

Using computing models from particle physics to investigate dose-toxicity correlations in cancer radiotherapy

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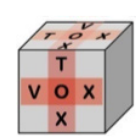
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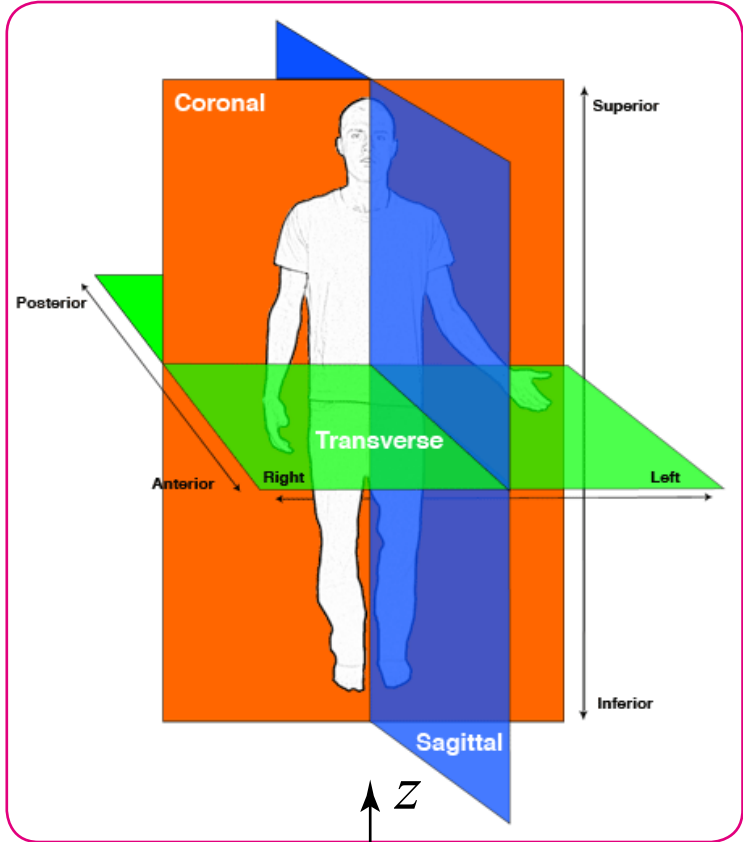
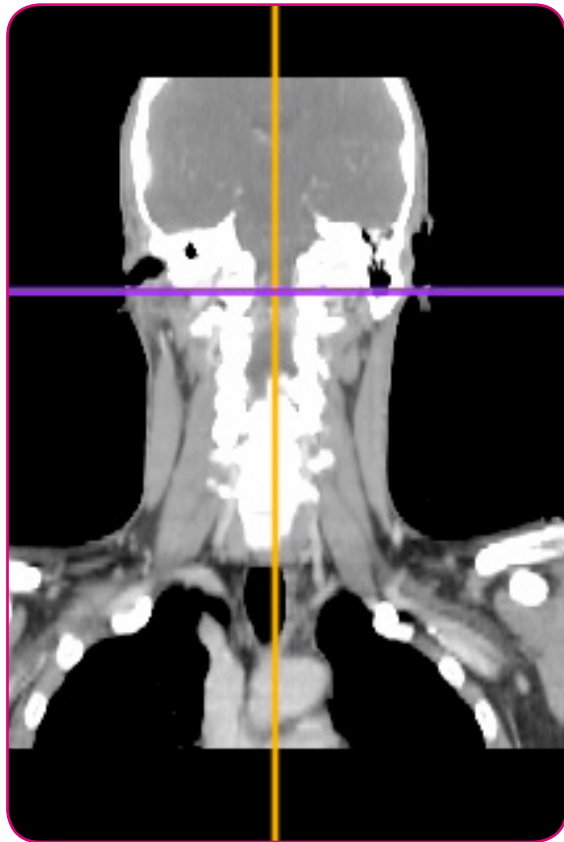
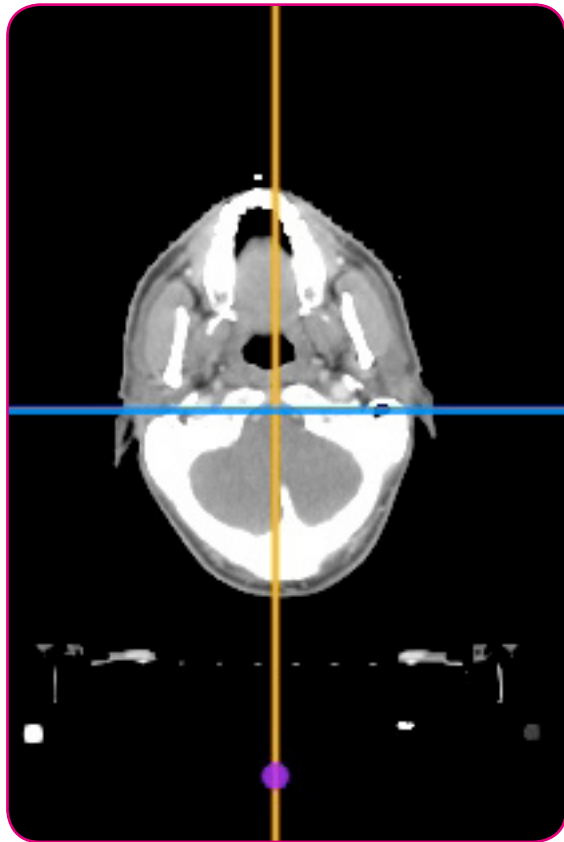
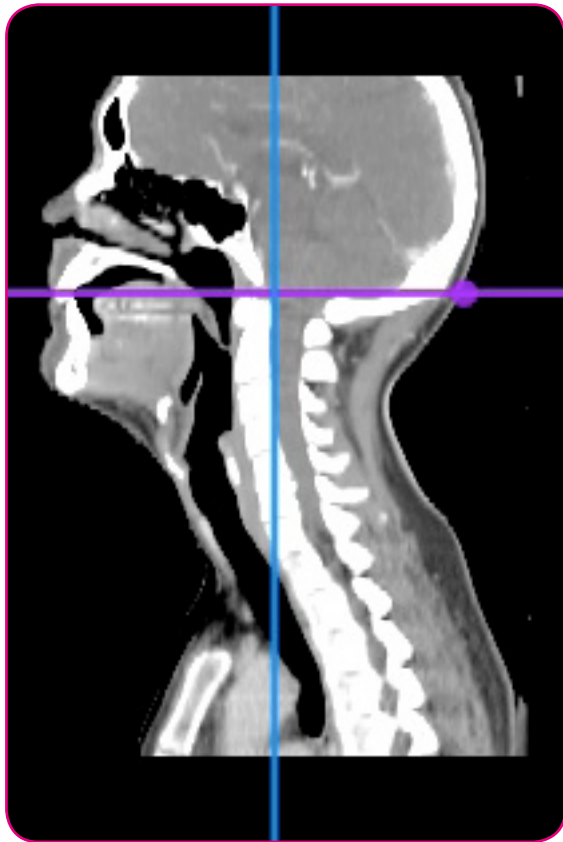
Computed Tomography (CT) scans

CT scans for diagnostic purposes are recorded with kilovoltage (kV) X-rays

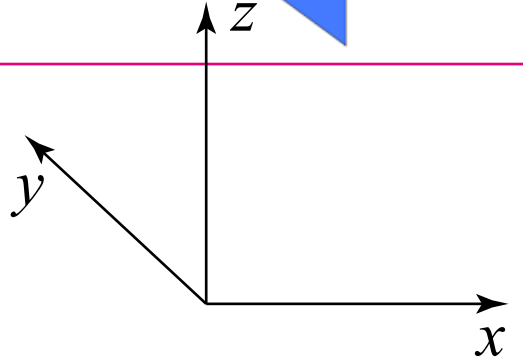
Sagittal plane

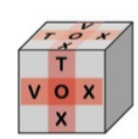
Axial plane

Coronal plane



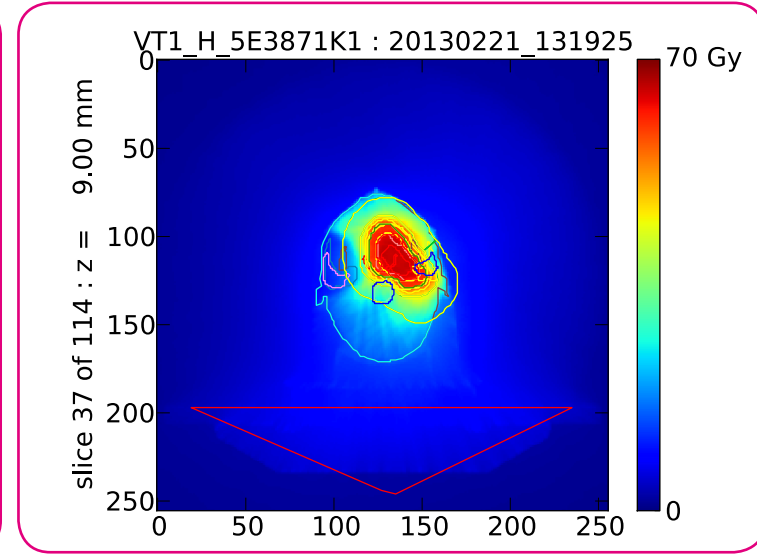
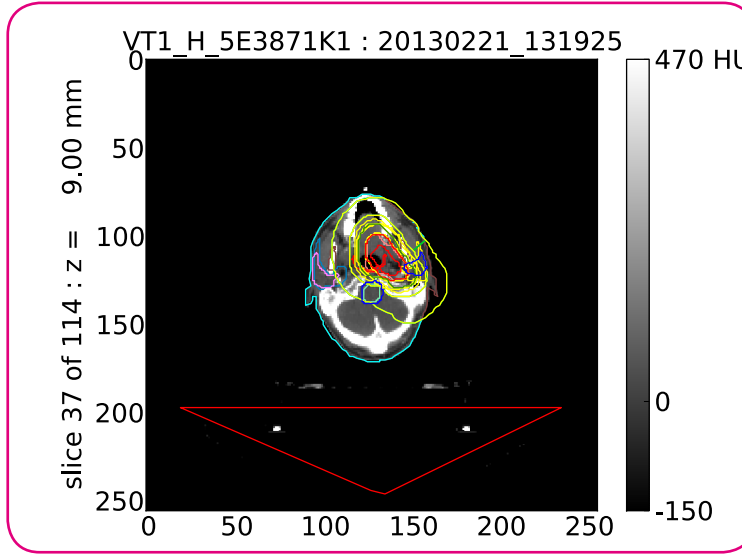
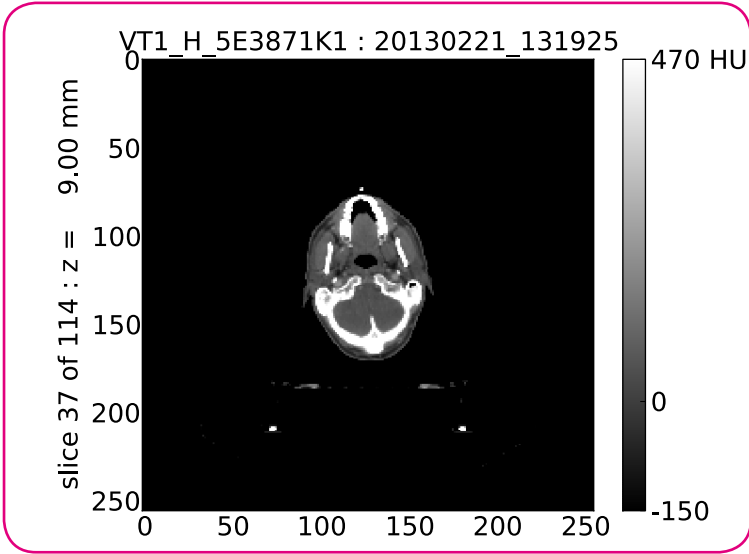
Radiodensity in Hounsfield Units (HU)



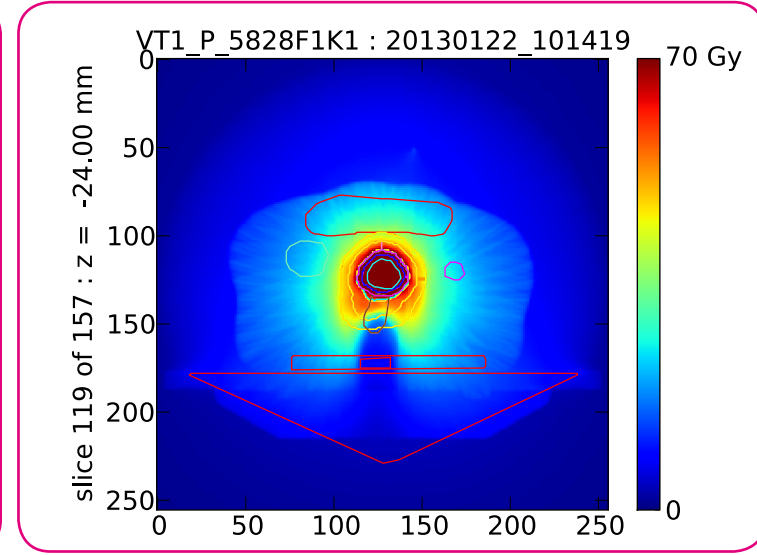
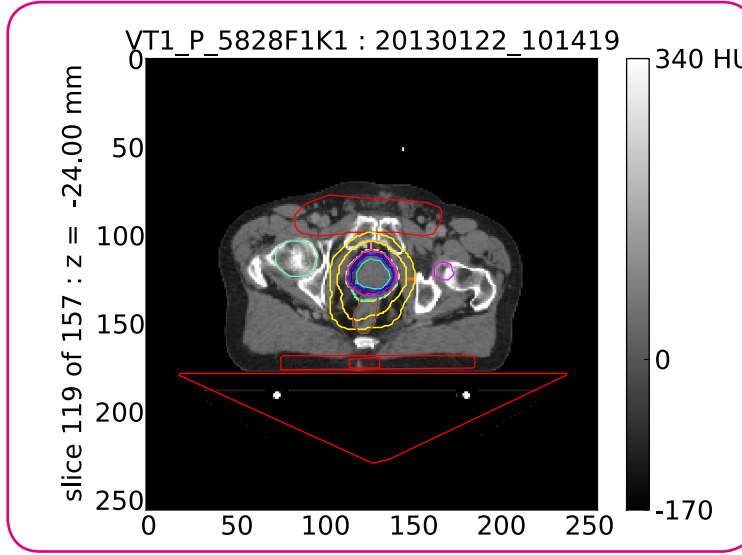
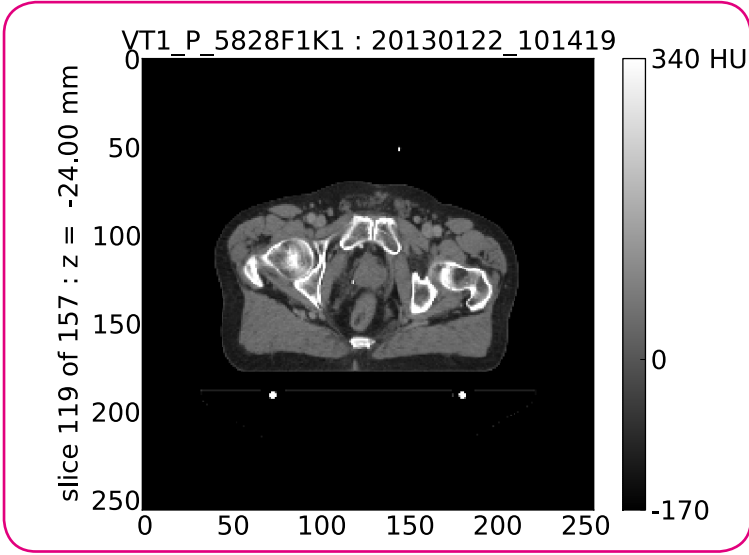


Radiotherapy planning

Cancer of head and neck



Cancer of prostate

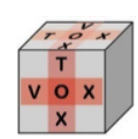


Slice thickness 3mm, pixel size 2.148mm x 2.148mm

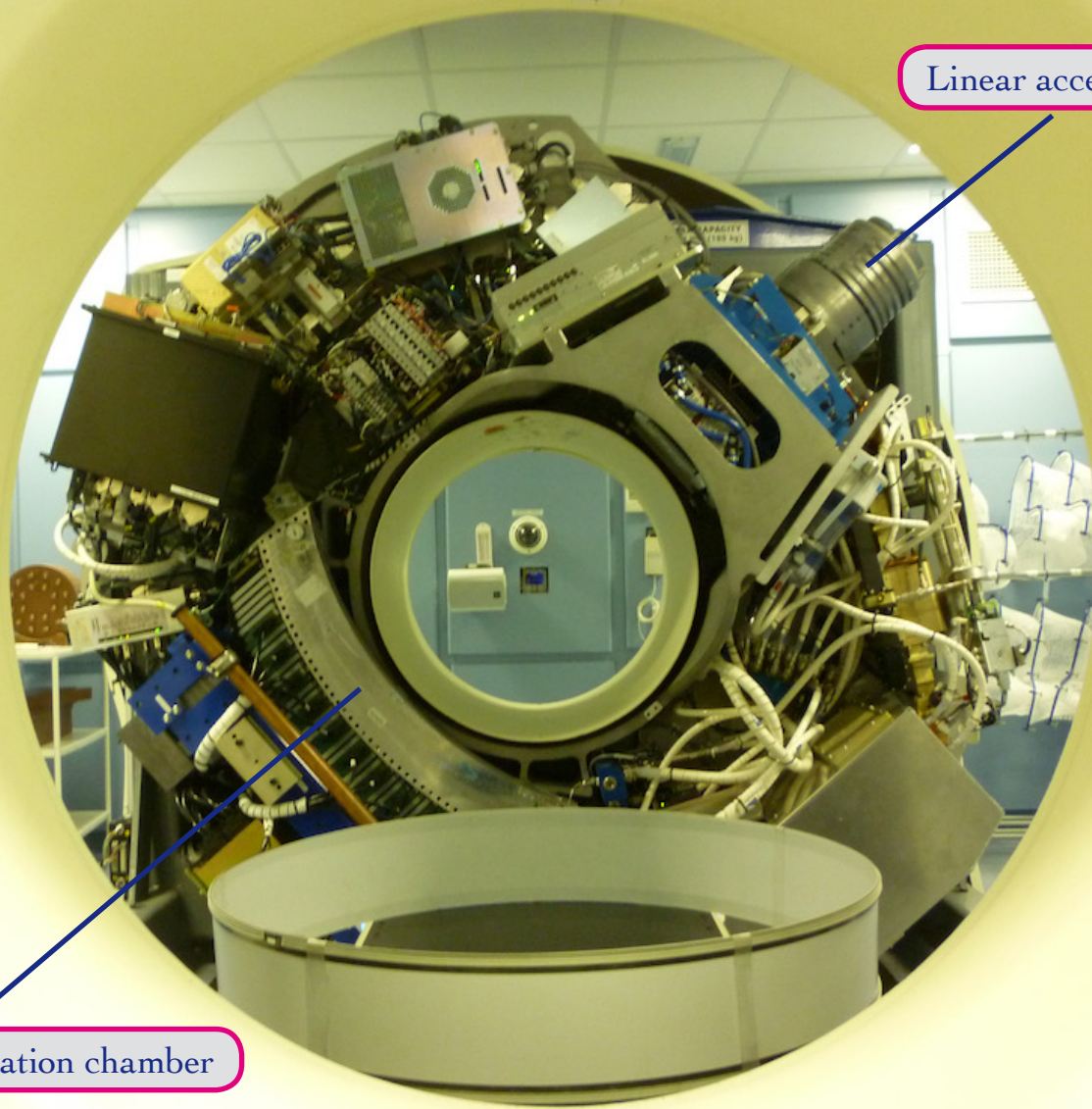
CT planning scan

Relevant structures manually outlined

Planned dose



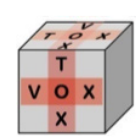
TomoTherapy treatment machine



Linear accelerator

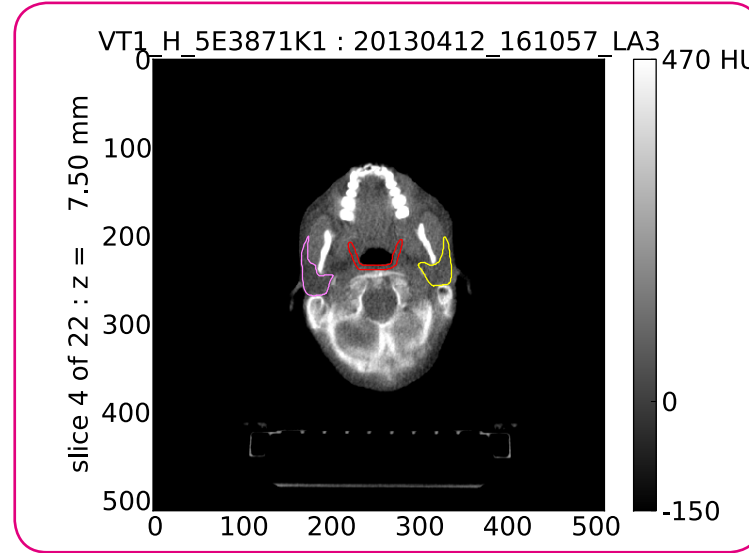
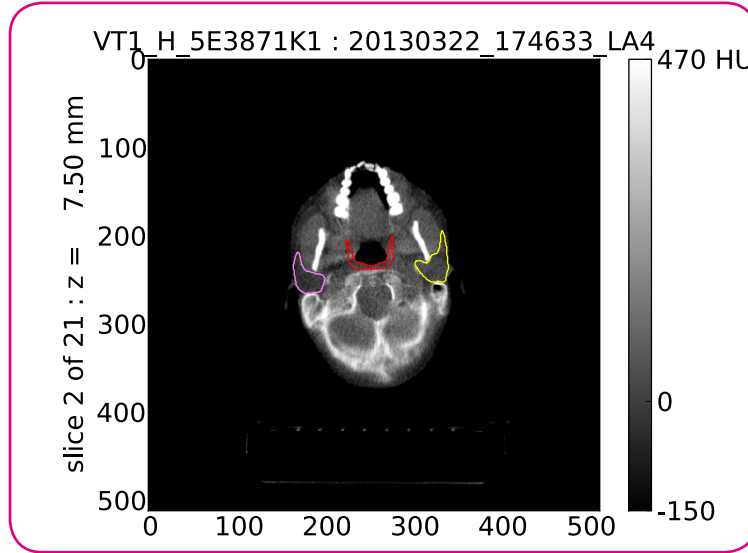
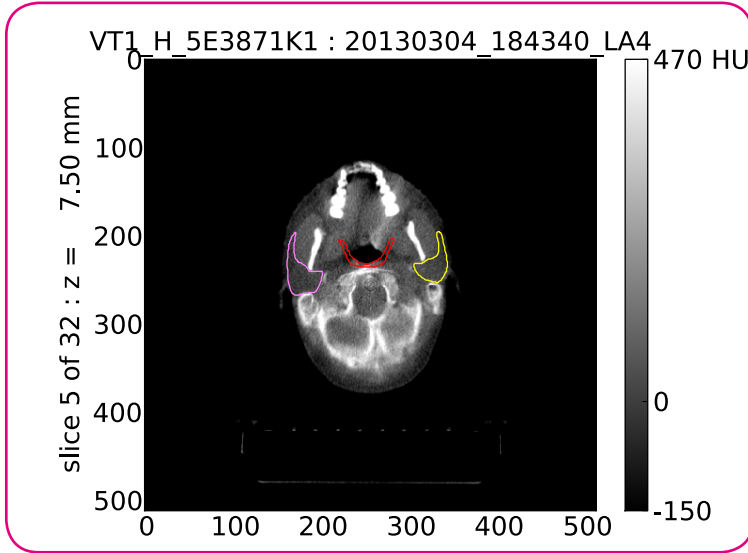
Xenon-gas ionisation chamber

- Addenbrooke's Hospital, Cambridge, UK, uses two TomoTherapy machines in delivering radiotherapy treatment
- TomoTherapy machine provides treatment beam of megavoltage (MV) X-rays
- Point of beam origin moves in helical path relative to patient
- Multileaf collimator allows intensity modulation
- Treatment beam used to perform CT scan immediately prior to treatment, to guide patient positioning



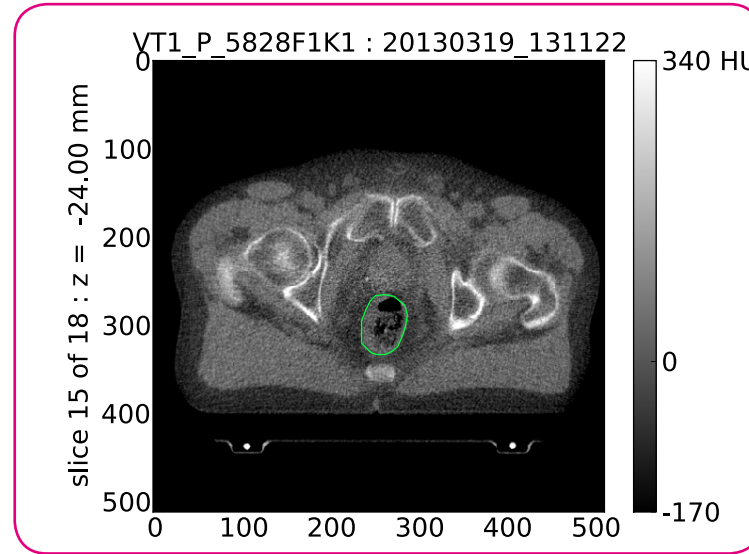
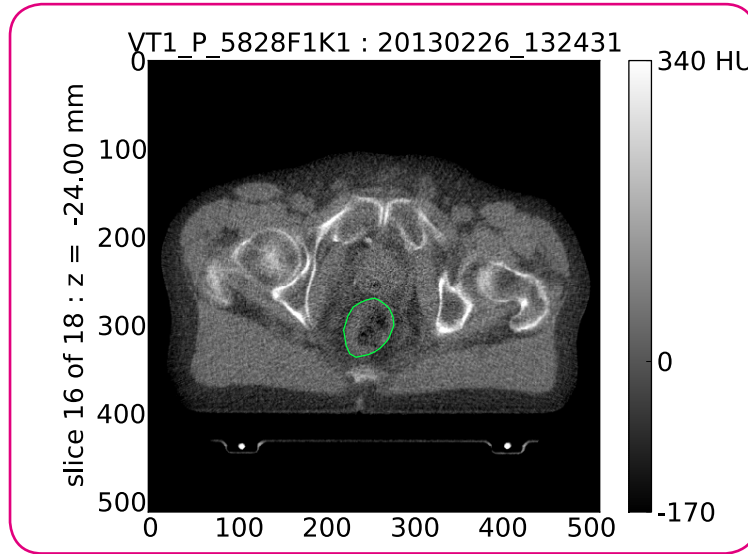
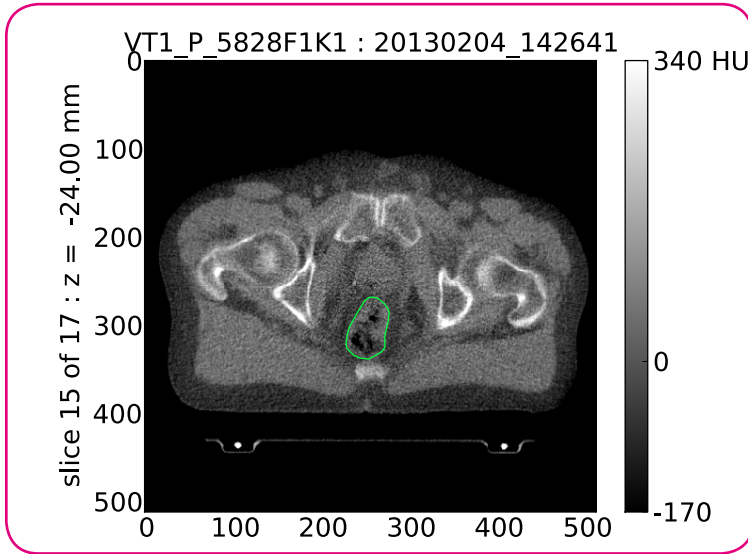
CT guidance scans for TomoThery treatment

Cancer of head and neck



Slice thickness 6mm,
pixel size 0.754mm x 0.754mm

Cancer of prostate

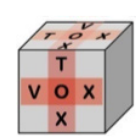


Slice thickness 6mm,
pixel size 0.7647mm x 0.7647mm

Session 01

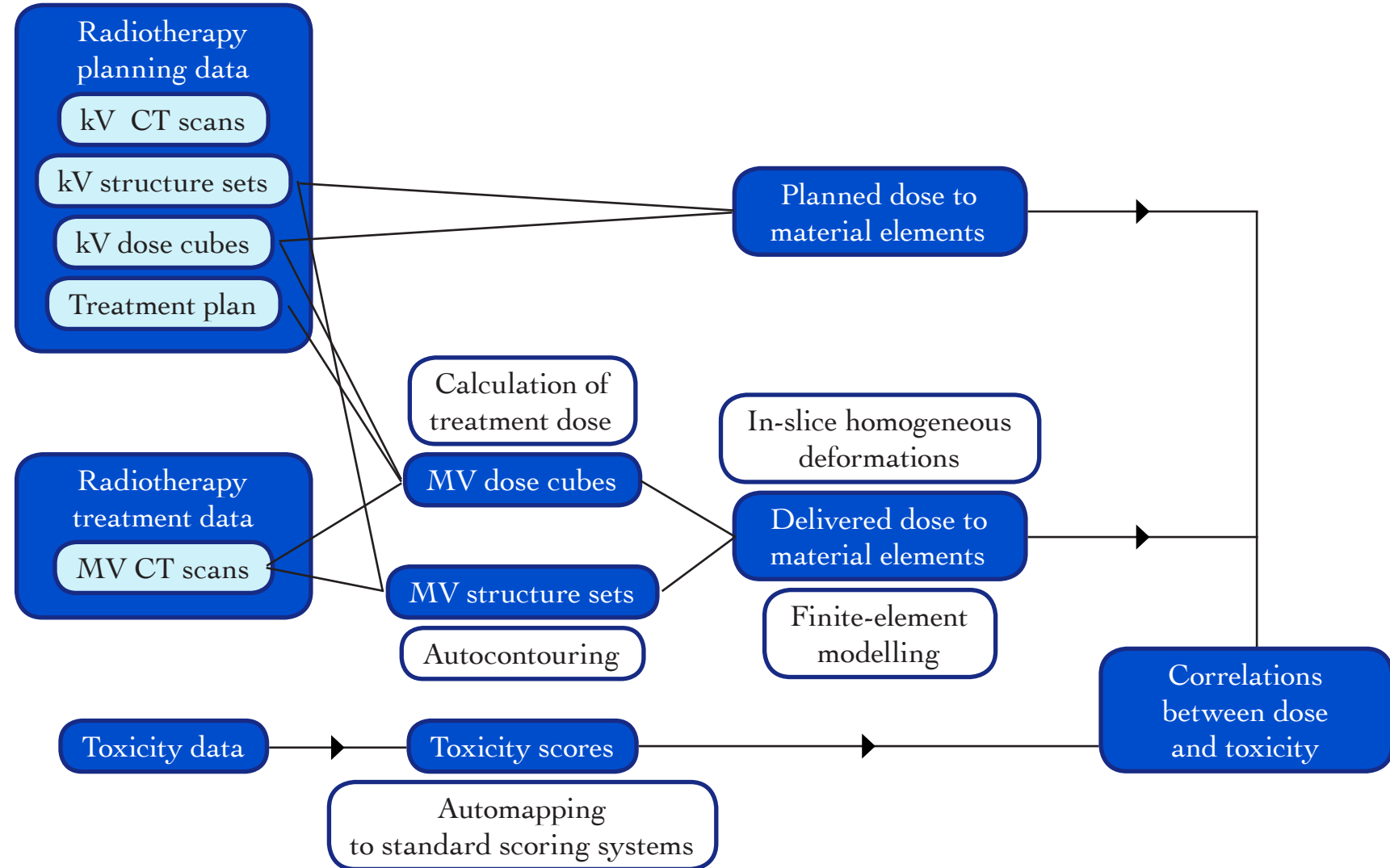
Session 15

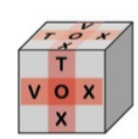
Session 30



VoxTox project

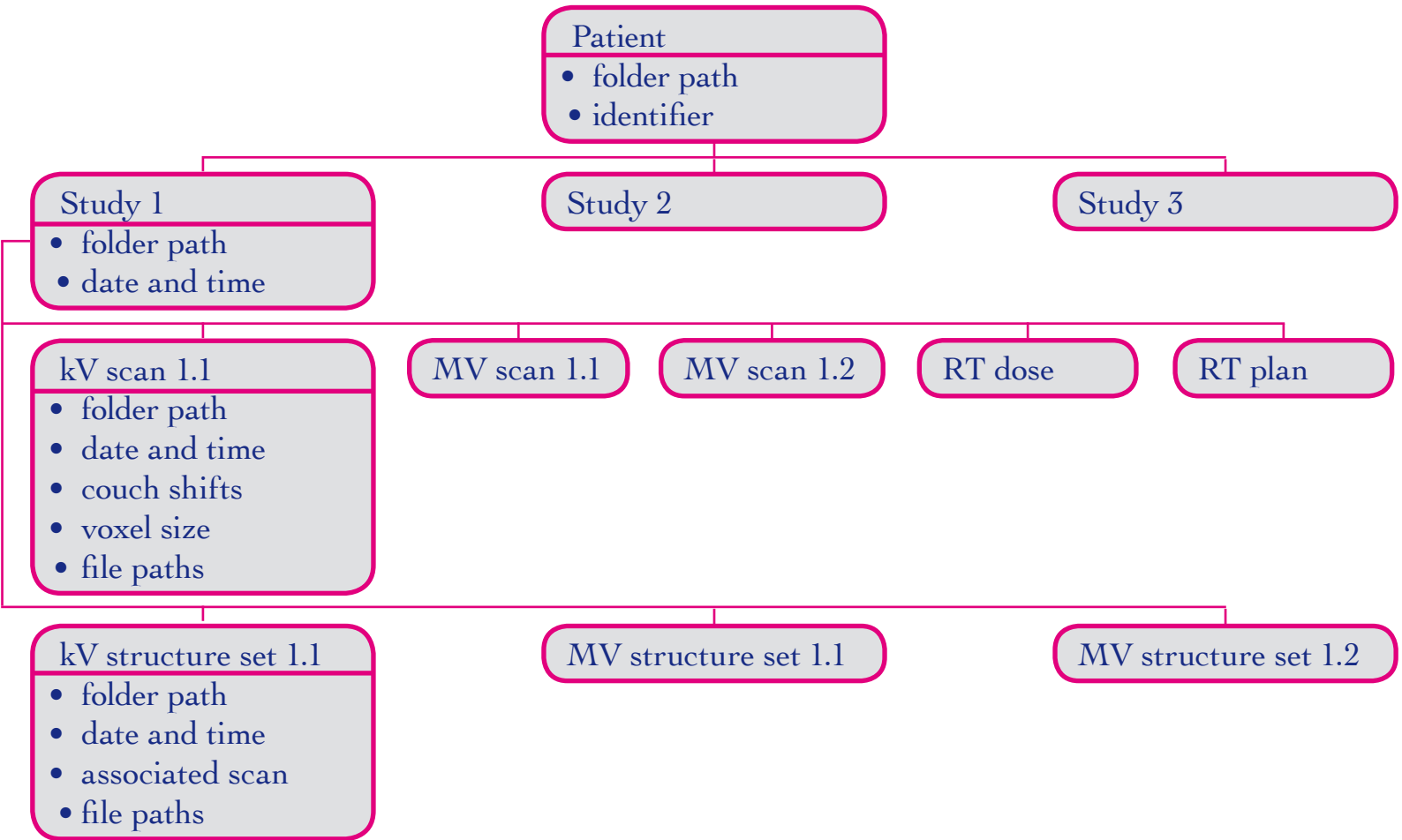
- In image-guided radiotherapy, tumour is accurately targeted at each treatment session
- Healthy organs near a tumour may move or change shape over a course of treatment
 - ▶ **Delivered dose to these organs may be different from planned**
- Cambridge-based VoxTox project, funded by Cancer Research UK, aims to measure delivered dose at the level of millimetre-scale volume elements (voxels) and to correlate with side effects (toxicity)
 - ▶ **Initial focus on patients treated for cancer of the prostate and for cancer of the head and neck**





Event data

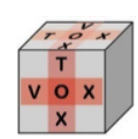
- An event in the context of radiotherapy corresponds to a patient study (investigation and treatment)
- Event data are distributed among multiple files, organised in folders
- A patient is represented by a data object that gives access to all of the patient's data



VoxTox data volumes to summer 2016

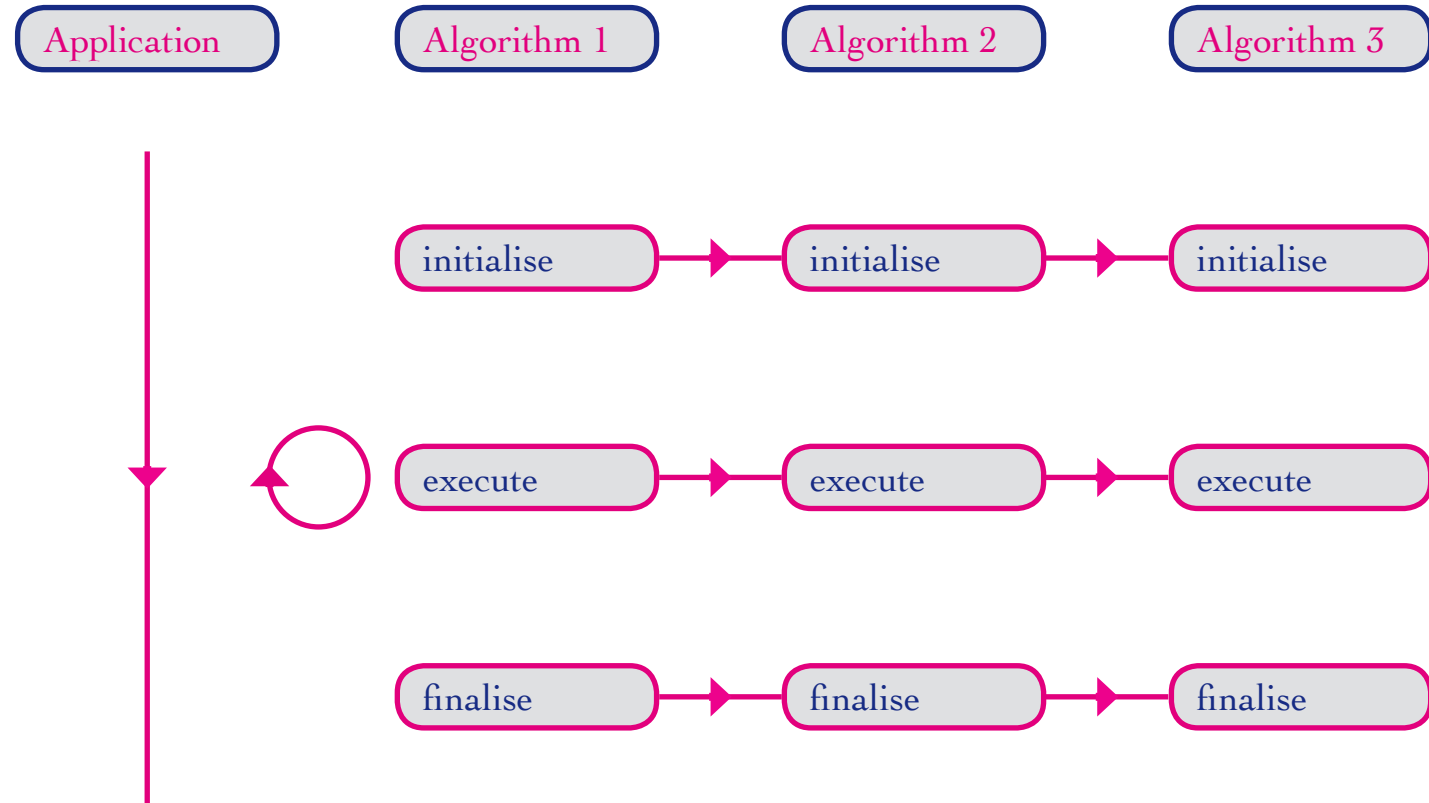
Cancer of prostate (about 230 MByte per patient)			
	Discovery	Consolidation	Total
Recruited	269	235	504
Data (GByte)	62	54	116

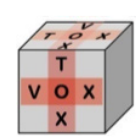
Cancer of head and neck (about 430 MByte per patient)			
	Discovery	Consolidation	Total
Recruited	96	164	260
Data (GByte)	41	71	112



Software framework

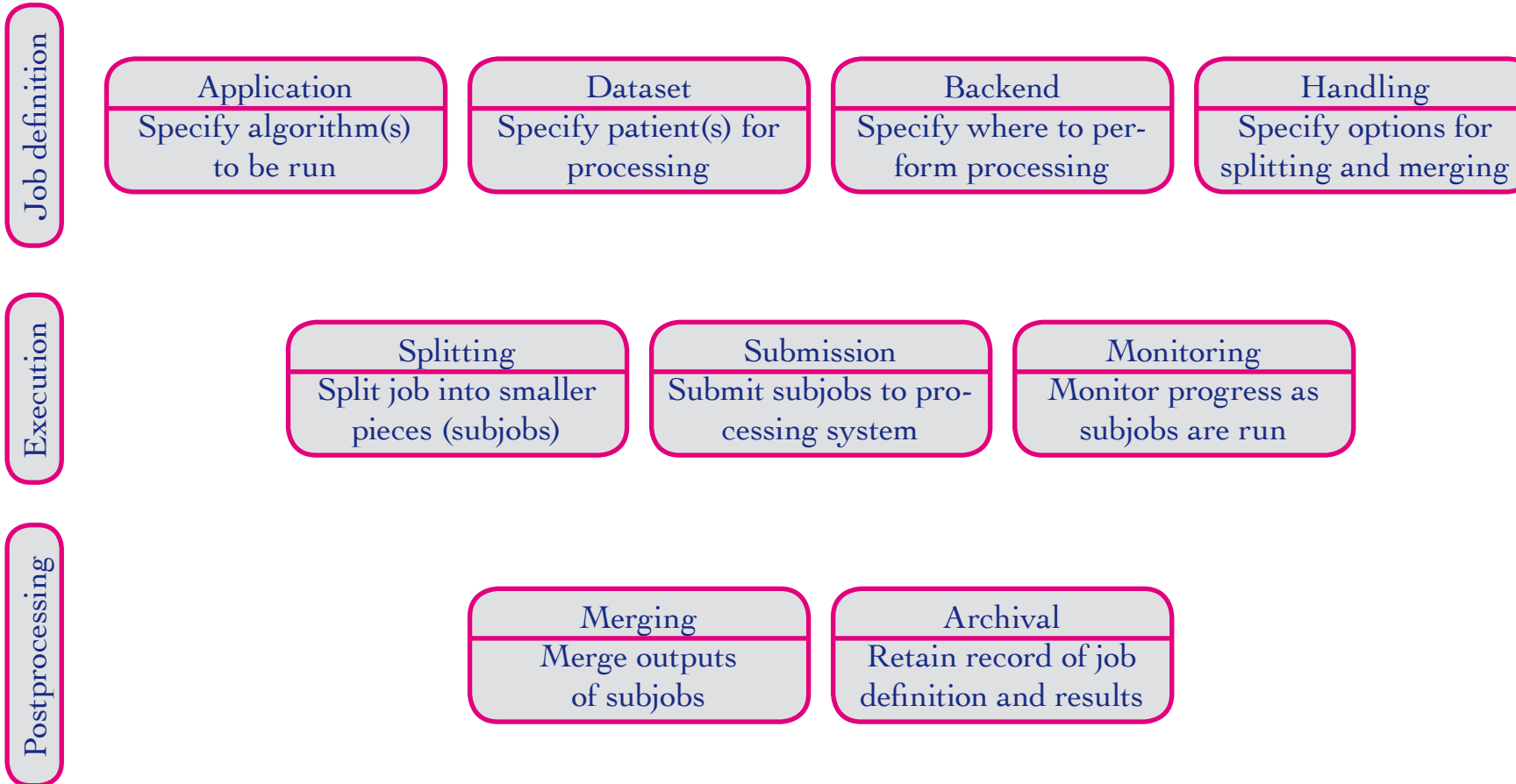
- Use Python software framework inspired by Gaudi/Athena C++ framework of ATLAS and LHCb
 - ▶ Separate data objects and processing objects
 - ▶ Provide services for common tasks
 - ▶ Pass configuration parameters at run time
- Basic processing object is an algorithm
 - ▶ Initialise, execute once for each patient, finalise
 - ▶ An algorithm may wrap non-Python code
- An application is built as a set of algorithms



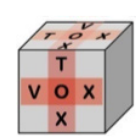


Job management

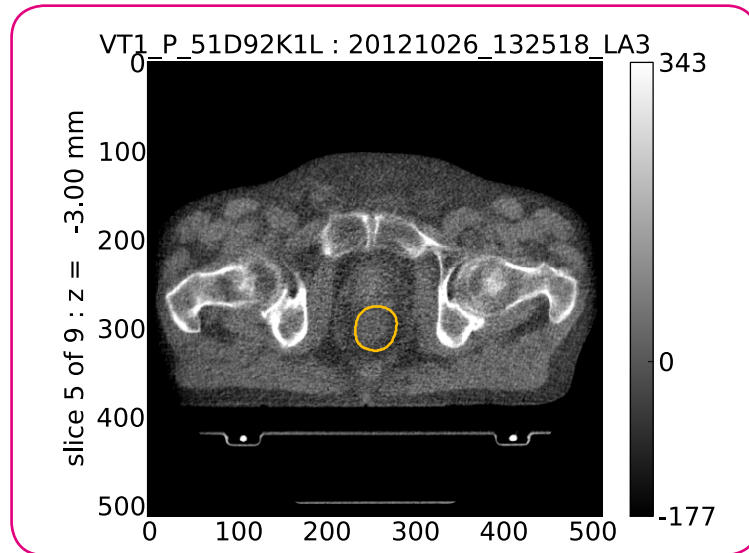
- Job management in VoxTox is performed using Ganga (Gaudi/Athena and Grid Alliance)
 - ▶ Ganga is an extensible system, developed for ATLAS and LHCb experiments
- Components developed for running VoxTox algorithms and for handling patient datasets



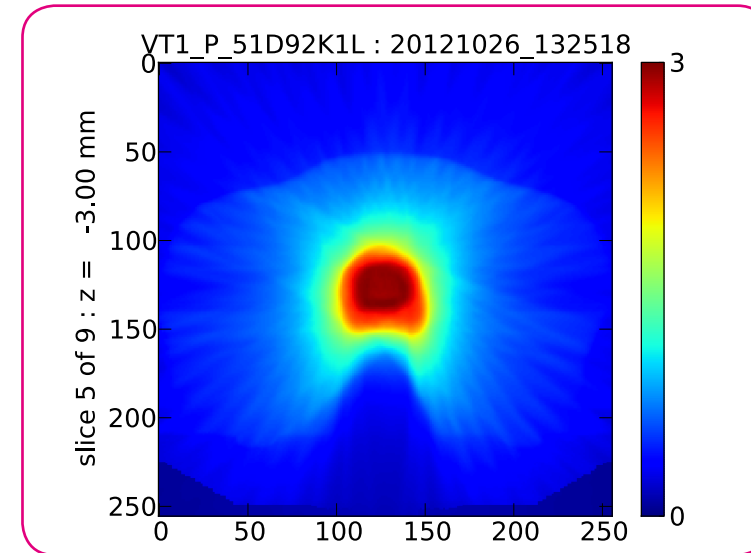
- Jobs currently run on a local HTCondor system, but could easily switch to running on Grid resources



Production tasks

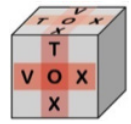


Pattern recognition: autocontouring of rectum



Calorimetry: calculation of treatment dose

- Processing time per guidance scan for patients with prostate cancer:
 - ▶ around 2 minutes for autocontouring rectum
 - ▶ around 6 hours for calculation of treatment dose
- Total processing time for all 6300 scans for set of 180 patients with prostate cancer:
 - ▶ around 210 hours for autocontouring rectum
 - ▶ around 38 000 hours (4.3 years) for calculation of treatment doses
- Processing for set of 180 patients achieved in under 3 weeks on HTCondor cluster of High-Energy Physics Group at Cavendish Laboratory, University of Cambridge
 - ▶ had 80 to 120 jobs continuously running in parallel, under Ganga control
- Processing requirements are tiny compared with LHC experiments, but are large for cancer research

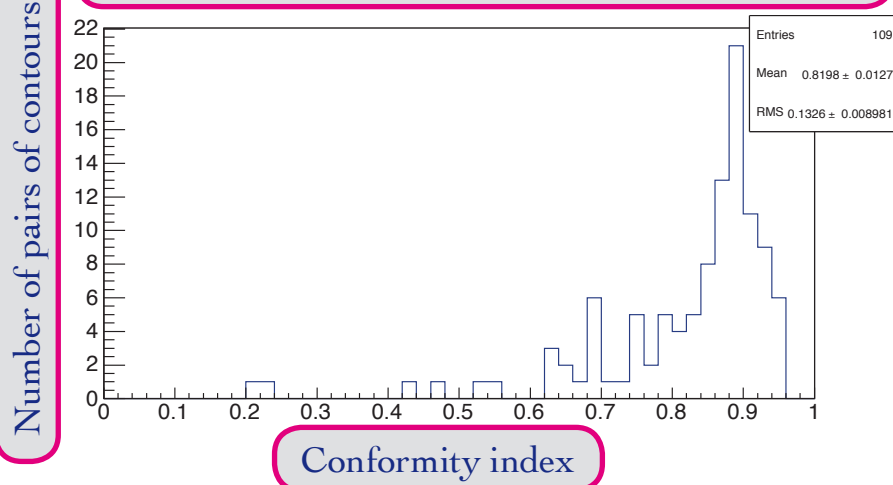


End-user analysis

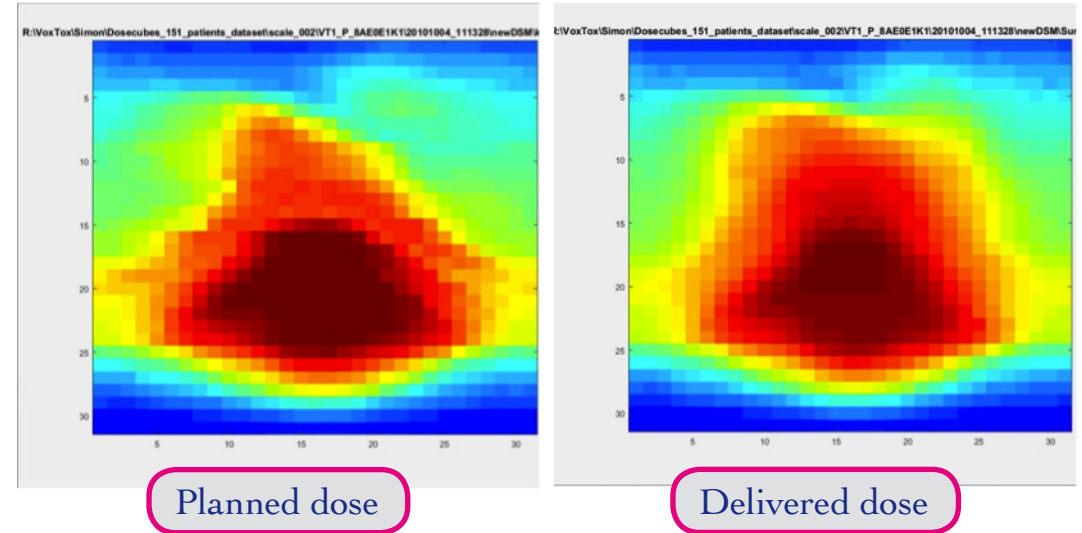
- End-user analyses developed in the VoxTox software framework, and make use of pyROOT

Work by Amelia Drew

Intra-observer variation in contouring the rectum



Dose to wall of rectum

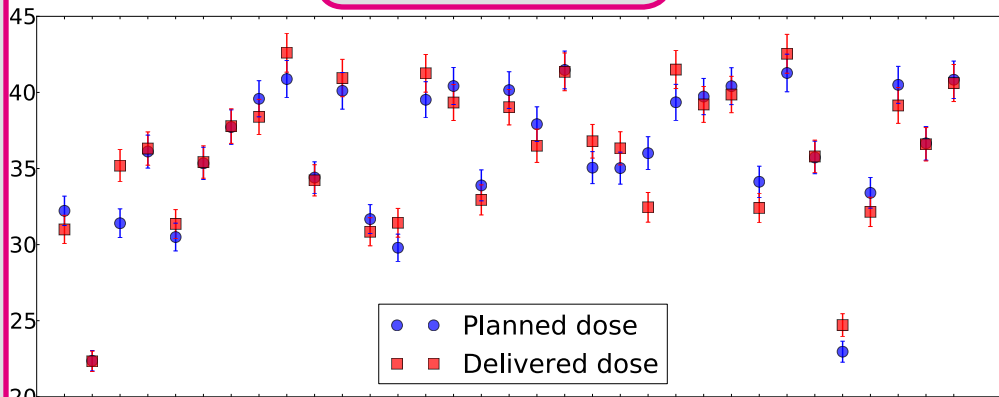


Work by Patrick Elwood

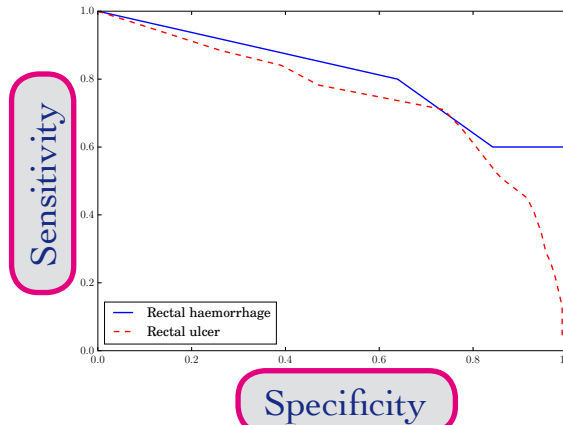
Work by Lin Yeap

Dose (Gy) for 98th percentile

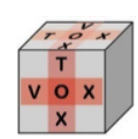
Dose to spinal cord



Machine-learning predictors of side effects to rectum



Work by Andrew Sultanta



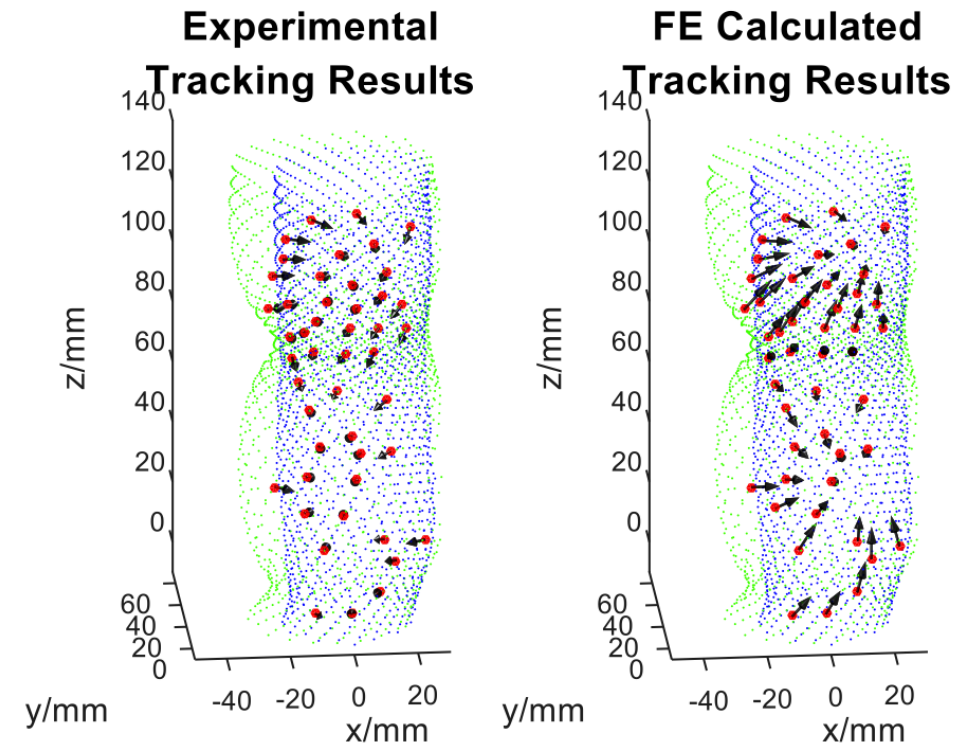
Alignment studies

- In summing doses over treatment sessions, organ changes are currently assumed to be homogeneous and contained within an axial plane
- Work is in progress to develop a more realistic model of the rectum, using finite-element methods
 - ▶ Resulting model will be wrapped as VoxTox algorithm

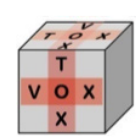
Work by Emma Silvester



Measuring point movements on physical model of rectum



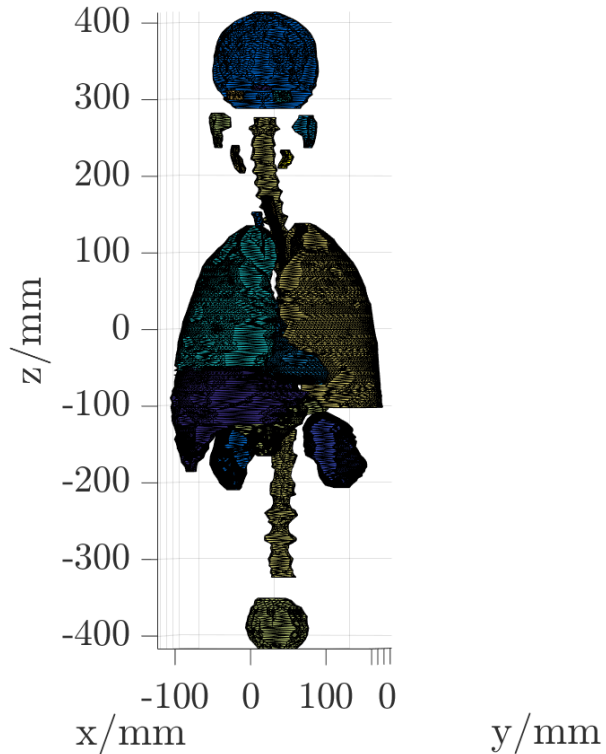
Measured point movements on physical model of rectum, and results of finite-element calculations



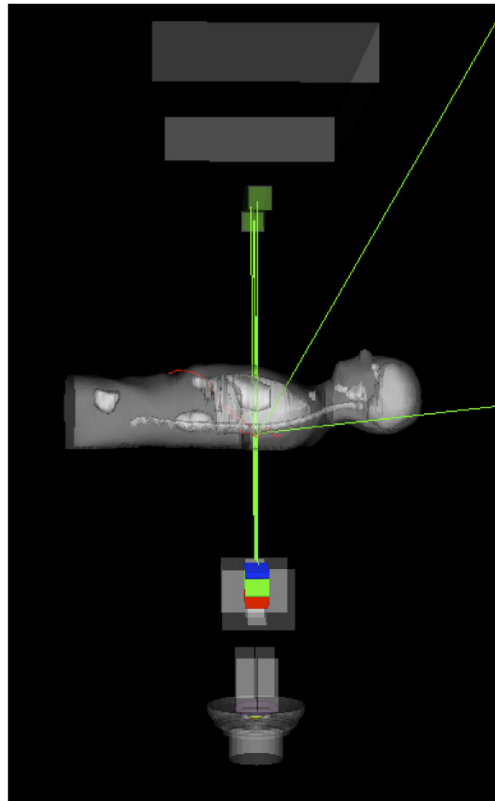
GEANT-based simulation

- Evaluations of pattern-recognition software currently based on comparing contours obtained with contours drawn manually by clinicians
 - ▶ Unsatisfactory both because statistics are low and because manually drawn contours can be unreliable
- Work started on GEANT-based simulation of treatment setup, where organ positions would be known exactly
 - ▶ Have demonstrated proof of principle

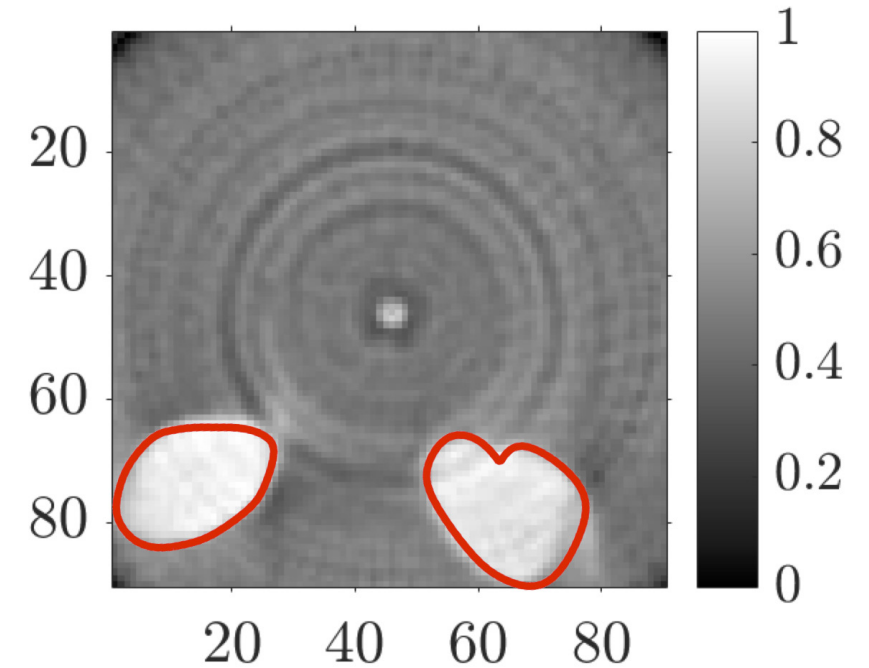
Work by Hannah Pullen



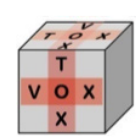
Organ geometries in GEANT



Simulated treatment setup



Simulated image of kidneys



Conclusions

- The VoxTox project aims to compute doses to healthy organs during radiotherapy treatment for cancer, and to correlate with side effects
 - ▶ Results may suggest improved treatment strategies
- Understanding doses over a course of radiotherapy is the problem of understanding energy depositions in a poorly designed calorimeter
 - ▶ Deal with components characterised by complicated and mutable geometries, large inhomogeneities, and alignment issues
- VoxTox data processing is based on computing models from particle physics
 - ▶ Use Python software framework inspired by Gaudi/Athena C++ software framework of ATLAS and LHCb
 - ▶ Use Ganga for job management
 - ▶ Use PyROOT in end-user analyses
 - ▶ Work started on GEANT-based simulation of treatment setup
- VoxTox data-processing system provides an efficient solution for current work, and would readily scale for higher-statistics studies