

Re-calculation of clinical proton therapy plans using GATE RTion at the Christie

GATE Technical Meeting
4th July 2019
Lyon, France

Dr. Adam Aitkenhead
adam.aitkenhead@christie.nhs.uk

Honorary Research Associate
School of Medical Sciences
The University of Manchester



The University of Manchester

Principal Clinical Scientist
Christie Medical Physics and Engineering
The Christie NHS Foundation Trust



The Christie
NHS Foundation Trust



The Christie NHS Foundation Trust

- 14 linacs (10 on main site, 4 in satellite centres)
- 1 MR-linac
- Proton therapy centre: 3 clinical rooms, 1 research room

The University of Manchester: Precise Group

- Close collaboration with the clinical department.
- Current research topics include:
 - Proton arc therapy
 - LET
 - Radiobiological modelling for proton therapy
 - Novel detectors for proton range verification
 - Pre-clinical dosimetry and research



Proton Therapy at the Christie

Delivery system: Varian ProBeam

- 3 matched pencil-beam-scanning treatment rooms
 - Gantry: 360°
 - Couch: 6 degrees-of-freedom (Only x,y,z,Θ used in practice)
 - Energy range: 70 – 245 MeV
 - Pre-absorber: 0, 2, 3, 5 cm Lexan (physical thickness)
- 1 research room
 - Fixed beamline
 - Due to open: Second half of 2019

Treatment Planning System: Varian Eclipse

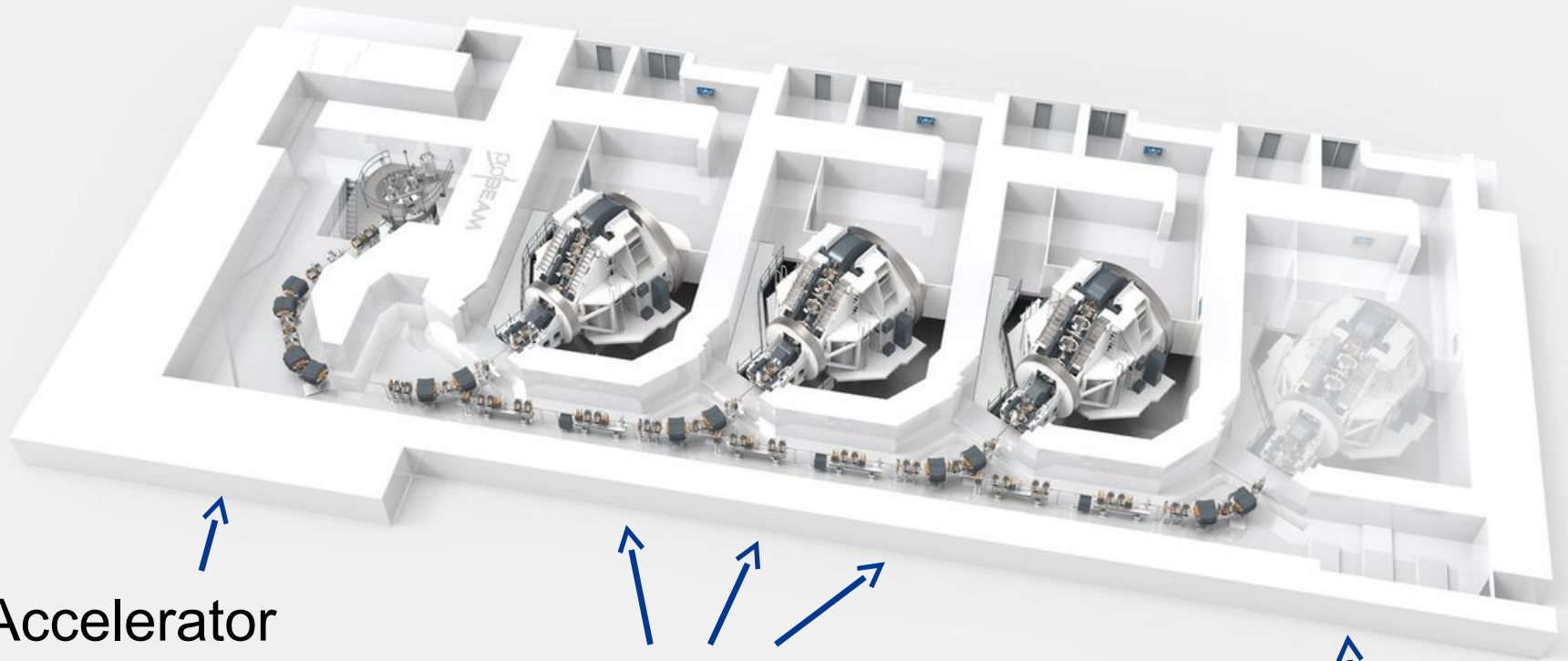
- Proton Convolution Superposition (PCS) algorithm used for dose calculation.

Clinical delivery:

- First patient: December 2018
- Patients started to date: 46



Proton Therapy at the Christie



Accelerator

- Cyclotron
- 245 MeV protons

3 treatment rooms

- Varian ProBeam systems
- 360° gantries
- Pencil beam scanning

Research room

- For use outside clinical hours



Varian ProBeam

Delivers energies from 70-245 MeV, treating up to 35 cm deep
Maximum field size 30x40 cm



Proton Therapy at the Christie: Clinical implementation of Monte Carlo

Application

- Independent re-calculation of clinical treatment plans.

Motivation

- In the UK, all clinical plans must be verified prior to treatment.
- This may be physical and/or software verification.
- Physical verification is currently performed for all proton plans:
 - 1-3 hours per plan
- By 2021, we expected to treat 750 patients per year:
 - 3 plans per day

➔ Software verification will allow us to reduce the physical verification workload.



Proton Therapy at the Christie:

Clinical implementation of Monte Carlo

- **2 identical Linux clusters:**
 - Clinical cluster: For routine plan verifications
 - Development cluster: For research work / Backup for clinical cluster
- **Hardware (each cluster):**
 - 8× Intel Xeon E3-1240 @ 3.7 GHz
 - → Total of 40 cores
- **Software:**
 - Geant4 v. 10.3.3
 - GATE v. 8.1 (GATE RTion)
 - Octave v. 4.2.2
 - AutoMC v. 0.7.4 (In-house Octave code)



AutoMC: In-house Monte-Carlo using GATE RTion

AutoMC main features:


- Automation:
 - Beam-model tuning
 - Calculation of treatment plans using GATE RTion
 - Evaluation of MC vs. TPS dose grid

- Modular
 - Beam-models
 - CT calibrations



AutoMC: In-house Monte-Carlo using GATE RTion


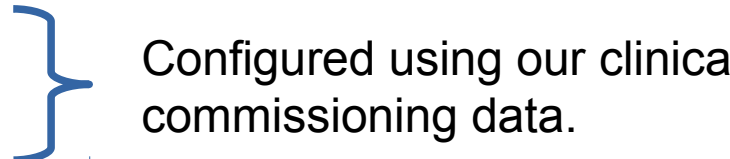
AutoMC main features:

- Automation: 
 - Beam-model tuning
 - Calculation of treatment plans using GATE RTion
 - Evaluation of MC vs. TPS dose grid
- Modular
 - Beam-models
 - CT calibrations



AutoMC: In-house Monte-Carlo using GATE RTion

AutoMC main features:

- Automation:
 - Beam-model tuning
 - Calculation of treatment plans using GATE RTion
 - Evaluation of MC vs. TPS dose grid
 - Safety
 - Ease of routine use
- Modular
 - Beam-models
 - CT calibrations

Configured using our clinical commissioning data.



AutoMC: In-house Monte-Carlo using GATE RTion

1. Dicom export to cluster:

- CT, RTSTRUCT, DOSE, RTION

2. Pre-processing of CT:

- CT overrides applied
- CT image cropped
- CT calibration applied

3. Generation of GATE macros:

- Dicom RTION file processed to generate the GATE macros to replicate each field
- Beam-model applied
- Pre-absorber is configured

4. GATE RTion simulation:

- Each job is split by energy layer and submitted to the cluster
- AutoMC monitors for completion of the simulation

5. Post simulation:

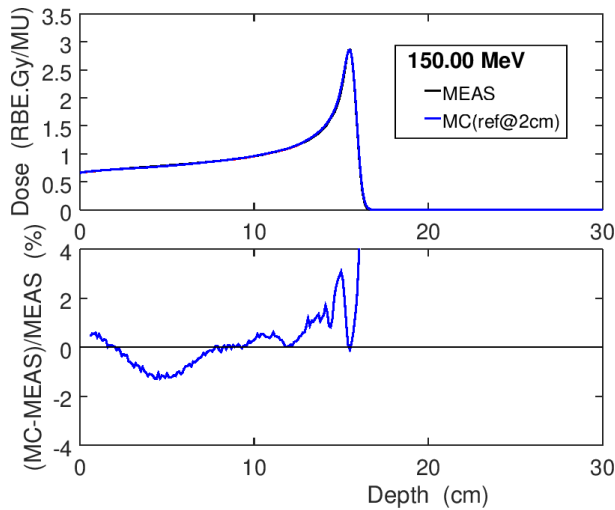
- The output of each split is combined, and the uncertainty is calculated
- 3D gamma analysis comparing MC vs. TPS
- Results written to database



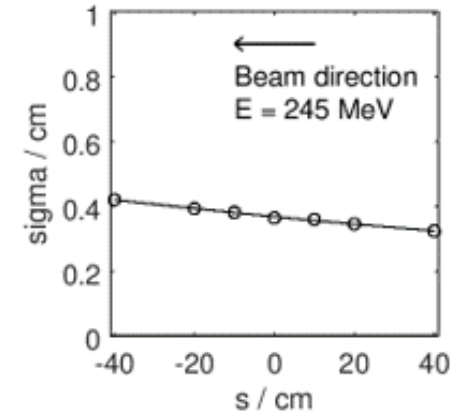
Beam-model overview

- A source plane within the nozzle is configured to reproduce commissioning data:

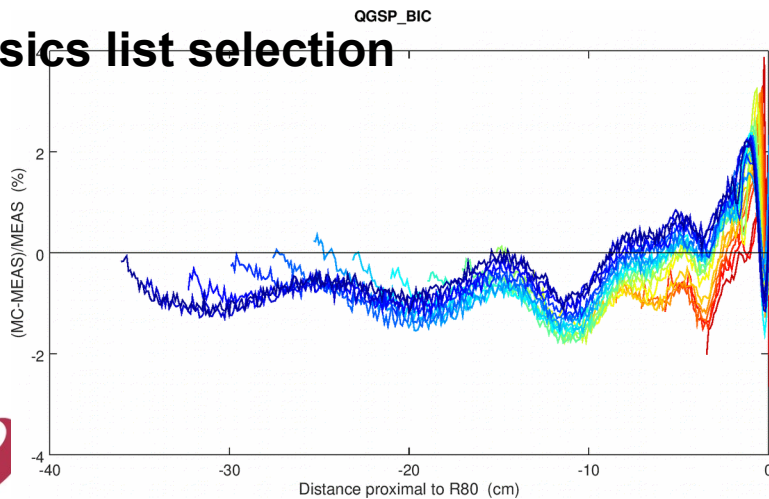
Energy tuning



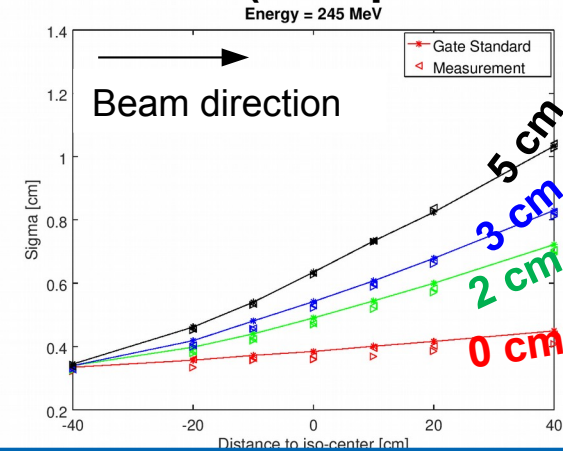
Optics definition (without pre-absorber)



Physics list selection



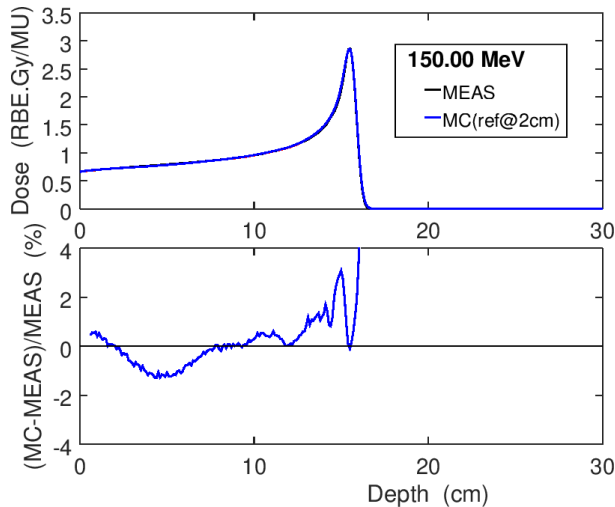
Optics validation (with pre-absorber)



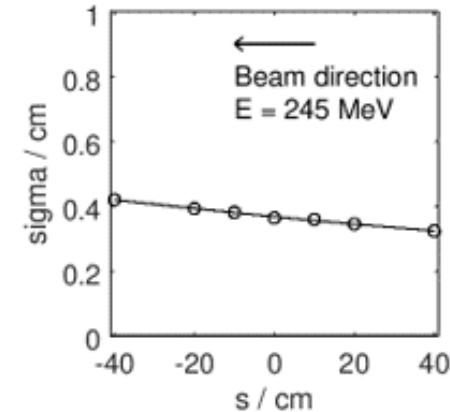
Beam-model overview

- A source plane within the nozzle is configured to reproduce commissioning data:

Energy tuning



Optics definition (without pre-absorber)



Physics list selection

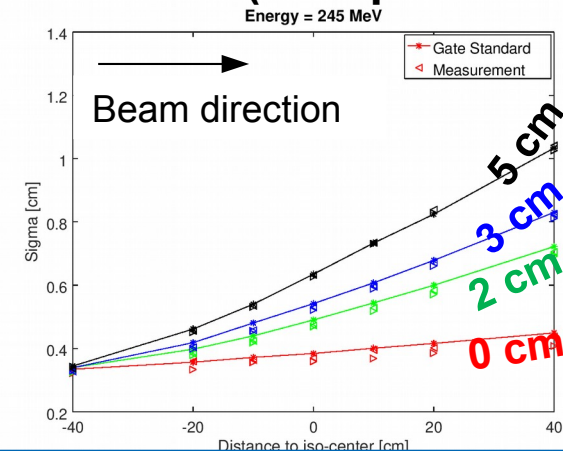
Collaborative study to establish guidelines on selecting a physics list:

Contact:

Carla.Winterhalter@manchester.ac.uk

Distance proximal to R80 (cm)

Optics validation (with pre-absorber)

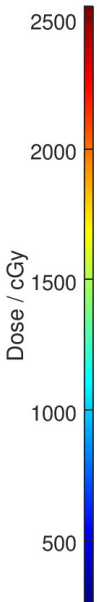
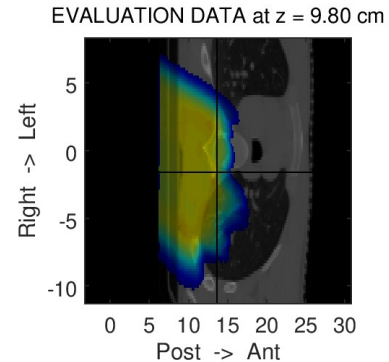
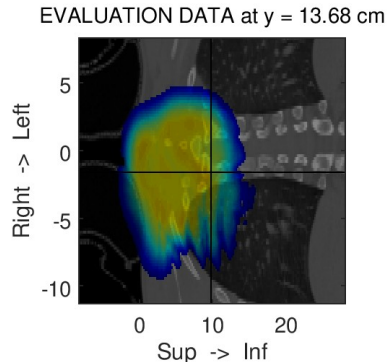
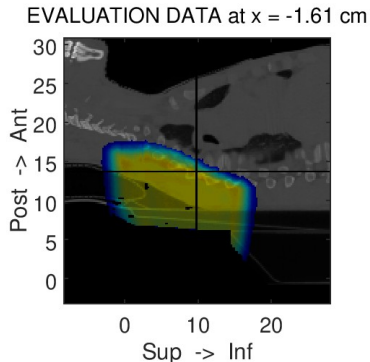


stie

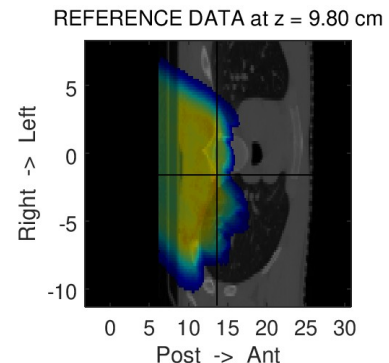
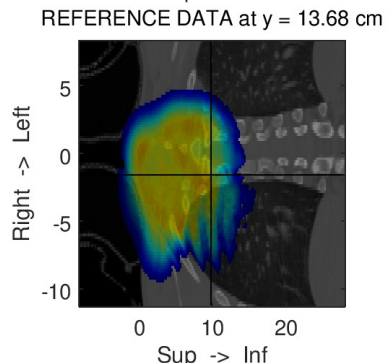
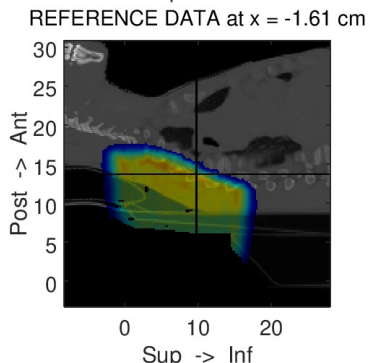
Plan re-calculation: Patient CT example

PatientID: RTPlanLabel: FINAL_Ph1 FieldName: G155_T0_RS5

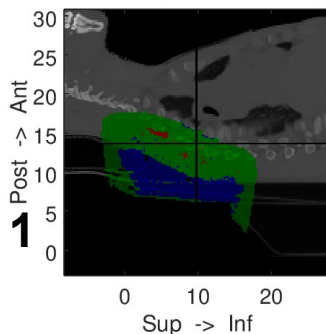
TPS



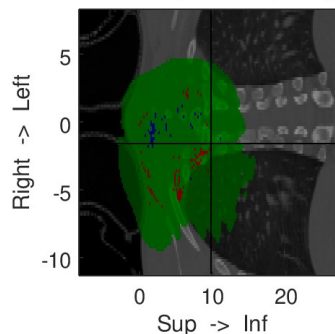
AutoMC



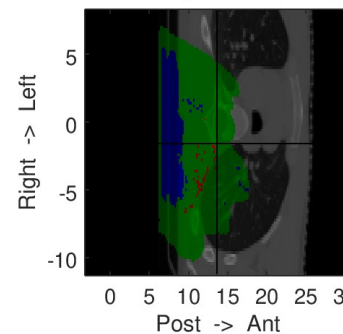
GAMMA (3%, 3mm, local)



GAMMA (3%, 3mm, local)



GAMMA (3%, 3mm, local)



Gamma

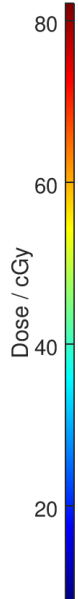
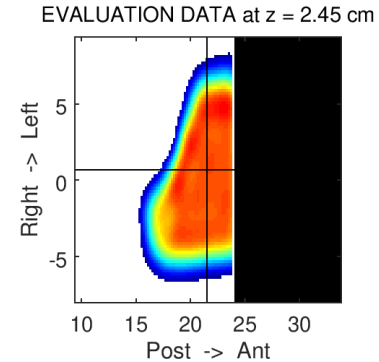
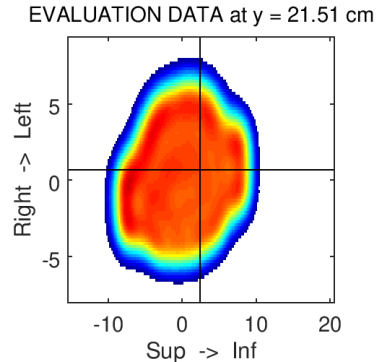
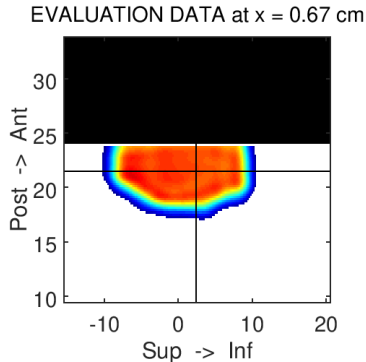
95.4% $\gamma \leq 1$

Plan re-calculation: Solid-water example

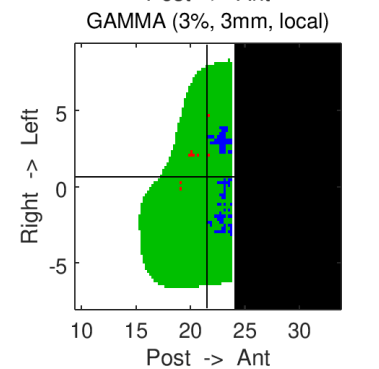
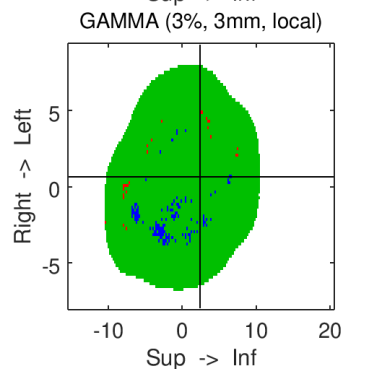
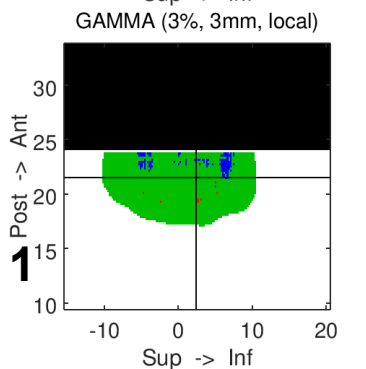
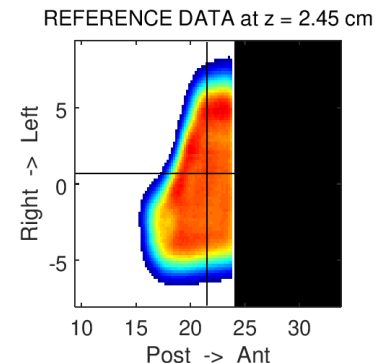
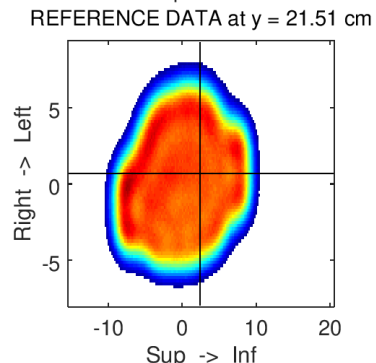
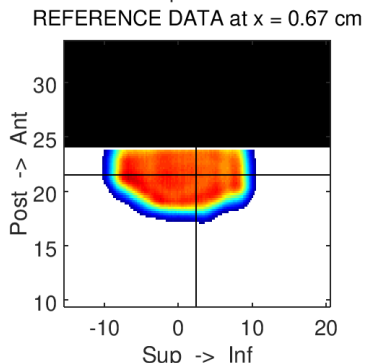
PatientID:

RTPlanLabel: G155T0RS5_Ph1 FieldName: G155_T0_RS5

TPS



AutoMC

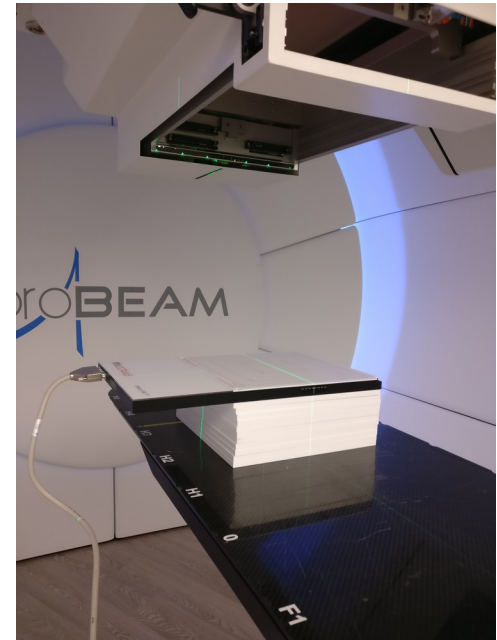


Gamma

96.0% $\gamma \leq 1$

Physical verification

- Physical verification in solid-water using:
 - 2D array: PTW 1500 XDR
 - Chamber: PTW semiflex
- Measurements typically done at:
 - Gantry angle 0°
 - At least 2 depths

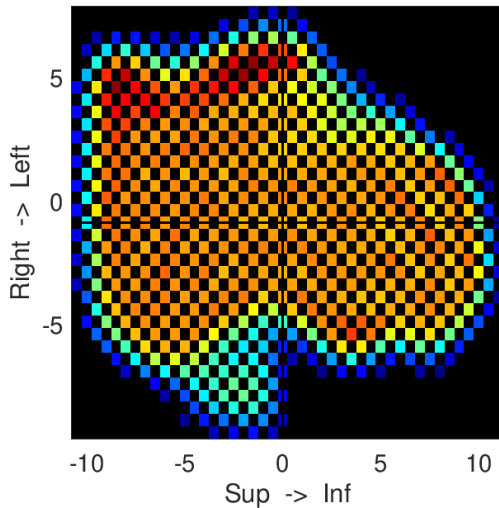


Physical verification: 2D array

- 2D array example measurement.
 - Diameter of each chamber: 0.44 cm
 - Chamber pitch: 1.00 cm

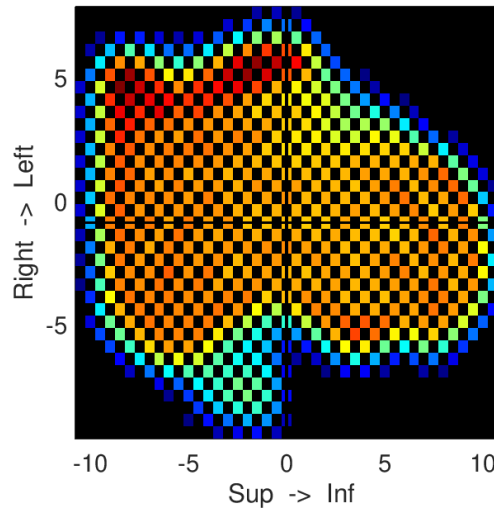
AutoMC

EVALUATION DATA at $y = 17.73$ cm



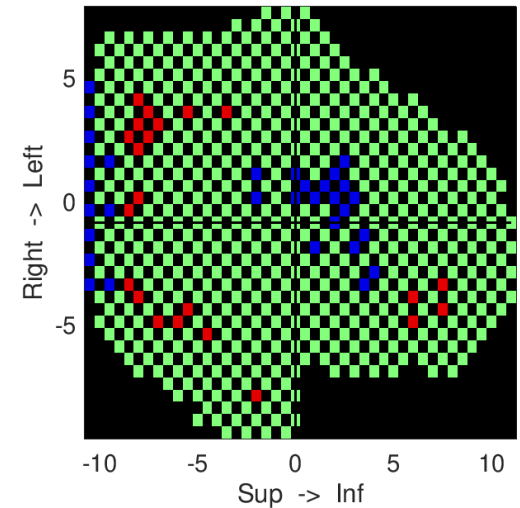
2D array

REFERENCE DATA at $y = 17.73$ cm



Gamma (2%, 2 mm)

GAMMA (2%, 2mm, local)

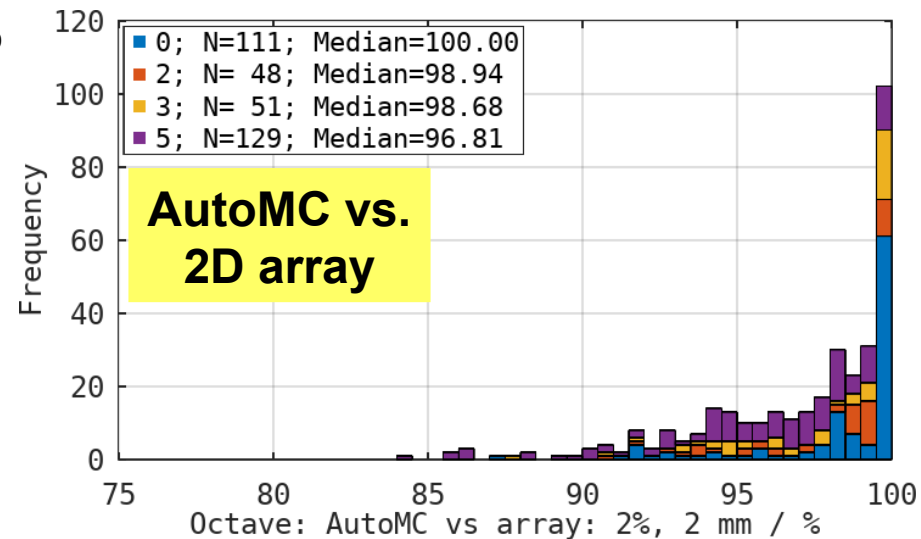
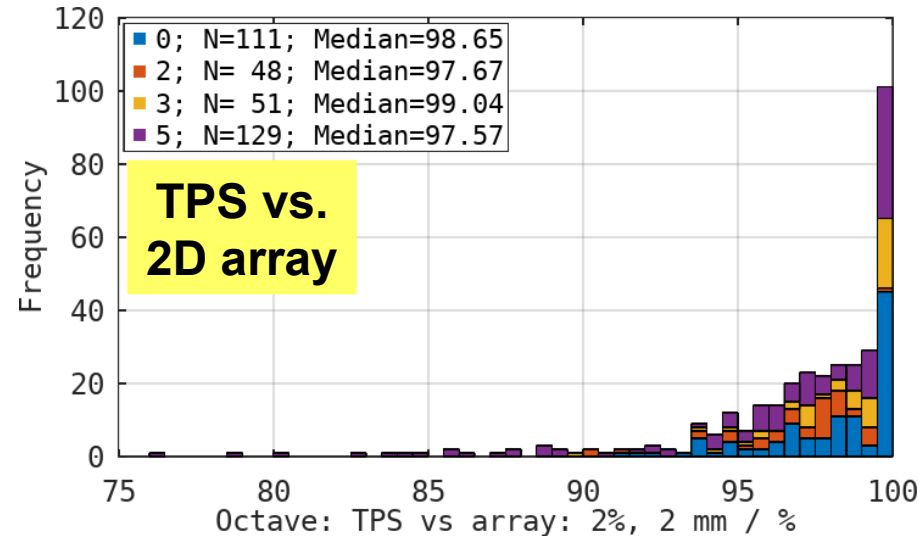


2D array vs. Calculation

- Number of plans: **15**
- Number of fields: **61**
- Number of array measurements: **339**

Gamma analyses (2%, 2mm):

- TPS and array planes where >90% of pixels have $\gamma \leq 1$: **94.4%**
- MC and array planes where >90% of pixels have $\gamma \leq 1$: **96.5%**
- The spread in the data is mainly due to variation in the array measurements.



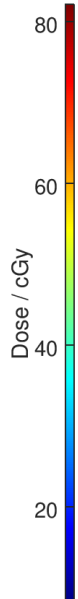
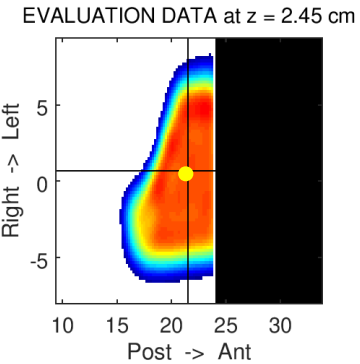
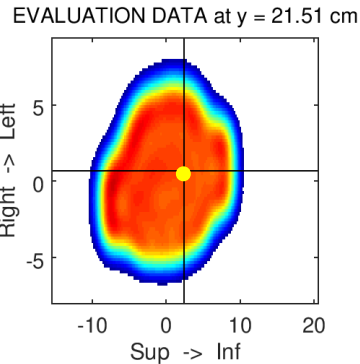
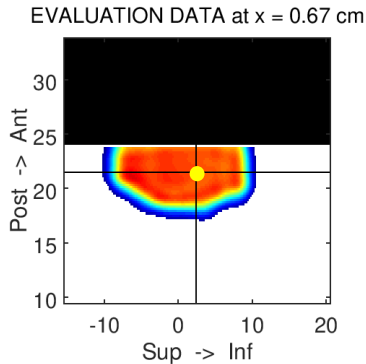
Physical verification: Chamber

PatientID:

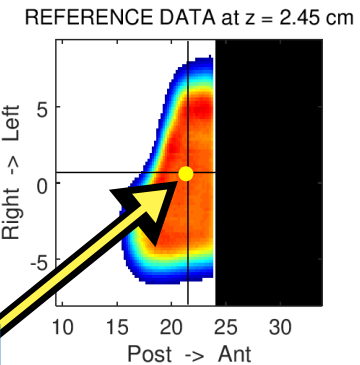
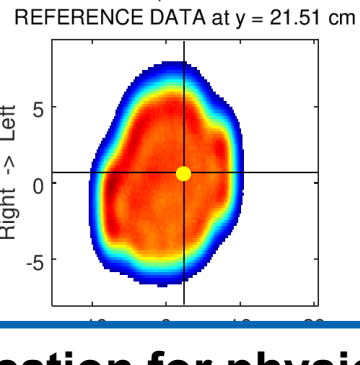
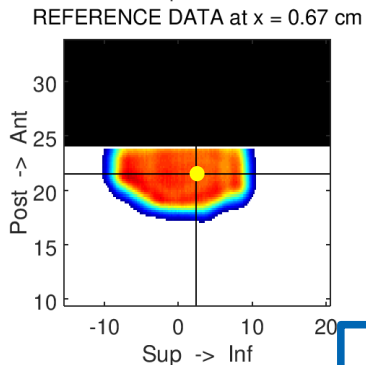
RTPlanLabel: G155T0RS5_Ph1

FieldName: G155_T0_RS5

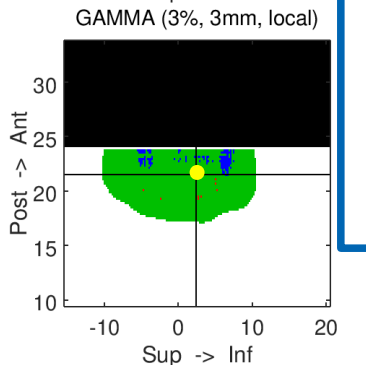
TPS



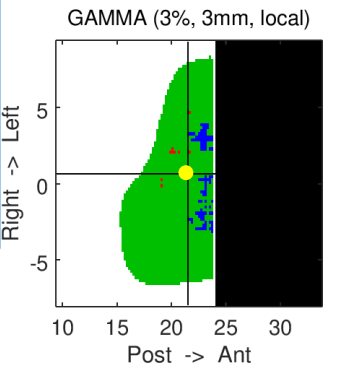
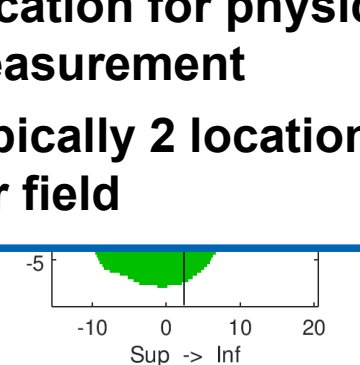
AutoMC



Gamma



- Location for physical measurement
- Typically 2 locations per field

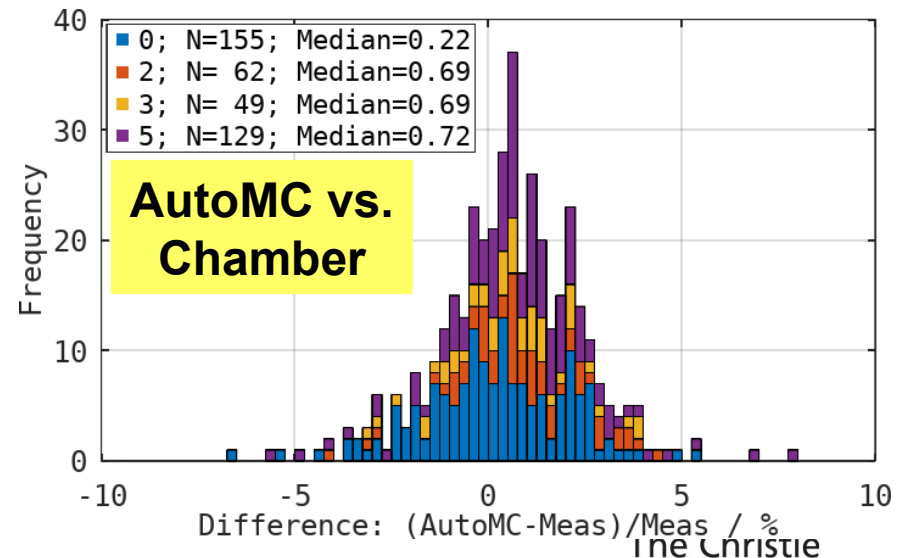
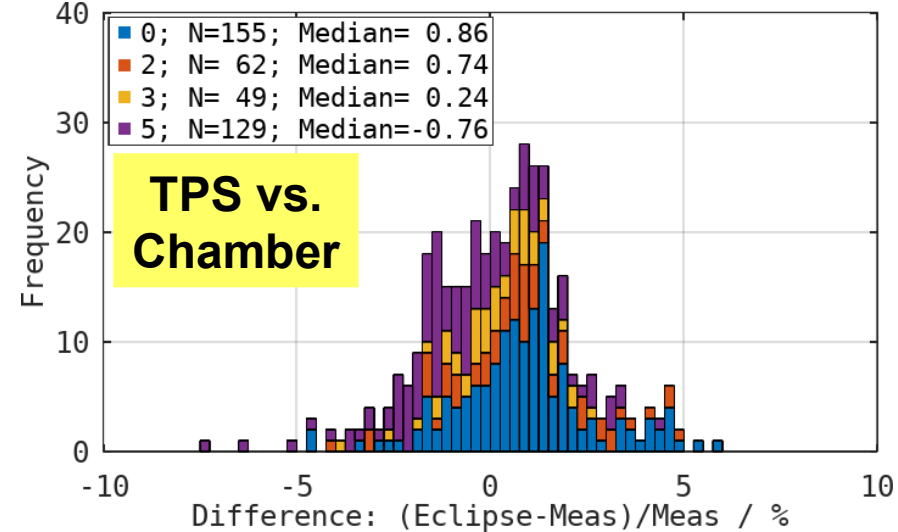


Chamber vs. Calculation

- Number of plans: **46**
- Number of fields: **172**
- Number of chamber locations: **396**

Dose difference comparisons:

- TPS and chamber agree (systematically) within: **+/- 0.9%**
- MC and chamber agree (systematically) within: **+/- 0.8%**
- The spread in the data is mainly due to variation in the chamber measurements ($\sigma = 1.8\%$).



Summary

Example of the use of GATE RTion for independent calculation of proton PBS treatment plans:

- Automation for routine clinical use.
- The same commissioning data is used to configure the beam-model and CT calibration in both TPS and MC.
- No post-commissioning correction factors are applied.

Results from first cohort of patients planned/verified at the Christie:

- Absolute dose distributions calculated in TPS and MC agree within the uncertainty of physical verification measurements.



Acknowledgements

www.opengatecollaboration.org/GateRTion

The University of Manchester

- Carla Winterhalter
- Ed Smith
- Nicholas Henthorn
- Tracy Underwood
- Michael Taylor
- Michael Merchant
- Norman Kirkby
- Karen Kirkby

Paul Scherrer Institut

- Yannick Klopfenstein
- Sairos Safai
- Francesca Albertini
- Tony Lomax

The Christie NHS Foundation Trust

- Jenny Richardson
- Peter Sitch
- Imran Patel
- Ranald MacKay
- Matthew Lowe
- Matthew Clarke
- David Lines
- Frances Charlwood
- Natalie Harrold
- Isaac Allen
- Stacey Kelly-Jones
- Jennifer Lee
- Joanna Horta Santos
- Anthony Carr

