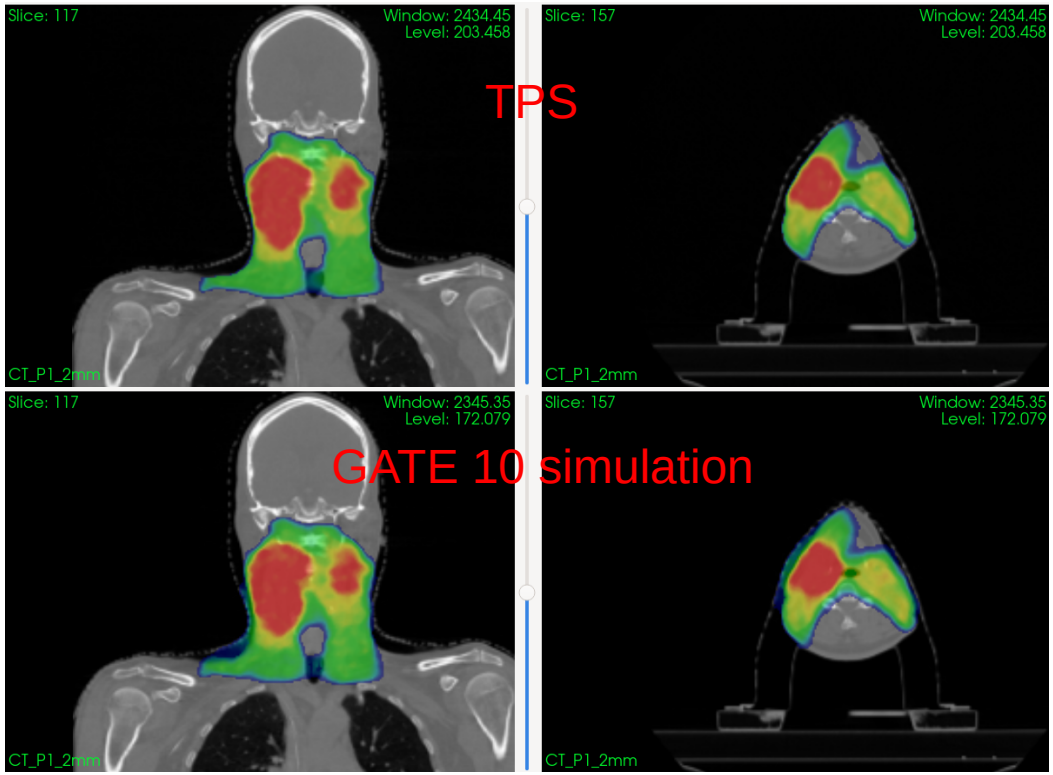


Elekta LINAC VERSA HD 6 MV simulation



Agility MLC

VMAT simulation



Comparison between the TPS and the GATE10 simulation

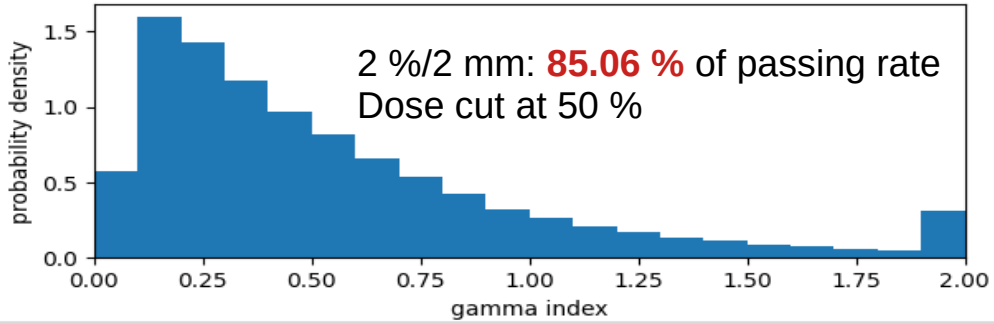
Simulation description

VMAT: 2 arcs, 121 CPs per arc

For every CPs:

- 160 leaves + 2 jaws motions
- LINAC head rotation
- MU adaptation

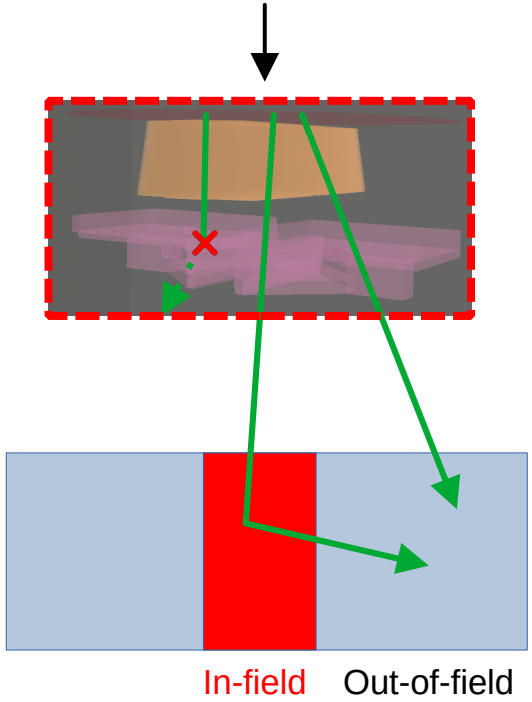
- 1% of statistical error at the isocenter
- 5000 hours of calculation



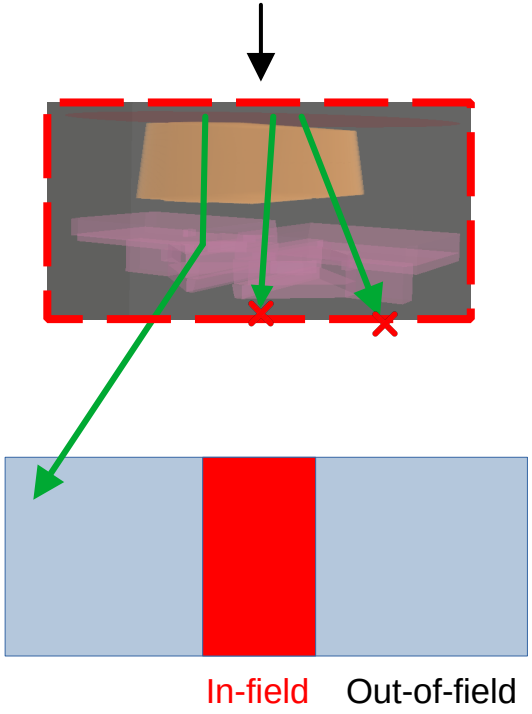
Gamma index passing rate for a 2mm/2% threshold

Variance reduction method :

Only non interacting particles



Only interacting particles



Simulation set-up

- Simulation one :
  - Primary particles at the linac exit
  - hybrid Tracking Length Estimator (hTLE) to the irradiated volume
- Simulation two :
  - Secondary particles at the linac head exit
  - Last Vertex Splitting applied to the LINAC head
  - hTLE applied to the irradiated volume

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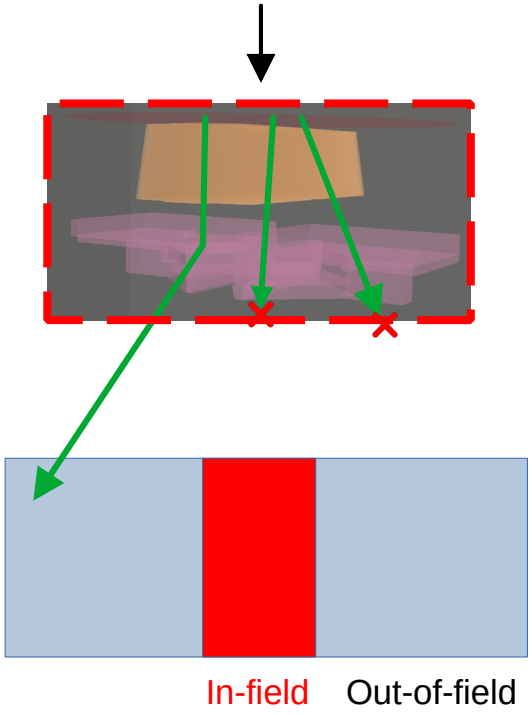

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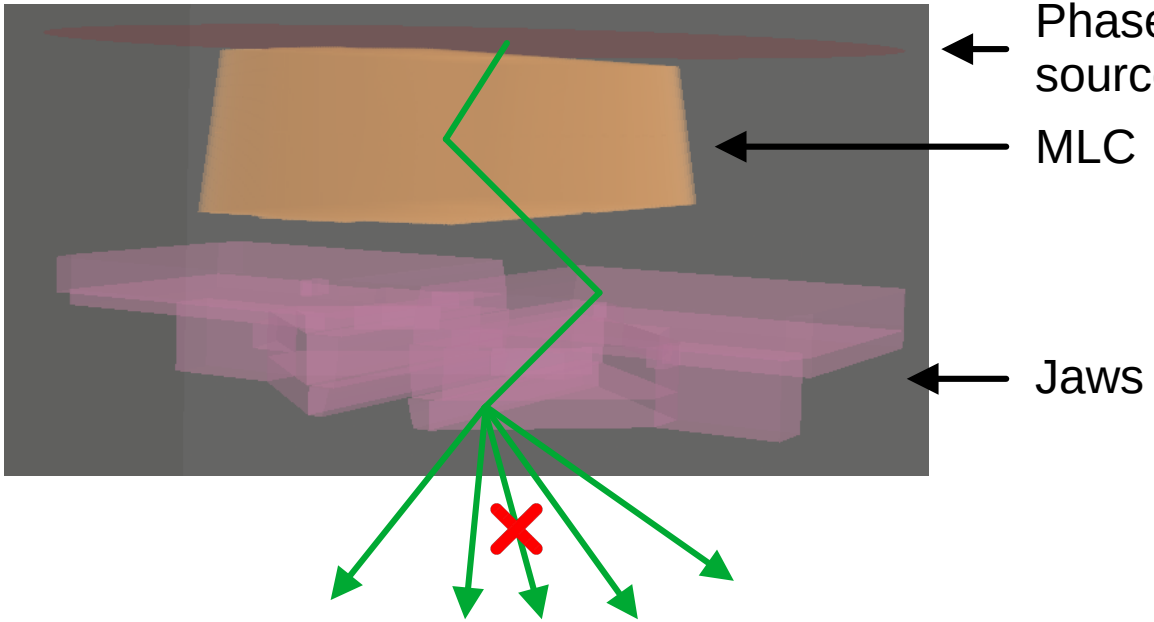
  - **Last Vertex Splitting applied to the LINAC head**
  - **hTLE applied to the patient**

Last vertex splitting (LVS) method

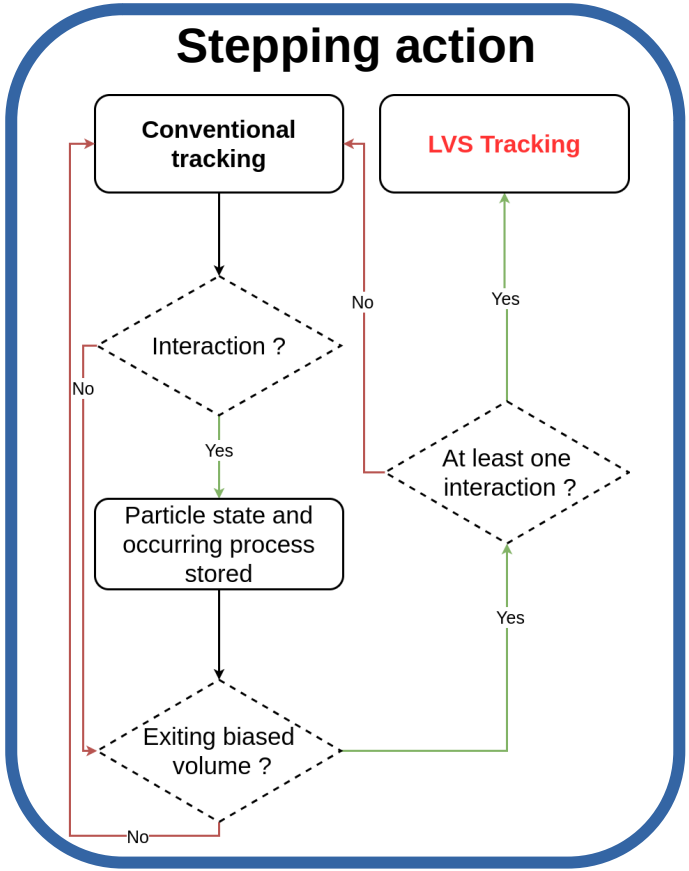


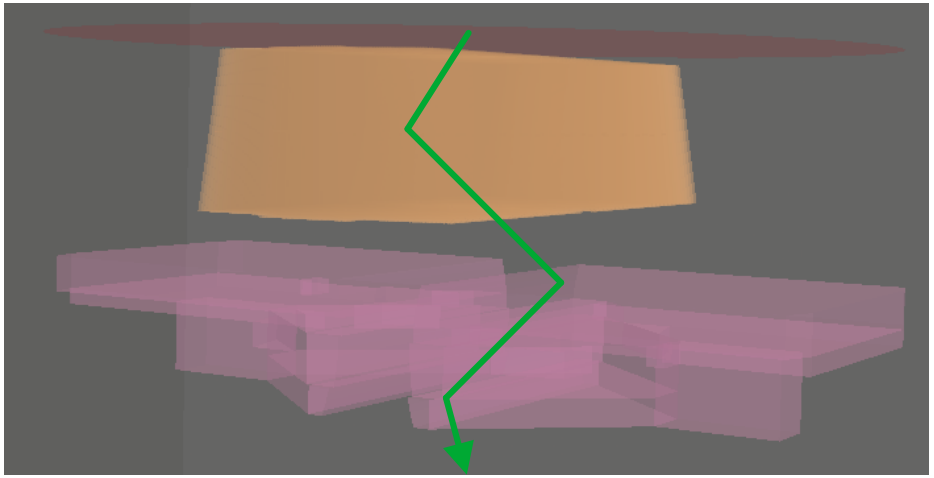
Sketch of the last vertex splitting applied to a triple Compton scattering

Last vertex splitting

- Interesting photons :
  - Rare events
  - ~ 1/100 photons exit the collimation
  - Collimation system scattering
- Split :
  - According to its last process
  - At its last vertex

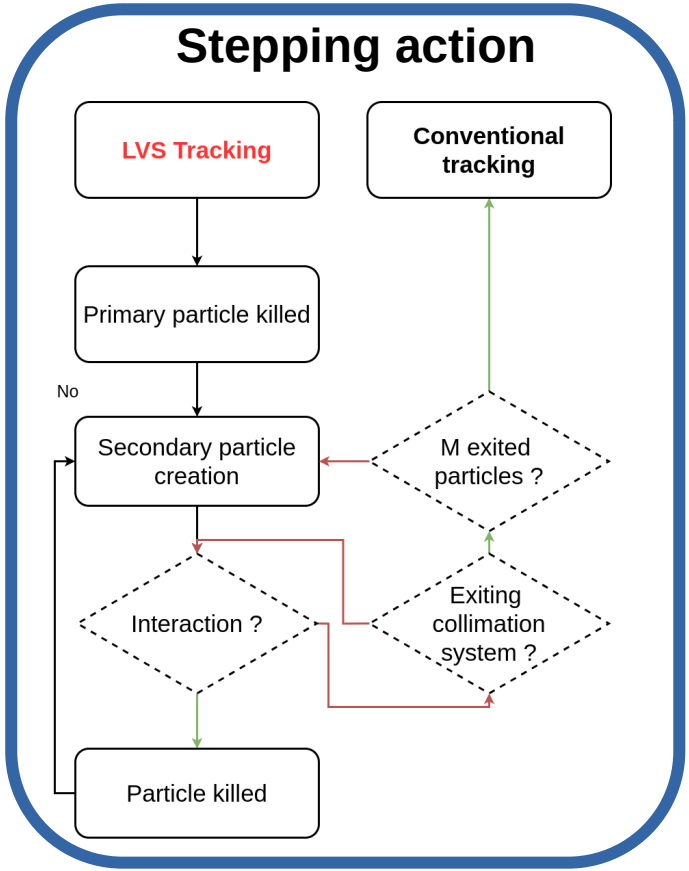
Last Vertex Splitting: Implementation

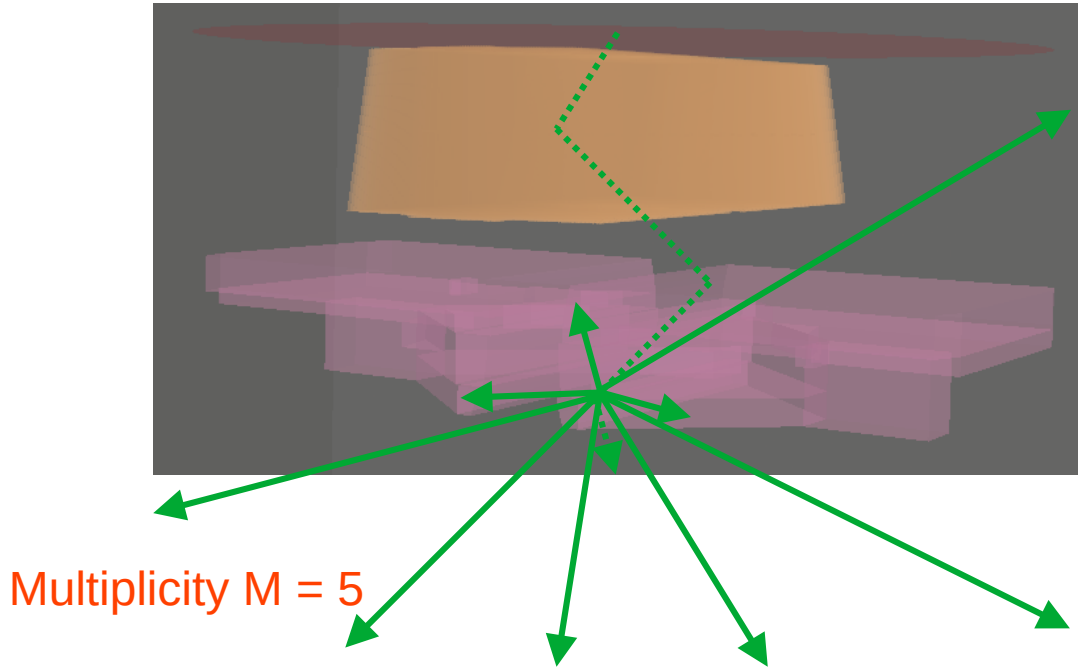




Sketch of the last vertex splitting applied to a triple Compton scattering

Last Vertex Splitting: Implementation





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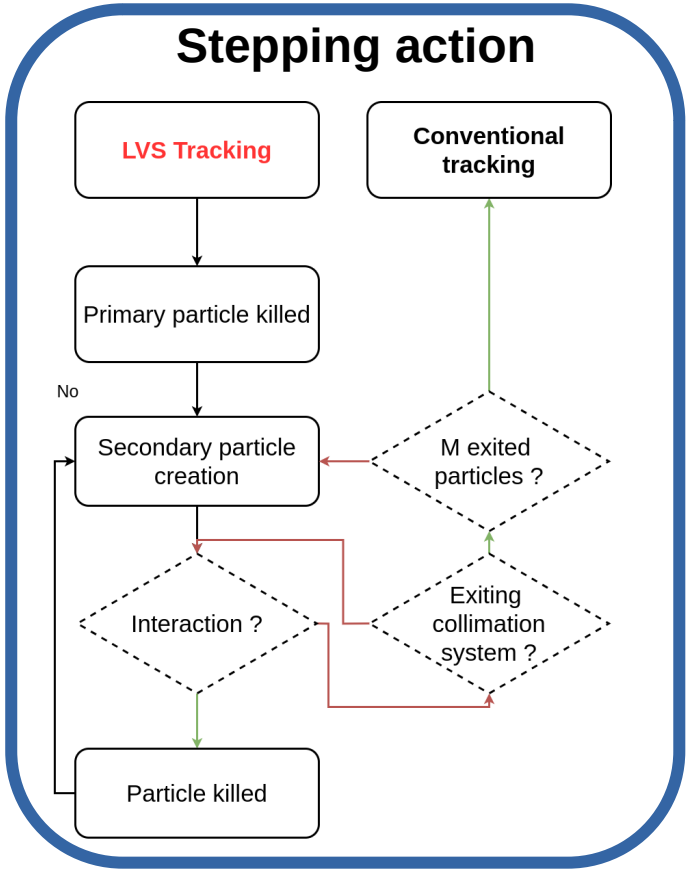
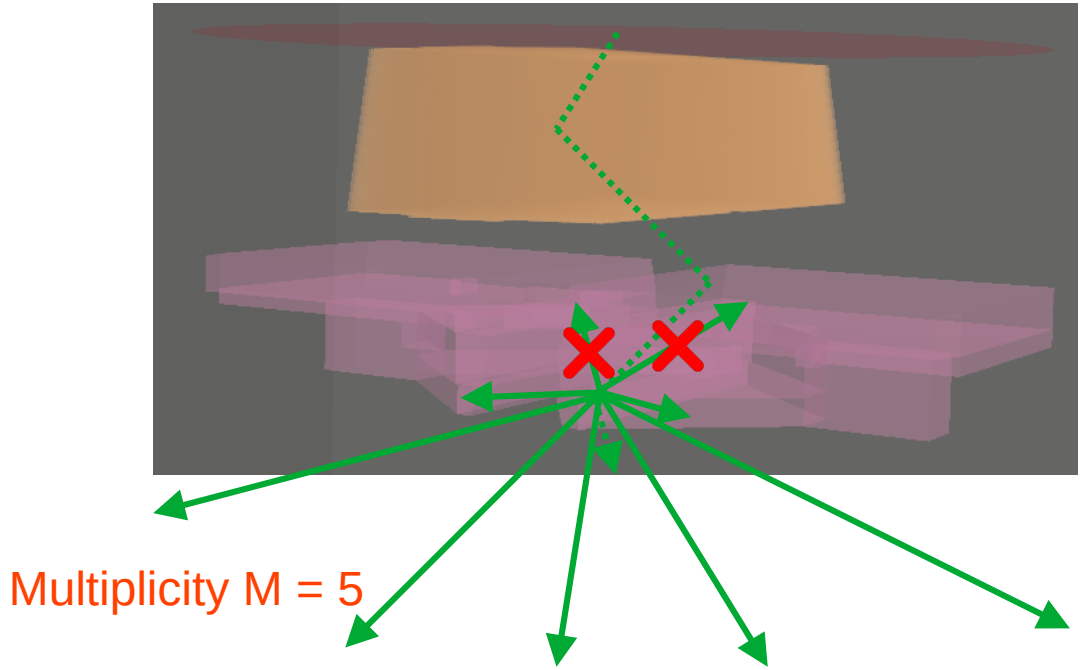
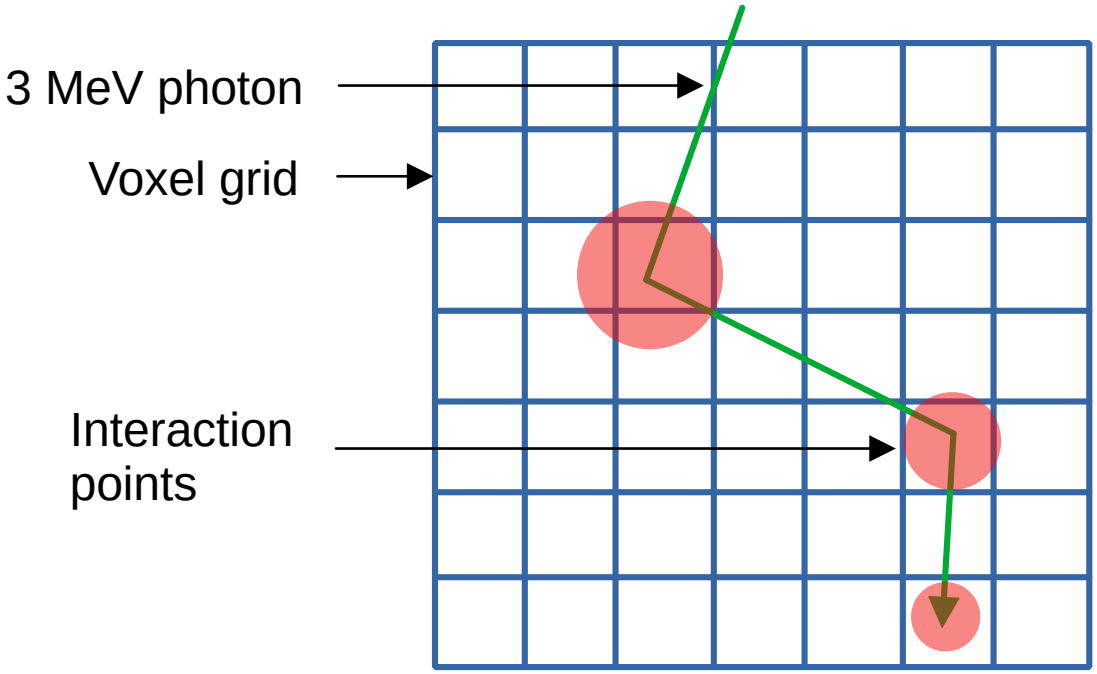




Sketch of the last vertex splitting applied to a triple Compton scattering

Hybrid Tracking Lenght Estimator (hTLE)

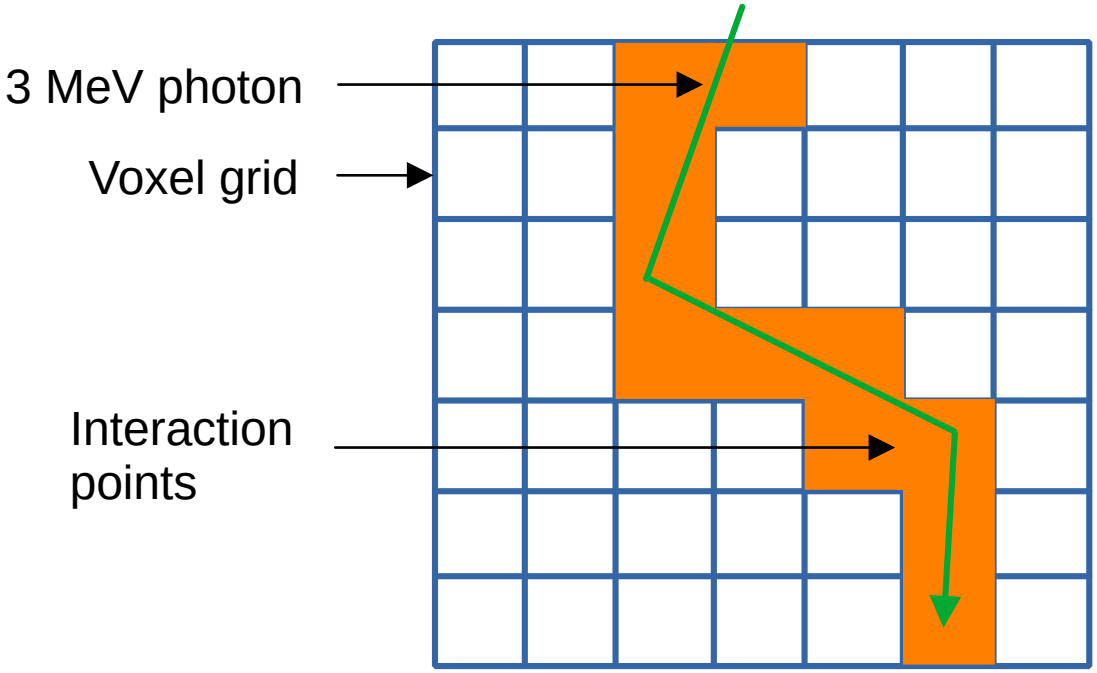


Sketch of deposited energy by a photon

Dose deposition methods

- **Analog**
- TLE :
  - $D_i^{\mathrm{TLE}} = \dfrac{E \times \mu_{\mathrm{en}}(E, m_i) \times L_i}{\rho_i \times V}$
- hTLE :
  - Energy threshold

Hybrid Tracking Lenght Estimator (hTLE)



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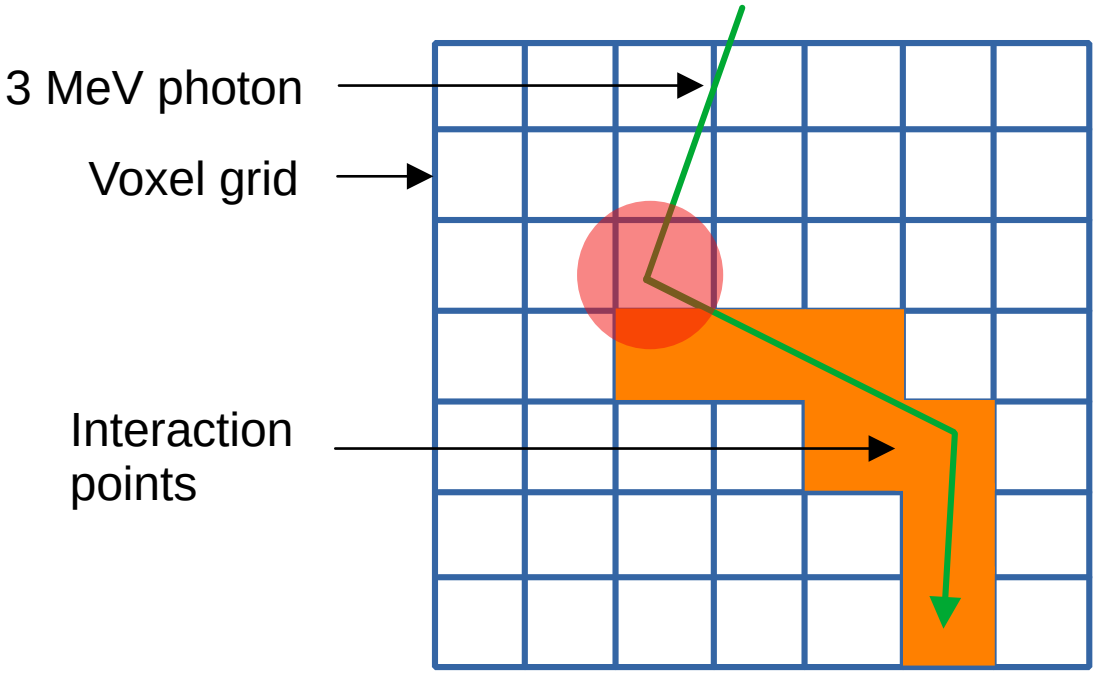

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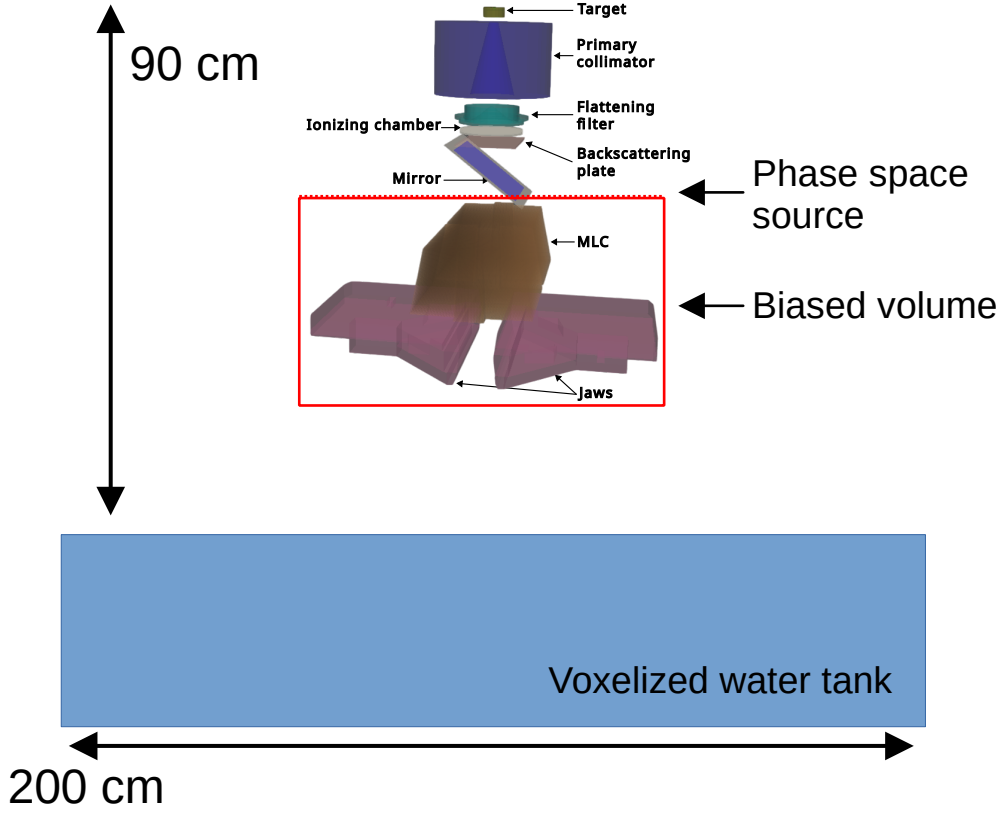
VRTs assessment: Set-up



Simulation set-up to assess the method

GATE 10 simulation

- Em standard 3
- High cut on e-
- 10x10 cm^2 field

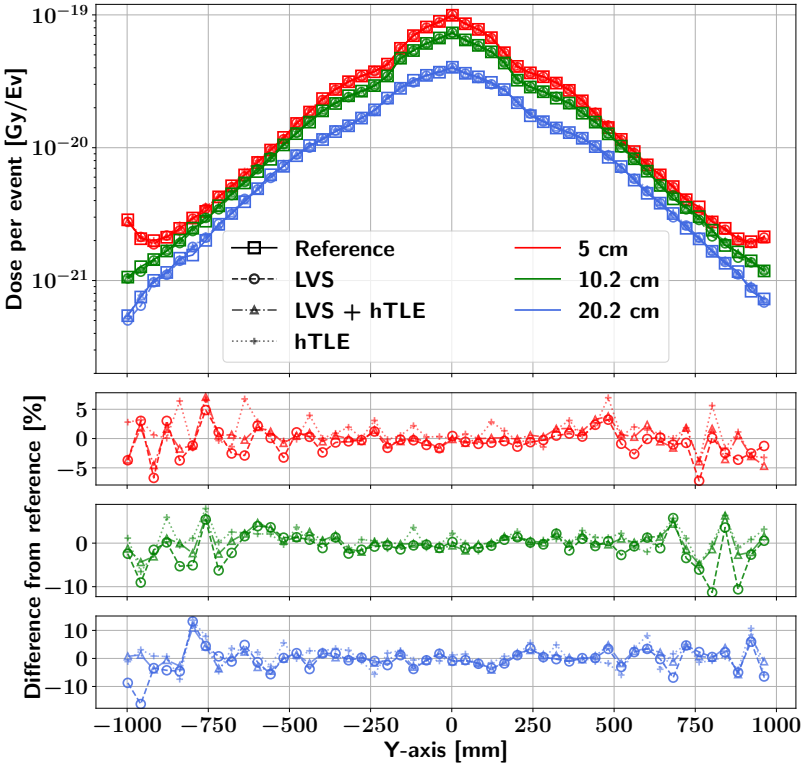
VRTs :

- LVS : On the biased volume
- hTLE : On the voxelized patient

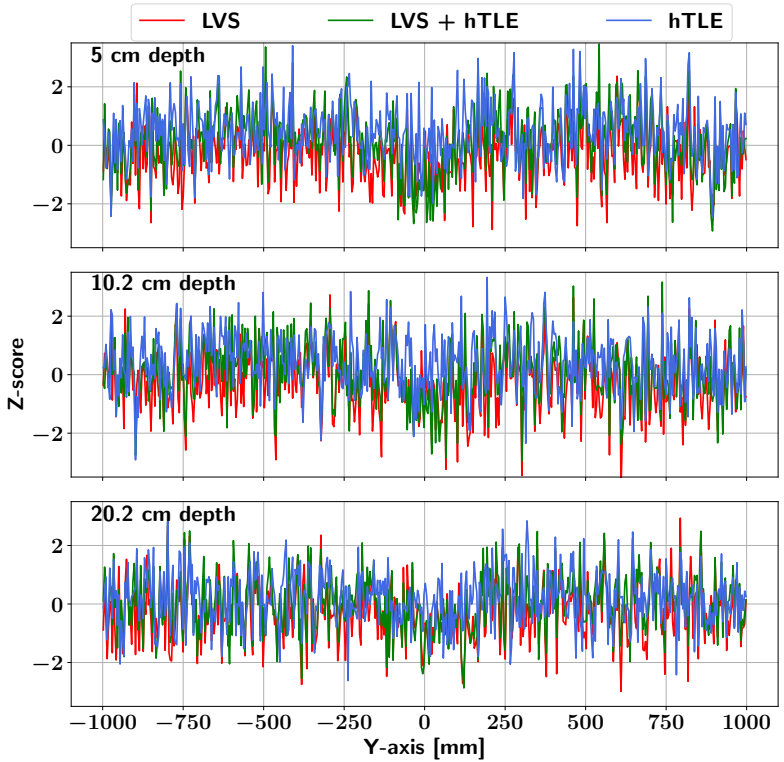
Set-up :

- Analog
- LVS
- hTLE
- LVS + hTLE

VRTs assessment: biasing

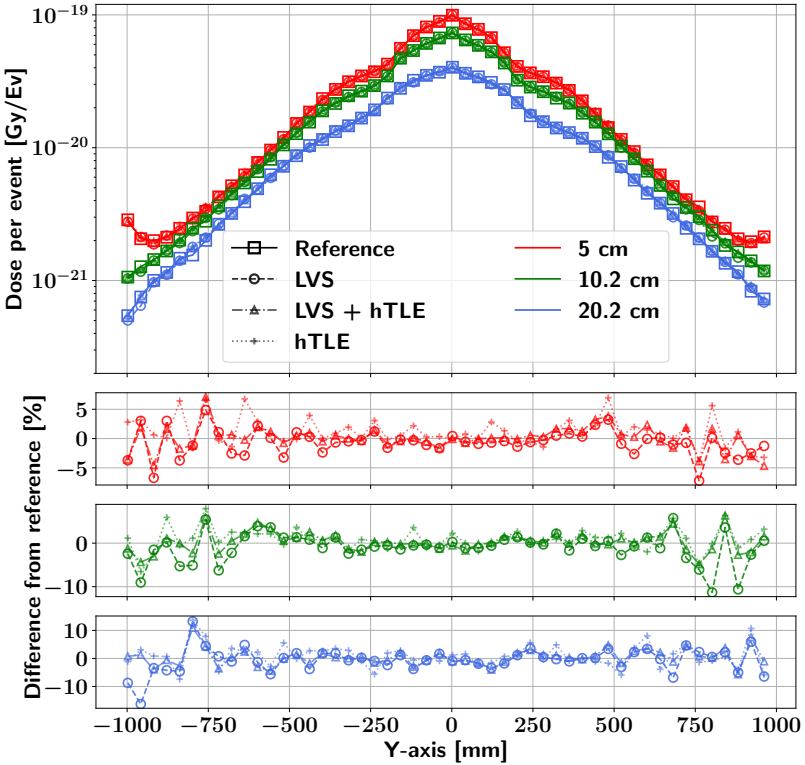


Deposited dose per event along the Y-axis at the water tank center



Calculated Z-score along the Y-axis at the water tank center

VRTs assessment: biasing



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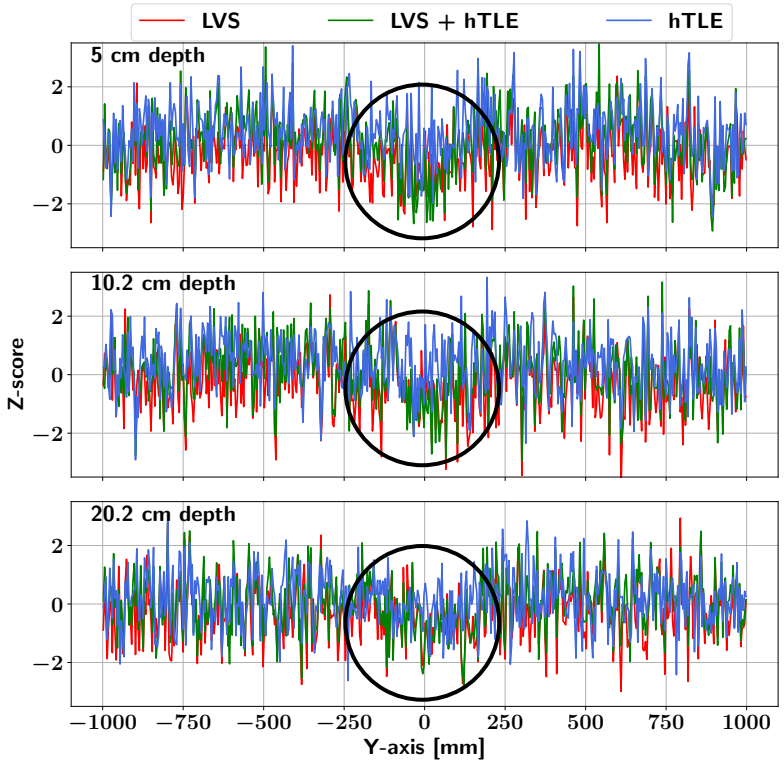
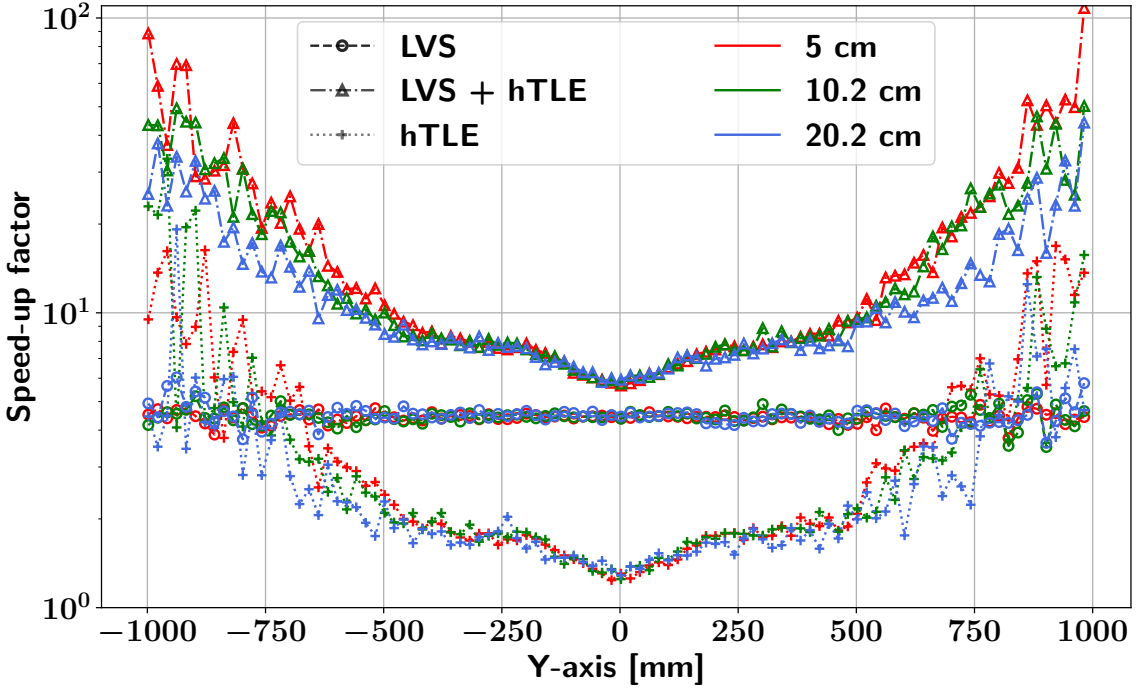


Calculated Z-score along the Y-axis at the water tank center

At a 2σ level :

- Minor biais in the in-field area
- No biais for the OOF area

VRT assessment: Speed-up



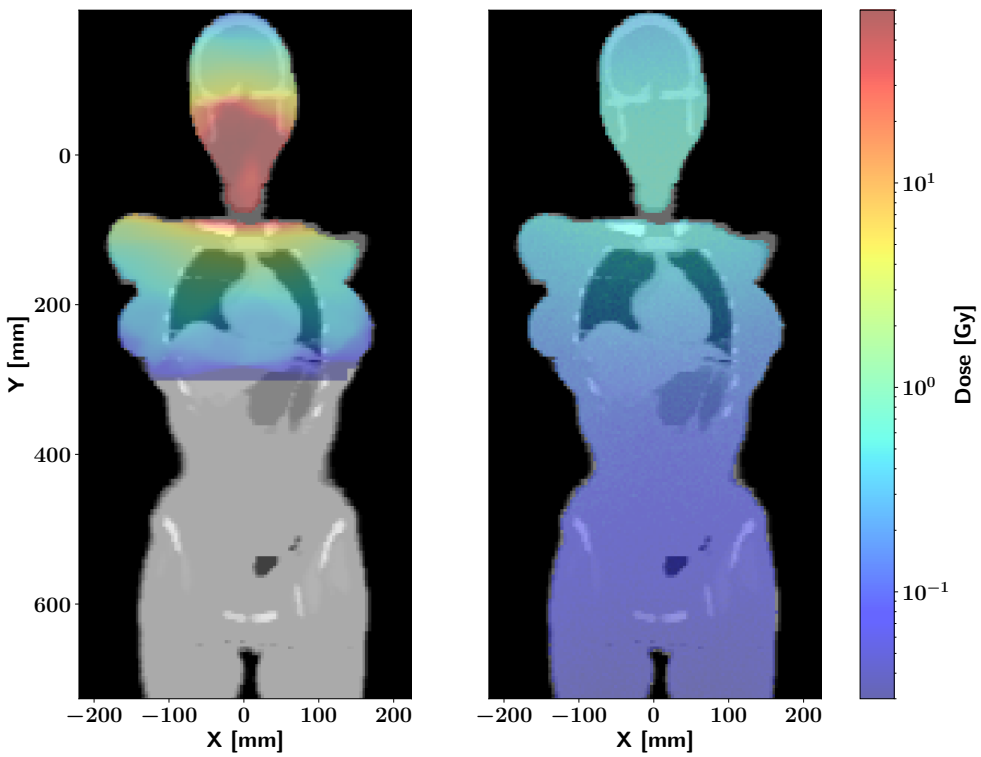
Calculated speed-up implying the different proposed VRTs compared to the analog simulation

VRTs speed-up

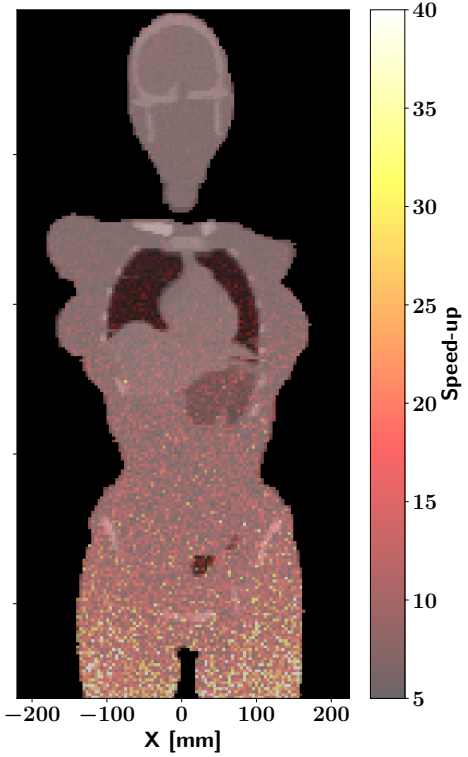
- Last Vertex Splitting :
  - Constant speed-up (~ x5)
- hTLE :
  - In-field :
    - Moderate speed-up (~ x1.5 – x2)
      - Photon mean energy too high
      - Analog dose deposition more than hTLE
  - OOF :
    - Increasing speed-up (Until x10 at 1 m)
    - Lower photon mean energy
- Last Vertex Splitting + hTLE
  - Independent methods :

    Total speed-up = speed-up$_{LVS}$ x speed-up$_{hTLE}$

VRTs assessment: Patient illustration



Calculated TPS dose for a 70 Gy VMAT session (left) and the LINAC-head interaction photons contribution (right)



Speed-up obtained using the VRTs

Patient simulation

TPS : 70 Gy

Interacting photons: 0.08 Gy

- x100 lower
- No bias consequences

Speed-up

- Smaller field
- LVS speed-up ~ x7
- hTLE speed-up from ~ x1 to x5
- LVS + hTLE speed-up: from ~ x7 to 35

Conclusion and discussion

- Development of a LINAC model using GATE10
  - In-field dose: Validated against experimental data and RT-plan based TPS
  - Out-of-field dose validation: work in progress

- New VRTs: Last vertex splitting + hybrid TLE
  - In-field biased around the percent
  - LVS speed-up around 5
    - Depends on field size and irradiated geometry
  - hTLE speed-up depending on the mean photon energy
    - Larger speed-up in the far OOF region (~ x10)
  - LVS + hTLE:
    - Total speed-up = LVS speed-up x hTLE speed-up
    - Both methods are generic

- Article to publish in PMB + available in GATE10