Towards Gate 10 for ion beam therapy applications

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MedAustron Ion Therapy Center

IDEAL v2

IDEAL v1

- Simulations: **GateRTion v1** (C++/mac)

- **3** different python **programs** to:
  - Preprocess the DICOM input
  - Write mac file to start the simulations in Gate
  - Postprocess dose output

- **Single threaded**
  - RAM limitation
  - need for external parallelization tools (HT Condor)

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IDEAL v2

- Simulations: **Gate10** (python interface, C++ core)

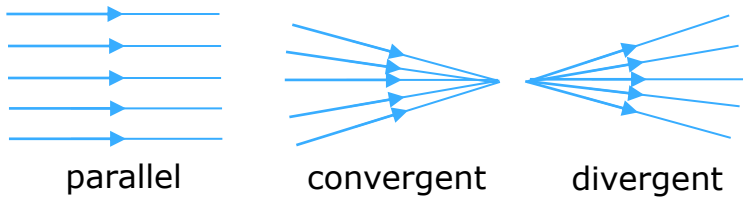
- **Single** python **program**:
  - Can directly read DICOM files
  - Simulations are started directly from python
  - Dose output available in python

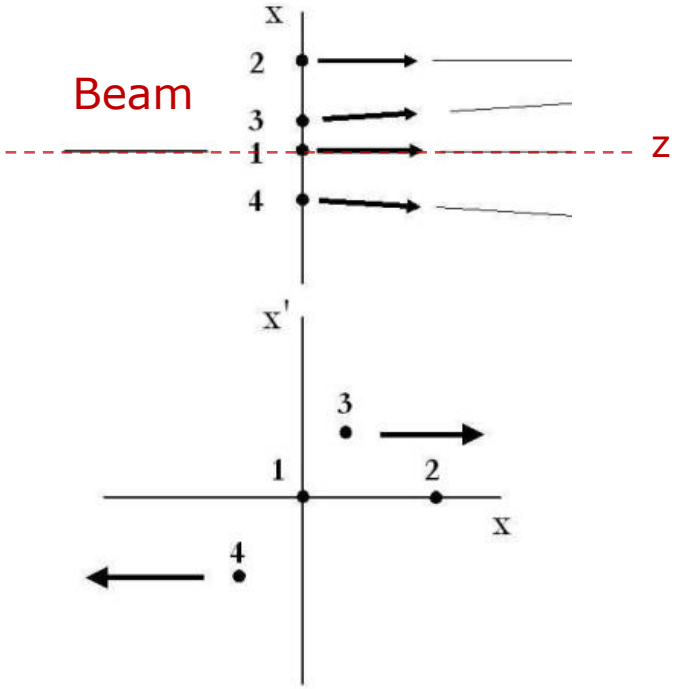
- **Multi-threading** possible
  - Potentially no need for external parallelization tools

Pencil beam source

Toward IDEAL v2: pencil beam source

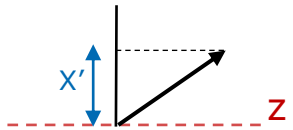
- Treatment plan is made of multiple pencil beams
- Beam has a convergence





- Pencil beam modelled according to Fermi-Eyges theory*
- Each particle is characterized by:
  - position x, y
  - direction x', y' (projected angles on x and y)
  - x and x' are correlated

  -> the bigger x' the bigger will be the drift in x direction



*Techniques of Proton Radiotherapy: Transport Theory B. Gottschalk May 1, 2012

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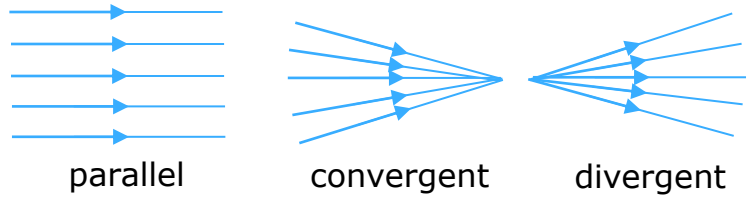

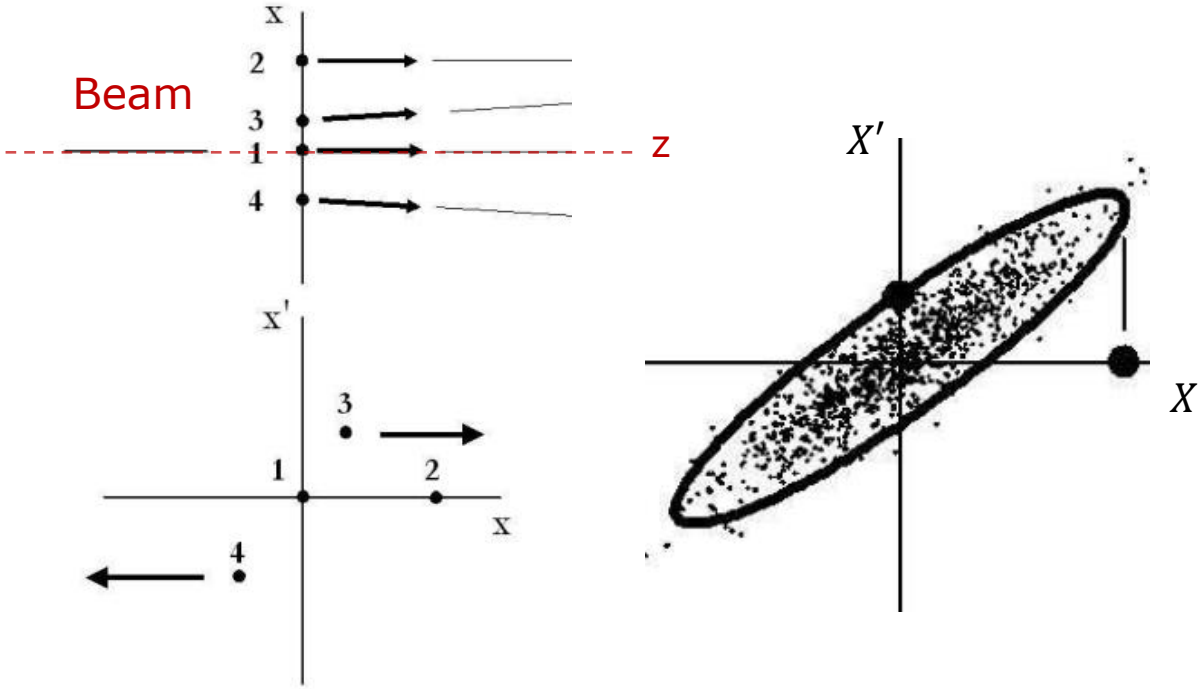

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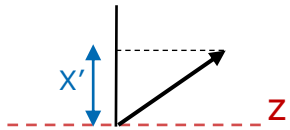

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Toward IDEAL v2: pencil beam source

- 8 parameters to describe the correlated momentum spread (each for the x and y)
  - spot size σ
  - divergence θ
  - emittance ε
  - convergence flag $[1,0]$

-> sample particle's position and direction

- 3 parameters to describe the energy type, mean energy and energy spread

-> spread of Bragg peak

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ADD TO SIMULTION

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source = sim.add_source("PencilBeamSource", "mysource")
source.energy.type = 'gauss'
source.energy.mono = 1440 * MeV
source.energy.sigma_gauss = 0.1
source.particle = "ion 6 12"  # carbon
source.position.type = "disc"
source.position.rotation = Rotation.from_euler("y", -90, degrees=True).as_matrix()
source.position.translation = [-100 * mm, 20 * mm, 30 * mm]
source.n = 20000
source.direction.partPhSp_x = [
    2.3335754 * mm,
    2.3335754 * mrad,
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source.direction.partPhSp_y = [
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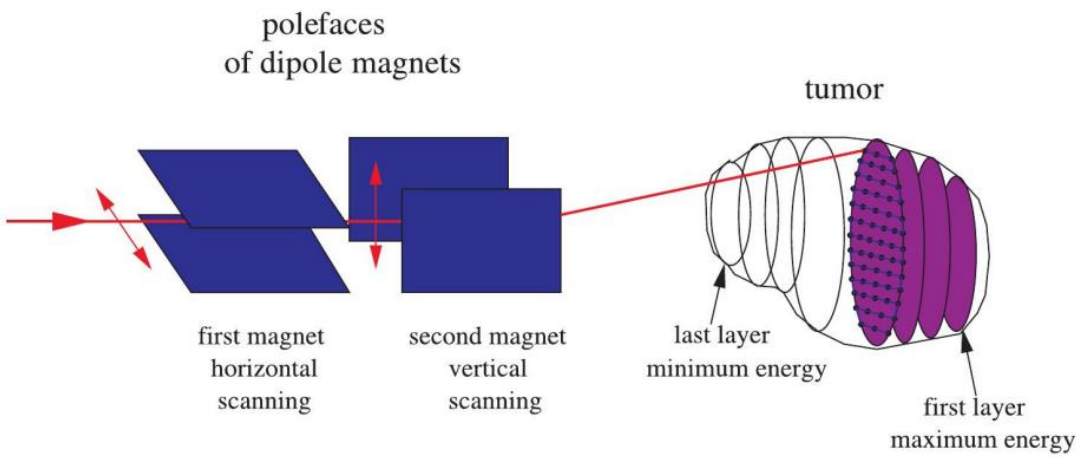
➡ Available in latest release !
(test044_pbs*)

Treatment plan source

Toward IDEAL v2: treatment plan source



- Treatment plan is made of multiple pencil beams, each irradiating a single spot
- Each spot is characterized by:
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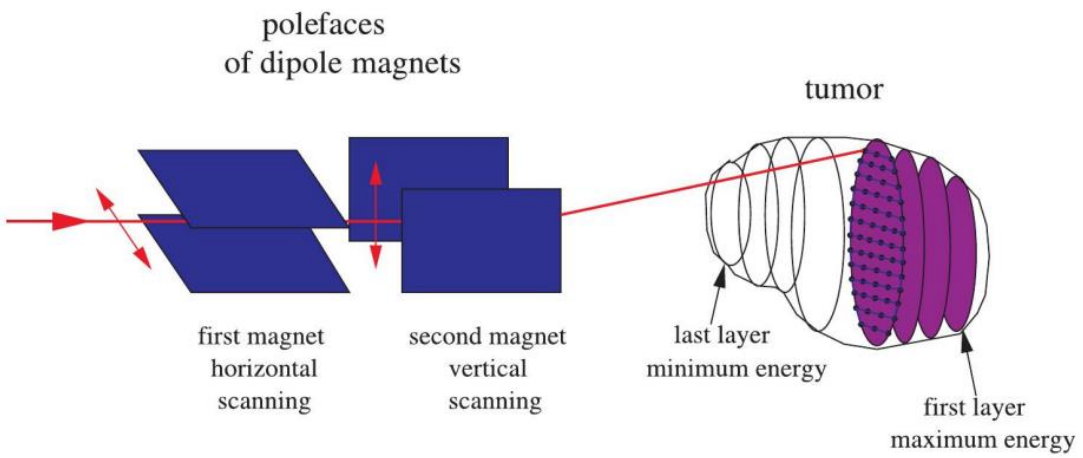

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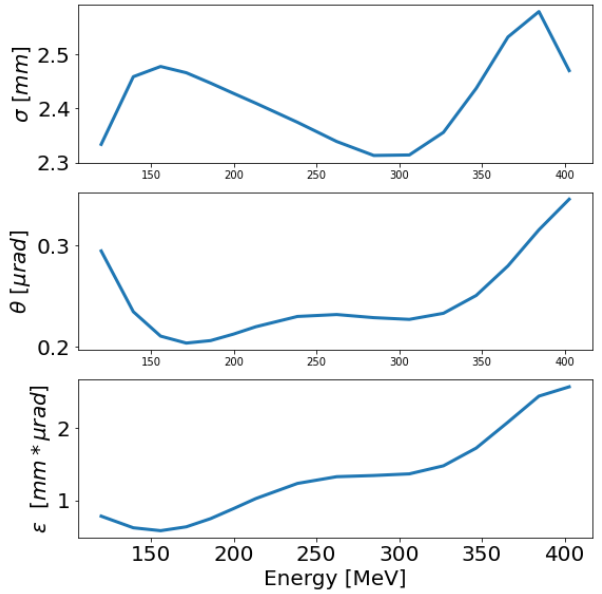
  - geometry: position of steering magnets



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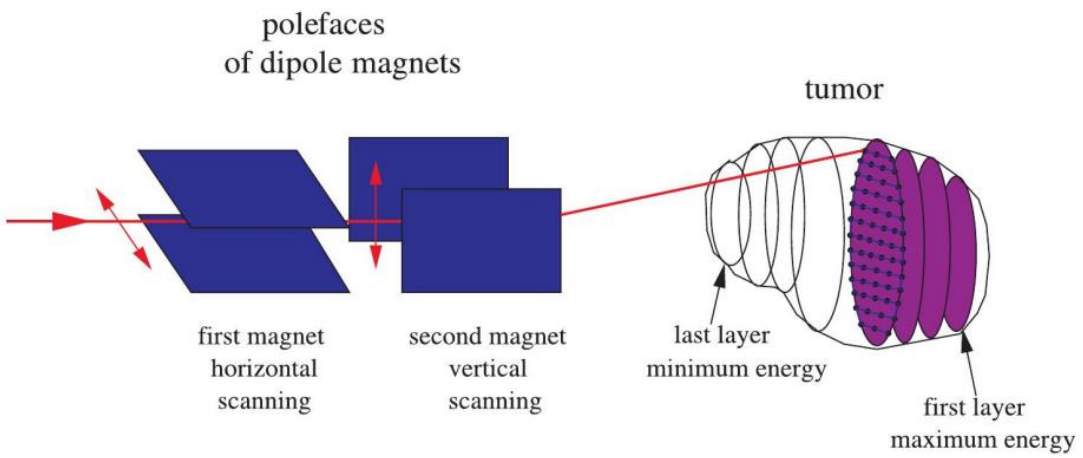

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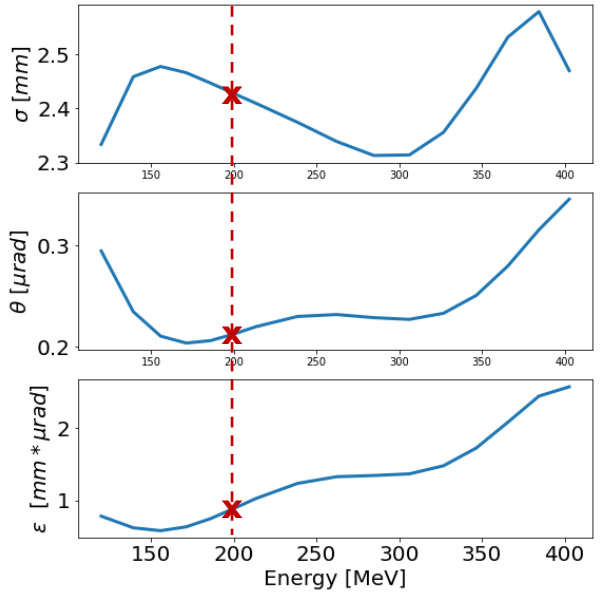

Toward IDEAL v2: treatment plan source

- Gate10 Treatment Plan source: array of Pencil Beam sources, one for each spot
  - Only on python side, no Cpp implementation needed

- Initialization:
  - Spots to scan
    - from DICOM RT plan file path
    - from .txt → backward compatibility Gate 9
    - each spot manually → testing and debugging
  - Beamline model
    - set Pencil Beam energy-dependent parameters
  - Total number of particles to simulate

ADD TO SIMULTION

From RT dicom path

```
tps = gate.TreatmentPlanSource("RT_plan", sim)
tps.set_beamline_model(IR2HBL)
tps.set_particles_to_simulate(nSim)
tps.set_spots_from_rtplan(rt_plan)
tps.initialize_tpsource()
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From .txt

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spots, ntot, energies, G = gate.spots_info_from_txt(
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→ Not yet available in latest release !
(PR #123)

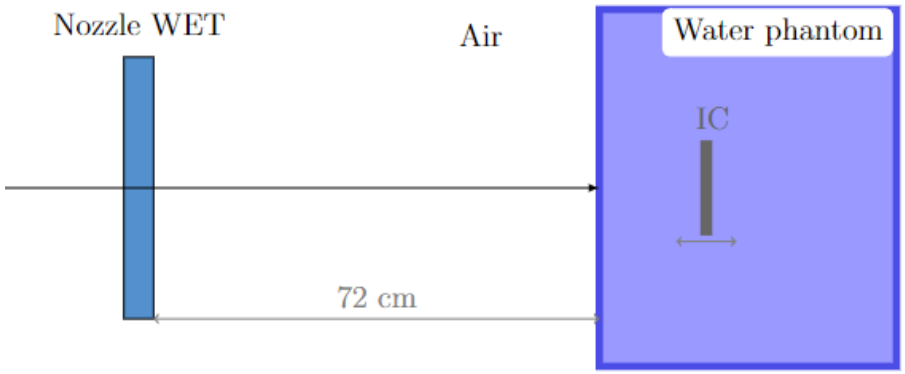
Benchmark against GateRTion v1

Range in water, absolute dose, optics, gantry rotation

Benchmark test cases

Test Gate 10 vs GateRTion

- Range in water
  - test051_TPsource_range_ref.py



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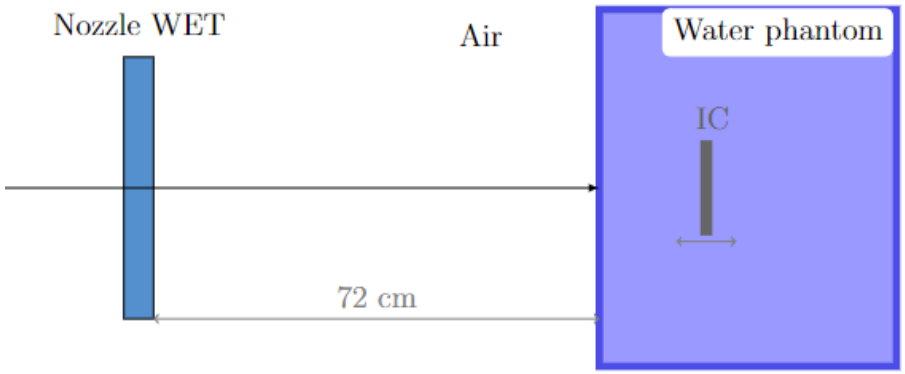
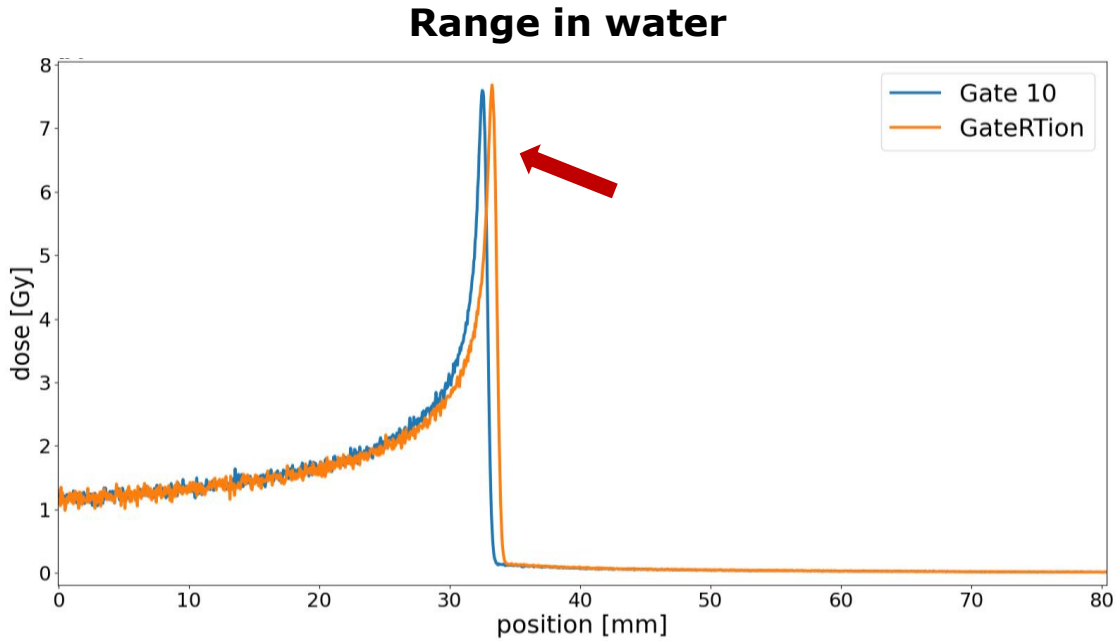


beam



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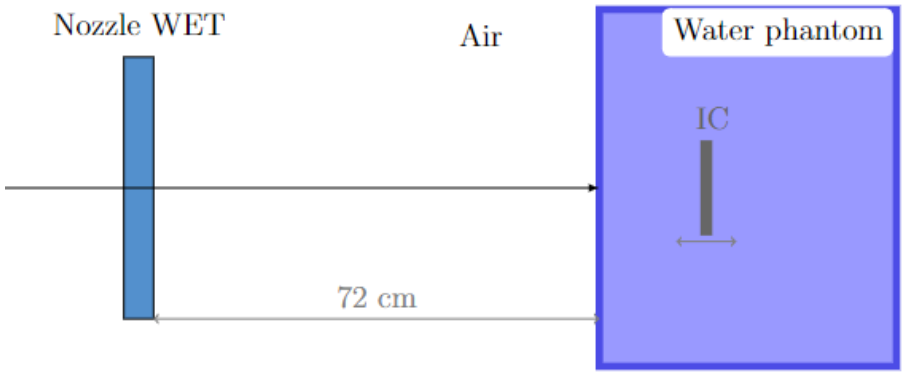

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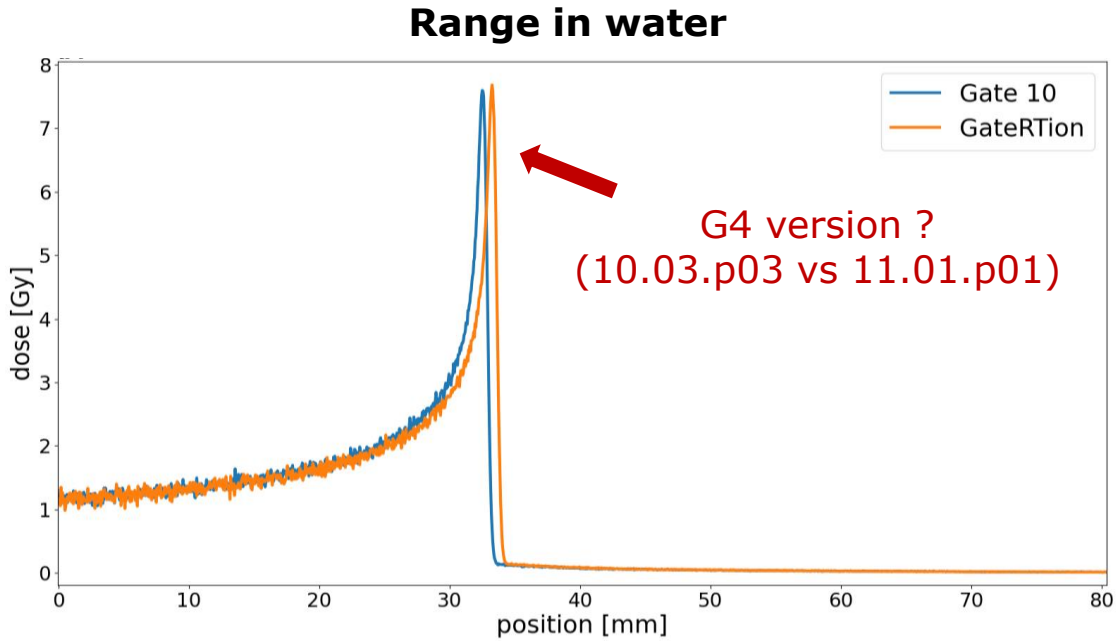

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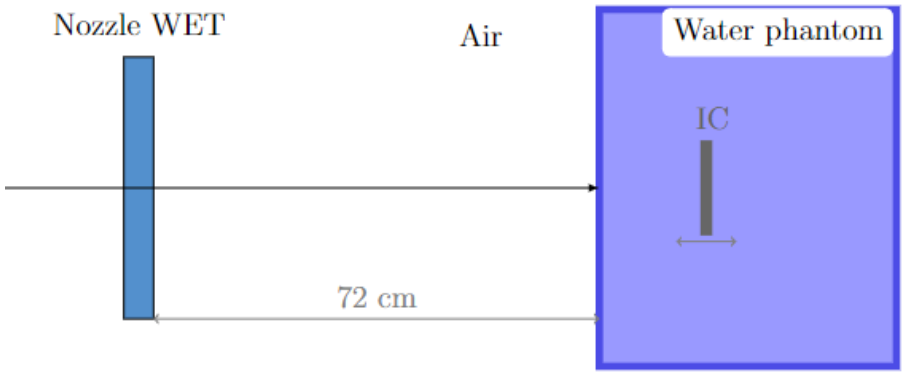

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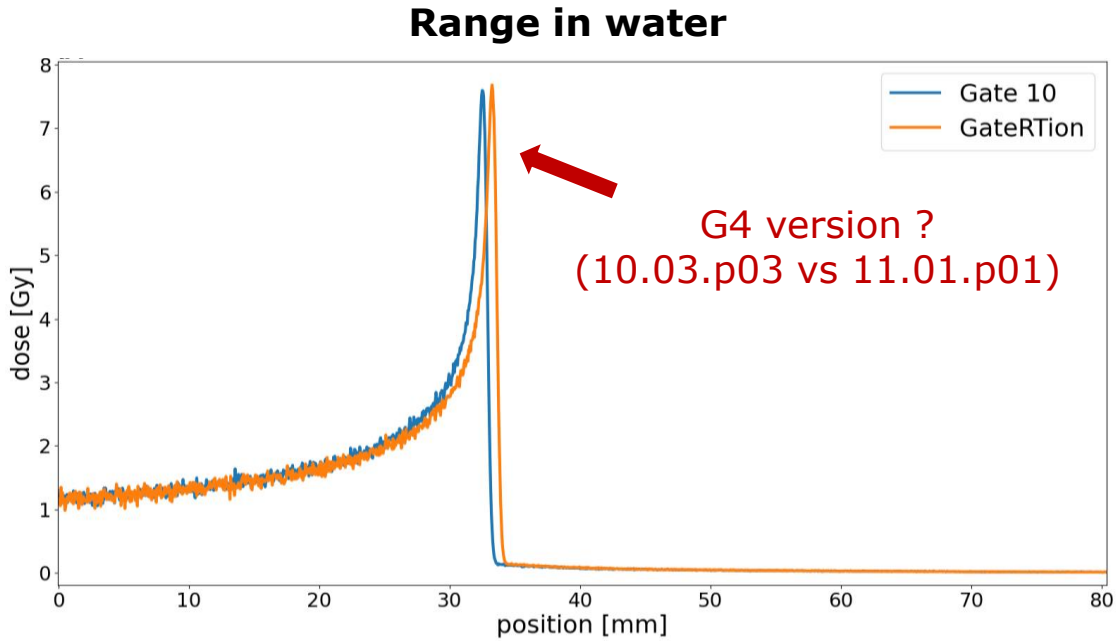

Range difference < 1 mm

Benchmark test cases

Test Gate 10 vs GateRTion

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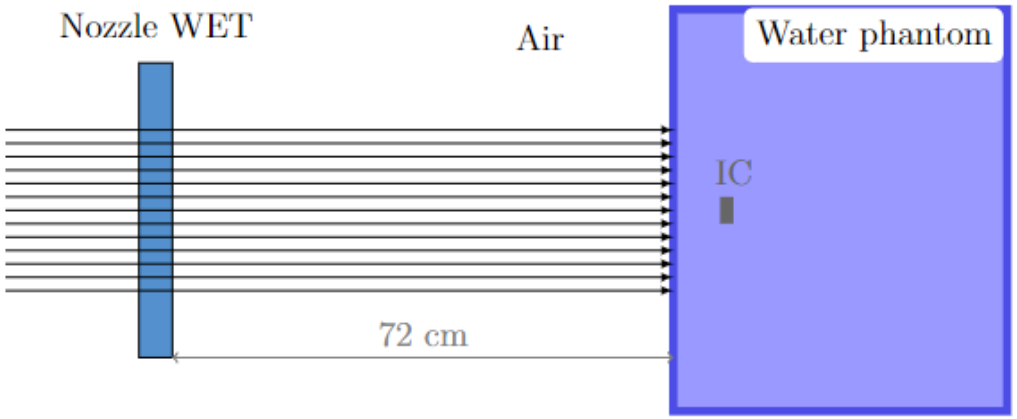
- Abs dose
  - test051_Tpsource_abs_dose.py



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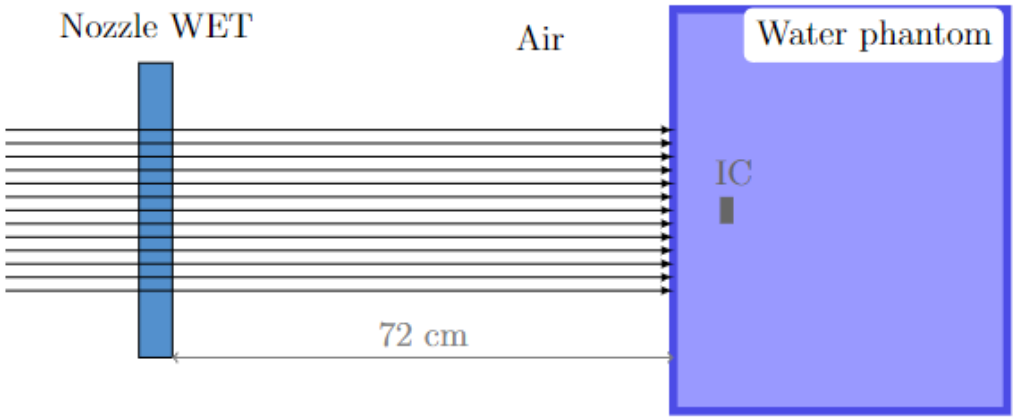

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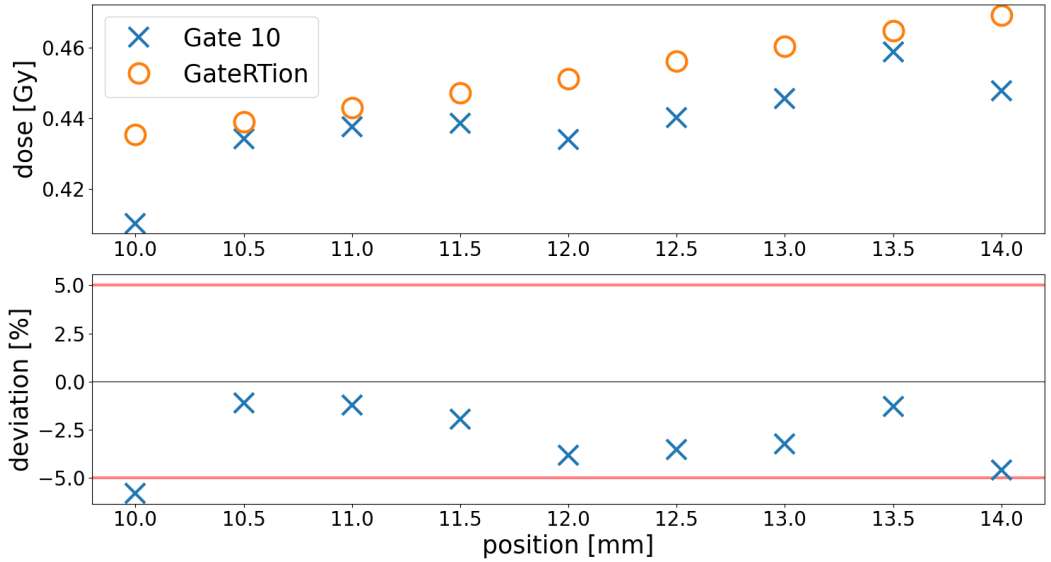

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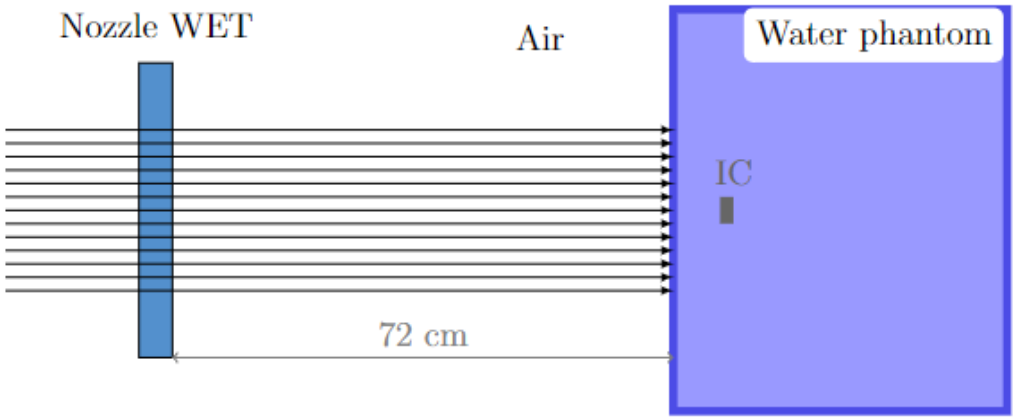

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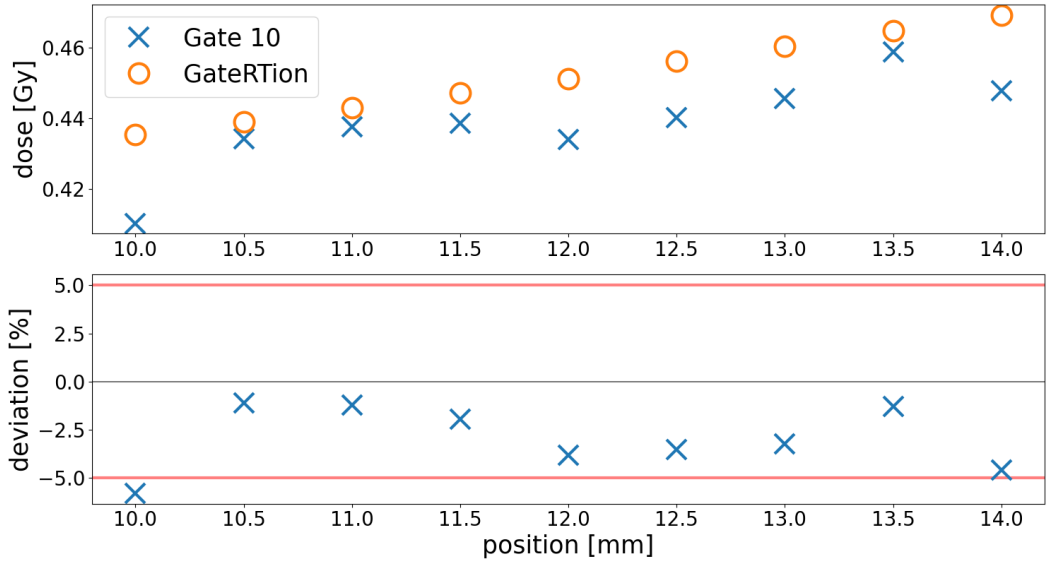

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- Abs dose
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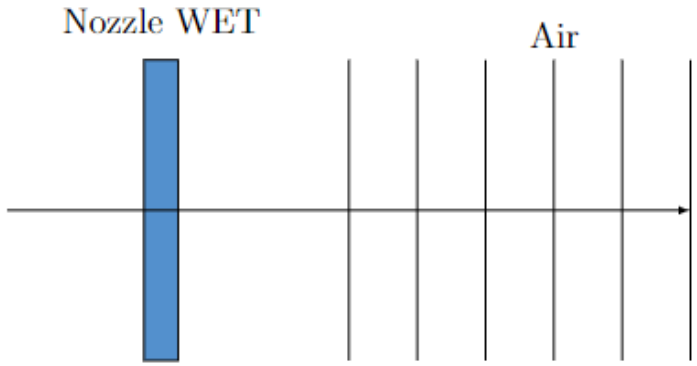
- Optics: spots sizes and positions
  - test051_TPsource_optics.py
  - test051_TPsource_optics_vbl.py



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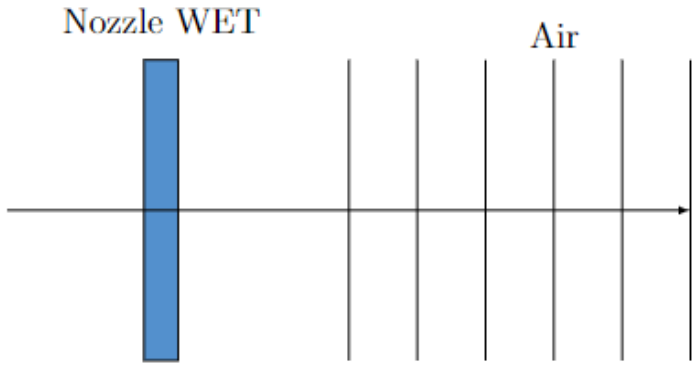
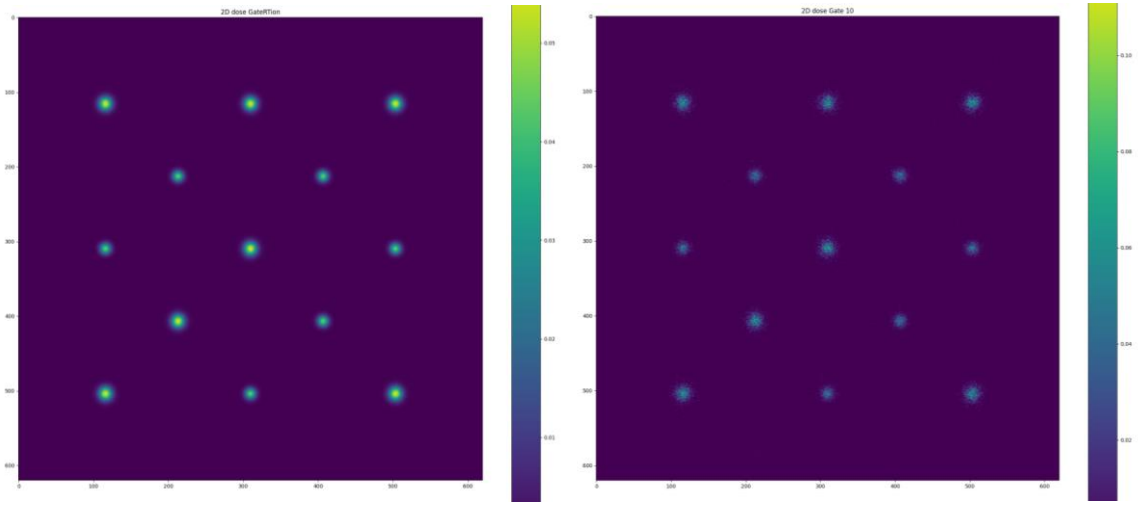
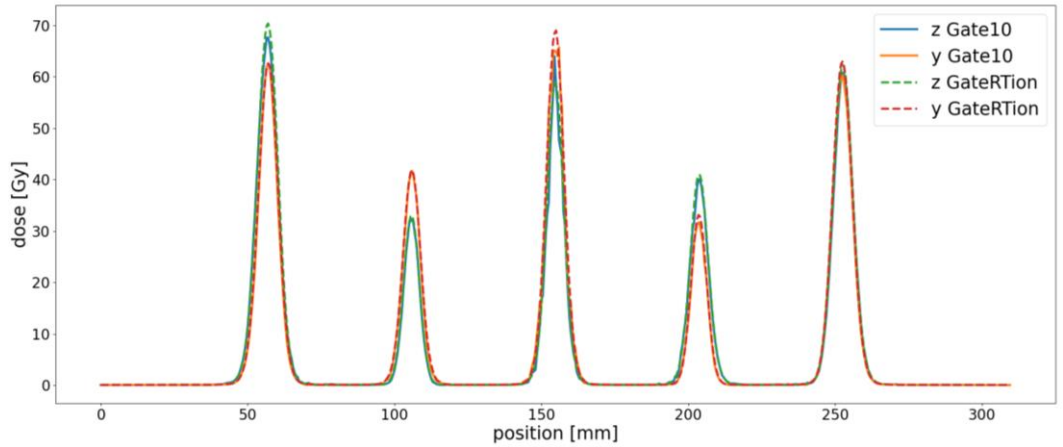


Optics

GateRTion **Gate 10 (lower statistics)**





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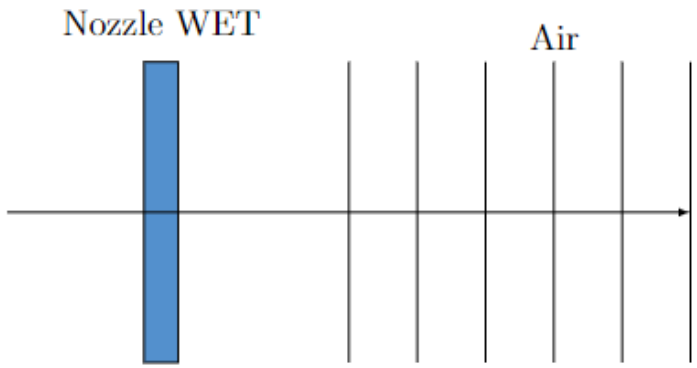

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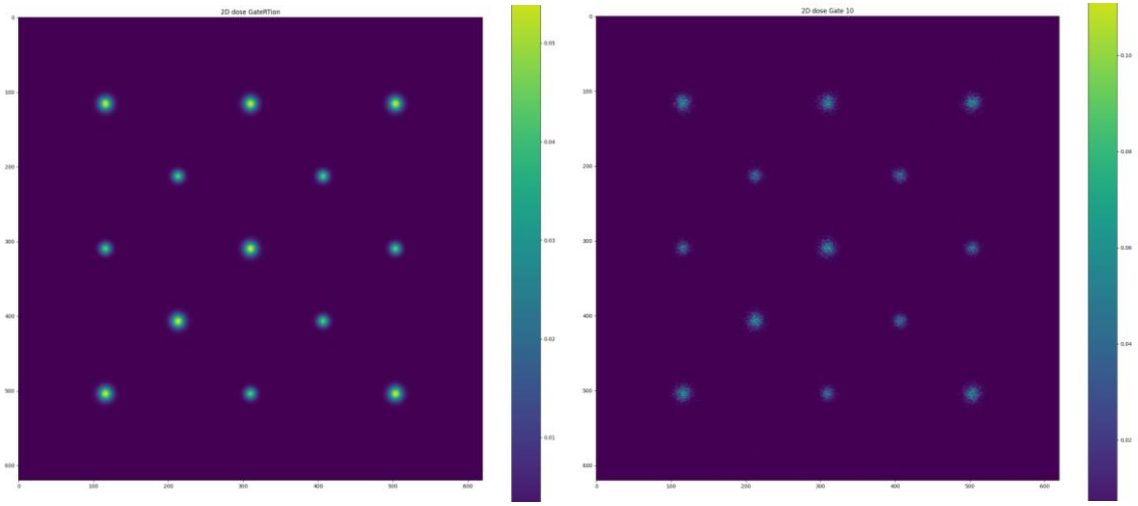

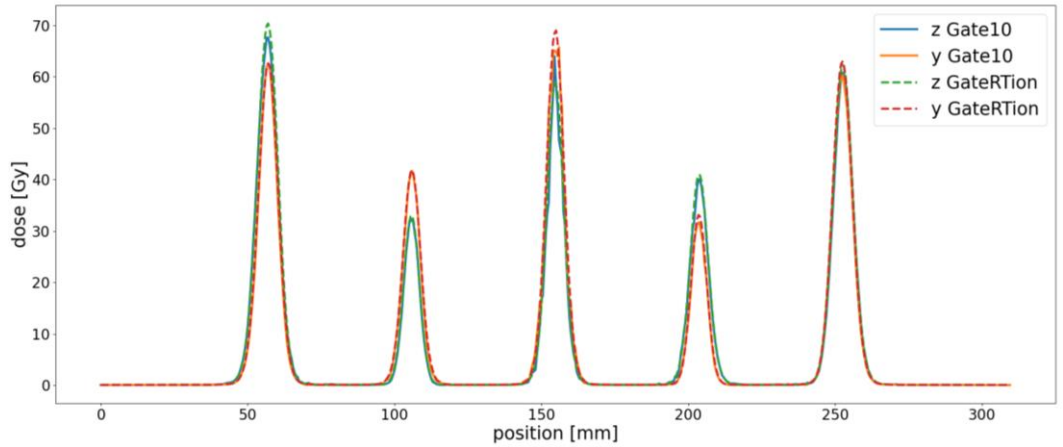

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  - test051_TPsource_optics_vbl.py ✓
- Gantry rotation: range in water HBL vs VBL
  - test051_TPsource_gantry_rot.py

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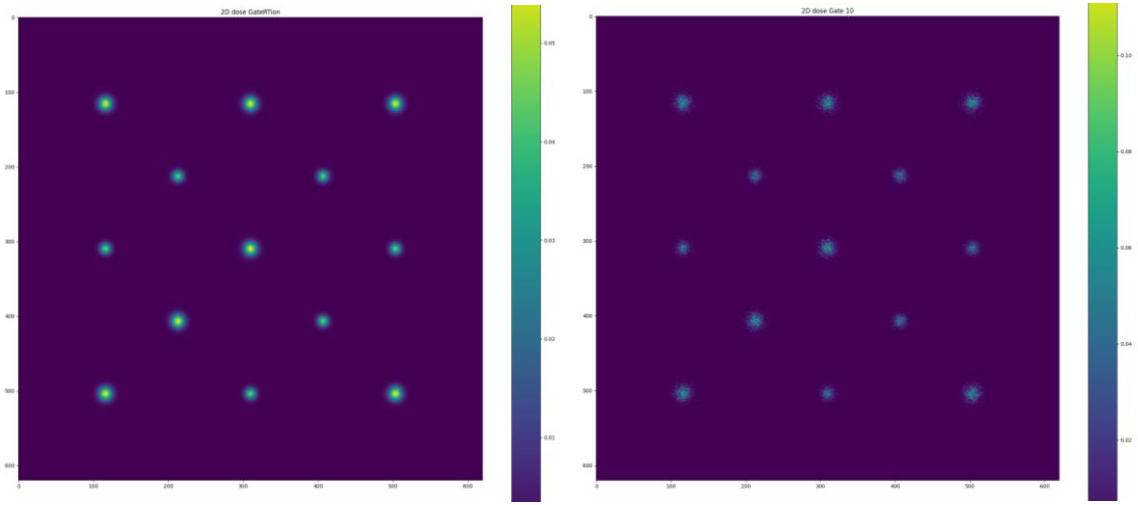
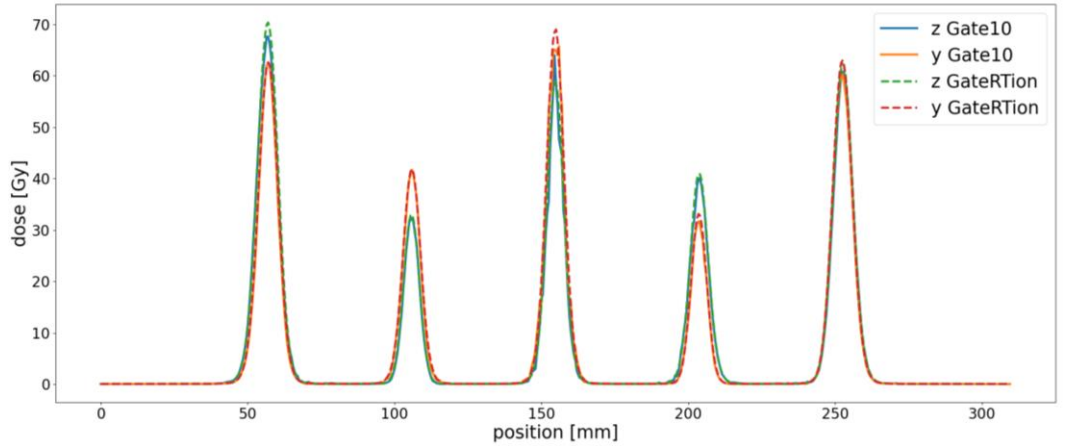
GateRTion **Gate 10 (lower statistics)**





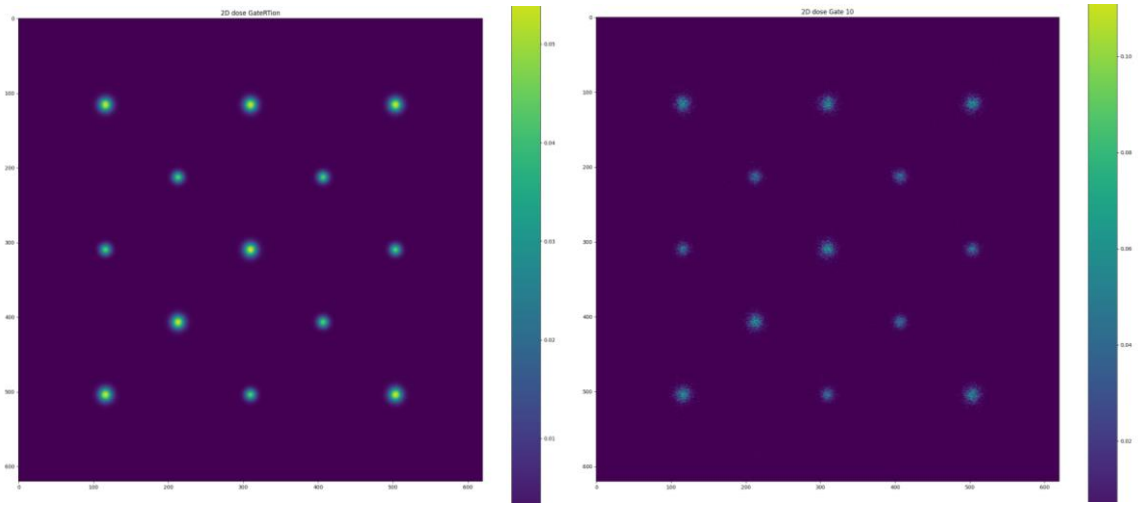
Benchmark test cases

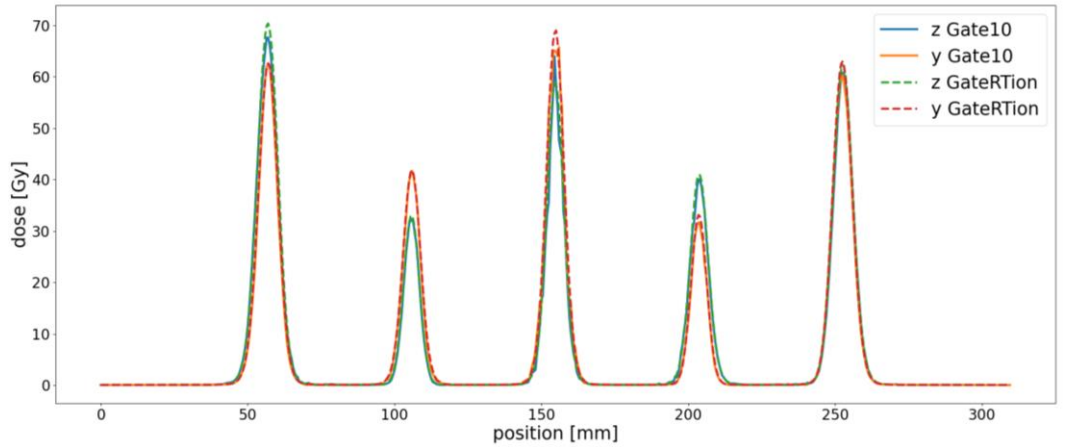
Test Gate 10 vs GateRTion

- Range in water
  - test051_TPsource_range_ref.py ✓
- Abs dose
  - test051_Tpsource_abs_dose.py ✓
- Optics: spots sizes and positions
  - test051_TPsource_optics.py
  - test051_TPsource_optics_vbl.py ✓
- Gantry rotation: range in water HBL vs VBL
  - test051_TPsource_gantry_rot.py ✓

Optics

GateRTion **Gate 10 (lower statistics)**





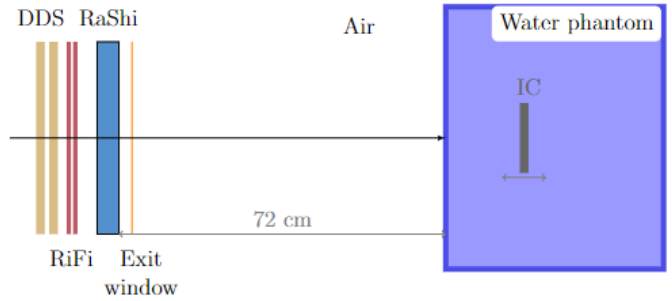
Benchmark against measurements

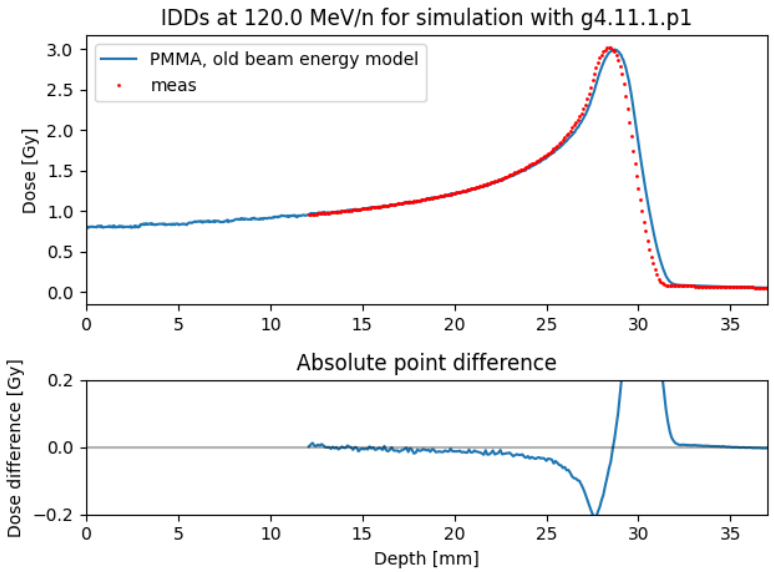
Range in water (MedAustron's data)

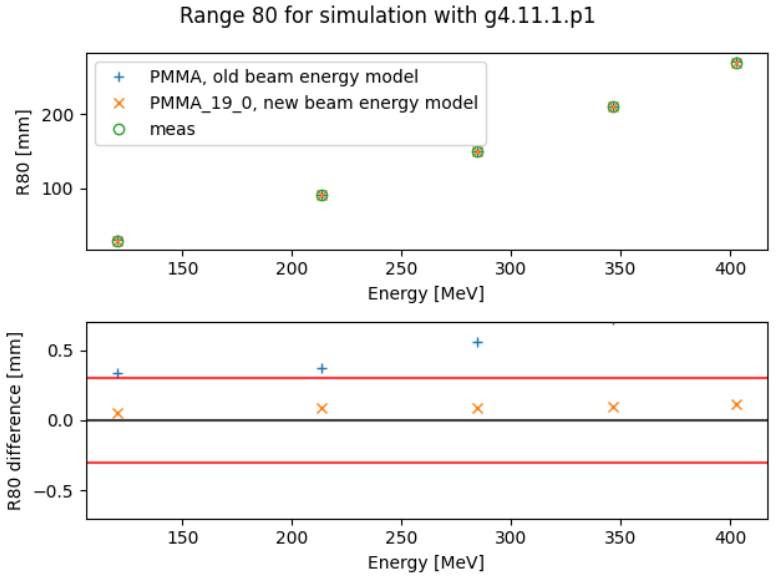
Benchmark against measurements

Tests against MedAustron measurement data

- MedAustron nozzle simulated in Gate 10
- Results before and after re-tuning beam energy model
- MA measurement vs Gate 10 (G4 11.1.p1)



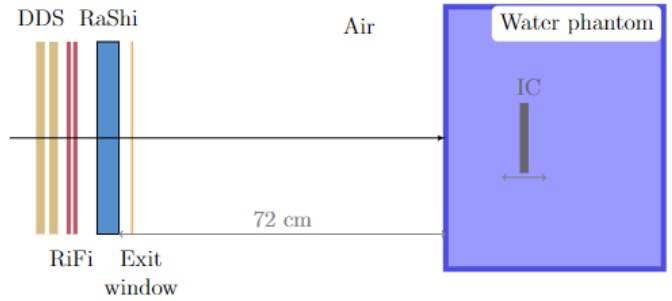


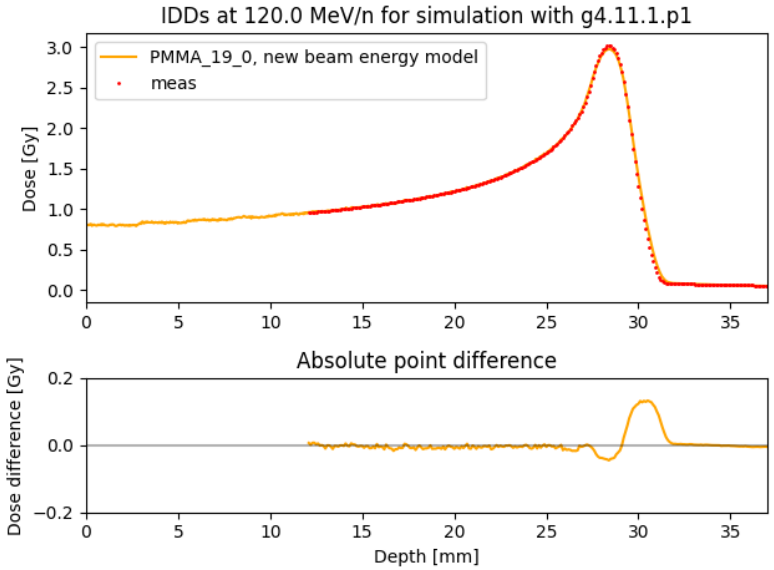


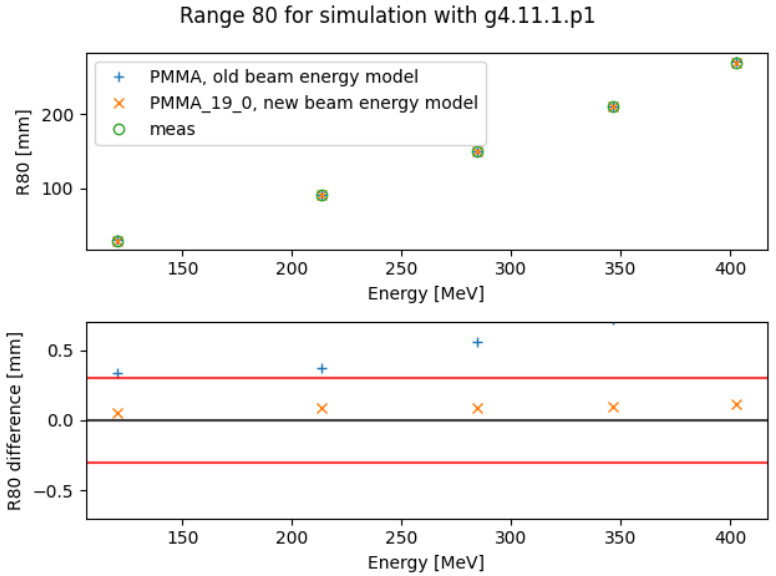
Benchmark against measurements

Tests against MedAustron measurement data

- MedAustron nozzle simulated in Gate 10
- Results before and after re-tuning beam energy model
- MA measurement vs Gate 10 (G4 11.1.p1)

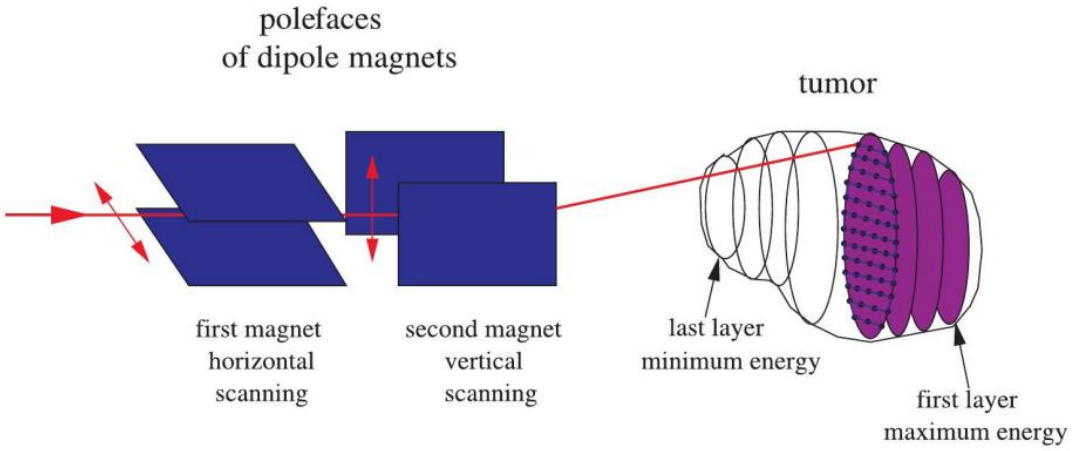






Conclusions

- IDEAL v2: simplify software architecture using Gate 10
- Features developed in Gate 10 for IDEAL v2:
  - **Pencil beam source** -> included in latest release
  - **Treatment plan source** -> pull request #123
- Treatment plan source validation
- First validation against MA measurements promising → **MORE COMING**



Range in water ✓
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Abs dose ✓
test051_Tpsource_abs_dose.py

Optics: spots sizes and positions ✓
test051_TPsource_optics.py
test051_TPsource_optics_vbl.py

Gantry rotation: range in water HBL vs VBL ✓
test051_TPsource_gantry_rot.py

Thank you for your attention!

Thanks to the collaboration of: David Sarrut, Thomas Baudier and all the others

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Kofinanziert von der Europäischen Union

MEDICAL UNIVERSITY OF VIENNA

MedAustron Ion Therapy Center

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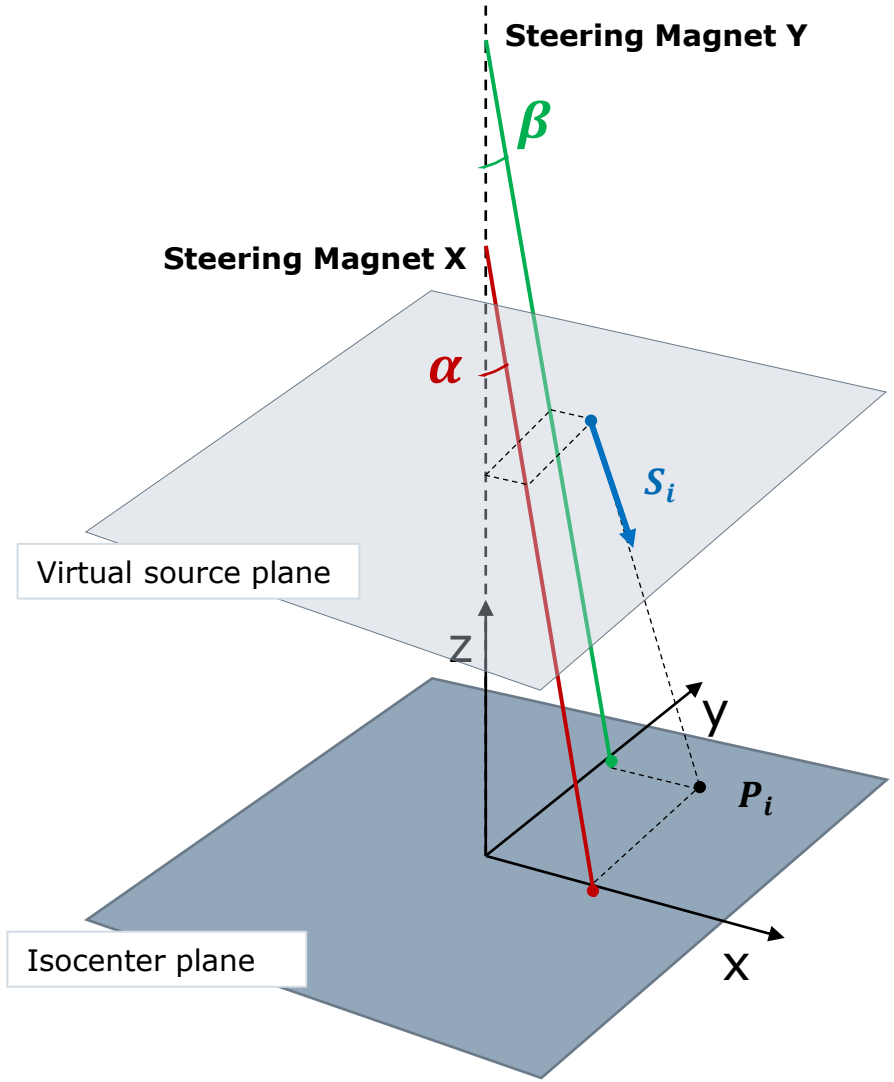
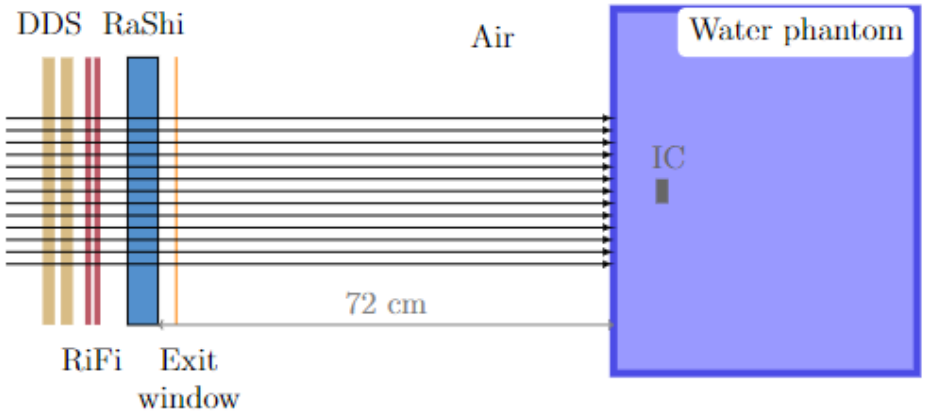
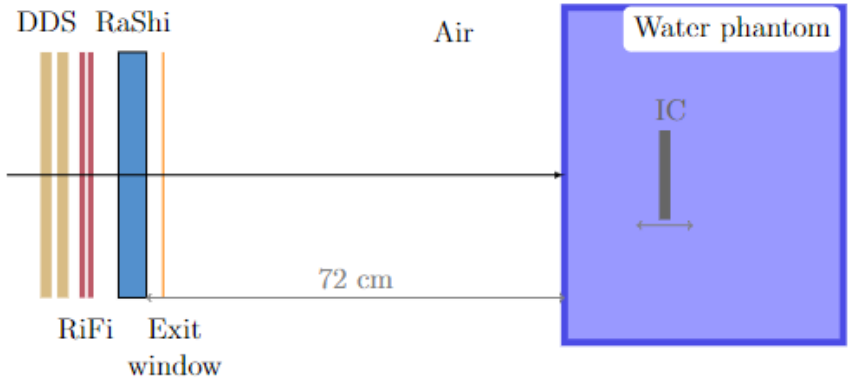
Implementation and features: (conventions are directly transferred from Gate 9)

- Each PBS is initialized at the nozzle exit and position and direction are calculated according to the beamline model provided, so that the beam reaches the planned spot.
- By default, the TPS is initialized at gantry angle 0 (vertical beamline).
- TPS rotation can be read from the treatment plan (if provided) or set manually.
- TPS translation is also possible.
- Each spot gets a fraction of the particles to simulate, proportional to the planned particles for that spot.




DDS
RaShi
Air
Water phantom
IC
72 cm
RiFi
Exit
window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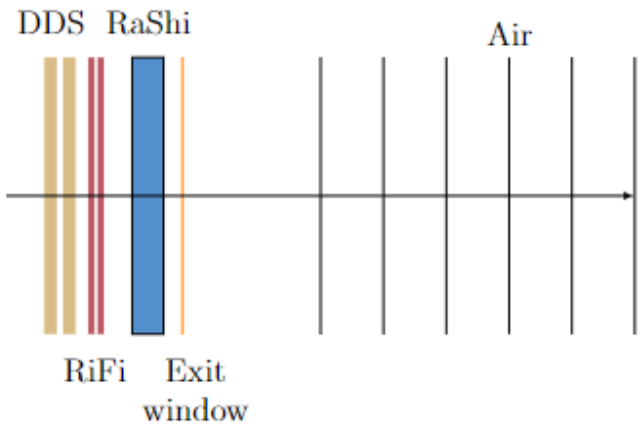
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