Optimising Geant4 settings for proton therapy

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20th – 22nd of July 2020

6th Annual Loma Linda workshop on Particle Imaging and Radiation Treatment Planning

Verification for proton therapy

Physical verification:

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

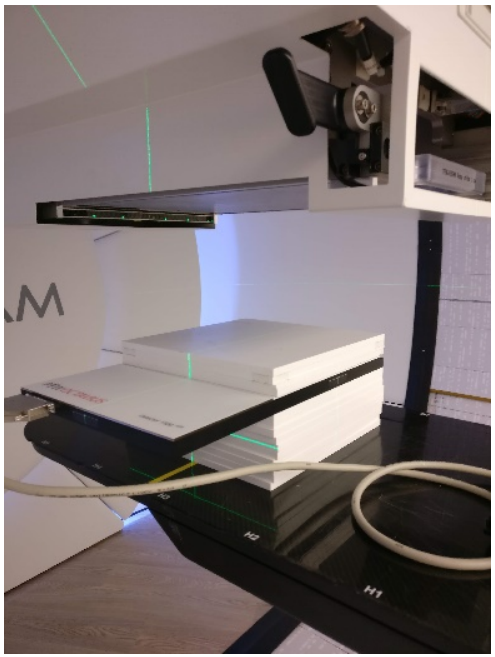
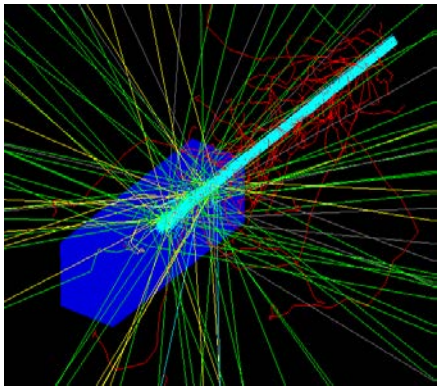


Figure courtesy: P. Sitch

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



Picture: C. Winterhalter, ETH Diss 25698

Software verification:

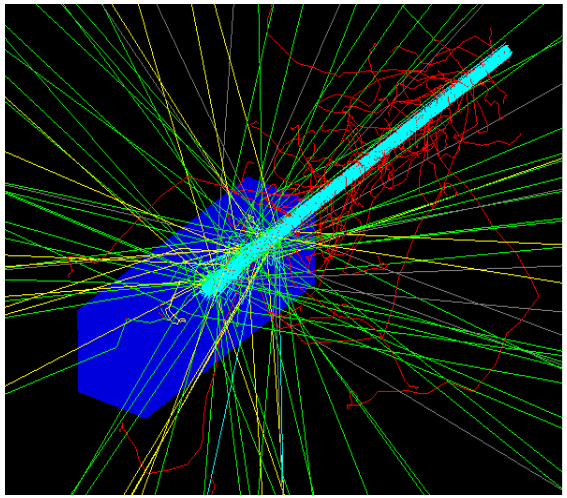
- Independent dose calculation engine
- Often Monte Carlo based
- At the Christie NHS Foundation Trust:
  - GATE [14] v8.1 / GEANT4 [11] v10.3.3, matching the versions used in GATE-RTION V1.0.
  - AUTOMC: Automatic re-calculation and analysis framework.
  - 40-core cluster.
  - Verified for 153 patients (730 fields) planned within the first year of the proton service.

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)
Grevillot, L., et al. "GATE-RTion: a GATE/Geant4 release for clinical applications in Scanned Ion Beam Therapy." *accepted in Medical Physics*. (2020)

Monte Carlo for proton therapy

Geant4 based dose calculations:

- Accurate modelling of geometry and interactions
- Calculation speed!



Proton, Electron, Gamma, Neutron

Picture: C. Winterhalter, ETH Diss 25698

AIM OF THIS PROJECT:

Investigate influence of GEANT4 settings on dose results and calculation time

GEANT 4 settings for proton therapy

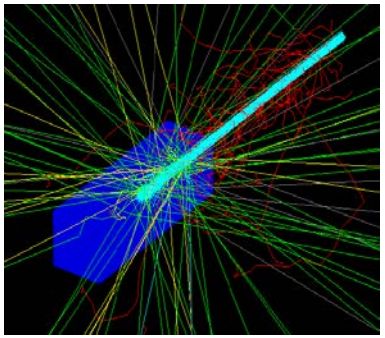
- Physics lists
  - QGSP_BIC
  - QGSP_BIC_EMY
  - QGSP_BIC_EMZ
  - QGSP_BIC_HP_EMZ

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

- Step limiter

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



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

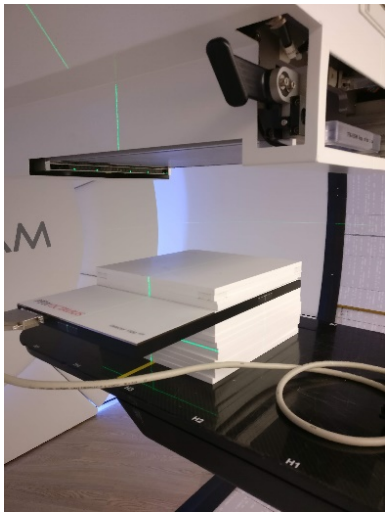

Figure courtesy: P. Sitch

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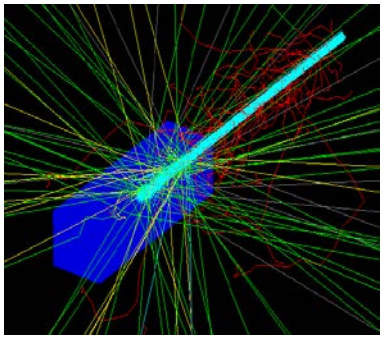

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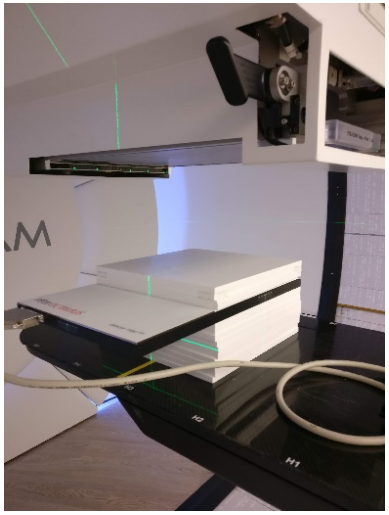
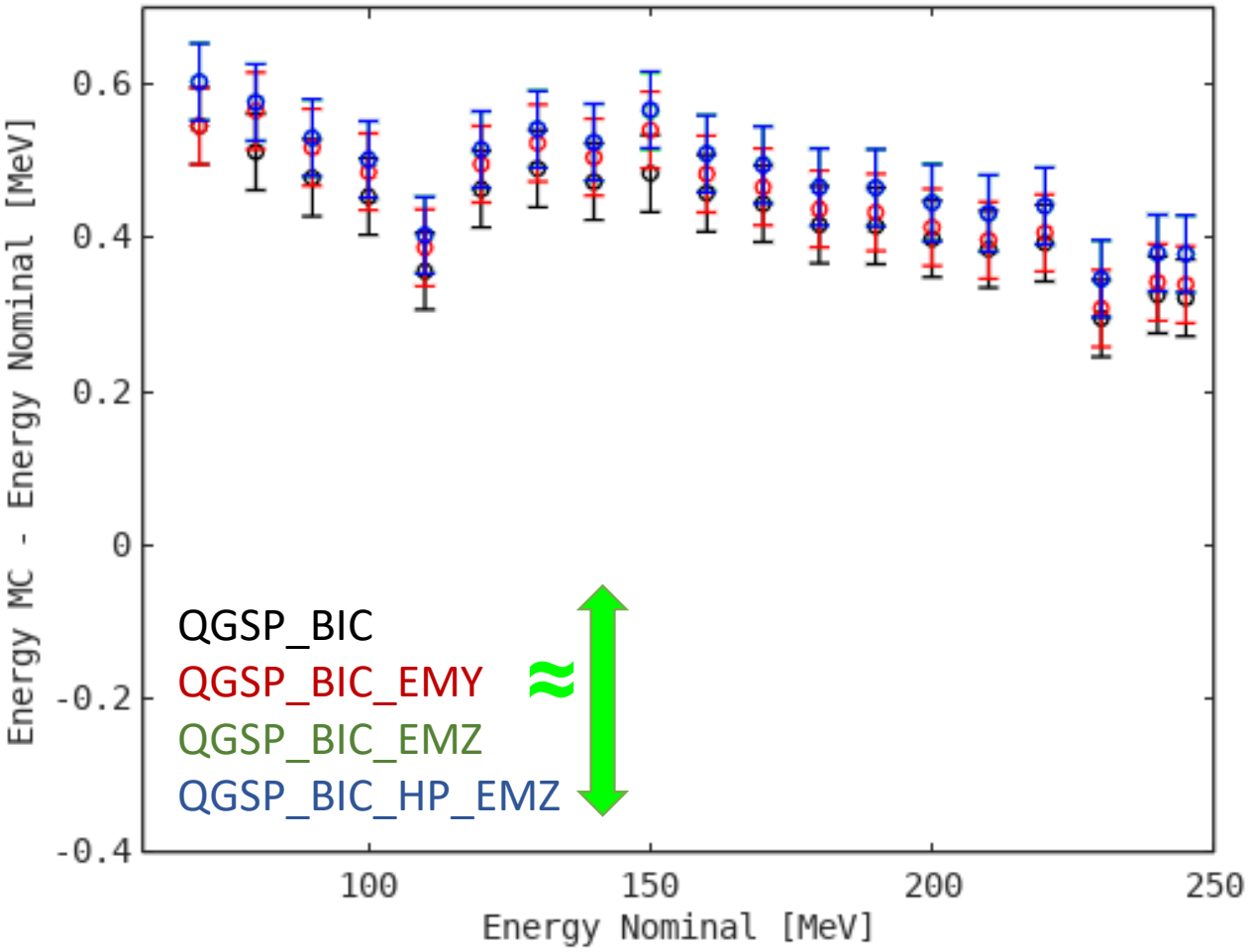


Figure courtesy: P. Sitch

Energy tuning

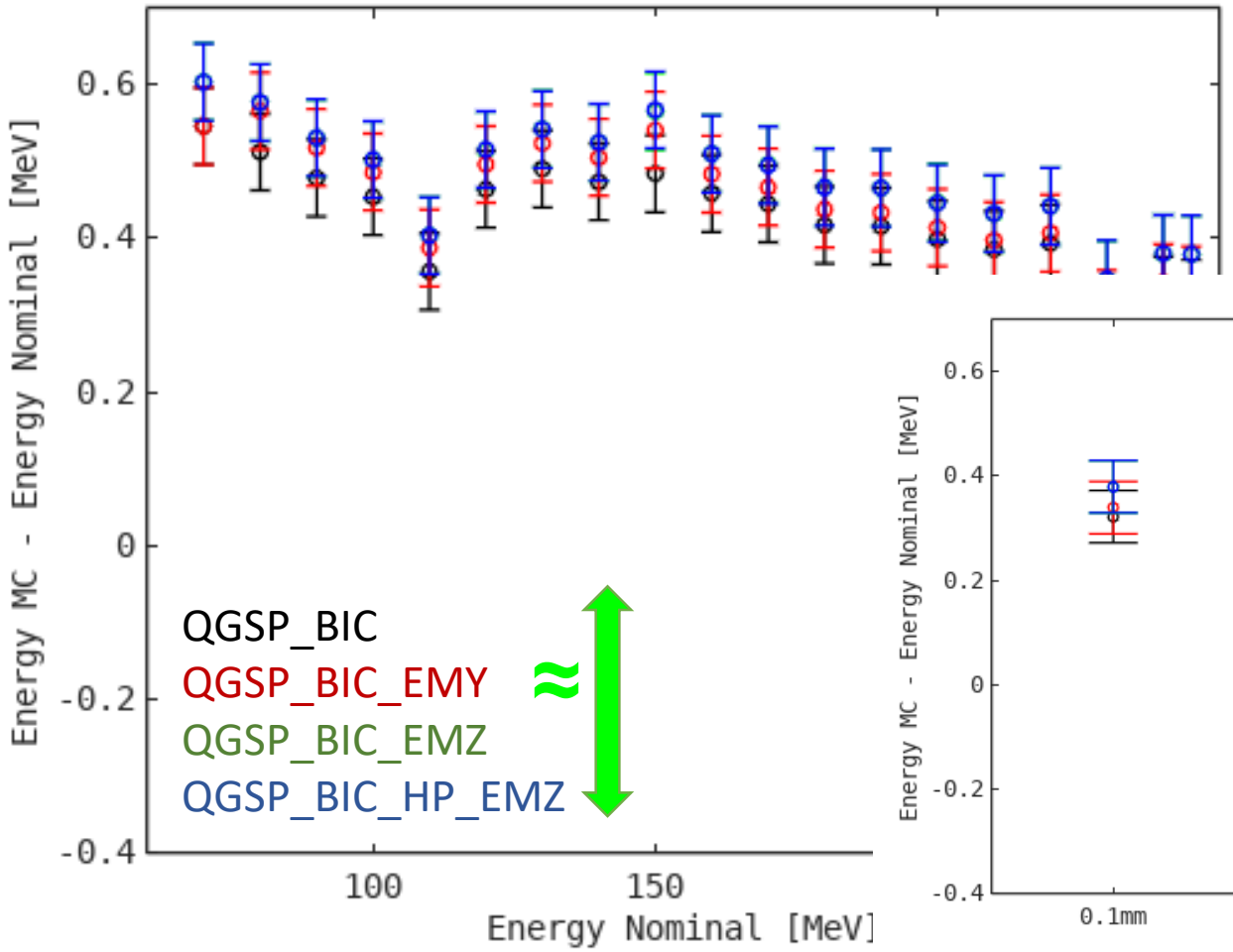


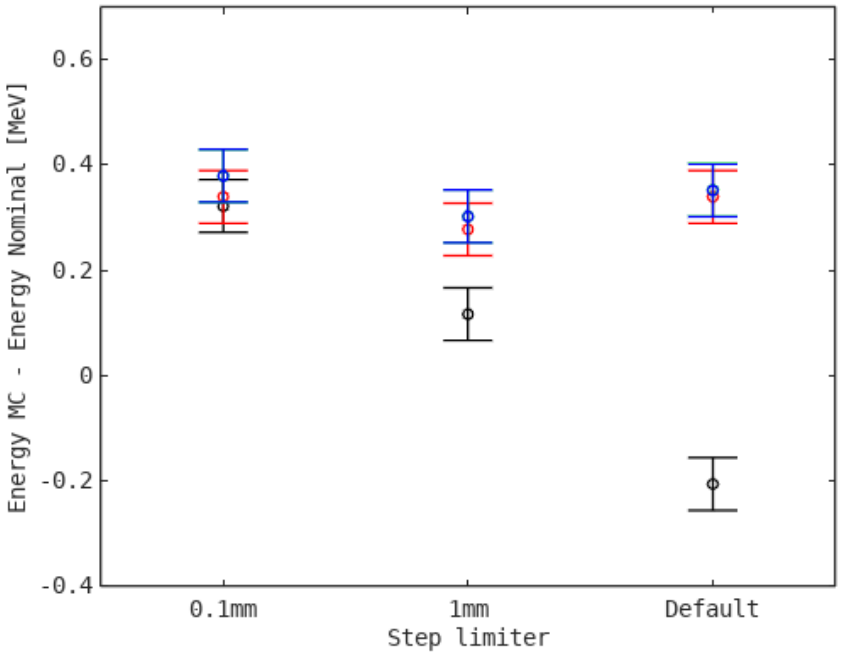
Agreement within error bars, no substantial dependence on physics models or cuts.

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.



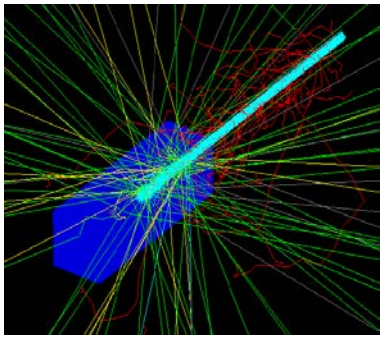


Energy tuning – calculation times

- Physics lists:
  - QGSP_BIC_EMY: **factor 1.2/1.5** faster than QGSP_BIC_HP_EMZ
  - QGSP_BIC_EMZ: **factor1.0/1.1** 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**



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

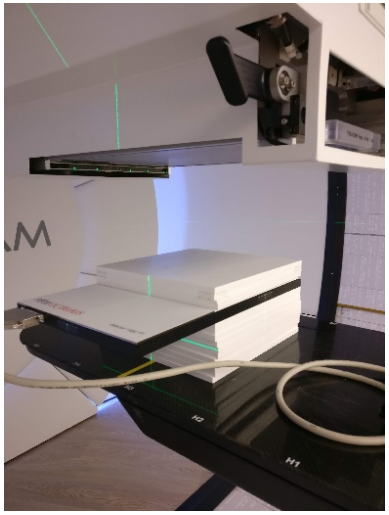
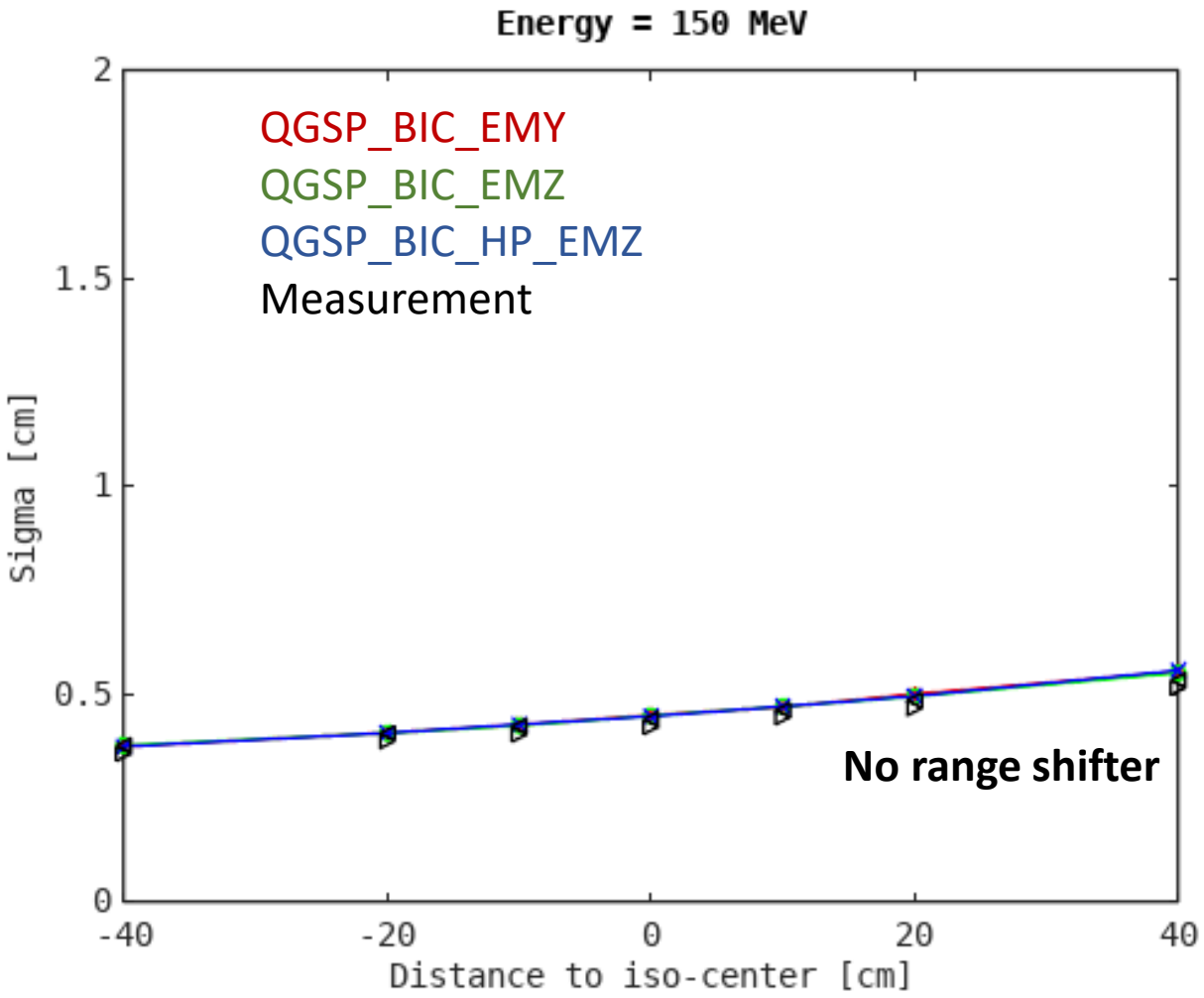
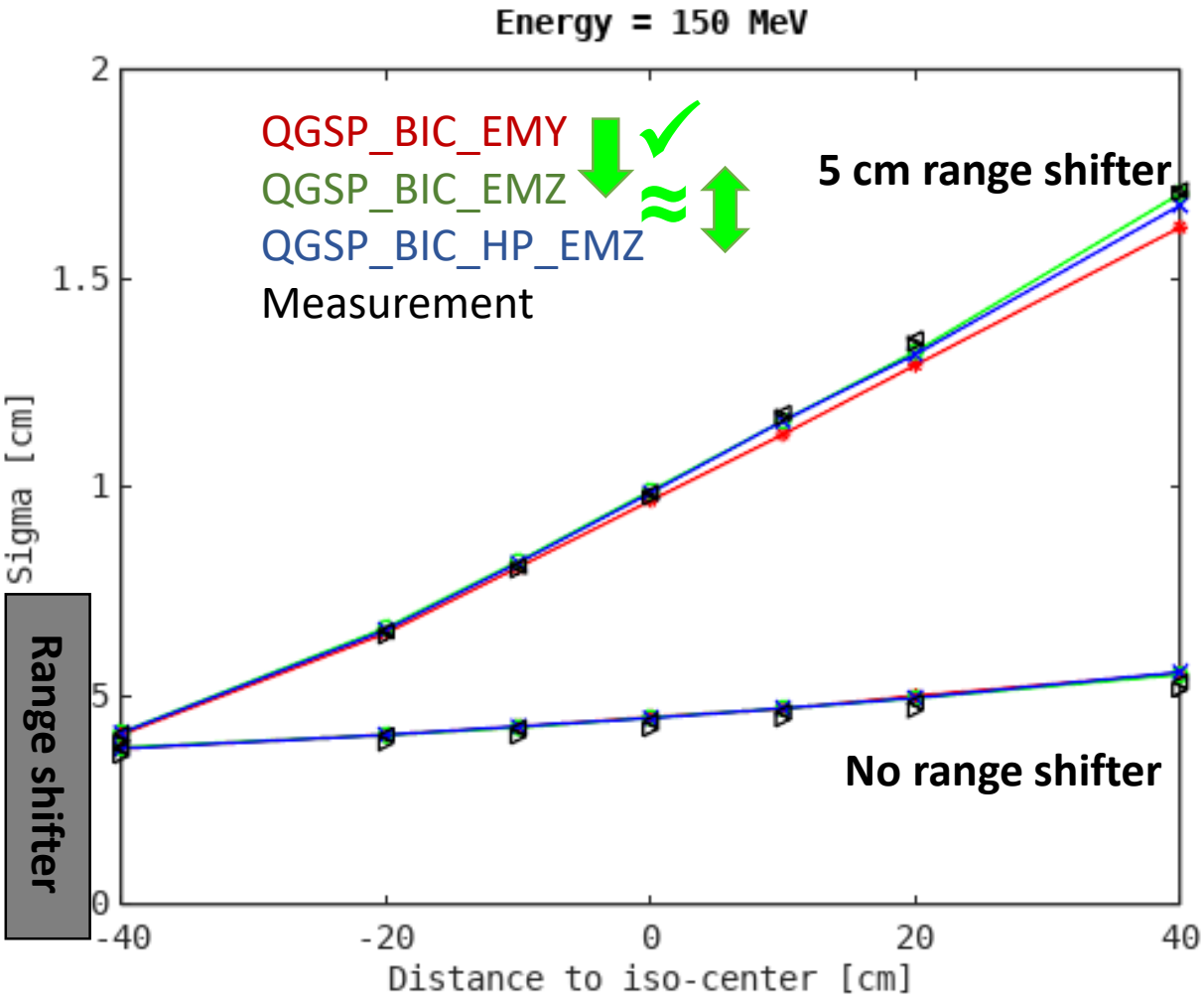


Figure courtesy: P. Sitch

Beam sizes in air



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.

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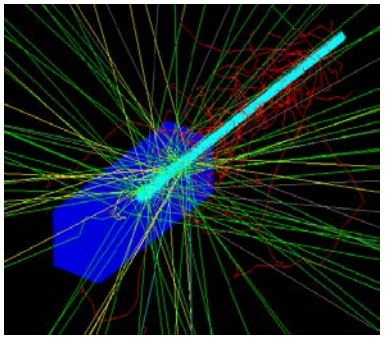

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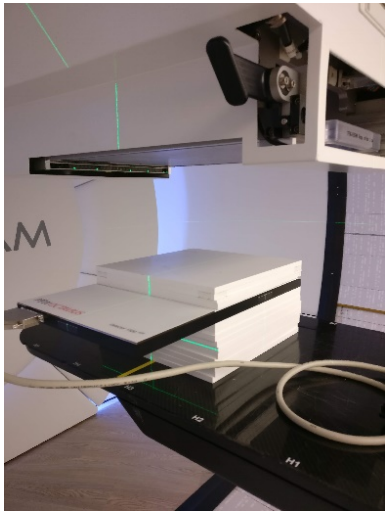

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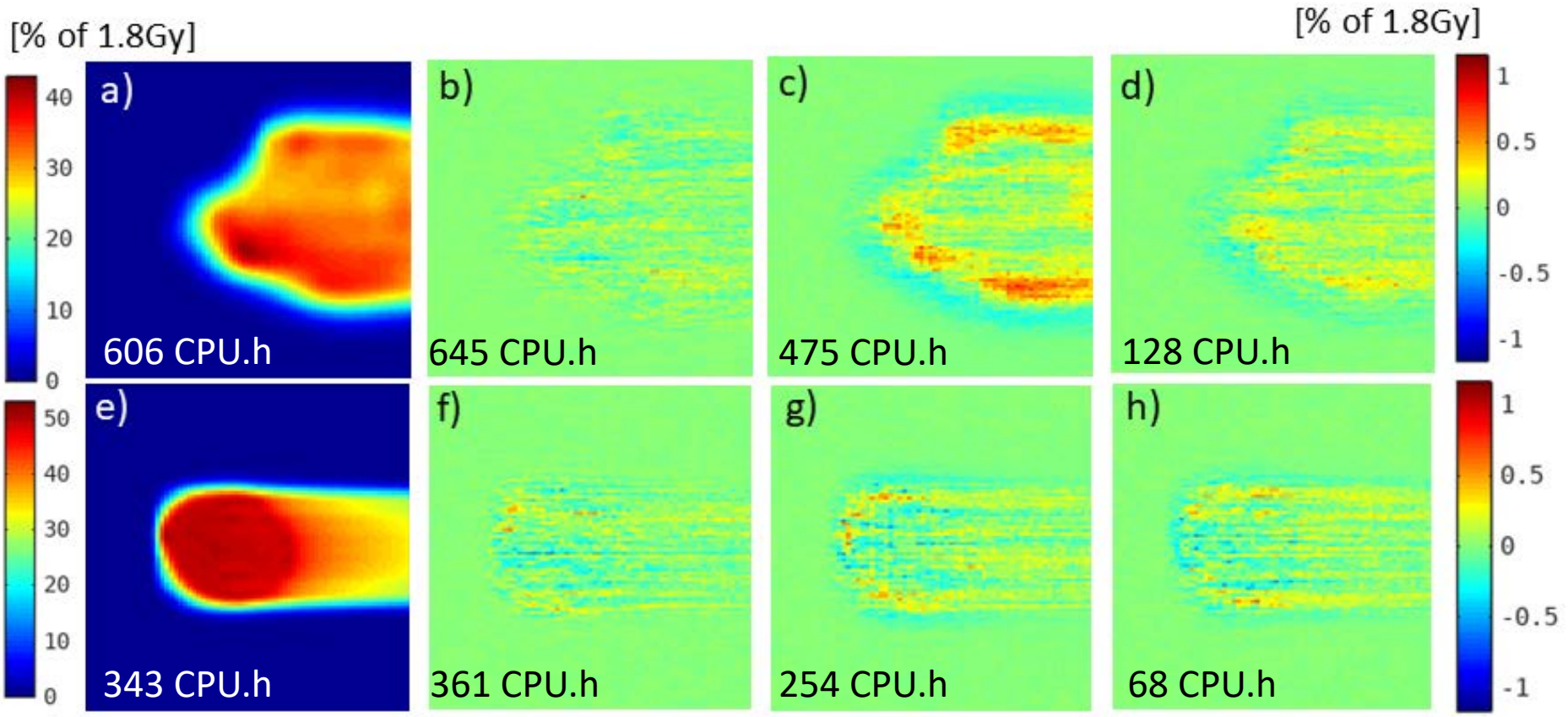
2 example fields



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)

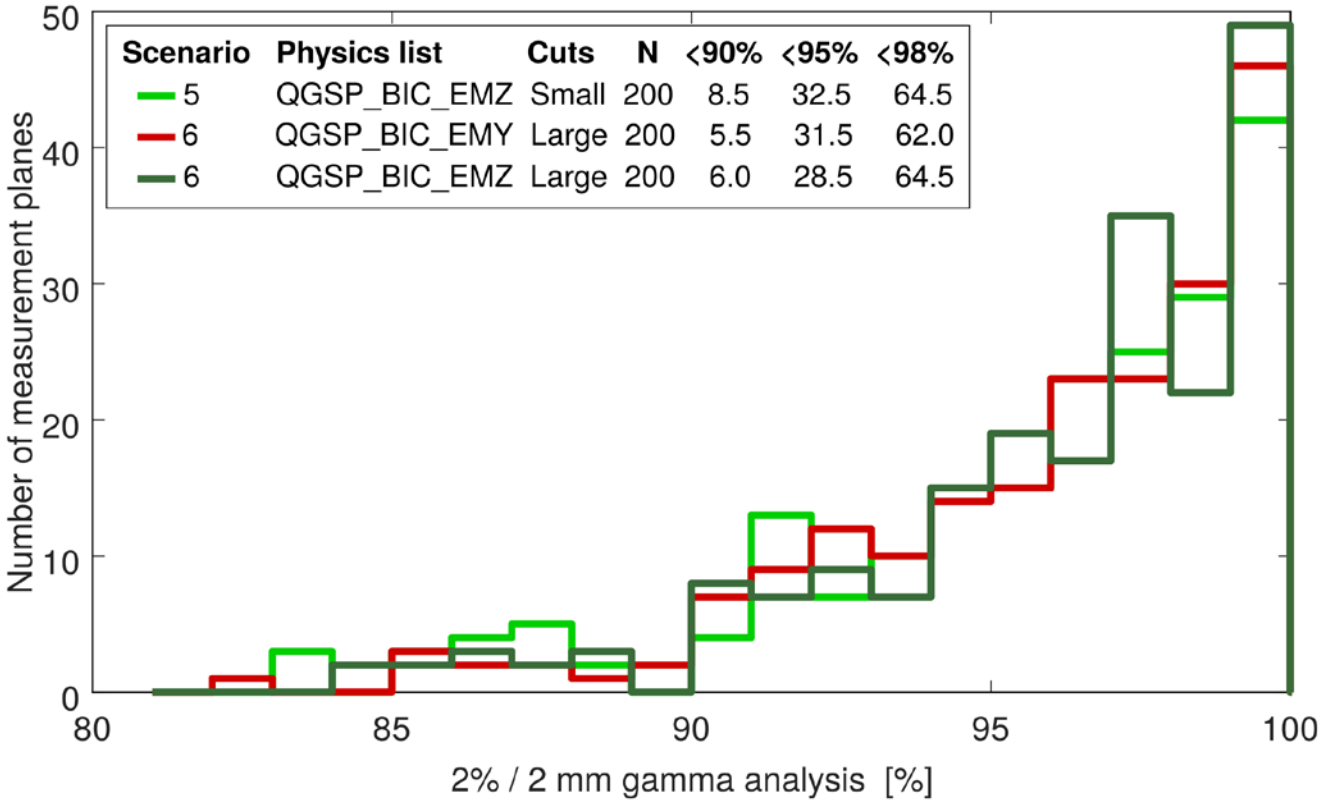
Comparison to solid water measurements

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)



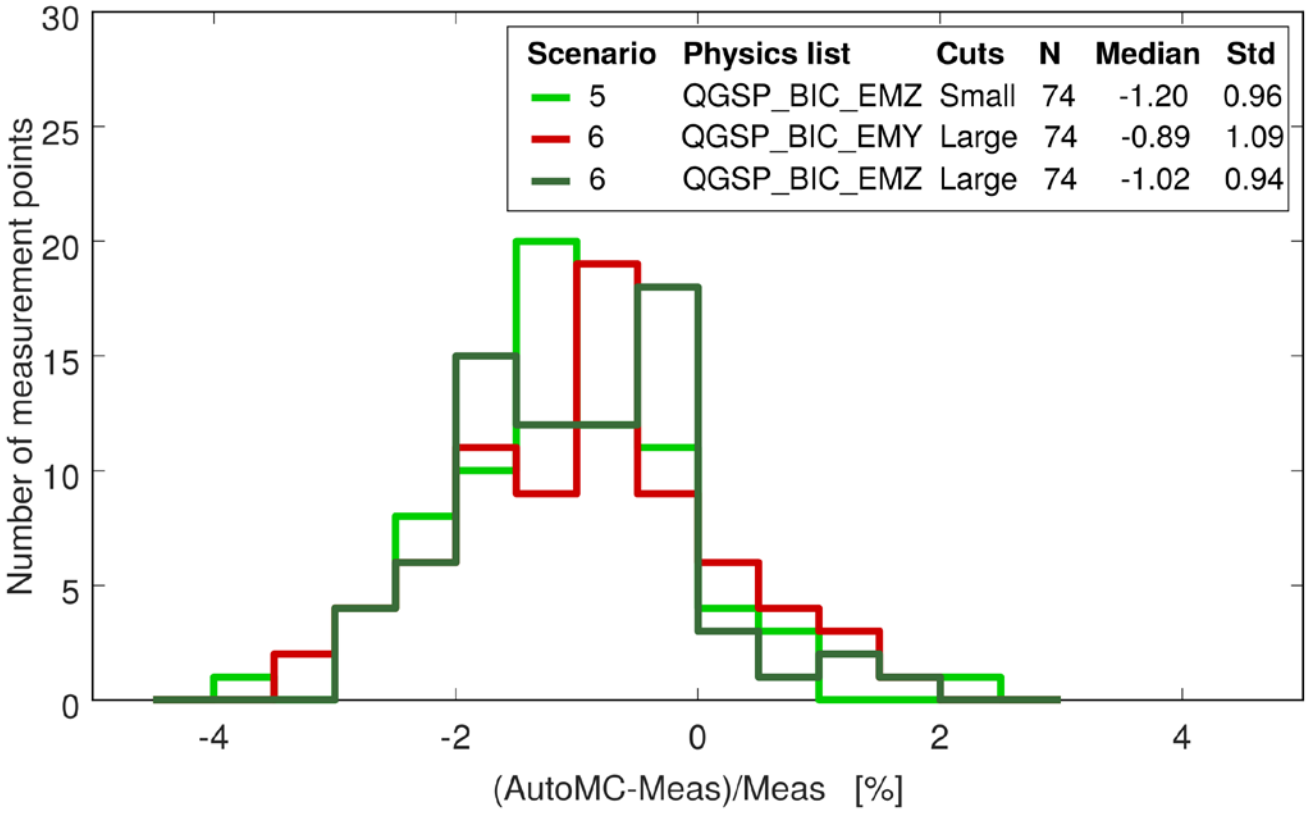
Comparison to solid water measurements

34 fields, 74 measurements:

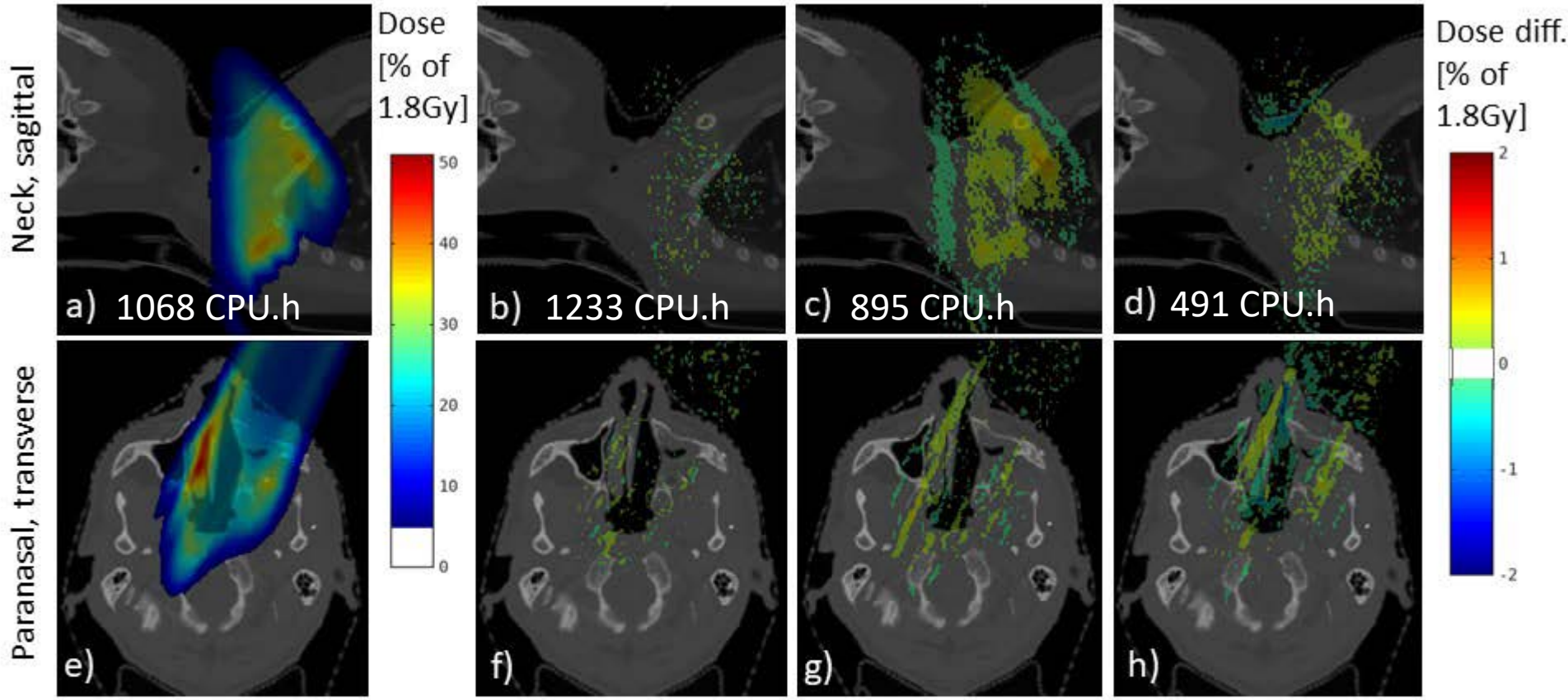
QGSP_BIC_EMZ (small cuts): -1.2%, 253 CPUh/field (0.6% uncertainty)

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



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,
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(1mm, 10mm) -
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GEANT 4 settings for proton therapy

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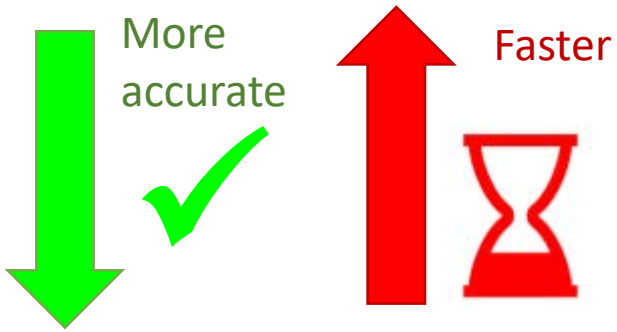
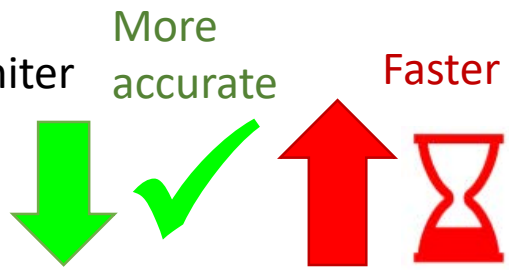


- Cuts in phantom/range shifter & cuts in world
  - 1 mm & 10 mm (large)
  - 0.1 mm & 1 mm (small)

- Step limiter

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**

Acknowledgements

- **Funding:**
  - Science and Technology Facilities Council (STFC) Advanced Radiotherapy Network, grant number ST/N002423/1,
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