Optimising Geant4 settings for proton therapy

Carla Winterhalter & Adam Aitkenhead

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Verification for proton therapy

Physical verification:

• Each field is measured in a solid water phantom
• Measurements at limited points
• In homogeneous geometry
• Time consuming

A. Aitkenhead et al. “Automated Monte-Carlo re-calculation of proton therapy plans using Geant4/Gate: Implementation and comparison to plan-specific quality assurance measurements”, accepted in BJR (2020)
Verification for proton therapy

Software verification:

• Independent dose calculation engine
• Often Monte Carlo based
• At the Christie NHS Foundation Trust:
  • **AUTOMC**: Automatic re-calculation and analysis framework.
  • 40-core cluster.
  • Verified for 153 patients (730 fields) planned within the first year of the proton service.

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Monte Carlo for proton therapy

Geant4 based dose calculations:
• Accurate modelling of geometry and interactions
• Calculation speed!

AIM OF THIS PROJECT:
Investigate influence of GEANT4 settings on dose results and calculation time
GEANT 4 settings for proton therapy

- Physics lists
  - QGSP_BIC
  - QGSP_BIC_EMY
  - QGSP_BIC_EMZ
  - QGSP_BIC_HP_EMZ

- Cuts in phantom/range shifter & cuts in world
  - 1 mm & 10 mm (large)
  - 0.1 mm & 1 mm (small)

- Step limiter

More accurate
Faster
How do these Geant4 settings influence...

• ... the agreement to commissioning measurements?
  • Depth dose curves of single energy proton spots in a water tank
  • Beam sizes in air after the range shifter

• ... the agreement to patient specific quality assurance measurements?
  • Patient fields simulated in a solid water phantom
How do these Geant4 settings influence...

• ... the agreement to commissioning measurements?
  • Depth dose curves of single energy proton spots in a water tank
  • Beam sizes in air after the range shifter

• ... the agreement to patient specific quality assurance measurements?
  • Patient fields simulated in a solid water phantom
Energy tuning

Agreement within error bars, no substantial dependence on physics models or cuts.
Energy tuning

Agreement within error bars, no substantial dependence on physics models or cuts.

QGSP_BIC depends on the step limiter, the others do not.
Energy tuning – calculation times

• Physics lists:
  • QGSP_BIC_EMY: factor **1.2/1.5** faster than QGSP_BIC_HP_EMZ
  • QGSP_BIC_EMZ: factor **1.0/1.1** faster than QGSP_BIC_HP_EMZ

• Cuts in phantom/range shifter & cuts in world
  • 1 mm & 10 mm vs 0.1 mm & 1 mm: factor **5.3-7.2**

• Step limiter: **Factor 4.5-5.9**
How do these Geant4 settings influence...

• ... the agreement to commissioning measurements?
  • Depth dose curves of single energy proton spots in a water tank
  • Beam sizes in air after the range shifter

• ... the agreement to patient specific quality assurance measurements?
  • Patient fields simulated in a solid water phantom
Beam sizes in air

Energy = 150 MeV

QGSP_BIC_EMY
QGSP_BIC_EMZ
QGSP_BIC_HP_EMZ
Measurement

No range shifter
Beam sizes in air

Beam size slightly underestimated by QGSP_BIC_EMY compared to measurements and compared to QGSP_BIC_EMZ/QGSP_BIC_HP_EMZ.
How do these Geant4 settings influence...

- ... the agreement to commissioning measurements?
  - Depth dose curves of single energy proton spots in a water tank
  - Beam sizes in air after the range shifter

- ... the agreement to patient specific quality assurance measurements?
  - Patient fields simulated in a solid water phantom

Picture: C. Winterhalter, ETH Diss 25698

Figure courtesy: P. Sitch
2 example fields

Dose, QGSP_BIC_EMZ (0.1mm, 1mm)

Dose difference, QGSP_BIC_HP_EMZ (0.1mm, 1mm) - QGSP_BIC_EMZ (0.1mm, 1mm)

Dose difference, QGSP_BIC_EMY (0.1mm, 1mm) - QGSP_BIC_EMZ (0.1mm, 1mm)

Dose difference, QGSP_BIC_EMZ (1mm, 10mm) - QGSP_BIC_EMZ (0.1mm, 1mm)
Comparison to solid water measurements

34 fields, 200 measurements:

- QGSP_BIC_EMZ (small cuts): 96.9%, 253 CPUh/field (0.6% uncertainty)
- QGSP_BIC_EMZ (large cuts): 97.0%, 54 CPUh/field (0.6% uncertainty)
- QGSP_BIC_EMY (large cuts): 97.1%, 46 CPUh/field (0.6% uncertainty)
Comparison to solid water measurements

34 fields, 74 measurements:

- QGSP_BIC_EMZ (small cuts): -1.2%, 253 CPUh/field (0.6% uncertainty)
- QGSP_BIC_EMZ (large cuts): -0.9%, 54 CPUh/field (0.6% uncertainty)
- QGSP_BIC_EMY (large cuts): -1.0%, 46 CPUh/field (0.6% uncertainty)
Dose in the patient CT

Neck, sagittal

a) 1068 CPU.h

Paranasal, transverse

e) Dose, QGSP_BIC_EMZ (0.1mm, 1mm)

Dose difference, QGSP_BIC_HP_EMZ (0.1mm, 1mm) - QGSP_BIC_EMZ (0.1mm, 1mm)

b) 1233 CPU.h

c) 895 CPU.h

d) 491 CPU.h

g) Dose difference, QGSP_BIC_EMY (0.1mm, 1mm) - QGSP_BIC_EMZ (0.1mm, 1mm)
h) Dose difference, QGSP_BIC_EMZ (1mm, 10mm) - QGSP_BIC_EMZ (0.1mm, 1mm)
GEANT 4 settings for proton therapy

- Physics lists
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  - QGSP_BIC_EMY
  - QGSP_BIC_EMZ
  - QGSP_BIC_HP_EMZ

- Cuts in phantom/range shifter & cuts in world
  - 1 mm & 10 mm (large)
  - 0.1 mm & 1 mm (small)

- Step limiter

More accurate
Faster
GEANT 4 settings for proton therapy

• Physics lists
  • QGSP_BIC – depends on step limiter
  • **QGSP_BIC_EMY**
  • **QGSP_BIC_EMZ**
  • QGSP_BIC_HP_EMZ – no change of dose in target region

• Cuts in phantom/range shifter & cuts in world
  • 1 mm & 10 mm (large)
  • 0.1 mm & 1 mm (small)

• Step limiter - default
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