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# Example: Photon Treatment Plan

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%%%

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%%%

In this example we will show (i) how to load patient data into matRad (ii) how to setup a photon dose calculation and (iii) how to inversely optimize beamlet intensities (iv) how to visually and quantitatively evaluate the result

## Patient Data Import

Let's begin with a clear Matlab environment. Then, import the TG119 phantom into your workspace. The phantom is comprised of a 'ct' and 'cst' structure defining the CT images and the structure set. Make sure the matRad root directory with all its subdirectories is added to the Matlab search path.

```
clc,clear,close all;  
load('TG119.mat');
```

The file TG119.mat contains two Matlab variables. Let's check what we have just imported. First, the 'ct' variable comprises the ct cube along

```
%with some meta information describing properties of the ct cube (cube  
% dimensions, resolution, number of CT scenarios). Please note that  
%multiple ct cubes (e.g. 4D CT) can be stored in the cell array  
ct.cube{}  
display(ct);
```

```
ct =
```

```

struct with fields:

    cube: {[167×167×129 double]}
    resolution: [1×1 struct]
        x: [1×167 double]
        y: [1×167 double]
        z: [1×129 double]
    cubeDim: [167 167 129]
    numOfCtScen: 1
    dicomInfo: [1×1 struct]
    dicomMeta: [1×1 struct]
    timeStamp: '22-Jan-2018 14:17:42'
    cubeHU: {[167×167×129 double]}
    hlut: [6×2 double]

```

The 'cst' cell array defines volumes of interests along with information required for optimization. Each row belongs to one certain volume of interest (VOI), whereas each column defines different properties. Specifically, the second and third column show the name and the type of the structure. The type can be set to OAR, TARGET or IGNORED. The fourth column contains a linear index vector that lists all voxels belonging to a certain VOI.

```
display(cst);
```

```
cst =
```

```
3×6 cell array
```

```
Columns 1 through 5
```

```

    {[0]}    {'Core'          }    {'OAR'    }    {1×1 cell}    {1×1
struct}
    {[1]}    {'OuterTarget' }    {'TARGET' }    {1×1 cell}    {1×1
struct}
    {[2]}    {'BODY'          }    {'OAR'    }    {1×1 cell}    {1×1
struct}

```

```
Column 6
```

```

    {1×1 struct}
    {1×1 struct}
    {1×1 struct}

```

The fifth column represents meta parameters for optimization. The overlap priority is used to resolve ambiguities of overlapping structures (voxels belonging to multiple structures will only be assigned to the VOI(s) with the highest overlap priority, i.e.. the lowest value). The parameters alphaX and betaX correspond to the tissue's photon-radiosensitivity parameter of the linear quadratic model. These parameter are required for biological treatment planning using a variable RBE. Let's output the meta optimization parameter of the target, which is stored in the third row:

```

ixTarget = 3;
display(cst{ixTarget,5});

```

```

Priority: 3
alphaX: 0.1000000000000000
betaX: 0.0500000000000000
Visible: 1
visibleColor: [0.666666666666667 0 1]

```

The sixth column contains optimization information such as objectives and constraints which are required to calculate the objective function value. Please note, that multiple objectives/constraints can be defined for individual structures. Here, we have defined a squared deviation objective making it 'expensive/costly' for the optimizer to over- and underdose the target structure (both are equally important).

```

display(cst{ixTarget,6});

type: 'square overdosing'
dose: 30
penalty: 100
EUD: NaN
volume: NaN
robustness: 'none'

```

## Treatment Plan

The next step is to define your treatment plan labeled as 'pln'. This matlab structure requires input from the treatment planner and defines the most important cornerstones of your treatment plan.

First of all, we need to define what kind of radiation modality we would like to use. Possible values are photons, protons or carbon. In this case we want to use photons. Then, we need to define a treatment machine to correctly load the corresponding base data. matRad includes base data for generic photon linear accelerator called 'Generic'. By this means matRad will look for 'photons\_Generic.mat' in our root directory and will use the data provided in there for dose calculation

```

pln.radiationMode = 'photons';
pln.machine       = 'Generic';

```

Define the flavor of optimization along with the quantity that should be used for optimization. Possible values are (none): physical optimization; const\_RBExD: constant RBE of 1.1; LEMIV\_effect: effect-based optimization; LEMIV\_RBExD: optimization of RBE-weighted dose. As we are using photons, we simply set the parameter to 'none' thereby indicating the physical dose should be optimized.

```

pln.propOpt.bioOptimization = 'none';

```

Now we have to set some beam parameters. We can define multiple beam angles for the treatment and pass these to the plan as a vector. matRad will then interpret the vector as multiple beams. In this case, we define linear spaced beams from 0 degree to 359 degree in 40 degree steps. This results in 9 beams. All corresponding couch angles are set to 0 at this point. Moreover, we set the bixelWidth to 5, which results in a beamlet size of 5 x 5 mm in the isocenter plane. The number of fractions is set to 30. Internally, matRad considers the fraction dose for optimization, however, objectives and constraints are defined for the entire treatment.

```

pln.numOfFractions      = 30;
pln.propStf.gantryAngles = [0:40:359];
pln.propStf.couchAngles  = zeros(1,numel(pln.propStf.gantryAngles));
pln.propStf.bixelWidth   = 5;

```

Obtain the number of beams and voxels from the existing variables and calculate the iso-center which is per default the center of gravity of all target voxels.

```
pln.propStf.numOfBeams      = numel(pln.propStf.gantryAngles);
pln.propStf.isoCenter       = ones(pln.propStf.numOfBeams,1) *
    matRad_getIsoCenter(ct,ct,0);
```

Enable sequencing and disable direct aperture optimization (DAO) for now. A DAO optimization is shown in a separate example.

```
pln.propOpt.runSequencing = 1;
pln.propOpt.runDAO        = 0;
```

and et voila our treatment plan structure is ready. Lets have a look:

```
display(pln);
```

```
pln =
```

```
struct with fields:

    radiationMode: 'photons'
    machine: 'Generic'
    propOpt: [1x1 struct]
    numOfFractions: 30
    propStf: [1x1 struct]
```

## Generate Beam Geometry STF

The steering file struct comprises the complete beam geometry along with ray position, pencil beam positions and energies, source to axis distance (SAD) etc.

```
stf = matRad_generateStf(ct,cst,pln);
```

```
matRad: Generating stf struct... Progress: 100.00 %
```

Let's display the beam geometry information of the 6th beam

```
display(stf(6));
```

```
    gantryAngle: 200
    couchAngle: 0
    bixelWidth: 5
    radiationMode: 'photons'
    SAD: 1000
    isoCenter: [1x3 double]
    numOfRays: 306
    ray: [1x306 struct]
    sourcePoint_bev: [0 -1000 0]
    sourcePoint: [-3.420201433256687e+02 9.396926207859084e+02
0]
    numOfBixelsPerRay: [1x306 double]
    totalNumOfBixels: 306
```

# Dose Calculation

Let's generate dosimetric information by pre-computing dose influence matrices for unit beamlet intensities. Having dose influences available allows subsequent inverse optimization.

```
dij = matRad_calcPhotonDose(ct,stf,pln,cst);

matRad: Photon dose calculation...
Beam 1 of 9:
matRad: calculate radiological depth cube...done
      SSD = 939mm
matRad: Uniform primary photon fluence -> pre-compute kernel
convolution for SSD = 939 mm ...
Progress: 100.00 %
Beam 2 of 9:
matRad: calculate radiological depth cube...done
      SSD = 920mm
matRad: Uniform primary photon fluence -> pre-compute kernel
convolution for SSD = 920 mm ...
Progress: 100.00 %
Beam 3 of 9:
matRad: calculate radiological depth cube...done
      SSD = 849mm
matRad: Uniform primary photon fluence -> pre-compute kernel
convolution for SSD = 849 mm ...
Progress: 100.00 %
Beam 4 of 9:
matRad: calculate radiological depth cube...done
      SSD = 828mm
matRad: Uniform primary photon fluence -> pre-compute kernel
convolution for SSD = 828 mm ...
Progress: 100.00 %
Beam 5 of 9:
matRad: calculate radiological depth cube...done
      SSD = 902mm
matRad: Uniform primary photon fluence -> pre-compute kernel
convolution for SSD = 902 mm ...
Progress: 100.00 %
Beam 6 of 9:
matRad: calculate radiological depth cube...done
      SSD = 902mm
matRad: Uniform primary photon fluence -> pre-compute kernel
convolution for SSD = 902 mm ...
Progress: 100.00 %
Beam 7 of 9:
matRad: calculate radiological depth cube...done
      SSD = 826mm
matRad: Uniform primary photon fluence -> pre-compute kernel
convolution for SSD = 826 mm ...
Progress: 100.00 %
Beam 8 of 9:
matRad: calculate radiological depth cube...done
      SSD = 847mm
```

```
matRad: Uniform primary photon fluence -> pre-compute kernel
convolution for SSD = 847 mm ...
Progress: 100.00 %
Beam 9 of 9:
matRad: calculate radiological depth cube...done
SSD = 920mm
matRad: Uniform primary photon fluence -> pre-compute kernel
convolution for SSD = 920 mm ...
Progress: 100.00 %
```

## Inverse Optimization for IMRT

The goal of the fluence optimization is to find a set of beamlet/pencil beam weights which yield the best possible dose distribution according to the clinical objectives and constraints underlying the radiation treatment. Once the optimization has finished, trigger once the GUI to visualize the optimized dose cubes.

```
resultGUI = matRad_fluenceOptimization(dij,cst,pln);
matRadGUI;
```

```
*****
This program contains Ipopt, a library for large-scale nonlinear
optimization.
Ipopt is released as open source code under the Eclipse Public
License (EPL).
For more information visit http://projects.coin-or.org/Ipopt
*****
```

```
This is Ipopt version 3.12.4, running with linear solver ma57.
```

```
Number of nonzeros in equality constraint Jacobian...:      0
Number of nonzeros in inequality constraint Jacobian.:      0
Number of nonzeros in Lagrangian Hessian.....:          0
```

```
Total number of variables.....:      2492
      variables with only lower bounds:      2492
      variables with lower and upper bounds:      0
      variables with only upper bounds:      0
Total number of equality constraints.....:      0
Total number of inequality constraints.....:      0
      inequality constraints with only lower bounds:      0
      inequality constraints with lower and upper bounds:      0
      inequality constraints with only upper bounds:      0
```

iter	objective	inf_pr	inf_du	lg(mu)	d	lg(rg)	alpha_du
0	1.7996997e+02	0.00e+00	5.68e+00	0.0	0.00e+00	-	0.00e+00
1	8.0783990e+01	0.00e+00	4.75e+00	-0.3	9.95e-01	-	9.89e-01
2	7.9945650e+01	0.00e+00	4.22e+00	-6.6	1.41e-01	-	1.00e+00
3	1.3595271e+01	0.00e+00	1.22e+00	-1.6	7.39e-02	-	9.99e-01

# Example: Photon Treatment Plan

4	1.0393560e+01	0.00e+00	6.74e-01	-2.5	1.75e-02	-	1.00e+00
1.00e+00f	1						
5	4.3987490e+00	0.00e+00	4.23e-01	-2.8	8.23e-02	-	1.00e+00
1.00e+00f	1						
6	3.1831236e+00	0.00e+00	6.17e-01	-3.6	5.77e-02	-	1.00e+00
1.00e+00f	1						
7	2.2534036e+00	0.00e+00	2.10e-01	-4.6	1.60e-02	-	1.00e+00
1.00e+00f	1						
8	2.0008723e+00	0.00e+00	1.33e-01	-5.9	1.98e-02	-	1.00e+00
8.49e-01f	1						
9	1.9741574e+00	0.00e+00	1.78e-01	-7.2	2.17e-02	-	1.00e+00
9.94e-02f	1						
iter	objective	inf_pr	inf_du	lg(mu)	d	lg(rg)	alpha_du
alpha_pr	ls						
10	1.8148399e+00	0.00e+00	1.43e-01	-7.4	4.96e-02	-	1.00e+00
2.45e-01f	1						
11	1.7076658e+00	0.00e+00	1.54e-01	-6.7	6.94e-02	-	1.00e+00
1.23e-01f	1						
12	1.5722397e+00	0.00e+00	3.06e-01	-4.1	7.32e-02	-	8.87e-01
1.56e-01f	1						
13	1.4483313e+00	0.00e+00	1.61e-01	-4.6	6.92e-02	-	1.00e+00
1.61e-01f	1						
14	1.2443981e+00	0.00e+00	3.12e-01	-3.2	7.28e-02	-	9.95e-01
3.61e-01f	1						
15	1.1799846e+00	0.00e+00	7.86e-01	-2.7	6.42e-02	-	8.04e-01
1.00e+00f	1						
16	1.0632856e+00	0.00e+00	6.81e-02	-3.8	2.94e-02	-	9.23e-01
1.00e+00f	1						
17	1.0085089e+00	0.00e+00	8.19e-02	-5.0	2.30e-02	-	1.00e+00
1.00e+00f	1						
18	9.9143746e-01	0.00e+00	6.33e-02	-6.2	1.94e-02	-	1.00e+00
3.12e-01f	1						
19	9.6031477e-01	0.00e+00	3.59e-02	-7.4	2.46e-02	-	1.00e+00
5.14e-01f	1						
iter	objective	inf_pr	inf_du	lg(mu)	d	lg(rg)	alpha_du
alpha_pr	ls						
20	9.5428047e-01	0.00e+00	1.02e-01	-5.0	1.41e-02	-	1.00e+00
1.37e-01f	1						
21	9.3629265e-01	0.00e+00	9.52e-02	-4.3	1.71e-02	-	7.12e-01
4.73e-01f	1						
22	9.1070646e-01	0.00e+00	6.32e-02	-4.6	1.85e-02	-	1.00e+00
8.06e-01f	1						
23	9.0263193e-01	0.00e+00	7.96e-02	-6.1	2.63e-02	-	6.68e-01
3.48e-01f	2						
24	8.9118702e-01	0.00e+00	5.63e-02	-4.0	7.44e-03	-	1.00e+00
1.00e+00f	1						
25	8.8173012e-01	0.00e+00	2.45e-02	-4.3	4.82e-03	-	8.97e-01
1.00e+00f	1						
26	8.7084310e-01	0.00e+00	3.43e-02	-4.6	6.78e-03	-	1.00e+00
1.00e+00f	1						
27	8.5989489e-01	0.00e+00	3.86e-02	-5.5	1.31e-02	-	1.00e+00
6.07e-01f	1						
28	8.5247425e-01	0.00e+00	5.38e-02	-6.1	2.24e-02	-	1.00e+00
2.40e-01f	1						

```

29  8.5390251e-01 0.00e+00 4.97e-02 -4.0 6.42e-03 - 9.85e-01
1.00e+00f 1
iter   objective   inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
30  8.4056217e-01 0.00e+00 2.41e-02 -4.1 8.82e-03 - 9.42e-01
1.00e+00f 1
31  8.2919724e-01 0.00e+00 3.44e-02 -4.8 1.33e-02 - 1.00e+00
5.23e-01f 1
32  8.1250480e-01 0.00e+00 1.20e-01 -5.4 2.08e-02 - 1.00e+00
5.78e-01f 1
33  8.0601220e-01 0.00e+00 2.90e-02 -4.7 1.49e-02 - 8.45e-01
3.48e-01f 1
34  8.0189614e-01 0.00e+00 5.49e-02 -5.4 1.28e-02 - 3.95e-01
2.56e-01f 1
35  7.9357978e-01 0.00e+00 5.34e-02 -5.2 1.95e-02 - 6.72e-01
3.84e-01f 1
36  7.8579310e-01 0.00e+00 1.64e-01 -4.5 2.61e-02 - 7.62e-01
7.63e-01f 1
37  7.8435636e-01 0.00e+00 5.80e-02 -10.6 8.03e-03 - 7.78e-01
1.73e-01f 1
38  7.7892439e-01 0.00e+00 3.29e-02 -4.9 1.34e-02 - 6.98e-01
4.18e-01f 1
39  7.7222432e-01 0.00e+00 5.00e-02 -5.0 1.44e-02 - 8.11e-01
5.24e-01f 1
iter   objective   inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
40  8.8485761e-01 0.00e+00 2.45e-01 -3.6 5.13e-02 - 7.37e-01
1.00e+00f 1
41  8.2647938e-01 0.00e+00 6.94e-02 -3.6 2.18e-02 - 1.00e+00
1.00e+00f 1
42  7.9616649e-01 0.00e+00 4.67e-02 -3.6 1.39e-02 - 1.00e+00
1.00e+00f 1
43  7.9174019e-01 0.00e+00 3.94e-02 -3.6 2.94e-03 - 1.00e+00
1.00e+00f 1
44  7.8636824e-01 0.00e+00 2.79e-02 -3.6 5.15e-03 - 1.00e+00
1.00e+00f 1
45  7.8292399e-01 0.00e+00 3.44e-02 -3.6 9.83e-03 - 1.00e+00
1.00e+00f 1
46  7.8402401e-01 0.00e+00 5.19e-02 -3.6 1.33e-02 - 1.00e+00
1.00e+00f 1
47  7.8070050e-01 0.00e+00 2.69e-02 -3.6 1.88e-03 - 1.00e+00
1.00e+00f 1
48  7.7858685e-01 0.00e+00 2.51e-02 -3.6 3.34e-03 - 1.00e+00
1.00e+00f 1
49  7.7631282e-01 0.00e+00 2.77e-02 -3.6 6.23e-03 - 1.00e+00
1.00e+00f 1
iter   objective   inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
50  7.7054562e-01 0.00e+00 3.30e-02 -3.6 1.57e-02 - 1.00e+00
1.00e+00f 1
51  7.6248182e-01 0.00e+00 2.28e-02 -4.5 1.25e-02 - 1.00e+00
1.00e+00f 1
52  7.5475025e-01 0.00e+00 2.22e-02 -6.0 6.05e-03 - 1.00e+00
1.00e+00f 1

```



# Example: Photon Treatment Plan

```

53  7.4769198e-01 0.00e+00 2.74e-02 -7.3 9.44e-03 - 1.00e+00
1.00e+00f 1
54  7.4416209e-01 0.00e+00 2.58e-02 -8.7 1.85e-02 - 1.00e+00
2.29e-01f 1
55  7.4391296e-01 0.00e+00 1.41e-01 -9.4 5.24e-03 - 1.00e+00
2.34e-02f 1
56  7.3896881e-01 0.00e+00 7.20e-02 -9.7 1.38e-02 - 1.00e+00
1.91e-01f 1
57  7.3588846e-01 0.00e+00 7.98e-02 -9.8 1.95e-02 - 1.00e+00
9.32e-02f 1
58  7.3264304e-01 0.00e+00 6.16e-02 -5.4 2.09e-02 - 2.77e-01
8.73e-02f 1
59  7.3012303e-01 0.00e+00 1.54e-01 -6.1 2.55e-02 - 1.00e+00
6.36e-02f 1
iter   objective   inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
60  7.1940623e-01 0.00e+00 5.50e-02 -4.3 2.35e-02 - 7.25e-01
3.49e-01f 1
61  7.1399077e-01 0.00e+00 1.14e-01 -4.2 4.59e-03 - 1.00e+00
1.00e+00f 1
62  7.1053666e-01 0.00e+00 2.18e-02 -4.2 3.02e-03 - 7.83e-01
1.00e+00f 1
63  7.0613246e-01 0.00e+00 1.69e-02 -4.4 5.04e-03 - 1.00e+00
1.00e+00f 1
64  6.9931423e-01 0.00e+00 2.16e-02 -5.5 1.31e-02 - 1.00e+00
5.74e-01f 1
65  6.9589265e-01 0.00e+00 5.58e-02 -6.5 1.22e-02 - 1.00e+00
2.84e-01f 1
66  6.9100265e-01 0.00e+00 3.82e-02 -6.3 1.46e-02 - 1.00e+00
3.88e-01f 1
67  6.8799495e-01 0.00e+00 4.23e-02 -7.3 1.95e-02 - 1.00e+00
2.14e-01f 1
68  6.8637718e-01 0.00e+00 5.48e-02 -5.8 1.23e-02 - 7.21e-01
1.88e-01f 1
69  6.8402532e-01 0.00e+00 4.99e-02 -5.9 2.02e-02 - 1.00e+00
1.58e-01f 1
iter   objective   inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
70  6.8206089e-01 0.00e+00 7.74e-02 -5.4 2.01e-02 - 6.88e-01
1.35e-01f 1
71  6.8011511e-01 0.00e+00 4.39e-02 -6.0 1.99e-02 - 4.20e-01
1.32e-01f 1
72  6.7619244e-01 0.00e+00 4.88e-02 -5.1 2.97e-02 - 9.78e-01
1.97e-01f 1
73  6.7479987e-01 0.00e+00 6.68e-02 -6.8 1.84e-02 - 4.35e-01
1.06e-01f 1
74  6.7074493e-01 0.00e+00 5.12e-02 -5.5 3.07e-02 - 9.31e-01
1.94e-01f 1
75  6.6797487e-01 0.00e+00 1.16e-01 -4.6 3.08e-02 - 4.41e-01
2.01e-01f 1
76  6.6508264e-01 0.00e+00 7.50e-02 -5.4 2.19e-02 - 6.25e-01
2.14e-01f 1
77  6.6301956e-01 0.00e+00 6.91e-02 -4.6 1.94e-02 - 6.31e-01
1.91e-01f 1

```

```

78  6.5843903e-01 0.00e+00 5.54e-02 -4.5 2.35e-02 - 6.68e-01
4.23e-01f 1
79  6.5533225e-01 0.00e+00 3.66e-02 -5.3 2.50e-02 - 7.55e-01
2.61e-01f 1
iter  objective      inf_pr  inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
80  6.5316788e-01 0.00e+00 7.00e-02 -6.2 1.59e-02 - 8.72e-01
2.66e-01f 1
81  6.4998361e-01 0.00e+00 4.65e-02 -5.6 2.94e-02 - 1.00e+00
2.43e-01f 1
82  6.4617409e-01 0.00e+00 2.08e-02 -5.0 2.55e-02 - 4.94e-01
3.56e-01f 1
83  6.4406505e-01 0.00e+00 6.22e-02 -4.7 1.08e-02 - 1.00e+00
6.60e-01f 1
84  6.4240387e-01 0.00e+00 2.76e-02 -4.5 1.08e-02 - 7.55e-01
1.00e+00f 1
85  6.3997888e-01 0.00e+00 1.51e-02 -5.4 7.27e-03 - 8.16e-01
8.75e-01f 1
86  6.3878835e-01 0.00e+00 1.11e-02 -6.7 6.48e-03 - 8.32e-01
3.37e-01f 1
87  6.3553798e-01 0.00e+00 5.15e-02 -5.3 1.15e-02 - 8.26e-01
5.26e-01f 1
88  6.3492577e-01 0.00e+00 3.25e-02 -4.7 8.70e-03 - 6.19e-01
1.00e+00f 1
89  6.3497158e-01 0.00e+00 3.07e-02 -4.4 7.12e-03 - 8.51e-01
1.00e+00f 1
iter  objective      inf_pr  inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
90  6.3304437e-01 0.00e+00 1.79e-02 -4.6 2.87e-03 - 1.00e+00
1.00e+00f 1
91  6.3057805e-01 0.00e+00 3.09e-02 -5.3 2.91e-03 - 1.00e+00
7.75e-01f 1
92  6.2882652e-01 0.00e+00 3.58e-02 -6.5 3.09e-03 - 1.00e+00
5.05e-01f 1
93  6.2669152e-01 0.00e+00 1.74e-02 -11.0 8.00e-03 - 8.44e-01
3.93e-01f 1
94  6.2503950e-01 0.00e+00 2.87e-02 -7.8 1.67e-02 - 1.00e+00
1.84e-01f 1
95  6.2366177e-01 0.00e+00 4.24e-02 -5.3 1.62e-02 - 8.06e-01
1.87e-01f 1
96  6.2184341e-01 0.00e+00 9.97e-02 -4.7 3.03e-02 - 8.22e-01
2.43e-01f 1
97  6.1967604e-01 0.00e+00 5.00e-02 -4.7 1.08e-02 - 7.23e-01
6.35e-01f 1
98  6.1766310e-01 0.00e+00 4.15e-02 -4.5 1.39e-02 - 6.63e-01
8.87e-01f 1
99  6.1437507e-01 0.00e+00 2.34e-02 -5.2 2.16e-02 - 1.00e+00
4.87e-01f 1
iter  objective      inf_pr  inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
100  6.1131539e-01 0.00e+00 5.51e-02 -5.2 2.82e-02 - 9.56e-01
3.61e-01f 1
101  6.0930618e-01 0.00e+00 5.60e-02 -4.9 1.75e-02 - 5.91e-01
3.74e-01f 1

```

```

102  6.0771401e-01 0.00e+00 4.88e-02 -4.6 1.01e-02 - 4.43e-01
4.69e-01f 1
103  6.0485645e-01 0.00e+00 4.55e-02 -4.8 1.38e-02 - 5.82e-01
6.62e-01f 1
104  6.0264834e-01 0.00e+00 4.95e-02 -4.9 1.90e-02 - 9.31e-01
4.51e-01f 1
105  6.0243003e-01 0.00e+00 3.69e-02 -5.9 6.26e-03 - 4.67e-01
6.78e-02f 1
106  6.0120126e-01 0.00e+00 4.56e-02 -5.2 1.37e-02 - 5.22e-01
1.52e-01f 1
107  5.9925883e-01 0.00e+00 3.52e-02 -4.9 1.42e-02 - 2.31e-01
2.59e-01f 1
108  6.0381497e-01 0.00e+00 6.44e-02 -4.2 5.91e-02 - 3.26e-01
1.00e+00f 1
109  5.9975778e-01 0.00e+00 2.28e-02 -4.6 1.41e-02 - 1.00e+00
4.70e-01f 1
iter   objective      inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
110  5.9667587e-01 0.00e+00 6.64e-02 -4.6 1.22e-02 - 1.00e+00
1.00e+00f 1
111  5.9538529e-01 0.00e+00 5.36e-02 -5.6 1.74e-02 - 1.00e+00
4.22e-01f 1
112  5.9445254e-01 0.00e+00 6.73e-02 -5.3 1.92e-02 - 1.00e+00
2.35e-01f 1
113  5.9420762e-01 0.00e+00 1.20e-02 -4.6 1.03e-02 - 7.08e-01
1.00e+00f 1
114  5.9489405e-01 0.00e+00 2.67e-02 -4.4 3.10e-02 - 5.14e-01
1.00e+00f 1

```

Number of Iterations.....: 114

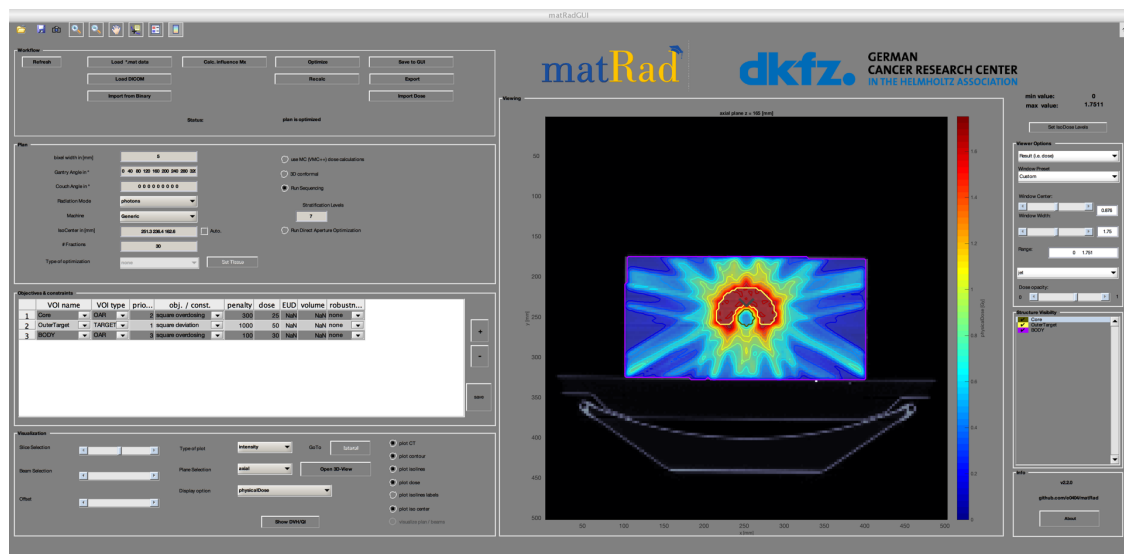
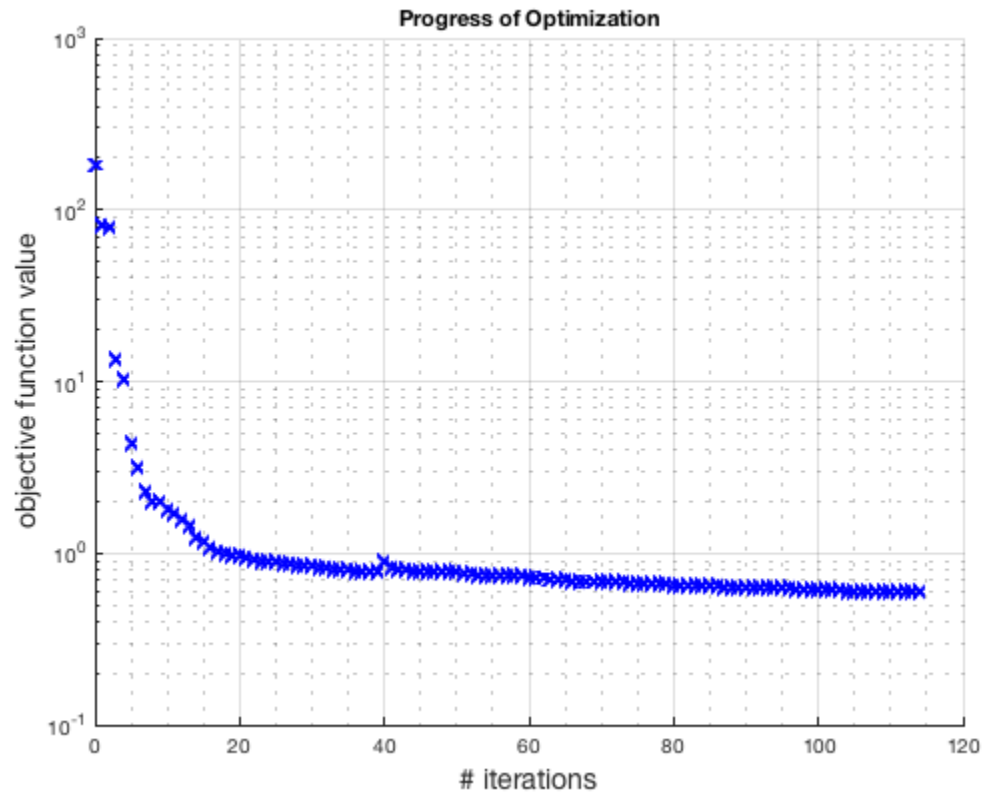
	(scaled)	(unscaled)
Objective.....:	5.9489405174093346e-01	
	5.9489405174093346e-01	
Dual infeasibility.....:	2.6701508588048799e-02	
	2.6701508588048799e-02	
Constraint violation.....:	0.0000000000000000e+00	
	0.0000000000000000e+00	
Complementarity.....:	2.2659178887796623e-04	
	2.2659178887796623e-04	
Overall NLP error.....:	2.6701508588048799e-02	
	2.6701508588048799e-02	

Number of objective function evaluations	= 120
Number of objective gradient evaluations	= 115
Number of equality constraint evaluations	= 0
Number of inequality constraint evaluations	= 0
Number of equality constraint Jacobian evaluations	= 0
Number of inequality constraint Jacobian evaluations	= 0
Number of Lagrangian Hessian evaluations	= 0
Total CPU secs in IPOPT (w/o function evaluations)	= 3.402
Total CPU secs in NLP function evaluations	= 58.351

EXIT: Solved To Acceptable Level.

\*\*\* IPOPT DONE \*\*\*

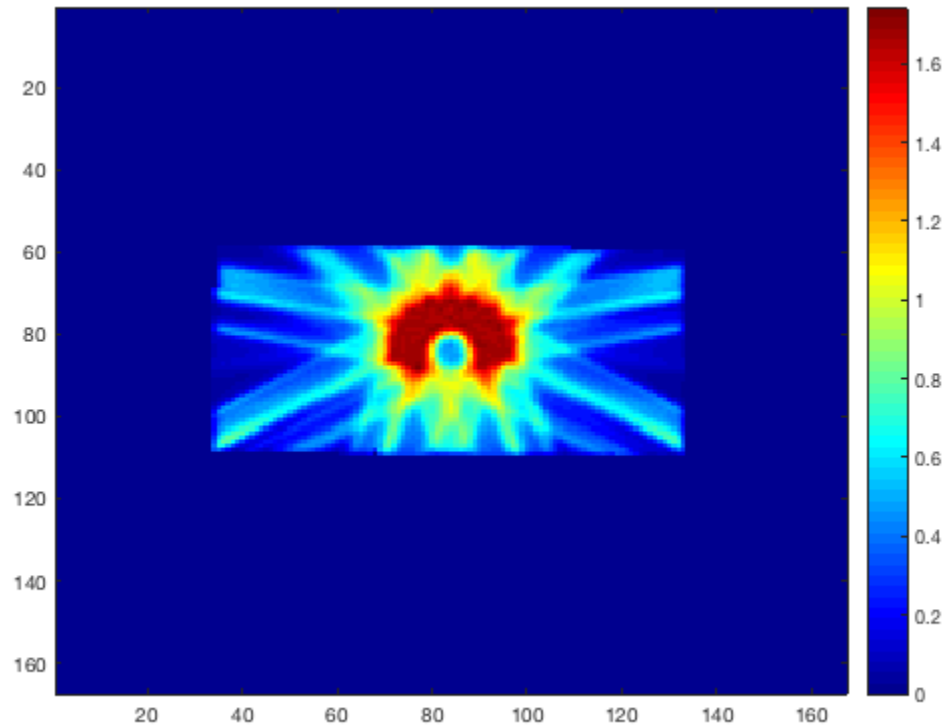
Calculating final cubes...



## Plot the Resulting Dose Slice

Let's plot the transversal iso-center dose slice

```
slice = round(pln.propStf.isoCenter(1,3)./ct.resolution.z);
figure
imagesc(resultGUI.physicalDose(:, :, slice)), colorbar, colormap(jet);
```



**Now let's create another treatment plan but this time use a coarser beam spacing.**

Instead of 40 degree spacing use a 50 degree gantry beam spacing

```
pln.propStf.gantryAngles = [0:50:359];
pln.propStf.couchAngles = zeros(1,numel(pln.propStf.gantryAngles));
pln.propStf.numOfBeams = numel(pln.propStf.gantryAngles);
stf = matRad_generateStf(ct,cst,pln);
pln.propStf.isoCenter = stf.isoCenter;
dij = matRad_calcPhotonDose(ct,stf,pln,cst);
resultGUI_coarse = matRad_fluenceOptimization(dij,cst,pln);
```

*matRad: Generating stf struct... Progress: 100.00 %*

*matRad: Photon dose calculation...*

*Beam 1 of 8:*

*matRad: calculate radiological depth cube...done*

*SSD = 939mm*

*matRad: Uniform primary photon fluence -> pre-compute kernel*

*convolution for SSD = 939 mm ...*

*Progress: 100.00 %*

```

Beam 2 of 8:
matRad: calculate radiological depth cube...done
        SSD = 905mm
matRad: Uniform primary photon fluence -> pre-compute kernel
        convolution for SSD = 905 mm ...
Progress: 100.00 %
Beam 3 of 8:
matRad: calculate radiological depth cube...done
        SSD = 849mm
matRad: Uniform primary photon fluence -> pre-compute kernel
        convolution for SSD = 849 mm ...
Progress: 100.00 %
Beam 4 of 8:
matRad: calculate radiological depth cube...done
        SSD = 894mm
matRad: Uniform primary photon fluence -> pre-compute kernel
        convolution for SSD = 894 mm ...
Progress: 100.00 %
Beam 5 of 8:
matRad: calculate radiological depth cube...done
        SSD = 902mm
matRad: Uniform primary photon fluence -> pre-compute kernel
        convolution for SSD = 902 mm ...
Progress: 100.00 %
Beam 6 of 8:
matRad: calculate radiological depth cube...done
        SSD = 840mm
matRad: Uniform primary photon fluence -> pre-compute kernel
        convolution for SSD = 840 mm ...
Progress: 100.00 %
Beam 7 of 8:
matRad: calculate radiological depth cube...done
        SSD = 878mm
matRad: Uniform primary photon fluence -> pre-compute kernel
        convolution for SSD = 878 mm ...
Progress: 100.00 %
Beam 8 of 8:
matRad: calculate radiological depth cube...done
        SSD = 938mm
matRad: Uniform primary photon fluence -> pre-compute kernel
        convolution for SSD = 938 mm ...
Progress: 100.00 %

*****
This program contains Ipopt, a library for large-scale nonlinear
optimization.
Ipopt is released as open source code under the Eclipse Public
License (EPL).
        For more information visit http://projects.coin-or.org/Ipopt
*****

This is Ipopt version 3.12.4, running with linear solver ma57.

Number of nonzeros in equality constraint Jacobian...:      0

```

```

Number of nonzeros in inequality constraint Jacobian.:      0
Number of nonzeros in Lagrangian Hessian.....:          0

Total number of variables.....:      2226
      variables with only lower bounds:      2226
      variables with lower and upper bounds:      0
      variables with only upper bounds:      0
Total number of equality constraints.....:      0
Total number of inequality constraints.....:      0
      inequality constraints with only lower bounds:      0
      inequality constraints with lower and upper bounds:      0
      inequality constraints with only upper bounds:      0

iter   objective   inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
  0  1.6778908e+02  0.00e+00  5.62e+00   0.0  0.00e+00   -  0.00e+00
0.00e+00  0
  1  9.1920940e+01  0.00e+00  5.53e+00  -0.3  1.05e+00   -  1.00e+00
2.63e-01f  1
  2  7.3843784e+01  0.00e+00  4.19e+00  -6.6  1.40e-01   -  1.00e+00
1.00e+00f  1
  3  1.6905198e+01  0.00e+00  1.38e+00  -1.6  6.87e-02   -  9.99e-01
1.00e+00f  1
  4  1.3133124e+01  0.00e+00  6.77e-01  -1.9  2.06e-02   -  9.96e-01
1.00e+00f  1
  5  7.0022693e+00  0.00e+00  4.29e-01  -2.2  6.34e-02   -  9.98e-01
1.00e+00f  1
  6  4.3355319e+00  0.00e+00  3.76e-01  -2.8  5.22e-02   -  1.00e+00
1.00e+00f  1
  7  3.8040340e+00  0.00e+00  6.65e-01  -3.4  9.30e-02   -  1.00e+00
9.00e-01f  1
  8  2.5907549e+00  0.00e+00  1.69e-01  -3.6  1.86e-02   -  1.00e+00
1.00e+00f  1
  9  2.4486831e+00  0.00e+00  1.52e-01  -5.0  8.52e-03   -  1.00e+00
1.00e+00f  1
iter   objective   inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
 10  2.3623952e+00  0.00e+00  1.52e-01  -5.9  2.57e-02   -  1.00e+00
2.00e-01f  1
 11  2.1880193e+00  0.00e+00  1.45e-01  -6.4  5.15e-02   -  1.00e+00
2.29e-01f  1
 12  2.0712214e+00  0.00e+00  2.44e-01  -4.9  6.18e-02   -  1.00e+00
1.31e-01f  1
 13  1.9697783e+00  0.00e+00  2.31e-01  -4.2  4.76e-02   -  1.00e+00
1.76e-01f  1
 14  1.8709723e+00  0.00e+00  1.57e-01  -4.5  6.20e-02   -  1.00e+00
1.96e-01f  1
 15  1.8162850e+00  0.00e+00  4.53e-01  -4.0  3.20e-02   -  1.00e+00
1.95e-01f  1
 16  1.7046515e+00  0.00e+00  1.26e-01  -4.2  3.39e-02   -  1.00e+00
5.29e-01f  1
 17  1.6407116e+00  0.00e+00  1.38e-01  -4.5  3.44e-02   -  1.00e+00
6.11e-01f  1

```

```

18  1.6415375e+00  0.00e+00  2.16e-01  -3.3  2.01e-02  -  9.97e-01
1.00e+00f  1
19  1.6097869e+00  0.00e+00  7.37e-02  -3.3  6.24e-03  -  1.00e+00
1.00e+00f  1
iter    objective    inf_pr    inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
20  1.5725553e+00  0.00e+00  6.70e-02  -9.3  9.07e-03  -  5.62e-01
1.00e+00f  1
21  1.5484222e+00  0.00e+00  8.12e-02  -4.3  9.04e-03  -  1.00e+00
1.00e+00f  1
22  1.5092581e+00  0.00e+00  9.15e-02  -4.6  2.79e-02  -  1.00e+00
5.83e-01f  1
23  1.4922050e+00  0.00e+00  9.98e-02  -5.3  2.60e-02  -  1.00e+00
2.39e-01f  1
24  1.4629999e+00  0.00e+00  8.10e-02  -6.3  3.34e-02  -  1.00e+00
3.35e-01f  1
25  1.4426076e+00  0.00e+00  5.08e-02  -6.8  3.85e-02  -  1.00e+00
2.35e-01f  1
26  1.4249625e+00  0.00e+00  1.01e-01  -7.4  4.72e-02  -  1.00e+00
1.70e-01f  1
27  1.4137651e+00  0.00e+00  1.41e-01  -7.9  4.26e-02  -  1.00e+00
1.26e-01f  1
28  1.3955501e+00  0.00e+00  1.35e-01  -8.4  4.63e-02  -  1.00e+00
1.86e-01f  1
29  1.3857931e+00  0.00e+00  8.24e-02  -8.6  4.63e-02  -  9.80e-01
8.97e-02f  1
iter    objective    inf_pr    inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
30  1.3797822e+00  0.00e+00  1.93e-01  -8.4  3.37e-02  -  8.69e-01
6.77e-02f  1
31  1.3648549e+00  0.00e+00  1.79e-01  -5.5  4.58e-02  -  8.24e-01
1.25e-01f  1
32  1.3536294e+00  0.00e+00  2.06e-01  -4.5  3.24e-02  -  8.28e-01
1.30e-01f  1
33  1.3441160e+00  0.00e+00  1.32e-01  -4.8  3.89e-02  -  6.77e-01
9.78e-02f  1
34  1.3301521e+00  0.00e+00  1.86e-01  -4.8  4.12e-02  -  1.00e+00
1.38e-01f  1
35  1.3045468e+00  0.00e+00  2.14e-01  -5.0  4.13e-02  -  1.00e+00
3.08e-01f  1
36  1.2968683e+00  0.00e+00  2.81e-01  -5.6  3.48e-02  -  1.00e+00
1.16e-01f  1
37  1.2870363e+00  0.00e+00  1.36e-01  -6.2  4.09e-02  -  1.00e+00
1.43e-01f  1
38  1.2697819e+00  0.00e+00  1.17e-01  -5.1  5.55e-02  -  1.00e+00
3.00e-01f  1
39  1.2576149e+00  0.00e+00  2.46e-01  -4.6  2.39e-02  -  1.00e+00
3.76e-01f  1
iter    objective    inf_pr    inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
40  1.2501380e+00  0.00e+00  1.40e-01  -4.6  2.18e-02  -  9.72e-01
2.35e-01f  1
41  1.2398063e+00  0.00e+00  1.17e-01  -5.9  2.05e-02  -  6.27e-01
3.52e-01f  1

```



# Example: Photon Treatment Plan

```

42  1.2812534e+00  0.00e+00  1.60e-01  -3.6  7.84e-02  -  3.89e-01
1.00e+00f  1
43  1.2521553e+00  0.00e+00  5.03e-02  -3.9  1.44e-02  -  1.00e+00
1.00e+00f  1
44  1.2356849e+00  0.00e+00  3.36e-02  -3.9  1.89e-02  -  1.00e+00
1.00e+00f  1
45  1.2129549e+00  0.00e+00  4.07e-02  -4.5  2.88e-02  -  1.00e+00
1.00e+00f  1
46  1.2032274e+00  0.00e+00  4.23e-02  -5.1  1.60e-02  -  1.00e+00
5.15e-01f  1
47  1.1961474e+00  0.00e+00  1.01e-01  -5.8  1.91e-02  -  8.41e-01
3.08e-01f  1
48  1.1854064e+00  0.00e+00  5.51e-02  -4.9  3.76e-02  -  8.84e-01
2.29e-01f  1
49  1.1809087e+00  0.00e+00  8.45e-02  -5.4  2.49e-02  -  3.95e-01
1.25e-01f  1
iter    objective    inf_pr    inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
50  1.1730716e+00  0.00e+00  1.55e-01  -4.1  7.28e-02  -  3.04e-01
2.79e-01f  1
51  1.1684948e+00  0.00e+00  6.83e-02 -10.5  1.84e-02  -  6.38e-01
1.52e-01f  1
52  1.1630378e+00  0.00e+00  1.05e-01  -5.1  2.00e-02  -  5.78e-01
1.97e-01f  1
53  1.1599847e+00  0.00e+00  7.48e-02  -6.1  1.59e-02  -  4.45e-01
1.27e-01f  1
54  1.1490089e+00  0.00e+00  7.53e-02  -5.6  2.70e-02  -  6.30e-01
3.21e-01f  1
55  1.1457329e+00  0.00e+00  6.28e-02  -6.0  2.35e-02  -  5.90e-01
1.17e-01f  1
56  1.1407197e+00  0.00e+00  9.86e-02  -6.3  2.67e-02  -  8.47e-01
1.42e-01f  1
57  1.1352557e+00  0.00e+00  1.80e-01  -6.5  2.50e-02  -  7.71e-01
1.81e-01f  1
58  1.1311398e+00  0.00e+00  6.59e-02  -6.3  3.30e-02  -  1.00e+00
1.18e-01f  1
59  1.1251796e+00  0.00e+00  7.65e-02  -4.3  3.68e-02  -  7.45e-01
2.58e-01f  1
iter    objective    inf_pr    inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
60  1.1230518e+00  0.00e+00  1.47e-01  -5.8  2.06e-02  -  6.81e-01
1.04e-01f  1
61  1.1175647e+00  0.00e+00  1.51e-01  -5.0  3.19e-02  -  9.98e-01
2.09e-01f  1
62  1.1096385e+00  0.00e+00  6.39e-02  -5.0  3.72e-02  -  1.00e+00
3.11e-01f  1
63  1.1068689e+00  0.00e+00  1.25e-01  -5.0  2.43e-02  -  7.58e-01
1.82e-01f  1
64  1.0989511e+00  0.00e+00  3.39e-02  -5.3  3.35e-02  -  9.14e-01
4.57e-01f  1
65  1.0967770e+00  0.00e+00  6.40e-02  -5.8  3.12e-02  -  9.73e-01
1.25e-01f  1
66  1.0999458e+00  0.00e+00  1.40e-01  -4.2  1.25e-02  -  9.84e-01
1.00e+00f  1

```

```

67  1.0952015e+00 0.00e+00 9.22e-02 -4.2 1.47e-02 - 8.47e-01
8.15e-01f 1
68  1.0984764e+00 0.00e+00 4.88e-02 -3.8 2.85e-02 - 5.61e-01
1.00e+00f 1
69  1.0916948e+00 0.00e+00 7.64e-02 -4.0 1.10e-02 - 1.00e+00
1.00e+00f 1
iter  objective    inf_pr  inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
70  1.0831331e+00 0.00e+00 4.38e-02 -10.0 1.85e-02 - 9.46e-01
5.50e-01f 1
71  1.0763388e+00 0.00e+00 1.14e-01 -6.4 1.79e-02 - 1.00e+00
4.51e-01f 1
72  1.0752092e+00 0.00e+00 6.84e-02 -11.0 1.12e-02 - 7.04e-01
8.33e-02f 1
73  1.0676006e+00 0.00e+00 1.08e-01 -5.6 2.33e-02 - 5.68e-01
3.86e-01f 1
74  1.0616966e+00 0.00e+00 1.50e-01 -4.6 1.65e-02 - 5.44e-01
1.00e+00f 1
75  1.0692623e+00 0.00e+00 5.43e-02 -4.1 2.32e-02 - 8.25e-01
1.00e+00f 1
76  1.0608602e+00 0.00e+00 3.97e-02 -4.3 2.78e-02 - 6.67e-01
5.50e-01f 1
77  1.0541946e+00 0.00e+00 1.44e-01 -5.0 2.12e-02 - 1.00e+00
4.19e-01f 1
78  1.0446974e+00 0.00e+00 6.41e-02 -5.6 2.72e-02 - 7.31e-01
5.27e-01f 1
79  1.0434643e+00 0.00e+00 9.42e-02 -5.7 3.37e-02 - 9.96e-01
4.57e-02f 1
iter  objective    inf_pr  inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
80  1.0357291e+00 0.00e+00 1.60e-01 -4.9 2.26e-02 - 1.00e+00
4.65e-01f 1
81  1.0336460e+00 0.00e+00 2.64e-02 -4.5 2.09e-02 - 6.35e-01
1.91e-01f 1
82  1.0285501e+00 0.00e+00 3.88e-02 -5.2 3.80e-02 - 4.04e-01
2.42e-01f 1
83  1.0255686e+00 0.00e+00 5.44e-02 -6.0 4.09e-02 - 3.50e-01
1.31e-01f 1
84  1.0247030e+00 0.00e+00 1.87e-01 -5.6 1.52e-02 - 1.00e+00
5.66e-02f 1
85  1.0188424e+00 0.00e+00 1.21e-01 -11.0 2.96e-02 - 3.84e-01
2.23e-01f 1
86  1.0158160e+00 0.00e+00 1.01e-01 -5.0 2.31e-02 - 1.69e-01
1.67e-01f 1
87  1.0140990e+00 0.00e+00 5.58e-02 -4.5 1.60e-02 - 4.99e-01
1.76e-01f 1
88  1.0116042e+00 0.00e+00 6.15e-02 -4.4 2.33e-02 - 4.84e-01
3.57e-01f 1
89  1.0077213e+00 0.00e+00 2.55e-02 -4.7 1.99e-02 - 5.56e-01
3.47e-01f 1
iter  objective    inf_pr  inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr ls
90  1.0052842e+00 0.00e+00 7.84e-02 -5.1 1.57e-02 - 9.85e-01
2.63e-01f 1

```

Example: Photon Treatment Plan

91	1.0025020e+00	0.00e+00	7.05e-02	-5.6	1.82e-02	-	8.97e-01
2.23e-01f	1						
92	1.0005979e+00	0.00e+00	5.53e-02	-4.5	1.85e-02	-	3.96e-01
4.32e-01f	1						
93	9.9858421e-01	0.00e+00	5.83e-02	-4.8	9.32e-03	-	5.20e-01
3.53e-01f	1						
94	9.9752825e-01	0.00e+00	5.49e-02	-5.1	1.16e-02	-	6.02e-01
1.37e-01f	1						
95	9.9641514e-01	0.00e+00	3.38e-02	-4.4	3.17e-02	-	4.78e-01
4.34e-01f	1						
96	9.9413835e-01	0.00e+00	3.64e-02	-5.4	1.35e-02	-	6.51e-01
2.33e-01f	1						
97	9.9274237e-01	0.00e+00	6.70e-02	-6.4	7.47e-03	-	7.96e-01
2.07e-01f	1						
98	9.9005227e-01	0.00e+00	7.29e-02	-6.4	1.58e-02	-	1.00e+00
2.37e-01f	1						
99	9.8541054e-01	0.00e+00	6.37e-02	-6.0	2.49e-02	-	1.00e+00
3.95e-01f	1						
iter	objective	inf_pr	inf_du	lg(mu)	d	lg(rg)	alpha_du
alpha_pr	ls						
100	9.8435560e-01	0.00e+00	3.12e-02	-6.1	2.09e-02	-	1.00e+00
1.10e-01f	1						
101	9.8339176e-01	0.00e+00	4.54e-02	-11.0	2.22e-02	-	7.18e-01
9.64e-02f	1						
102	9.8047927e-01	0.00e+00	3.89e-02	-6.1	3.54e-02	-	7.96e-01
2.08e-01f	1						
103	9.7934917e-01	0.00e+00	4.29e-02	-6.3	1.93e-02	-	4.47e-01
1.54e-01f	1						
104	9.7819667e-01	0.00e+00	3.88e-02	-6.1	2.71e-02	-	1.00e+00
1.24e-01f	1						
105	9.7652095e-01	0.00e+00	4.15e-02	-4.9	2.77e-02	-	7.26e-01
2.79e-01f	1						
106	9.7572062e-01	0.00e+00	5.17e-02	-6.9	1.80e-02	-	5.69e-01
1.47e-01f	1						
107	9.7454669e-01	0.00e+00	5.84e-02	-5.7	2.49e-02	-	1.00e+00
1.72e-01f	1						
108	9.7599679e-01	0.00e+00	3.93e-02	-4.7	2.60e-02	-	6.85e-01
6.51e-01f	1						
109	9.7195348e-01	0.00e+00	6.55e-02	-4.9	5.38e-03	-	1.00e+00
1.00e+00f	1						
iter	objective	inf_pr	inf_du	lg(mu)	d	lg(rg)	alpha_du
alpha_pr	ls						
110	9.7061138e-01	0.00e+00	3.08e-02	-5.0	4.64e-03	-	9.10e-01
9.90e-01f	1						
111	9.6998934e-01	0.00e+00	4.29e-02	-5.7	2.40e-03	-	7.76e-01
3.03e-01f	1						
112	9.6696203e-01	0.00e+00	4.07e-02	-5.4	8.35e-03	-	1.00e+00
6.82e-01f	1						
113	9.6865537e-01	0.00e+00	2.20e-02	-4.7	1.16e-02	-	1.00e+00
1.00e+00f	1						
114	9.6729345e-01	0.00e+00	1.82e-02	-4.8	1.19e-02	-	2.96e-01
5.19e-01f	1						
115	9.6618232e-01	0.00e+00	4.42e-02	-4.8	5.11e-03	-	9.61e-01
1.00e+00f	1						

```

116  9.6775637e-01 0.00e+00 1.32e-02 -4.5 1.16e-02 - 6.79e-01
1.00e+00f 1
117  9.6531270e-01 0.00e+00 9.01e-03 -4.7 3.01e-03 - 1.00e+00
1.00e+00f 1
118  9.6118821e-01 0.00e+00 1.21e-02 -5.7 8.49e-03 - 1.00e+00
7.32e-01f 1
119  9.5958035e-01 0.00e+00 1.92e-02 -6.7 9.98e-03 - 1.00e+00
2.83e-01f 1
iter   objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
alpha_pr  ls
120  9.5832073e-01 0.00e+00 3.90e-02 -7.5 9.26e-03 - 1.00e+00
2.42e-01f 1
121  9.5592221e-01 0.00e+00 2.52e-02 -8.0 2.08e-02 - 9.03e-01
2.90e-01f 1
122  9.5582357e-01 0.00e+00 6.86e-02 -7.0 7.18e-03 - 8.51e-01
2.63e-02f 1
123  9.5526353e-01 0.00e+00 5.22e-02 -11.0 1.12e-02 - 3.18e-01
1.01e-01f 1
124  9.5465730e-01 0.00e+00 4.65e-02 -6.2 3.17e-02 - 1.21e-01
8.58e-02f 1

```

Number of Iterations.....: 124

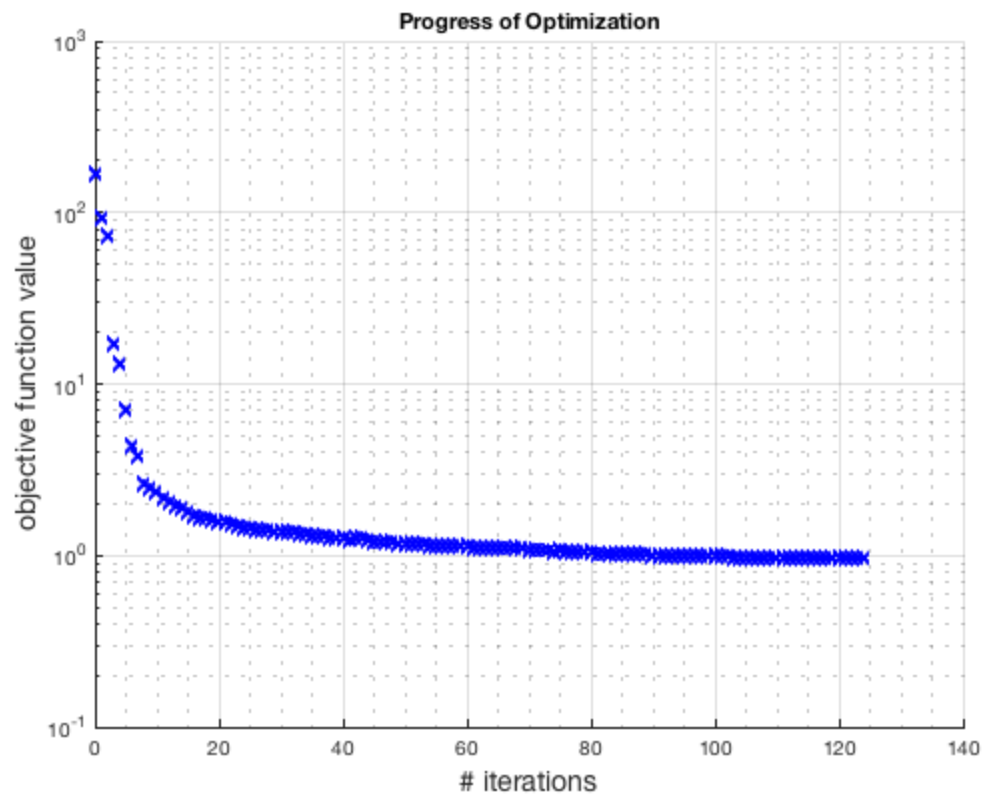
	(scaled)	(unscaled)
Objective.....:	9.5465730399184290e-01	
	9.5465730399184290e-01	
Dual infeasibility.....:	4.6497049039574204e-02	
	4.6497049039574204e-02	
Constraint violation.....:	0.0000000000000000e+00	
	0.0000000000000000e+00	
Complementarity.....:	1.3419396966888447e-04	
	1.3419396966888447e-04	
Overall NLP error.....:	4.6497049039574204e-02	
	4.6497049039574204e-02	

Number of objective function evaluations	=	125
Number of objective gradient evaluations	=	125
Number of equality constraint evaluations	=	0
Number of inequality constraint evaluations	=	0
Number of equality constraint Jacobian evaluations	=	0
Number of inequality constraint Jacobian evaluations	=	0
Number of Lagrangian Hessian evaluations	=	0
Total CPU secs in IPOPT (w/o function evaluations)	=	4.689
Total CPU secs in NLP function evaluations	=	54.468

EXIT: Solved To Acceptable Level.

\*\*\* IPOPT DONE \*\*\*

Calculating final cubes...

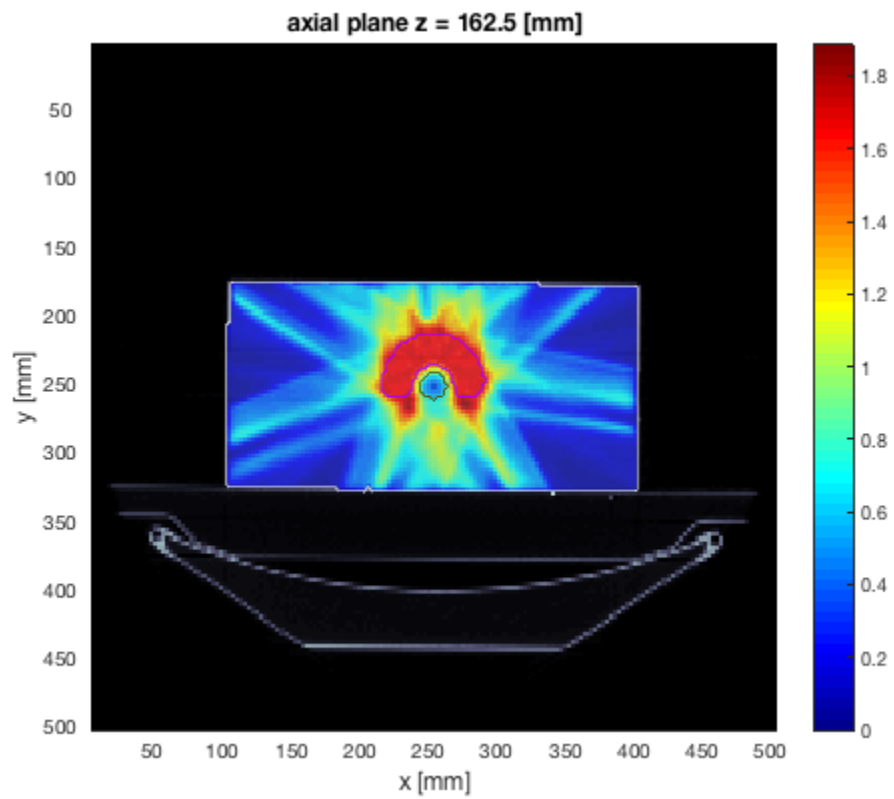
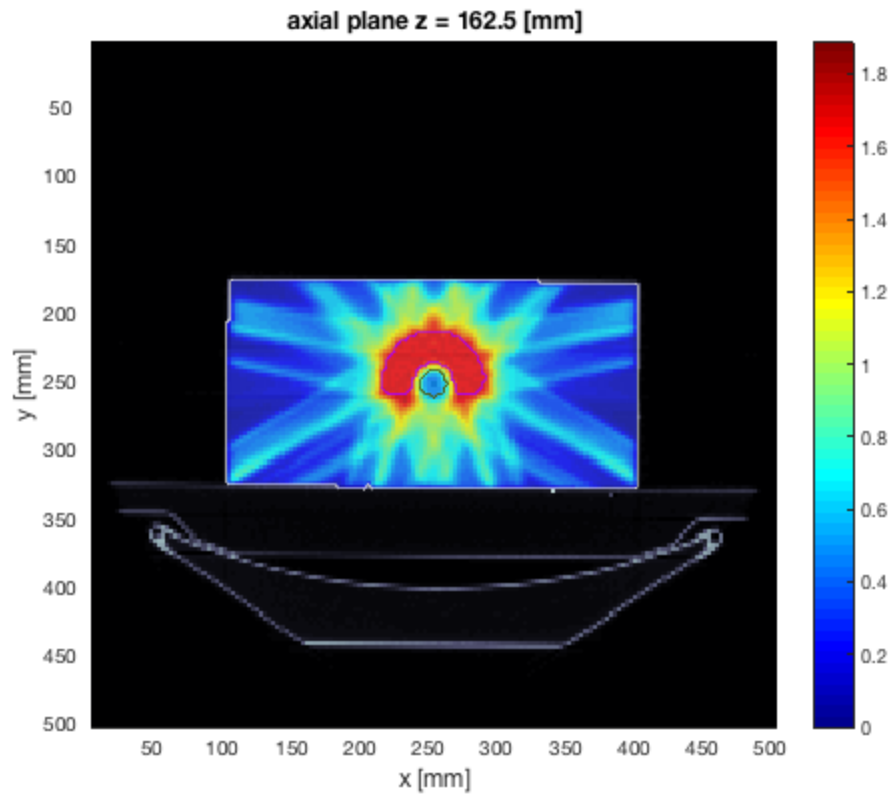


## Visual Comparison of results

Let's compare the new recalculation against the optimization result. Check if you have added all subdirectories to the Matlab search path, otherwise it will not find the plotting function

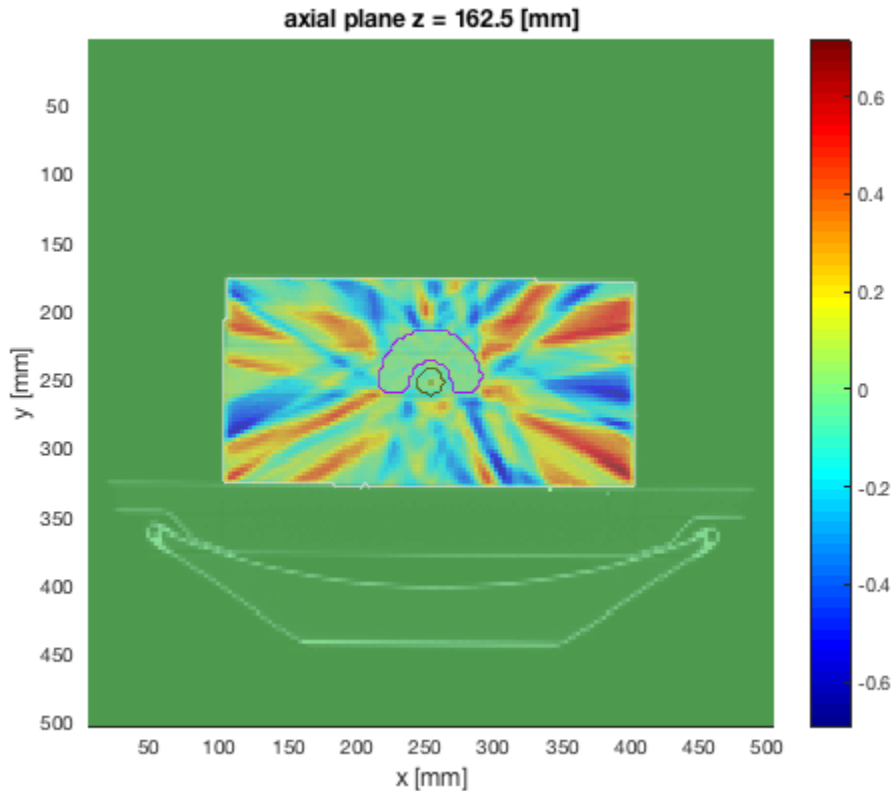
```
plane      = 3;
doseWindow = [0 max([resultGUI.physicalDose(:);
    resultGUI_coarse.physicalDose(:)])];

figure,title('original plan - fine beam spacing')
matRad_plotSliceWrapper(gca,ct,cst,1,resultGUI.physicalDose,plane,slice,
    [],0.75,colorcube,[],doseWindow,[]);
figure,title('modified plan - coarse beam spacing')
matRad_plotSliceWrapper(gca,ct,cst,1,resultGUI_coarse.physicalDose,plane,slice,
    [],0.75,colorcube,[],doseWindow,[]);
```



At this point we would like to see the absolute difference of the first optimization (finer beam spacing) and the second optimization (coarser beam spacing)

```
absDiffCube = resultGUI.physicalDose-resultGUI_coarse.physicalDose;
figure,title( 'fine beam spacing plan - coarse beam spacing plan')
matRad_plotSliceWrapper(gca,ct,cst,1,absDiffCube,plane,slice,[],
[],colorcube);
```



## Obtain dose statistics

Two more columns will be added to the cst structure depicting the DVH and standard dose statistics such as D95,D98, mean dose, max dose etc.

```
[dvh,qi] = matRad_indicatorWrapper(cst,pln,resultGUI);
[dvh_coarse,qi_coarse] =
matRad_indicatorWrapper(cst,pln,resultGUI_coarse);
```

0	Core - Mean dose = 0.56 Gy +/- 0.16 Gy (Max dose = 0.87 Gy, Min dose = 0.20 Gy)
	D2% = 0.86 Gy, D5% = 0.85 Gy, D50% = 0.54 Gy, D95% = 0.35 Gy, D98% = 0.22 Gy,
	V0Gy = 100.00%, V0.3Gy = 96.52%, V0.7Gy = 22.73%, V1Gy = 0.00%, V1.4Gy = 0.00%, V1.7Gy = 0.00%,
1	OuterTarget - Mean dose = 1.67 Gy +/- 0.02 Gy (Max dose = 1.72 Gy, Min dose = 1.54 Gy)

$D2\% = 1.70 \text{ Gy}$ ,  $D5\% = 1.69 \text{ Gy}$ ,  $D50\% = 1.67 \text{ Gy}$ ,  $D95\% = 1.64 \text{ Gy}$ ,  $D98\% = 1.63 \text{ Gy}$ ,  
 $V0\text{Gy} = 100.00\%$ ,  $V0.3\text{Gy} = 100.00\%$ ,  $V0.7\text{Gy} = 100.00\%$ ,  $V1\text{Gy} = 100.00\%$ ,  $V1.4\text{Gy} = 100.00\%$ ,  $V1.7\text{Gy} = 0.95\%$ ,  
 $CI = 0.8524$ ,  $HI = 3.21$  for reference dose  
of 1.7 Gy

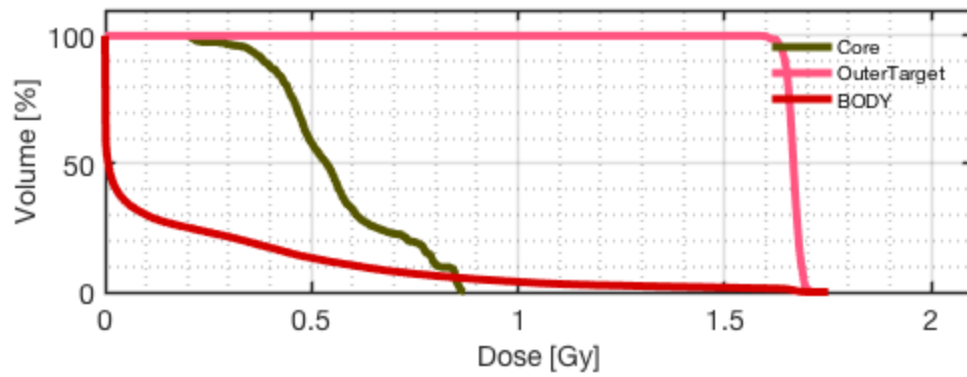
2                      BODY - Mean dose = 0.18 Gy +/- 0.33 Gy (Max dose = 1.75 Gy, Min dose = 0.00 Gy)  
 $D2\% = 1.41 \text{ Gy}$ ,  $D5\% = 0.90 \text{ Gy}$ ,  $D50\% = 0.01 \text{ Gy}$ ,  $D95\% = 0.00 \text{ Gy}$ ,  $D98\% = 0.00 \text{ Gy}$ ,  
 $V0\text{Gy} = 100.00\%$ ,  $V0.3\text{Gy} = 21.52\%$ ,  $V0.7\text{Gy} = 8.00\%$ ,  $V1\text{Gy} = 3.96\%$ ,  $V1.4\text{Gy} = 2.02\%$ ,  $V1.7\text{Gy} = 0.02\%$ ,

0                      Core - Mean dose = 0.58 Gy +/- 0.17 Gy (Max dose = 0.90 Gy, Min dose = 0.19 Gy)  
 $D2\% = 0.88 \text{ Gy}$ ,  $D5\% = 0.88 \text{ Gy}$ ,  $D50\% = 0.56 \text{ Gy}$ ,  $D95\% = 0.32 \text{ Gy}$ ,  $D98\% = 0.22 \text{ Gy}$ ,  
 $V0\text{Gy} = 100.00\%$ ,  $V0.3\text{Gy} = 96.06\%$ ,  $V0.7\text{Gy} = 23.03\%$ ,  $V1.1\text{Gy} = 0.00\%$ ,  $V1.5\text{Gy} = 0.00\%$ ,  $V1.8\text{Gy} = 0.00\%$ ,

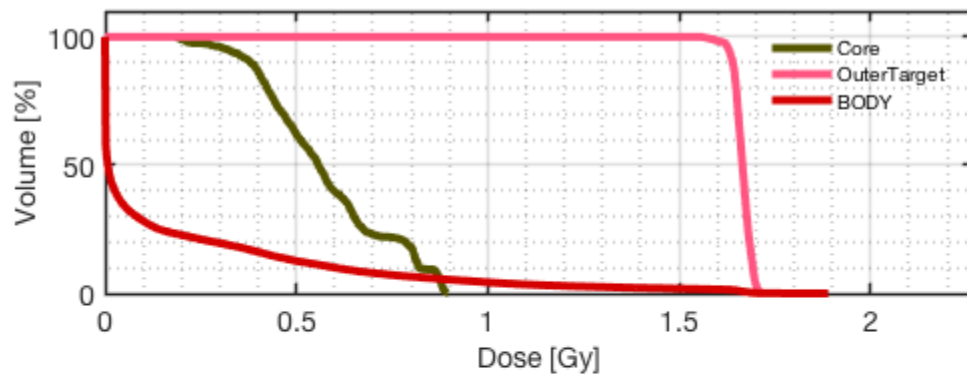
1                      OuterTarget - Mean dose = 1.66 Gy +/- 0.02 Gy (Max dose = 1.72 Gy, Min dose = 1.54 Gy)  
 $D2\% = 1.70 \text{ Gy}$ ,  $D5\% = 1.70 \text{ Gy}$ ,  $D50\% = 1.67 \text{ Gy}$ ,  $D95\% = 1.63 \text{ Gy}$ ,  $D98\% = 1.61 \text{ Gy}$ ,  
 $V0\text{Gy} = 100.00\%$ ,  $V0.3\text{Gy} = 100.00\%$ ,  $V0.7\text{Gy} = 100.00\%$ ,  $V1.1\text{Gy} = 100.00\%$ ,  $V1.5\text{Gy} = 100.00\%$ ,  $V1.8\text{Gy} = 0.00\%$ ,  
 $CI = 0.7578$ ,  $HI = 4.11$  for reference dose  
of 1.7 Gy

2                      BODY - Mean dose = 0.17 Gy +/- 0.34 Gy (Max dose = 1.89 Gy, Min dose = 0.00 Gy)  
 $D2\% = 1.45 \text{ Gy}$ ,  $D5\% = 0.94 \text{ Gy}$ ,  $D50\% = 0.01 \text{ Gy}$ ,  $D95\% = 0.00 \text{ Gy}$ ,  $D98\% = 0.00 \text{ Gy}$ ,  
 $V0\text{Gy} = 100.00\%$ ,  $V0.3\text{Gy} = 19.61\%$ ,  $V0.7\text{Gy} = 7.97\%$ ,  $V1.1\text{Gy} = 3.47\%$ ,  $V1.5\text{Gy} = 1.85\%$ ,  $V1.8\text{Gy} = 0.02\%$ ,





	mean	std	max	min	D <sub>95</sub>
Core	0.5614	0.1585	0.8724	0.1987	0
OuterTarget	1.6652	0.0168	1.7201	1.5385	1
BODY	0.1762	0.3341	1.7511	0	1



	mean	std	max	min	D <sub>95</sub>
Core	0.5751	0.1726	0.8981	0.1870	0
OuterTarget	1.6649	0.0225	1.7216	1.5362	1
BODY	0.1701	0.3387	1.8907	0	1

The treatment plan using more beams should in principle result in a better OAR sparing. Therefore lets have a look at the D95 of the OAR of both plans

```
ixOAR = 2;  
display(qi(ixOAR).D_95);  
display(qi_coarse(ixOAR).D_95);
```

```
1.637028404251090
```

```
1.629587314343785
```

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