22/7/5
Specialised Course on
Heavy Ion Therapy
Research

Introduction to matRad

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Treatment Planning

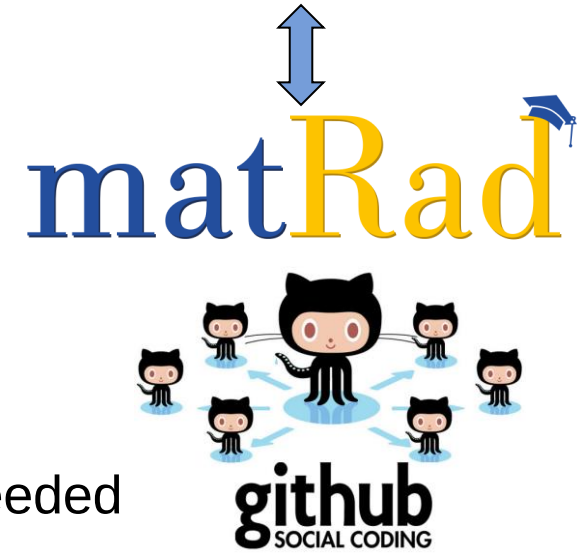
- computerized process
- dose is numerically simulated and optimized

Commercial solutions are closed systems (Black Box)		Research needs flexible, accessible software

Examples for research topics “at the core”:

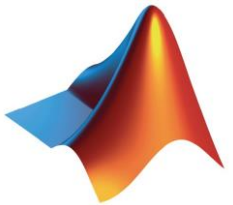
- Biological Optimization/Planning
  (RBE, effect, mixed-modality, FLASH)
- Probabilistic dose calculation & optimization

→ low-level access to dose calculation / optimization needed



What is matRad?

- toolkit for three-dimensional intensity-modulated treatment planning for photons, protons and carbon ions
- Entirely written in Matlab & open source
- matRad implements well-established radiotherapy algorithms for research & education



Properties:

- **open-source code, patients and machine files on GitHub**
- **graphical user interface**
- **Non-linear constrained dose optimization (IPOPT)**
- **Import & export functionalities (DICOM, binary formats)**
- **No Matlab? → Octave compatibility & downloadable standalone**

Why? Supporting open science, reproducibility and education

www.matrad.org

Team

GERMAN CANCER RESEARCH CENTER
IN THE HELMHOLTZ ASSOCIATION

Heidelberger Ionenstrahl-Therapiezentrum

DFG Deutsche Forschungsgemeinschaft

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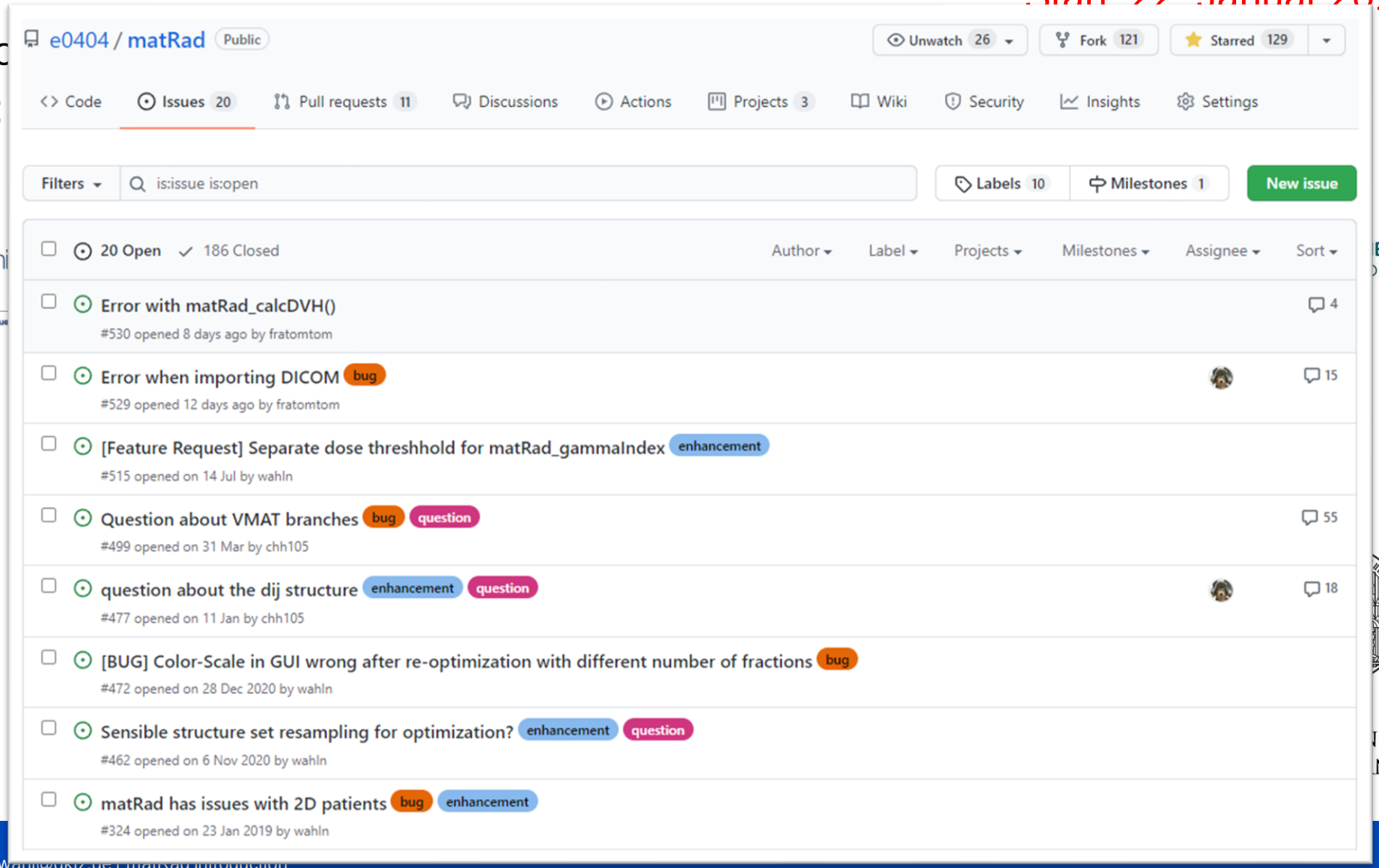
H.-P. Wieser *et al.* (all authors above in **bold**), "Development of the open-source dose calculation and optimization toolkit matRad," *Med Phys*, vol. 44, no. 6, pp. 2556–2568, 2017, doi: 10.1002/mp.12251.

All Code Contributors: https://github.com/e0404/matRad/blob/master/AUTHORS.txt

More than 25 confirmed institutes somehow working with matRad

Start: 22. Januar 2015

- Github-Fo
- Citations:



Current Release “Blaise” 2.10.1

- 3D dose calculation (validated)
  - Photons: SVD pencil-beam algorithm + sequencing
    MC interface to ompMC (open source)
  - Protons: Pencil-Beam algorithm + const. RBE
    MC interface to MCsquare (open source)
  - Carbon ions: Pencil-Beam algorithm + biol. effect / RBE
- Base data
  - Patient data (CORT data set) & DICOM Import
  - Physical (& biological) base data for photon LINAC as well as a proton and a carbon machine
- Inverse planning with new optimization interface
  - Photons: Physical dose optimization & DAO
  - Protons: + Constant RBE optimization
  - Carbon-ions: + RBE (1.1 or variable) or effect optimization
- Scripting & Graphical User Interface

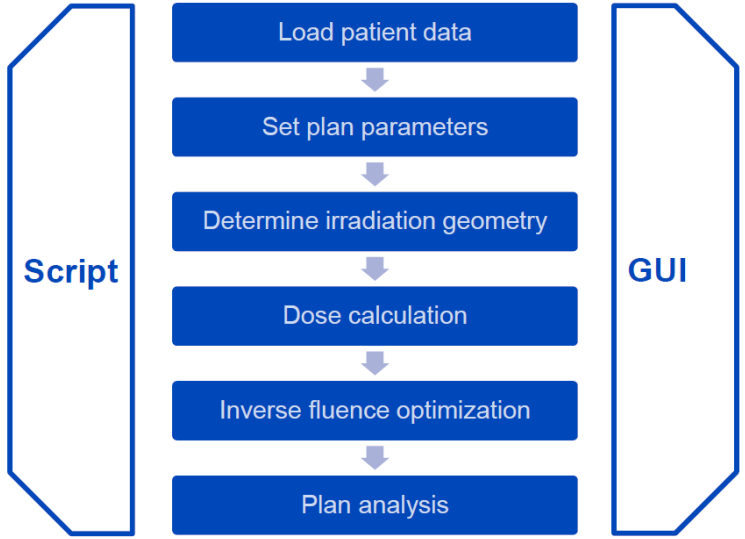
MEDICAL PHYSICS
The International Journal of Medical Physics Research and Practice

Research Article | Open Access

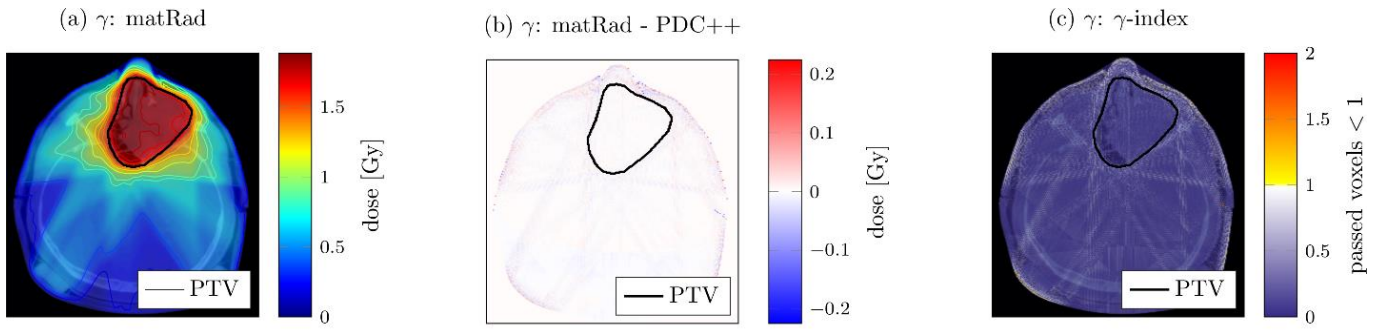
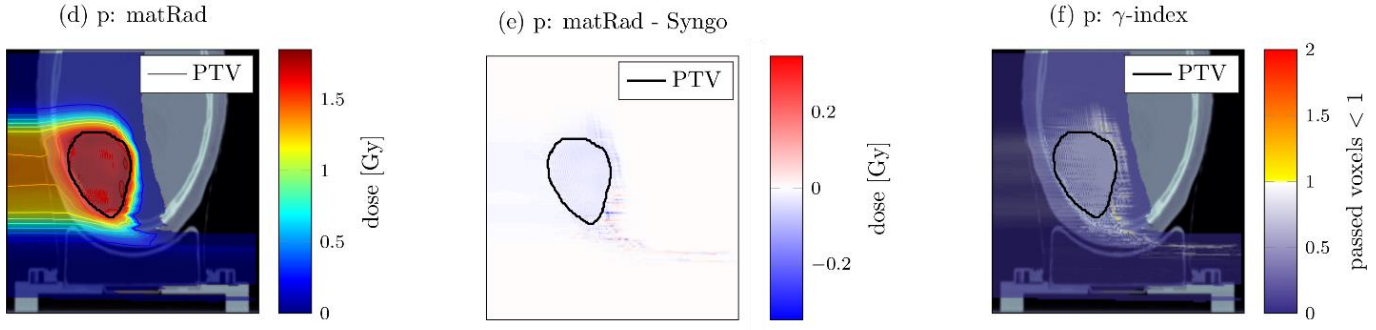
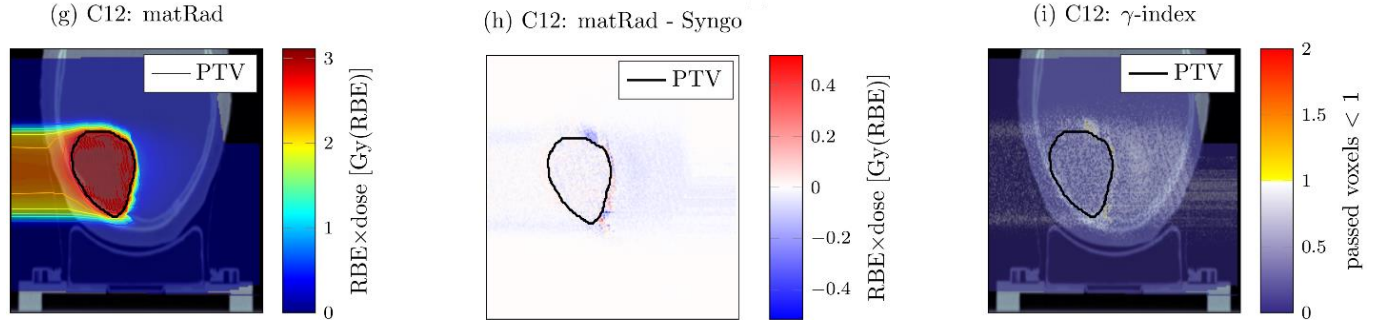
Development of the open-source dose calculation and optimization toolkit matRad

Hans-Peter Wieser, Eduardo Cisternas, Niklas Wahl, Silke Ulrich, Alexander Stadler, Henning Mescher, Lucas-Raphael Müller, Thomas Klinge, Hubert Gabrys, Lucas Burigo, Andrea Mairani, Swantje Ecker, Benjamin Ackermann, Malte Ellerbrock, Katia Parodi, Oliver Jäkel, Mark Bangert

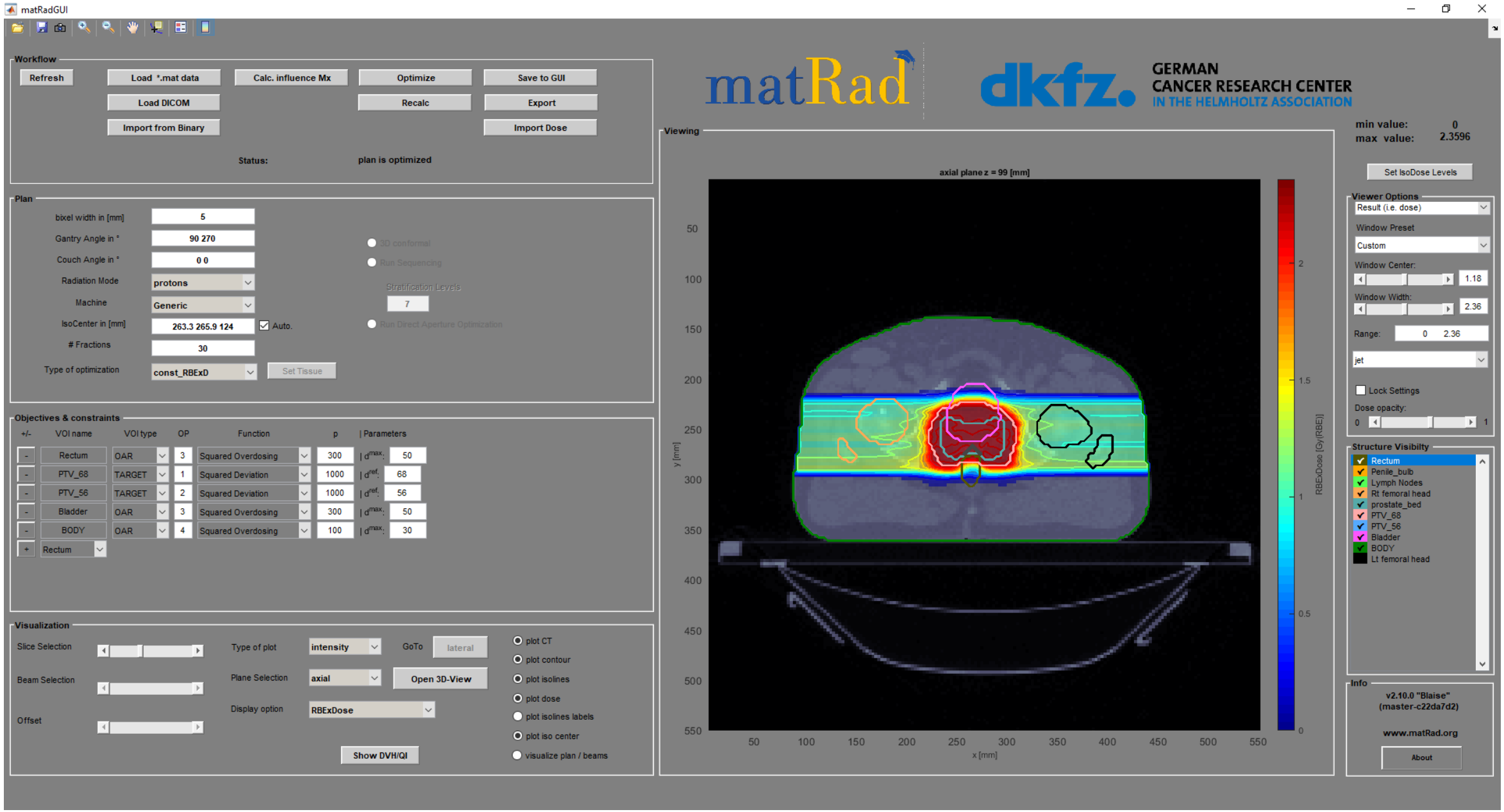
Wieser et al., 2017, Med Phys 44(6)
- among top 20 downloaded Med Phys papers in 2017 -



Validation of dose calculation

		γ–pass rate (2%/2mm)
Photons		99.82%
Protons		99.84%
Carbon ions		99.67%

Wieser et al. *"Development of the open-source dose calculation and optimization toolkit matRad."* Medical Physics (**2017**).


matRadGUI
Workflow
Refresh
Load *.mat data
Calc. influence Mx
Optimize
Save to GUI
Load DICOM
Recalc
Export
Import from Binary
Import Dose
Status:
plan is optimized
matRad
dkfz.
GERMAN CANCER RESEARCH CENTER
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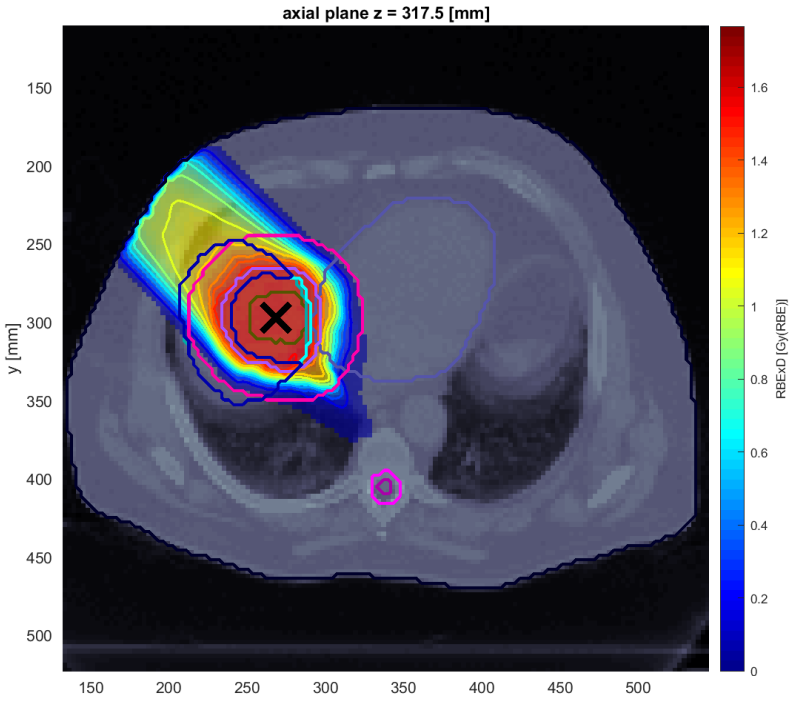
Plan
bixel width in [mm]
5
Gantry Angle in °
90 270
Couch Angle in °
0 0
Radiation Mode
protons
Machine
Generic
IsoCenter in [mm]
263.3 265.9 124
Auto.
Fractions
30
Type of optimization
const_RBExD
Set Tissue
3D conformal
Run Sequencing
Stratification Levels
7
Run Direct Aperture Optimization
Objectives & constraints
+/- VOI name VOI type OP Function p | Parameters
Rectum OAR 3 Squared Overdosing 300 | d^max: 50
PTV_68 TARGET 1 Squared Deviation 1000 | d^ref: 68
PTV_56 TARGET 2 Squared Deviation 1000 | d^ref: 56
Bladder OAR 3 Squared Overdosing 300 | d^max: 50
BODY OAR 4 Squared Overdosing 100 | d^max: 30
Visualization
Slice Selection
Beam Selection
Offset
Type of plot
intensity
GoTo
lateral
Plane Selection
axial
Open 3D-View
Display option
RBExDose
Show DVH/QI
plot CT
plot contour
plot isolines
plot dose
plot isolines labels
plot iso center
visualize plan / beams
Viewing
axial plane z = 99 [mm]
y [mm]
x [mm]
RBExDose [Gy(RBE)]
min value: 0
max value: 2.3596
Set IsoDose Levels
Viewer Options
Result (i.e. dose)
Window Preset
Custom
Window Center: 1.18
Window Width: 2.36
Range: 0 2.36
jet
Lock Settings
Dose opacity: 0 1
Structure Visibilty
Rectum
Penile_bulb
Lymph Nodes
Rt femoral head
prostate_bed
PTV_68
PTV_56
Bladder
BODY
Lt femoral head
Info
v2.10.0 "Blaise"
(master-c22da7d2)
www.matRad.org
About

Development & Research Branches

- Helium base data (physical & biological)
  `-dev_varRBErobOpt`
- Robust / probabilistic optimization & uncertainty quantification
  `-dev_varRBErobOpt`
- Variable RBE & effect for protons
  `-dev_varRBErobOpt`
- New GUI (Object-oriented & modular, Octave compatible)
  `-dev_classGUI`
- Extended MC interfaces
  `-dev_MonteCarlo`
- Superiorization
  `-research/superiorization`
- External contributions:
  - VMAT `-dev_VMAT(Eric Christiansen)`
  - optimization `-dev_exactOpt (Steven van de Water)`



Helium Plan

MATLAB

GNU Octave

GPL v3 Free Software
Free as in Freedom

GitHub

www.matrad.org

matRad

Data IO

- DICOM
- *.nrrd, *.mha, *.vtk
- CERR
- VOXELPLAN

Dose calculation

- Photons
  - SVD pencil beam
  - ompMC interface
- Particles
  - IMPT pencil beam
  - MCSquare interface
  - TOPAS interface
  - Analytical probabilistic modeling

Analysis & visualization

- GUI CT & dose distribution browser
- Dose statistics
- DVHs

Dose optimization

- Fluence and experimental direct aperture optimization
- IPOPT https://projects.coin-or.org/Ipopt
- Matlab's proprietary fmincon
- Superiorization
- Objectives: Quad. dose deviation, mean dose, EUD, DVH
- Constraints: Min, max, mean dose, EUD, DVH
- Xia, Engel, Siochi MLC sequencer
- Robust and stochastic optimization
- Variable RBE optimization for protons
- Coverage based optimization
- Analytical probabilistic modeling
- VMAT

Base data

- Patient data (CT & RTSS)
- Photon pencil beam base data
  → https://github.com/e0404/photonPencilBeamKernelCalc
- Generic proton and carbon ion pencil beam base data
- Carbon ion biological base data (LEM IV)
- Helium pencil beam base data
- Helium biological model

Thank you for your attention!

Features in blue are available on development branches

Exercise to hand in:

- Choose one of the datasets:
  BOXPHANTOM, TG119, LIVER, HEAD_AND_NECK, PROSTATE

- Compare the three modalities in matRad
  → Export dose slices and dose-volume histograms (DVH)

  - Create a multi-beam IMRT photon plan (5-9 beams)

  - Create a proton IMPT plan (1-3 beams)

  - Create a carbon ion plan (1-2 beams)