Example: Proton Treatment Plan with Manipulated CT values

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In this example we will show (i) how to load patient data into matRad (ii) how to setup a proton dose calculation (iii) how to inversely optimize the pencil beam intensities directly from command window in MATLAB. (iv) how to re-optimize a treatment plan (v) how to manipulate the CT cube by adding noise to the cube (vi) how to recalculate the dose considering the manipulated CT cube and the previously optimized pencil beam intensities (vii) how to compare the two results

Patient Data Import

Let's begin with a clear Matlab environment and import the prostate patient into your workspace.

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

Treatment Plan

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

```
pln.radiationMode           = 'protons';
pln.machine                 = 'Generic';
pln.numOfFractions          = 30;
```

```
pln.propOpt.bioOptimization = 'const_RBExD';
pln.propStf.gantryAngles    = [90 270];
pln.propStf.couchAngles     = [0 0];
pln.propStf.bixelWidth      = 3;
pln.propStf.numOfBeams      = numel(pln.propStf.gantryAngles);
pln.propStf.isoCenter       = ones(pln.propStf.numOfBeams,1) *
 matRad_getIsoCenter(cst,ct,0);
pln.propOpt.runDAO          = 0;
pln.propOpt.runSequencing   = 0;
```

Generate Beam Geometry STF

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

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

Dose Calculation

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

```
matRad: Using a constant RBE of 1.1
Warning: Surface for SSD calculation starts directly in first voxel of
 CT
matRad: Particle dose calculation...
Beam 1 of 2:
matRad: calculate radiological depth cube...done.
matRad: calculate lateral cutoff...done.
Progress: 100.00 %
Beam 2 of 2:
matRad: calculate radiological depth cube...done.
matRad: calculate lateral cutoff...done.
Progress: 100.00 %
```

Inverse Optimization for IMPT

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

```

******************************************************************************
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............................:    45333
                     variables with only lower bounds:    45333
                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  4.3873631e+02 0.00e+00 1.07e+00   0.0 0.00e+00    -  0.00e+00
 0.00e+00   0
   1  4.0759581e+02 0.00e+00 7.38e-02  -1.1 7.87e-02    -  9.91e-01
 1.00e+00f  1
   2  7.3211108e+01 0.00e+00 2.02e-02  -1.7 1.37e+00    -  9.95e-01
 1.00e+00f  1
   3  3.8669378e+01 0.00e+00 1.33e-02  -3.4 3.92e-01    -  9.76e-01
 1.00e+00f  1
   4  3.1369069e+01 0.00e+00 1.09e-02  -3.9 2.89e-01    -  9.91e-01
 1.00e+00f  1
   5  2.4979899e+01 0.00e+00 1.05e-02  -4.8 4.52e-01    -  9.98e-01
 1.00e+00f  1
   6  2.0983319e+01 0.00e+00 1.42e-02  -5.5 7.01e-01    -  1.00e+00
 1.00e+00f  1
   7  1.7675867e+01 0.00e+00 7.63e-03  -6.0 2.78e-01    -  1.00e+00
 1.00e+00f  1
   8  1.6447624e+01 0.00e+00 6.12e-03  -7.2 2.32e-01    -  1.00e+00
 1.00e+00f  1
   9  1.4931143e+01 0.00e+00 5.02e-03  -8.5 4.21e-01    -  1.00e+00
 1.00e+00f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
  10  1.2970620e+01 0.00e+00 4.15e-03  -9.5 6.30e-01    -  1.00e+00
 1.00e+00f  1
  11  1.2308371e+01 0.00e+00 4.93e-03 -10.1 9.11e-01    -  1.00e+00
 3.28e-01f  1
  12  1.2304433e+01 0.00e+00 4.92e-03 -11.0 5.39e-01    -  1.00e+00
 2.27e-03f  1
  13  1.2290515e+01 0.00e+00 1.57e-02 -11.0 7.62e-01    -  1.00e+00
 5.00e-03f  1
  14  1.1995743e+01 0.00e+00 4.54e-03  -8.5 9.93e-01    -  9.33e-01
 8.31e-02f  1
  15  1.1946252e+01 0.00e+00 4.47e-03  -6.5 1.12e+00    -  1.45e-01
 1.25e-02f  1
  16  1.1292055e+01 0.00e+00 3.46e-03  -7.7 1.20e+00    -  1.00e+00
 1.78e-01f  1
  17  1.1288120e+01 0.00e+00 6.81e-03  -8.6 1.13e+00    -  1.00e+00
 1.28e-03f  1
  18  1.1154663e+01 0.00e+00 8.08e-03  -6.5 1.14e+00    -  1.53e-01
 4.40e-02f  1
  19  1.0832457e+01 0.00e+00 1.88e-02  -5.3 1.19e+00    -  9.44e-01
 1.11e-01f  1
```

```
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
  20  1.0772410e+01 0.00e+00 2.37e-02  -4.5 1.24e+00    -  1.00e+00
 2.20e-02f  1
  21  1.0358877e+01 0.00e+00 8.77e-03  -4.8 1.29e+00    -  5.88e-01
 1.61e-01f  1
  22  1.0083883e+01 0.00e+00 1.05e-02  -4.4 1.26e+00    -  1.00e+00
 1.29e-01f  1
  23  9.7434140e+00 0.00e+00 1.02e-02  -4.4 1.23e+00    -  8.87e-01
 1.99e-01f  1
  24  9.3764057e+00 0.00e+00 9.25e-03  -4.1 1.15e+00    -  9.30e-01
 3.02e-01f  1
  25  9.2184245e+00 0.00e+00 6.87e-03  -5.3 8.83e-01    -  6.14e-01
 2.07e-01f  1
  26  9.0714610e+00 0.00e+00 1.80e-02  -4.5 8.16e-01    -  8.50e-01
 2.62e-01f  1
  27  8.9006009e+00 0.00e+00 5.45e-03  -4.1 7.78e-01    -  7.68e-01
 3.86e-01f  1
  28  8.8003450e+00 0.00e+00 4.41e-03  -5.5 6.98e-01    -  4.63e-01
 2.42e-01f  1
  29  8.7485973e+00 0.00e+00 4.80e-03  -4.2 7.40e-01    -  6.36e-01
 1.10e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
  30  8.5225360e+00 0.00e+00 5.26e-03  -4.0 1.06e+00    -  3.89e-01
 3.34e-01f  1
  31  8.3978542e+00 0.00e+00 3.97e-03  -3.9 7.74e-01    -  3.83e-01
 2.09e-01f  1
  32  8.2488685e+00 0.00e+00 5.18e-03  -4.1 8.01e-01    -  4.06e-01
 2.55e-01f  1
  33  8.1164631e+00 0.00e+00 6.27e-03  -4.1 7.81e-01    -  4.11e-01
 2.25e-01f  1
  34  8.0065792e+00 0.00e+00 3.29e-03  -6.2 6.67e-01    -  2.72e-01
 2.32e-01f  1
  35  7.9047812e+00 0.00e+00 9.28e-03  -4.6 6.79e-01    -  9.92e-01
 2.47e-01f  1
  36  7.7590106e+00 0.00e+00 5.24e-03  -4.2 5.46e-01    -  4.06e-01
 6.48e-01f  1
  37  7.6711185e+00 0.00e+00 2.45e-03  -4.7 3.43e-01    -  8.58e-01
 8.37e-01f  1
  38  7.5829603e+00 0.00e+00 5.90e-03  -4.3 1.21e-01    -  8.64e-01
 1.00e+00f  1
  39  7.4625863e+00 0.00e+00 1.59e-03  -4.4 2.17e-01    -  4.11e-01
 1.00e+00f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
  40  7.3769763e+00 0.00e+00 9.57e-04  -4.3 1.98e-01    -  8.20e-01
 1.00e+00f  1
  41  7.3356227e+00 0.00e+00 1.77e-03  -4.7 3.56e-01    -  9.86e-01
 3.17e-01f  2
  42  7.2741518e+00 0.00e+00 9.50e-04  -5.0 1.23e-01    -  1.00e+00
 8.91e-01f  1
  43  7.2330398e+00 0.00e+00 2.53e-03  -4.7 1.97e-01    -  1.00e+00
 3.32e-01f  1
```

```
  44  7.1402542e+00 0.00e+00 2.66e-03  -4.5 5.06e-01    -  5.84e-01
 4.74e-01f  1
  45  7.1103231e+00 0.00e+00 5.33e-03  -4.8 4.63e-01    -  8.85e-01
 1.61e-01f  1
  46  7.0866714e+00 0.00e+00 5.94e-03  -4.2 3.47e-01    -  9.11e-01
 1.45e-01f  1
  47  6.9915681e+00 0.00e+00 6.19e-03  -4.7 6.15e-01    -  6.14e-01
 4.07e-01f  1
  48  9.0032491e+00 0.00e+00 8.47e-03  -2.5 7.04e+00    -  1.05e-01
 2.69e-01f  1
  49  7.0843202e+00 0.00e+00 5.41e-03  -3.5 1.72e+00    -  8.10e-01
 1.00e+00f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
  50  6.9619232e+00 0.00e+00 5.40e-03  -3.5 2.39e-01    -  1.00e+00
 1.00e+00f  1
  51  6.9116610e+00 0.00e+00 5.27e-03  -4.3 4.37e-01    -  8.47e-01
 3.72e-01f  1
  52  6.8143634e+00 0.00e+00 3.23e-03  -4.6 6.70e-01    -  9.99e-01
 7.55e-01f  1
  53  6.7565957e+00 0.00e+00 6.17e-03  -5.0 5.38e-01    -  9.99e-01
 4.45e-01f  1
  54  6.7217306e+00 0.00e+00 3.08e-03  -4.5 2.46e-01    -  5.81e-01
 5.49e-01f  1
  55  7.6316222e+00 0.00e+00 5.94e-03  -2.6 1.07e+01    -  1.82e-02
 2.18e-01f  1
  56  7.0683086e+00 0.00e+00 7.95e-03  -4.3 2.93e+00    -  1.82e-01
 7.50e-01f  1
  57  6.8430036e+00 0.00e+00 1.60e-02  -4.3 1.04e+00    -  7.08e-01
 2.31e-01f  1
  58  6.7124481e+00 0.00e+00 1.24e-02  -4.3 6.09e-01    -  5.36e-01
 2.49e-01f  1
  59  6.5984020e+00 0.00e+00 1.87e-02  -4.6 6.57e-01    -  1.00e+00
 3.19e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
  60  6.5470229e+00 0.00e+00 1.12e-02  -4.9 5.53e-01    -  1.00e+00
 2.34e-01f  1
  61  6.5077251e+00 0.00e+00 1.12e-02  -5.4 5.26e-01    -  9.53e-01
 2.33e-01f  1
  62  6.4672534e+00 0.00e+00 1.09e-02  -6.3 5.52e-01    -  1.00e+00
 2.99e-01f  1
  63  6.4422879e+00 0.00e+00 8.66e-03  -4.7 3.93e-01    -  7.01e-01
 2.90e-01f  1
  64  6.4229276e+00 0.00e+00 1.16e-02  -4.9 4.01e-01    -  7.92e-01
 2.47e-01f  1
  65  6.4026381e+00 0.00e+00 8.15e-03  -6.1 4.79e-01    -  4.37e-01
 2.42e-01f  1
  66  6.3920783e+00 0.00e+00 1.07e-02  -6.1 5.31e-01    -  8.45e-01
 1.16e-01f  1
  67  6.3669945e+00 0.00e+00 1.05e-02  -6.0 7.50e-01    -  8.48e-01
 1.96e-01f  1
  68  6.3458893e+00 0.00e+00 8.79e-03  -5.9 8.28e-01    -  6.61e-01
 1.46e-01f  1
```

```
  69  6.3302564e+00 0.00e+00 9.58e-03  -5.9 1.24e+00    -  8.73e-01
 6.83e-02f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
  70  6.2672384e+00 0.00e+00 3.65e-03  -5.5 2.10e+00    -  1.00e+00
 1.58e-01f  1
  71  6.2290540e+00 0.00e+00 5.49e-03  -4.3 9.72e-01    -  3.61e-01
 1.87e-01f  1
  72  1.0157874e+01 0.00e+00 9.07e-03  -2.7 2.03e+01    -  7.57e-03
 3.39e-01f  1
  73  6.4117859e+00 0.00e+00 4.46e-03  -4.4 8.62e+00    -  6.27e-02
 7.49e-01f  1
  74  6.2934081e+00 0.00e+00 2.90e-03  -4.4 1.32e+00    -  7.46e-01
 2.03e-01f  1
  75  6.2579655e+00 0.00e+00 2.20e-02  -4.4 1.12e+00    -  9.56e-01
 9.95e-02f  1
  76  6.2086129e+00 0.00e+00 1.32e-02  -4.4 7.86e-01    -  6.65e-01
 1.85e-01f  1
  77  6.1189136e+00 0.00e+00 1.97e-02  -4.7 8.04e-01    -  9.63e-01
 4.18e-01f  1
  78  6.0968479e+00 0.00e+00 7.97e-03  -4.7 4.73e-01    -  8.50e-01
 2.06e-01f  1
  79  6.0729888e+00 0.00e+00 9.55e-03 -10.7 6.53e-01    -  4.96e-01
 1.90e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
  80  6.0455396e+00 0.00e+00 8.63e-03  -5.7 7.06e-01    -  9.41e-01
 2.30e-01f  1
  81  6.0183843e+00 0.00e+00 7.93e-03  -6.4 7.22e-01    -  9.30e-01
 2.47e-01f  1
  82  6.0038361e+00 0.00e+00 9.42e-03  -6.7 7.73e-01    -  7.93e-01
 1.33e-01f  1
  83  5.9894075e+00 0.00e+00 1.16e-02 -11.0 1.04e+00    -  6.92e-01
 1.00e-01f  1
  84  5.9769568e+00 0.00e+00 5.46e-03  -6.2 1.37e+00    -  9.25e-01
 6.66e-02f  1
  85  5.9416078e+00 0.00e+00 4.13e-03  -7.2 1.63e+00    -  5.26e-01
 1.67e-01f  1
  86  5.9180552e+00 0.00e+00 8.44e-03  -6.6 1.61e+00    -  7.26e-01
 1.16e-01f  1
  87  5.9046801e+00 0.00e+00 4.89e-03  -5.2 8.32e-01    -  3.93e-01
 1.31e-01f  1
  88  6.2383777e+00 0.00e+00 8.96e-03  -4.0 5.82e+00    -  2.31e-01
 1.00e+00f  1
  89  6.1256617e+00 0.00e+00 7.69e-03  -4.6 3.73e+00    -  3.93e-01
 2.09e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
  90  6.0929699e+00 0.00e+00 5.68e-03  -4.6 2.17e+00    -  4.21e-01
 7.37e-02f  1
  91  6.0213922e+00 0.00e+00 6.86e-03  -4.6 1.57e+00    -  2.30e-01
 1.84e-01f  1
  92  5.9421673e+00 0.00e+00 1.30e-02  -4.6 1.38e+00    -  5.93e-01
 2.71e-01f  1
```

```
 93  5.8985886e+00 0.00e+00 9.54e-03  -4.6 9.04e-01    -  6.42e-01
 2.52e-01f  1
 94  5.8653670e+00 0.00e+00 7.82e-03  -4.9 7.74e-01    -  8.19e-01
 2.58e-01f  1
 95  5.8445779e+00 0.00e+00 9.78e-03  -5.7 6.93e-01    -  5.89e-01
 2.06e-01f  1
 96  5.8269158e+00 0.00e+00 6.59e-03  -6.0 7.15e-01    -  8.88e-01
 1.89e-01f  1
 97  5.8078218e+00 0.00e+00 8.00e-03  -5.7 6.72e-01    -  6.22e-01
 2.36e-01f  1
 98  5.7930219e+00 0.00e+00 8.76e-03  -5.7 6.39e-01    -  7.29e-01
 2.05e-01f  1
 99  5.7768952e+00 0.00e+00 5.72e-03  -5.1 6.86e-01    -  6.84e-01
 2.16e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 100  5.7561293e+00 0.00e+00 2.72e-03  -4.5 3.04e-01    -  5.18e-01
 6.18e-01f  1
 101  5.7374218e+00 0.00e+00 1.76e-03  -4.4 2.25e-01    -  3.92e-01
 6.50e-01f  1
 102  5.6981688e+00 0.00e+00 1.23e-03  -4.3 6.54e-01    -  4.54e-01
 4.60e-01f  1
 103  5.6777599e+00 0.00e+00 8.11e-03  -4.7 1.07e+00    -  4.64e-01
 1.47e-01f  1
 104  5.6720387e+00 0.00e+00 8.85e-03  -6.6 1.06e+00    -  4.02e-01
 4.33e-02f  1
 105  5.6376567e+00 0.00e+00 5.63e-03  -6.6 1.71e+00    -  3.23e-01
 1.69e-01f  1
 106  5.6292255e+00 0.00e+00 6.52e-03  -7.0 1.59e+00    -  3.14e-01
 4.33e-02f  1
 107  5.5967590e+00 0.00e+00 5.53e-03  -5.2 1.78e+00    -  3.41e-01
 1.59e-01f  1
 108  6.1655582e+00 0.00e+00 6.17e-03  -3.1 2.66e+01    -  3.70e-02
 1.55e-01f  1
 109  5.8513275e+00 0.00e+00 5.83e-03  -4.5 3.65e+00    -  9.30e-03
 3.49e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 110  5.7363732e+00 0.00e+00 4.97e-03  -4.5 2.09e+00    -  5.53e-01
 2.32e-01f  1
 111  5.6734649e+00 0.00e+00 8.09e-03  -4.5 1.47e+00    -  7.07e-01
 1.89e-01f  1
 112  5.5894769e+00 0.00e+00 1.24e-02  -4.5 1.04e+00    -  6.08e-01
 3.88e-01f  1
 113  5.5502883e+00 0.00e+00 6.74e-03  -4.1 2.41e-01    -  6.40e-01
 1.00e+00f  1
 114  5.5392051e+00 0.00e+00 6.02e-03  -5.0 4.35e-01    -  8.82e-01
 2.24e-01f  1
 115  5.5203424e+00 0.00e+00 1.26e-02  -5.5 7.24e-01    -  1.00e+00
 2.59e-01f  1
 116  5.5022283e+00 0.00e+00 7.64e-03  -6.2 8.39e-01    -  9.98e-01
 2.34e-01f  1
 117  5.4754477e+00 0.00e+00 4.87e-03  -6.0 1.21e+00    -  8.92e-01
 2.64e-01f  1
```

```
 118  5.4603671e+00 0.00e+00 4.89e-03  -5.5 9.19e-01    -  4.93e-01
 1.94e-01f  1
 119  5.5439585e+00 0.00e+00 1.08e-02  -4.1 3.14e+00    -  1.75e-01
 1.00e+00f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 120  5.5117901e+00 0.00e+00 6.41e-03  -4.9 1.57e+00    -  5.81e-01
 2.10e-01f  1
 121  5.4829909e+00 0.00e+00 1.71e-03  -4.9 2.00e+00    -  4.69e-01
 1.35e-01f  1
 122  5.4793397e+00 0.00e+00 9.14e-03  -4.9 1.03e+00    -  4.24e-01
 3.47e-02f  1
 123  5.4450212e+00 0.00e+00 6.94e-03  -4.9 1.49e+00    -  2.49e-01
 2.24e-01f  1
 124  5.4082859e+00 0.00e+00 4.04e-03  -4.6 3.80e+00    -  4.79e-01
 2.88e-01f  1
 125  5.4004431e+00 0.00e+00 5.71e-03  -5.0 4.19e+00    -  4.66e-01
 6.46e-02f  1
 126  5.3814757e+00 0.00e+00 9.82e-03  -5.3 5.10e+00    -  8.08e-01
 1.49e-01f  1
 127  5.7462797e+00 0.00e+00 8.83e-03  -3.1 1.66e+01    -  1.76e-02
 1.71e-01f  1
 128  5.6514869e+00 0.00e+00 8.50e-03  -4.7 4.69e+00    -  2.04e-02
 1.47e-01f  1
 129  5.3772949e+00 0.00e+00 5.93e-03  -4.7 4.27e+00    -  7.47e-01
 6.67e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 130  5.3578723e+00 0.00e+00 1.13e-02  -4.4 1.57e+00    -  1.00e+00
 3.51e-01f  1
 131  5.6282087e+00 0.00e+00 1.03e-02  -2.4 5.81e+01    -  1.55e-03
 4.18e-02f  1
 132  5.4192280e+00 0.00e+00 2.97e-03  -4.4 4.69e+00    -  5.03e-01
 1.00e+00f  1
 133  5.3279444e+00 0.00e+00 1.39e-03  -4.4 1.36e+00    -  1.00e+00
 1.00e+00f  1
 134  5.3223453e+00 0.00e+00 7.44e-03  -5.2 6.65e-01    -  9.96e-01
 1.24e-01f  1
 135  5.3002813e+00 0.00e+00 5.86e-03  -6.4 1.01e+00    -  1.00e+00
 3.44e-01f  1
 136  5.2797877e+00 0.00e+00 1.80e-03  -4.9 1.42e+00    -  7.73e-01
 4.76e-01f  1
 137  5.2765792e+00 0.00e+00 4.43e-03  -5.2 1.00e+00    -  3.47e-01
 1.04e-01f  1
 138  5.8966043e+00 0.00e+00 3.99e-03  -3.1 3.22e+01    -  4.07e-03
 1.82e-01f  1
 139  5.3153153e+00 0.00e+00 3.86e-03  -4.9 1.08e+01    -  2.95e-02
 6.93e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 140  5.2811037e+00 0.00e+00 3.24e-03  -4.9 7.27e+00    -  5.02e-01
 5.29e-02f  2
 141  5.2741099e+00 0.00e+00 4.09e-03  -4.9 1.39e+00    -  7.07e-01
 8.37e-02f  1
```

```
 142  5.2518247e+00 0.00e+00 3.91e-03  -4.9 1.41e+00    -  9.98e-01
 2.79e-01f  1
 143  5.2422959e+00 0.00e+00 1.18e-02 -10.9 1.46e+00    -  7.03e-01
 1.43e-01f  1
 144  5.2396163e+00 0.00e+00 1.53e-02  -7.5 1.45e+00    -  7.97e-01
 4.51e-02f  1
 145  5.2161771e+00 0.00e+00 6.44e-03  -5.4 1.72e+00    -  5.50e-01
 3.86e-01f  1
 146  5.2070040e+00 0.00e+00 4.22e-03  -4.9 9.63e-01    -  6.17e-01
 3.31e-01f  1
 147  5.1971643e+00 0.00e+00 2.13e-03  -4.7 4.63e-01    -  3.97e-01
 1.00e+00f  1
 148  5.1939683e+00 0.00e+00 4.65e-03  -5.4 1.10e+00    -  5.88e-01
 1.32e-01f  1
 149  5.1872551e+00 0.00e+00 4.49e-03  -5.4 1.75e+00    -  9.97e-01
 1.69e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 150  5.1764179e+00 0.00e+00 3.39e-03  -5.0 1.65e+00    -  6.78e-01
 2.86e-01f  1
 151  5.1608540e+00 0.00e+00 1.86e-03  -4.7 1.33e+00    -  3.21e-01
 5.08e-01f  1
 152  5.1517156e+00 0.00e+00 2.06e-03  -4.7 1.40e+00    -  2.74e-01
 2.48e-01f  1
 153  5.1168228e+00 0.00e+00 9.34e-04  -4.5 2.41e+00    -  3.86e-01
 5.96e-01f  1
 154  5.1107575e+00 0.00e+00 9.51e-03  -5.0 2.04e+00    -  6.42e-01
 1.10e-01f  1
 155  5.0984779e+00 0.00e+00 7.45e-03  -5.4 2.55e+00    -  8.22e-01
 1.98e-01f  1
 156  5.0943759e+00 0.00e+00 6.09e-03  -5.5 2.24e+00    -  4.97e-01
 7.61e-02f  1
 157  5.0792497e+00 0.00e+00 4.36e-03  -5.8 3.13e+00    -  7.71e-01
 2.13e-01f  1
 158  5.0732716e+00 0.00e+00 3.79e-03  -5.3 2.40e+00    -  2.99e-01
 1.13e-01f  1
 159  5.0651329e+00 0.00e+00 3.85e-03  -5.1 2.86e+00    -  6.67e-01
 1.31e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 160  5.0537938e+00 0.00e+00 5.00e-03  -5.3 2.82e+00    -  3.06e-01
 1.87e-01f  1
 161  5.0401234e+00 0.00e+00 3.72e-03 -11.0 3.73e+00    -  2.35e-01
 1.84e-01f  1
 162  5.0327249e+00 0.00e+00 4.53e-03  -5.9 3.63e+00    -  6.85e-01
 1.01e-01f  1
 163  5.0219279e+00 0.00e+00 3.07e-03  -6.1 3.28e+00    -  2.35e-01
 1.64e-01f  1
 164  5.1861227e+00 0.00e+00 3.19e-03  -3.7 2.17e+01    -  2.25e-02
 2.04e-01f  1
 165  5.1157534e+00 0.00e+00 3.45e-03  -5.2 7.92e+00    -  1.50e-02
 2.26e-01f  1
 166  5.1003448e+00 0.00e+00 5.27e-03  -5.2 6.20e+00    -  6.96e-01
 6.69e-02f  1
```

```
 167  5.0580055e+00 0.00e+00 7.72e-03  -5.2 5.29e+00    -  4.88e-01
 2.19e-01f  1
 168  5.0249617e+00 0.00e+00 6.12e-03  -5.2 3.94e+00    -  6.15e-01
 2.55e-01f  1
 169  5.0140981e+00 0.00e+00 3.45e-03  -5.2 2.49e+00    -  5.93e-01
 1.37e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 170  4.9978747e+00 0.00e+00 8.21e-03  -5.3 2.07e+00    -  7.10e-01
 2.57e-01f  1
 171  5.1680528e+00 0.00e+00 8.31e-03  -3.4 2.12e+01    -  2.22e-02
 2.90e-01f  1
 172  4.9864678e+00 0.00e+00 7.83e-03  -4.9 7.80e+00    -  4.28e-01
 9.09e-01f  1
 173  4.9816180e+00 0.00e+00 8.17e-03  -5.6 1.82e+00    -  1.00e+00
 7.42e-02f  1
 174  4.9740463e+00 0.00e+00 8.97e-03  -7.0 1.53e+00    -  8.58e-01
 1.46e-01f  1
 175  4.9642860e+00 0.00e+00 6.45e-03  -6.3 1.52e+00    -  8.14e-01
 2.05e-01f  1
 176  4.9558072e+00 0.00e+00 1.13e-02  -5.9 1.35e+00    -  7.58e-01
 2.22e-01f  1
 177  4.9481910e+00 0.00e+00 9.49e-03  -6.0 1.47e+00    -  9.87e-01
 2.15e-01f  1
 178  4.9406065e+00 0.00e+00 5.13e-03  -5.6 1.29e+00    -  8.05e-01
 2.77e-01f  1
 179  4.9350252e+00 0.00e+00 2.65e-03  -5.0 4.71e-01    -  3.17e-01
 5.73e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 180  4.9318309e+00 0.00e+00 1.91e-03  -5.0 2.36e-01    -  4.72e-01
 7.12e-01f  1
 181  4.9290659e+00 0.00e+00 5.47e-03  -5.5 7.47e-01    -  5.58e-01
 2.18e-01f  1
 182  4.9273414e+00 0.00e+00 4.15e-03  -5.6 1.24e+00    -  7.83e-01
 7.91e-02f  1

Number of Iterations....: 182

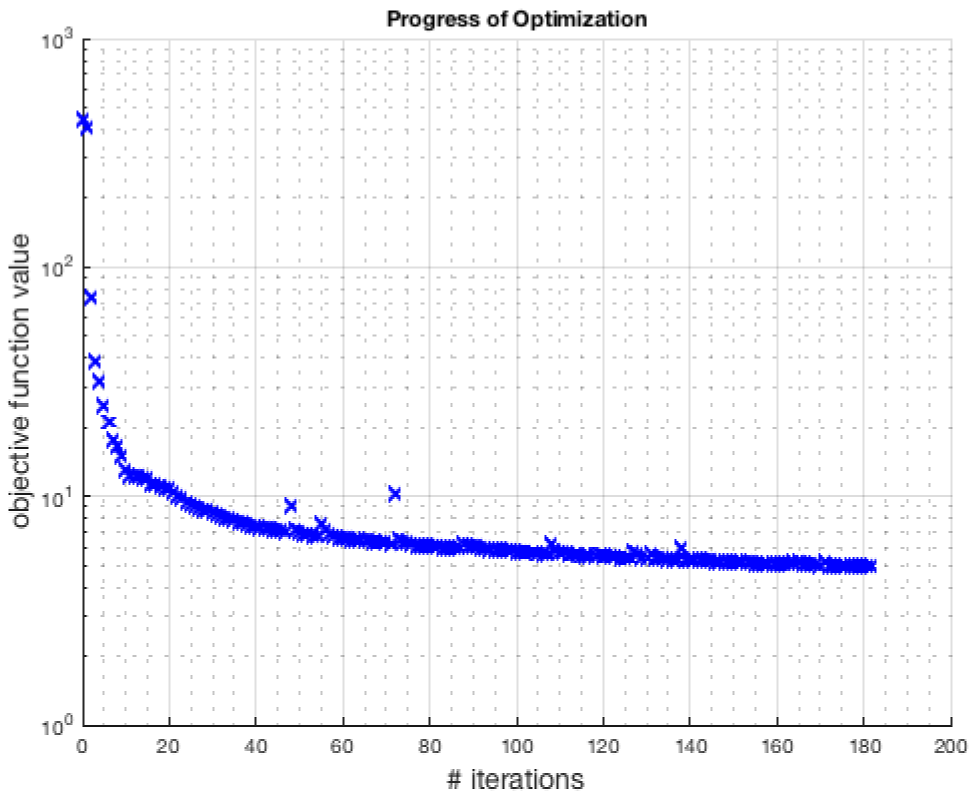
                                   (scaled)                 (unscaled)
Objective...............:   4.9273413692900743e+00
 4.9273413692900743e+00
Dual infeasibility......:   4.1477500774598679e-03
 4.1477500774598679e-03
Constraint violation....:   0.0000000000000000e+00
 0.0000000000000000e+00
Complementarity.........:   1.4640735011706293e-05
 1.4640735011706293e-05
Overall NLP error.......:   4.1477500774598679e-03
 4.1477500774598679e-03


Number of objective function evaluations             = 193
Number of objective gradient evaluations             = 183
```

```
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)   =     11.819
Total CPU secs in NLP function evaluations           =    106.296

EXIT: Solved To Acceptable Level.

*** IPOPT DONE ***
Calculating final cubes...
matRad: applying a constant RBE of 1.1
```



Calculate quality indicators

```
[dvh,qi]       = matRad_indicatorWrapper(cst,pln,resultGUI);
ixRectum       = 8;
display(qi(ixRectum).D_5);
```

```
  0               Rectum - Mean dose =  0.88 Gy +/-  0.68 Gy (Max dose
 =  2.35 Gy, Min dose =  0.00 Gy)
                           D2% =  2.26 Gy, D5% =  2.11 Gy, D50% =
 0.96 Gy, D95% =  0.00 Gy, D98% =  0.00 Gy,
                           V0Gy = 100.00%, V0.4Gy =  65.71%, V0.9Gy =
 51.89%, V1.4Gy =  20.87%, V1.8Gy =   8.52%, V2.3Gy =   1.13%,
```

```
 1          Penile_bulb - Mean dose =  0.04 Gy +/-  0.06 Gy (Max dose
=  0.18 Gy, Min dose =  0.00 Gy)
                          D2% =  0.17 Gy, D5% =  0.17 Gy, D50% =
0.00 Gy, D95% =  0.00 Gy, D98% =  0.00 Gy,
                          V0Gy = 100.00%, V0.4Gy =   0.00%, V0.9Gy =
 0.00%, V1.4Gy =   0.00%, V1.8Gy =   0.00%, V2.3Gy =   0.00%,

 2          Lymph Nodes - Mean dose =  1.90 Gy +/-  0.10 Gy (Max dose
=  2.33 Gy, Min dose =  1.80 Gy)
                          D2% =  2.29 Gy, D5% =  2.19 Gy, D50% =
1.87 Gy, D95% =  1.85 Gy, D98% =  1.83 Gy,
                          V0Gy = 100.00%, V0.4Gy = 100.00%, V0.9Gy =
100.00%, V1.4Gy = 100.00%, V1.8Gy = 100.00%, V2.3Gy =   1.13%,

 3      Rt femoral head - Mean dose =  0.66 Gy +/-  0.52 Gy (Max dose
=  1.42 Gy, Min dose =  0.00 Gy)
                          D2% =  1.31 Gy, D5% =  1.27 Gy, D50% =
0.90 Gy, D95% =  0.00 Gy, D98% =  0.00 Gy,
                          V0Gy = 100.00%, V0.4Gy =  61.83%, V0.9Gy =
49.48%, V1.4Gy =   0.03%, V1.8Gy =   0.00%, V2.3Gy =   0.00%,

 4         prostate_bed - Mean dose =  2.27 Gy +/-  0.02 Gy (Max dose
=  2.34 Gy, Min dose =  2.21 Gy)
                          D2% =  2.30 Gy, D5% =  2.29 Gy, D50% =
2.27 Gy, D95% =  2.24 Gy, D98% =  2.23 Gy,
                          V0Gy = 100.00%, V0.4Gy = 100.00%, V0.9Gy =
100.00%, V1.4Gy = 100.00%, V1.8Gy = 100.00%, V2.3Gy =   1.82%,

 5               PTV_68 - Mean dose =  2.26 Gy +/-  0.04 Gy (Max dose
=  2.36 Gy, Min dose =  1.95 Gy)
                          D2% =  2.32 Gy, D5% =  2.31 Gy, D50% =
2.27 Gy, D95% =  2.16 Gy, D98% =  2.12 Gy,
                          V0Gy = 100.00%, V0.4Gy = 100.00%, V0.9Gy =
100.00%, V1.4Gy = 100.00%, V1.8Gy = 100.00%, V2.3Gy =   8.96%,
                          CI = 0.9136, HI =  6.32 for reference dose
of 2.3 Gy

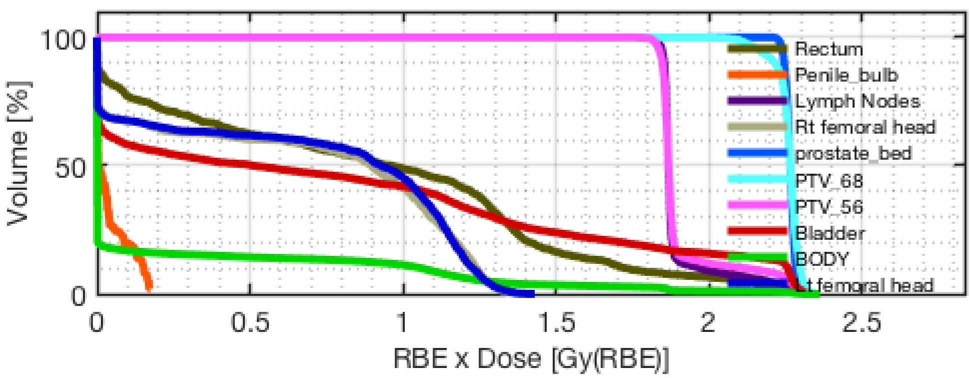
 6               PTV_56 - Mean dose =  1.91 Gy +/-  0.12 Gy (Max dose
=  2.36 Gy, Min dose =  1.74 Gy)
                          D2% =  2.29 Gy, D5% =  2.26 Gy, D50% =
1.87 Gy, D95% =  1.84 Gy, D98% =  1.82 Gy,
                          V0Gy = 100.00%, V0.4Gy = 100.00%, V0.9Gy =
100.00%, V1.4Gy = 100.00%, V1.8Gy =  99.61%, V2.3Gy =   1.42%,
                          CI = 0.5130, HI = 22.70 for reference dose
of 1.9 Gy

 7              Bladder - Mean dose =  0.80 Gy +/-  0.85 Gy (Max dose
=  2.35 Gy, Min dose =  0.00 Gy)
                          D2% =  2.29 Gy, D5% =  2.28 Gy, D50% =
0.51 Gy, D95% =  0.00 Gy, D98% =  0.00 Gy,
                          V0Gy = 100.00%, V0.4Gy =  51.31%, V0.9Gy =
43.51%, V1.4Gy =  25.90%, V1.8Gy =  18.56%, V2.3Gy =   1.44%,
```

```
 8                 BODY - Mean dose =  0.19 Gy +/-  0.48 Gy (Max dose
=  2.36 Gy, Min dose =  0.00 Gy)
                          D2% =  1.86 Gy, D5% =  1.27 Gy, D50% =
0.00 Gy, D95% =  0.00 Gy, D98% =  0.00 Gy,
                          V0Gy = 100.00%, V0.4Gy =  14.87%, V0.9Gy =
12.39%, V1.4Gy =   3.82%, V1.8Gy =   2.63%, V2.3Gy =   0.09%,

 9       Lt femoral head - Mean dose =  0.68 Gy +/-  0.52 Gy (Max dose
=  1.43 Gy, Min dose =  0.00 Gy)
                          D2% =  1.32 Gy, D5% =  1.27 Gy, D50% =
0.93 Gy, D95% =  0.00 Gy, D98% =  0.00 Gy,
                          V0Gy = 100.00%, V0.4Gy =  62.82%, V0.9Gy =
51.81%, V1.4Gy =   0.13%, V1.8Gy =   0.00%, V2.3Gy =   0.00%,

  2.275438245075841
```



	mean	std	max	min
Rectum	0.8764	0.6816	2.3523	
Penile_bulb	0.0418	0.0584	0.1760	
Lymph Nodes	1.8978	0.0998	2.3269	1.80
Rt femoral head	0.6642	0.5199	1.4200	
prostate_bed	2.2656	0.0157	2.3445	2.21
PTV_68	2.2587	0.0432	2.3637	1.95

Let's change the optimization parameter of the rectum in such a way that it will be better spared. We increase the penalty and lower the threshold of the squared overdose objective function. Afterwards we re-optimize the treatment plan and evaluate dose statistics one more time.

```
cst{ixRectum,6}.penalty = 500;
cst{ixRectum,6}.dose    = 40;
resultGUI               = matRad_fluenceOptimization(dij,cst,pln);
[dvh2,qi2]              = matRad_indicatorWrapper(cst,pln,resultGUI);
display(qi2(ixRectum).D_5);
```

```
******************************************************************************
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............................:    45333
                     variables with only lower bounds:    45333
                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  4.6807049e+02 0.00e+00 1.07e+00   0.0 0.00e+00    -  0.00e+00
 0.00e+00   0
   1  4.3434493e+02 0.00e+00 7.38e-02  -1.1 8.03e-02    -  9.91e-01
 1.00e+00f  1
   2  8.3100873e+01 0.00e+00 2.06e-02  -1.7 1.35e+00    -  1.00e+00
 1.00e+00f  1
   3  4.8222733e+01 0.00e+00 1.35e-02  -3.4 3.92e-01    -  9.74e-01
 1.00e+00f  1
   4  4.0663972e+01 0.00e+00 1.10e-02  -3.9 2.88e-01    -  9.89e-01
 1.00e+00f  1
   5  3.3924446e+01 0.00e+00 1.11e-02  -4.7 4.51e-01    -  1.00e+00
 1.00e+00f  1
   6  2.9153561e+01 0.00e+00 1.46e-02  -5.5 7.20e-01    -  1.00e+00
 1.00e+00f  1
   7  2.5285291e+01 0.00e+00 8.01e-03  -6.1 3.34e-01    -  1.00e+00
 1.00e+00f  1
   8  2.3710571e+01 0.00e+00 6.46e-03  -7.2 2.57e-01    -  1.00e+00
 1.00e+00f  1
   9  2.1776586e+01 0.00e+00 5.26e-03  -8.4 4.64e-01    -  1.00e+00
 1.00e+00f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
  10  1.9601992e+01 0.00e+00 4.79e-03  -9.1 6.19e-01    -  1.00e+00
 1.00e+00f  1
  11  1.8982846e+01 0.00e+00 4.44e-03  -9.2 1.04e+00    -  1.00e+00
 2.04e-01f  1
```

```
  12  1.8979424e+01 0.00e+00 4.44e-03 -10.0 5.31e-01    -  1.00e+00
 1.84e-03f  1
  13  1.8897165e+01 0.00e+00 1.12e-02  -9.0 8.75e-01    -  1.00e+00
 2.41e-02f  1
  14  1.8730836e+01 0.00e+00 4.26e-03  -6.9 1.31e+00    -  9.78e-01
 3.17e-02f  1
  15  1.8608735e+01 0.00e+00 4.16e-03  -4.9 1.39e+00    -  2.44e-02
 2.12e-02f  1
  16  1.8470648e+01 0.00e+00 1.67e-02  -4.4 1.37e+00    -  9.19e-01
 2.54e-02f  1
  17  1.7877156e+01 0.00e+00 6.34e-03  -5.0 1.53e+00    -  4.87e-01
 9.41e-02f  1
  18  1.7420780e+01 0.00e+00 2.21e-02  -3.4 1.25e+00    -  5.47e-01
 1.02e-01f  1
  19  1.6344009e+01 0.00e+00 7.99e-03  -9.7 1.43e+00    -  5.50e-01
 2.91e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
  20  1.5938159e+01 0.00e+00 1.87e-02  -4.0 1.32e+00    -  8.60e-01
 1.18e-01f  1
  21  1.5358422e+01 0.00e+00 1.62e-02  -3.7 9.03e-01    -  9.71e-01
 3.44e-01f  1
  22  1.4984106e+01 0.00e+00 6.13e-03  -4.1 1.08e+00    -  7.03e-01
 3.71e-01f  1
  23  2.6448681e+01 0.00e+00 2.75e-02  -2.2 3.00e+00    -  1.86e-01
 1.00e+00f  1
  24  1.5501129e+01 0.00e+00 1.20e-02  -2.9 2.89e+00    -  1.00e+00
 1.00e+00f  1
  25  1.5084539e+01 0.00e+00 5.76e-03  -2.9 6.59e-01    -  1.00e+00
 2.50e-01f  3
  26  1.4405956e+01 0.00e+00 3.42e-03  -4.4 4.57e-01    -  9.36e-01
 1.00e+00f  1
  27  1.4235929e+01 0.00e+00 1.82e-03  -5.6 2.97e-01    -  1.00e+00
 1.00e+00f  1
  28  1.4001495e+01 0.00e+00 2.63e-03  -5.8 5.14e-01    -  9.99e-01
 4.22e-01f  1
  29  1.3804833e+01 0.00e+00 4.87e-03  -6.6 7.15e-01    -  1.00e+00
 2.47e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
  30  1.3583019e+01 0.00e+00 3.29e-03  -7.7 9.99e-01    -  8.04e-01
 2.19e-01f  1
  31  1.3468561e+01 0.00e+00 1.83e-02  -4.4 1.43e+00    -  2.89e-01
 1.58e-01f  1
  32  1.3300754e+01 0.00e+00 3.06e-03  -4.4 6.95e-01    -  4.80e-01
 2.05e-01f  1
  33  1.3163627e+01 0.00e+00 4.74e-03  -3.9 6.02e-01    -  4.15e-01
 1.91e-01f  1
  34  1.3009807e+01 0.00e+00 4.85e-03  -3.9 5.57e-01    -  4.99e-01
 2.73e-01f  1
  35  1.2851040e+01 0.00e+00 4.04e-03  -4.2 6.91e-01    -  4.94e-01
 2.79e-01f  1
  36  1.2735759e+01 0.00e+00 9.52e-03  -4.2 6.22e-01    -  9.20e-01
 2.47e-01f  1
```

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 37  1.2559414e+01 0.00e+00 3.82e-03  -4.2 6.44e-01    -  8.28e-01
4.51e-01f  1
 38  1.2525715e+01 0.00e+00 8.25e-03  -5.7 7.23e-01    -  5.88e-01
7.05e-02f  1
 39  1.2356165e+01 0.00e+00 6.18e-03  -4.2 6.51e-01    -  6.54e-01
4.52e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 40  2.4172234e+01 0.00e+00 2.16e-02  -2.3 2.55e+01    -  1.23e-01
2.48e-01f  1
 41  1.2729577e+01 0.00e+00 1.79e-02  -3.2 4.38e+00    -  1.00e+00
1.00e+00f  1
 42  1.2511196e+01 0.00e+00 7.06e-03  -3.2 1.27e-01    -  1.00e+00
1.00e+00f  1
 43  1.2443563e+01 0.00e+00 2.22e-03  -3.2 2.61e-01    -  8.42e-01
1.00e+00f  1
 44  1.2212903e+01 0.00e+00 2.44e-03  -4.8 4.87e-01    -  8.48e-01
9.62e-01f  1
 45  1.2112251e+01 0.00e+00 6.95e-03  -5.1 9.94e-01    -  9.95e-01
3.33e-01f  1
 46  1.2046801e+01 0.00e+00 6.19e-03  -6.1 7.86e-01    -  1.00e+00
3.55e-01f  1
 47  1.1936962e+01 0.00e+00 2.51e-03  -5.0 1.56e+00    -  8.07e-01
2.92e-01f  1
 48  1.1822539e+01 0.00e+00 1.16e-02  -4.2 6.81e-01    -  4.01e-01
5.13e-01f  1
 49  1.1692703e+01 0.00e+00 3.55e-03  -4.1 6.02e-01    -  3.64e-01
4.24e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 50  1.1682188e+01 0.00e+00 5.30e-03  -4.9 9.06e-01    -  3.00e-01
1.82e-02f  1
 51  1.1578878e+01 0.00e+00 8.22e-03  -5.2 9.12e-01    -  4.05e-01
1.93e-01f  1
 52  1.1450065e+01 0.00e+00 3.80e-03  -5.1 1.20e+00    -  1.00e+00
2.29e-01f  1
 53  1.1397717e+01 0.00e+00 5.22e-03 -11.0 9.19e-01    -  2.83e-01
1.25e-01f  1
 54  1.1284229e+01 0.00e+00 3.57e-03  -5.3 1.17e+00    -  9.47e-01
2.45e-01f  1
 55  1.1229392e+01 0.00e+00 4.87e-03  -5.0 1.01e+00    -  3.76e-01
1.33e-01f  1
 56  1.1136046e+01 0.00e+00 2.31e-03  -4.0 3.73e-01    -  3.59e-01
7.55e-01f  1
 57  1.1111773e+01 0.00e+00 5.81e-03  -4.6 5.75e-01    -  5.64e-01
1.18e-01f  1
 58  1.1070237e+01 0.00e+00 1.12e-02  -4.5 5.57e-01    -  6.80e-01
2.25e-01f  1
 59  1.1004953e+01 0.00e+00 5.27e-03  -5.0 7.92e-01    -  6.40e-01
2.66e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 60  1.3260658e+01 0.00e+00 5.62e-03  -2.7 1.53e+01    -  2.57e-02
2.70e-01f  1
```

```
  61  1.1146731e+01 0.00e+00 5.93e-03  -4.2 3.63e+00    -  2.39e-01
 7.78e-01f  1
  62  1.0974335e+01 0.00e+00 1.10e-02  -4.2 7.87e-01    -  1.00e+00
 4.87e-01f  1
  63  1.0897434e+01 0.00e+00 1.10e-02  -4.2 2.82e-01    -  8.07e-01
 7.28e-01f  1
  64  1.0867798e+01 0.00e+00 8.76e-03  -4.7 3.63e-01    -  8.44e-01
 2.32e-01f  1
  65  1.0809944e+01 0.00e+00 5.01e-03  -4.7 5.46e-01    -  9.93e-01
 3.31e-01f  1
  66  1.0763045e+01 0.00e+00 4.65e-03  -5.2 6.81e-01    -  6.53e-01
 2.33e-01f  1
  67  1.1510215e+01 0.00e+00 3.79e-03  -3.1 5.92e+00    -  2.18e-02
 3.17e-01f  1
  68  1.1110745e+01 0.00e+00 3.69e-03  -4.6 2.88e+00    -  2.46e-02
 3.11e-01f  1
  69  1.0660548e+01 0.00e+00 3.86e-02  -4.6 2.12e+00    -  6.27e-01
 5.92e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
  70  1.0636031e+01 0.00e+00 5.34e-03  -4.7 5.93e-01    -  8.86e-01
 1.36e-01f  1
  71  1.0604667e+01 0.00e+00 1.25e-02  -4.8 4.99e-01    -  8.04e-01
 2.32e-01f  1
  72  1.0569520e+01 0.00e+00 6.65e-03  -6.2 7.06e-01    -  7.36e-01
 1.93e-01f  1
  73  1.0521965e+01 0.00e+00 6.48e-03  -5.4 8.85e-01    -  4.90e-01
 2.17e-01f  1
  74  1.0482875e+01 0.00e+00 4.24e-03  -4.5 6.36e-01    -  4.10e-01
 2.47e-01f  1
  75  1.0451256e+01 0.00e+00 2.17e-03  -4.3 4.37e-01    -  2.83e-01
 2.85e-01f  1
  76  1.0427196e+01 0.00e+00 6.39e-03  -5.3 9.12e-01    -  2.72e-01
 1.10e-01f  1
  77  1.0391493e+01 0.00e+00 7.79e-03  -4.8 1.08e+00    -  6.80e-01
 1.40e-01f  1
  78  1.0350847e+01 0.00e+00 3.76e-03  -5.1 1.21e+00    -  3.42e-01
 1.36e-01f  1
  79  1.0318843e+01 0.00e+00 4.96e-03 -10.8 1.14e+00    -  2.70e-01
 1.18e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
  80  1.0264665e+01 0.00e+00 2.22e-03  -4.4 1.30e+00    -  4.88e-01
 1.99e-01f  1
  81  1.0241014e+01 0.00e+00 7.26e-03  -5.1 1.11e+00    -  2.99e-01
 9.19e-02f  1
  82  1.0188564e+01 0.00e+00 4.04e-03  -4.8 1.32e+00    -  5.85e-01
 1.76e-01f  1
  83  1.0162791e+01 0.00e+00 4.83e-03 -10.7 8.84e-01    -  2.29e-01
 1.34e-01f  1
  84  1.0145204e+01 0.00e+00 3.88e-03  -5.1 1.02e+00    -  4.20e-01
 8.01e-02f  1
  85  1.0093511e+01 0.00e+00 4.98e-03 -10.9 1.52e+00    -  2.08e-01
 1.67e-01f  1
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  86  1.0073134e+01 0.00e+00 1.00e-02  -5.6 1.22e+00    -  4.39e-01
 8.44e-02f  1
  87  1.0036653e+01 0.00e+00 5.80e-03  -5.3 1.23e+00    -  3.16e-01
 1.56e-01f  1
  88  1.0019922e+01 0.00e+00 4.23e-03 -11.0 1.07e+00    -  2.16e-01
 8.14e-02f  1
  89  9.9871300e+00 0.00e+00 4.90e-03  -5.3 1.58e+00    -  7.34e-01
 1.12e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
  90  1.0236070e+01 0.00e+00 1.04e-02  -3.3 1.94e+01    -  2.70e-02
 1.39e-01f  1
  91  1.0026881e+01 0.00e+00 1.05e-02  -4.8 2.38e+00    -  1.61e-02
 4.09e-01f  1
  92  9.9920279e+00 0.00e+00 8.27e-03  -4.8 1.71e+00    -  6.73e-01
 8.50e-02f  1
  93  9.9676333e+00 0.00e+00 1.85e-02  -4.8 8.36e-01    -  4.91e-01
 1.34e-01f  1
  94  9.9143820e+00 0.00e+00 4.44e-03  -4.5 7.53e-01    -  7.20e-01
 3.46e-01f  1
  95  9.8788060e+00 0.00e+00 4.65e-03  -4.3 1.67e+00    -  5.41e-01
 5.14e-01f  1
  96  9.8653907e+00 0.00e+00 1.46e-02  -4.7 1.50e+00    -  7.34e-01
 1.77e-01f  1
  97  9.8501583e+00 0.00e+00 1.08e-02  -5.1 2.36e+00    -  8.35e-01
 1.16e-01f  1
  98  9.7920118e+00 0.00e+00 3.58e-03  -5.0 4.59e+00    -  6.94e-01
 2.72e-01f  1
  99  9.7815245e+00 0.00e+00 8.16e-03 -11.0 2.11e+00    -  4.05e-01
 7.73e-02f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 100  9.7485516e+00 0.00e+00 5.60e-03  -5.9 4.16e+00    -  2.47e-01
 1.38e-01f  1
 101  9.7130828e+00 0.00e+00 3.26e-03  -4.4 3.89e+00    -  7.14e-01
 1.97e-01f  1
 102  9.6989618e+00 0.00e+00 4.97e-03  -4.6 1.78e+00    -  2.80e-01
 1.86e-01f  1
 103  1.0369427e+01 0.00e+00 2.81e-03  -3.2 1.14e+01    -  1.82e-02
 4.87e-01f  1
 104  9.9710865e+00 0.00e+00 2.64e-03  -4.4 8.54e+00    -  2.08e-02
 4.33e-01f  1
 105  9.7353407e+00 0.00e+00 6.97e-03  -4.4 6.06e+00    -  5.90e-01
 5.54e-01f  1
 106  9.6775726e+00 0.00e+00 8.09e-03  -4.4 3.13e+00    -  6.26e-01
 3.35e-01f  1
 107  9.6643801e+00 0.00e+00 7.11e-03  -4.5 1.82e+00    -  7.31e-01
 1.45e-01f  1
 108  9.6380735e+00 0.00e+00 6.96e-03  -4.9 2.60e+00    -  6.26e-01
 2.11e-01f  1
 109  9.6085276e+00 0.00e+00 5.12e-03  -4.8 2.52e+00    -  5.98e-01
 2.70e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
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 110  9.5979368e+00 0.00e+00 6.55e-03 -10.8 2.58e+00    -  3.63e-01
 9.73e-02f  1
 111  9.5712428e+00 0.00e+00 4.31e-03  -5.0 3.05e+00    -  5.74e-01
 2.19e-01f  1
 112  9.5403641e+00 0.00e+00 3.58e-03  -4.7 2.35e+00    -  5.57e-01
 3.43e-01f  1
 113  9.5327563e+00 0.00e+00 2.93e-03  -4.5 1.16e+00    -  5.24e-01
 1.71e-01f  1
 114  9.4943176e+00 0.00e+00 1.87e-03  -4.4 1.57e+00    -  4.14e-01
 6.33e-01f  1
 115  9.4881935e+00 0.00e+00 5.22e-03  -5.0 3.62e+00    -  3.77e-01
 4.23e-02f  1
 116  9.4546720e+00 0.00e+00 3.10e-03  -5.3 5.05e+00    -  3.22e-01
 1.68e-01f  1
 117  9.4359868e+00 0.00e+00 5.64e-03  -5.1 4.68e+00    -  4.96e-01
 9.71e-02f  1
 118  9.4233162e+00 0.00e+00 4.75e-03 -10.9 3.67e+00    -  1.95e-01
 8.24e-02f  1
 119  9.3934542e+00 0.00e+00 3.80e-03  -5.2 4.64e+00    -  2.81e-01
 1.55e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 120  9.3705760e+00 0.00e+00 3.15e-03  -4.4 2.56e+00    -  4.02e-01
 2.03e-01f  1
 121  9.3549139e+00 0.00e+00 4.71e-03  -6.6 3.41e+00    -  2.65e-01
 1.11e-01f  1
 122  9.3248219e+00 0.00e+00 2.57e-03  -5.0 4.61e+00    -  4.95e-01
 1.65e-01f  1
 123  9.3192557e+00 0.00e+00 4.11e-03 -10.9 2.48e+00    -  1.50e-01
 5.41e-02f  1
 124  9.2803868e+00 0.00e+00 2.46e-03  -5.3 4.50e+00    -  4.19e-01
 2.17e-01f  1
 125  9.2729612e+00 0.00e+00 5.40e-03  -5.0 2.22e+00    -  3.41e-01
 7.27e-02f  1
 126  9.2557944e+00 0.00e+00 3.88e-03  -4.3 5.60e-01    -  3.98e-01
 7.03e-01f  1
 127  9.4293766e+00 0.00e+00 3.21e-03  -2.6 8.95e+01    -  9.36e-04
 3.50e-02f  1
 128  9.3563677e+00 0.00e+00 3.32e-03  -4.6 4.84e+00    -  8.69e-03
 2.40e-01f  1
 129  9.2183800e+00 0.00e+00 3.49e-02  -4.6 3.54e+00    -  2.84e-01
 9.00e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 130  9.2149322e+00 0.00e+00 1.06e-02  -4.9 1.81e+00    -  7.72e-01
 3.78e-02f  1
 131  9.1991820e+00 0.00e+00 7.64e-03  -6.4 1.89e+00    -  7.26e-01
 1.63e-01f  1
 132  9.1841951e+00 0.00e+00 6.78e-03  -5.4 1.60e+00    -  5.84e-01
 1.79e-01f  1
 133  9.1613963e+00 0.00e+00 9.46e-03  -5.5 2.07e+00    -  7.12e-01
 2.24e-01f  1
 134  9.1467219e+00 0.00e+00 4.33e-03  -4.9 1.32e+00    -  4.53e-01
 2.41e-01f  1
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 135  9.1349175e+00 0.00e+00 4.79e-03  -5.7 1.85e+00    -  3.83e-01
 1.44e-01f  1
 136  9.1219648e+00 0.00e+00 3.34e-03  -6.0 2.22e+00    -  7.40e-01
 1.36e-01f  1
 137  9.1140177e+00 0.00e+00 4.81e-03  -6.3 2.02e+00    -  3.36e-01
 9.08e-02f  1
 138  9.0927513e+00 0.00e+00 4.23e-03  -6.3 2.83e+00    -  6.07e-01
 1.78e-01f  1
 139  9.0849773e+00 0.00e+00 3.41e-03  -5.6 1.66e+00    -  3.04e-01
 1.09e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 140  9.1009469e+00 0.00e+00 1.40e-03  -4.6 2.32e-01    -  4.66e-01
 1.00e+00f  1
 141  9.0894462e+00 0.00e+00 1.01e-03  -4.9 1.70e+00    -  1.97e-01
 1.45e-01f  1
 142  9.0625647e+00 0.00e+00 2.68e-03  -4.9 2.18e+00    -  5.05e-01
 2.47e-01f  1
 143  9.0534372e+00 0.00e+00 2.37e-03  -5.1 2.16e+00    -  4.08e-01
 7.62e-02f  1
 144  9.0423358e+00 0.00e+00 3.73e-03  -6.1 2.21e+00    -  3.47e-01
 8.98e-02f  1
 145  9.0283647e+00 0.00e+00 6.09e-03  -6.3 2.23e+00    -  3.51e-01
 1.15e-01f  1
 146  9.0162459e+00 0.00e+00 5.23e-03  -5.9 2.28e+00    -  3.68e-01
 9.95e-02f  1
 147  8.9975212e+00 0.00e+00 4.89e-03 -11.0 2.25e+00    -  1.80e-01
 1.61e-01f  1
 148  8.9912457e+00 0.00e+00 3.54e-03  -6.0 2.24e+00    -  3.25e-01
 5.37e-02f  1
 149  9.0742745e+00 0.00e+00 1.32e-02  -3.6 1.53e+01    -  1.59e-02
 9.41e-02f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 150  9.0674977e+00 0.00e+00 1.29e-02  -5.2 3.81e+00    -  8.88e-02
 2.94e-02f  1
 151  9.0082200e+00 0.00e+00 1.07e-02  -5.2 5.11e+00    -  3.90e-01
 2.06e-01f  1
 152  8.9794982e+00 0.00e+00 6.53e-03  -5.2 3.51e+00    -  3.93e-01
 1.51e-01f  1
 153  8.9604002e+00 0.00e+00 3.79e-03  -4.6 1.05e+00    -  7.29e-01
 3.68e-01f  1
 154  8.9455514e+00 0.00e+00 1.32e-03  -4.5 1.38e+00    -  4.87e-01
 7.86e-01f  1
 155  8.9406134e+00 0.00e+00 1.11e-02  -4.9 1.05e+00    -  6.91e-01
 1.23e-01f  1
 156  8.9305168e+00 0.00e+00 6.18e-03  -6.0 1.43e+00    -  5.71e-01
 1.44e-01f  1
 157  8.9139360e+00 0.00e+00 5.66e-03  -6.2 1.68e+00    -  4.85e-01
 1.88e-01f  1
 158  8.9028110e+00 0.00e+00 3.61e-03  -5.6 1.74e+00    -  2.37e-01
 1.25e-01f  1
 159  8.8913372e+00 0.00e+00 2.80e-03  -7.1 2.02e+00    -  1.69e-01
 1.08e-01f  1
```

```
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 160  8.8844327e+00 0.00e+00 3.52e-03  -4.9 1.45e+00    -  7.59e-01
 1.10e-01f  1
 161  8.8682510e+00 0.00e+00 2.82e-03  -4.7 1.98e+00    -  5.09e-01
 3.42e-01f  1
 162  8.8600166e+00 0.00e+00 3.03e-03  -4.8 2.24e+00    -  2.80e-01
 1.74e-01f  1
 163  8.8510114e+00 0.00e+00 2.69e-03  -4.8 2.95e+00    -  2.64e-01
 1.64e-01f  1
 164  8.8332974e+00 0.00e+00 2.24e-03  -4.8 4.21e+00    -  5.00e-01
 2.38e-01f  1
 165  8.8299747e+00 0.00e+00 5.32e-03  -5.4 2.78e+00    -  4.58e-01
 5.02e-02f  1
 166  8.8166637e+00 0.00e+00 3.70e-03  -6.9 3.90e+00    -  1.76e-01
 1.27e-01f  1
 167  8.8042664e+00 0.00e+00 2.86e-03  -5.6 4.52e+00    -  1.45e-01
 9.48e-02f  1
 168  8.7969137e+00 0.00e+00 2.89e-03  -4.9 2.84e+00    -  4.13e-01
 9.86e-02f  1
 169  8.7795308e+00 0.00e+00 2.66e-03  -5.1 3.95e+00    -  1.83e-01
 1.63e-01f  1
iter    objective    inf_pr   inf_du lg(mu)  ||d||  lg(rg) alpha_du
 alpha_pr  ls
 170  8.7687422e+00 0.00e+00 6.01e-03  -5.3 4.26e+00    -  4.22e-01
 9.49e-02f  1
 171  8.7516511e+00 0.00e+00 3.50e-03  -5.1 4.31e+00    -  3.30e-01
 1.50e-01f  1
 172  8.7474828e+00 0.00e+00 1.55e-03  -4.5 7.96e-01    -  2.34e-01
 7.13e-01f  1
 173  8.7461846e+00 0.00e+00 7.99e-03  -5.0 1.22e+00    -  4.11e-01
 3.67e-02f  1
 174  8.7342486e+00 0.00e+00 3.69e-03  -4.6 2.08e+00    -  3.91e-01
 2.31e-01f  1
 175  8.7262649e+00 0.00e+00 1.62e-03  -4.5 1.53e+00    -  2.88e-01
 2.78e-01f  1
 176  8.7192483e+00 0.00e+00 2.95e-03  -5.0 1.76e+00    -  4.31e-01
 1.39e-01f  1
 177  8.7116757e+00 0.00e+00 4.03e-03  -5.2 2.02e+00    -  5.27e-01
 1.27e-01f  1

Number of Iterations....: 177

                                   (scaled)                 (unscaled)
Objective...............:   8.7116756510904718e+00
 8.7116756510904718e+00
Dual infeasibility......:   4.0270607054328405e-03
 4.0270607054328405e-03
Constraint violation....:   0.0000000000000000e+00
 0.0000000000000000e+00
Complementarity.........:   3.4015835990586807e-05
 3.4015835990586807e-05
Overall NLP error.......:   4.0270607054328405e-03
 4.0270607054328405e-03
```

```
Number of objective function evaluations             = 184
Number of objective gradient evaluations             = 178
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)   =     11.630
Total CPU secs in NLP function evaluations           =    102.843

EXIT: Solved To Acceptable Level.

*** IPOPT DONE ***
Calculating final cubes...
matRad: applying a constant RBE of 1.1
  0               Rectum - Mean dose =  0.87 Gy +/-  0.68 Gy (Max dose
 =  2.35 Gy, Min dose =  0.00 Gy)
                           D2% =  2.26 Gy, D5% =  2.11 Gy, D50% =
 0.96 Gy, D95% =  0.00 Gy, D98% =  0.00 Gy,
                           V0Gy = 100.00%, V0.4Gy =  65.82%, V0.9Gy =
 51.72%, V1.4Gy =  20.70%, V1.9Gy =   7.39%, V2.3Gy =   1.13%,

  1          Penile_bulb - Mean dose =  0.04 Gy +/-  0.06 Gy (Max dose
 =  0.18 Gy, Min dose =  0.00 Gy)
                           D2% =  0.17 Gy, D5% =  0.17 Gy, D50% =
 0.00 Gy, D95% =  0.00 Gy, D98% =  0.00 Gy,
                           V0Gy = 100.00%, V0.4Gy =   0.00%, V0.9Gy =
  0.00%, V1.4Gy =   0.00%, V1.9Gy =   0.00%, V2.3Gy =   0.00%,

  2          Lymph Nodes - Mean dose =  1.90 Gy +/-  0.10 Gy (Max dose
 =  2.33 Gy, Min dose =  1.79 Gy)
                           D2% =  2.29 Gy, D5% =  2.19 Gy, D50% =
 1.87 Gy, D95% =  1.85 Gy, D98% =  1.83 Gy,
                           V0Gy = 100.00%, V0.4Gy = 100.00%, V0.9Gy =
 100.00%, V1.4Gy = 100.00%, V1.9Gy =  12.96%, V2.3Gy =   1.07%,

  3      Rt femoral head - Mean dose =  0.66 Gy +/-  0.53 Gy (Max dose
 =  1.51 Gy, Min dose =  0.00 Gy)
                           D2% =  1.37 Gy, D5% =  1.32 Gy, D50% =
 0.88 Gy, D95% =  0.00 Gy, D98% =  0.00 Gy,
                           V0Gy = 100.00%, V0.4Gy =  61.36%, V0.9Gy =
 47.62%, V1.4Gy =   1.12%, V1.9Gy =   0.00%, V2.3Gy =   0.00%,

  4         prostate_bed - Mean dose =  2.26 Gy +/-  0.02 Gy (Max dose
 =  2.34 Gy, Min dose =  2.20 Gy)
                           D2% =  2.30 Gy, D5% =  2.29 Gy, D50% =
 2.26 Gy, D95% =  2.23 Gy, D98% =  2.23 Gy,
                           V0Gy = 100.00%, V0.4Gy = 100.00%, V0.9Gy =
 100.00%, V1.4Gy = 100.00%, V1.9Gy = 100.00%, V2.3Gy =   1.86%,

  5               PTV_68 - Mean dose =  2.26 Gy +/-  0.06 Gy (Max dose
 =  2.40 Gy, Min dose =  1.86 Gy)
```

```
                          D2% =  2.33 Gy, D5% =  2.32 Gy, D50% =
2.27 Gy, D95% =  2.14 Gy, D98% =  2.06 Gy,
                          V0Gy = 100.00%, V0.4Gy = 100.00%, V0.9Gy =
100.00%, V1.4Gy = 100.00%, V1.9Gy =  99.94%, V2.3Gy =  11.31%,
                          CI = 0.8973, HI =  7.83 for reference dose
of 2.3 Gy

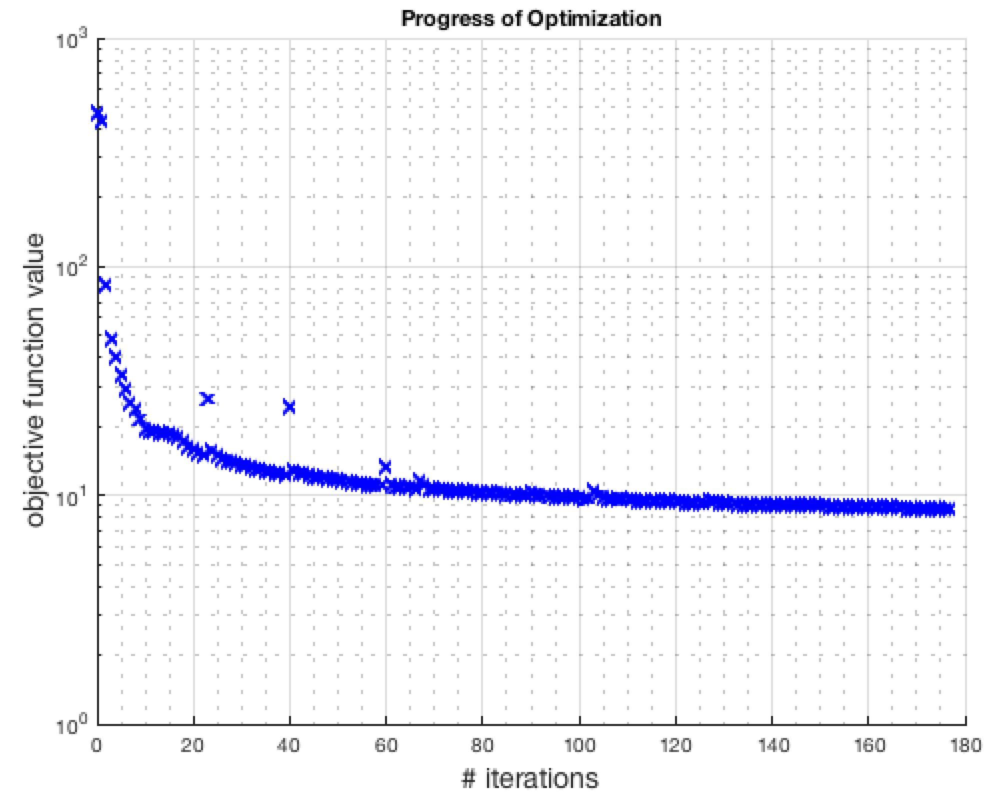
 6               PTV_56 - Mean dose =  1.91 Gy +/-  0.12 Gy (Max dose
=  2.35 Gy, Min dose =  1.57 Gy)
                          D2% =  2.29 Gy, D5% =  2.26 Gy, D50% =
1.87 Gy, D95% =  1.83 Gy, D98% =  1.81 Gy,
                          V0Gy = 100.00%, V0.4Gy = 100.00%, V0.9Gy =
100.00%, V1.4Gy = 100.00%, V1.9Gy =  16.34%, V2.3Gy =   1.45%,
                          CI = 0.5144, HI = 22.84 for reference dose
of 1.9 Gy

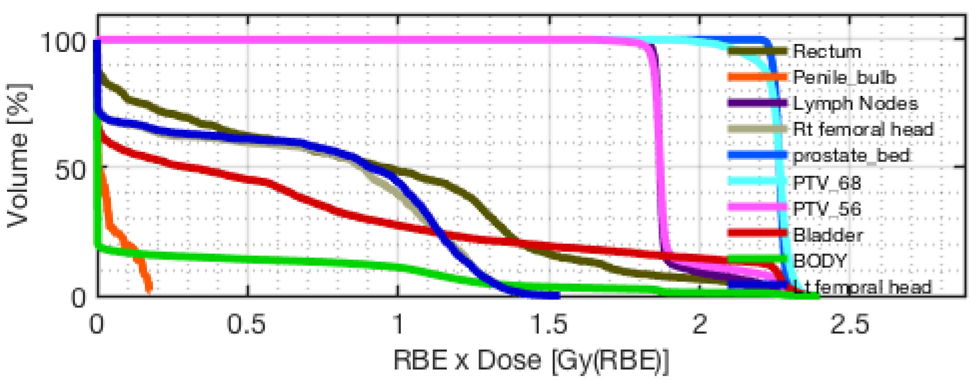
 7              Bladder - Mean dose =  0.68 Gy +/-  0.81 Gy (Max dose
=  2.40 Gy, Min dose =  0.00 Gy)
                          D2% =  2.31 Gy, D5% =  2.28 Gy, D50% =
0.31 Gy, D95% =  0.00 Gy, D98% =  0.00 Gy,
                          V0Gy = 100.00%, V0.4Gy =  47.94%, V0.9Gy =
29.75%, V1.4Gy =  20.50%, V1.9Gy =  15.33%, V2.3Gy =   2.60%,

 8                 BODY - Mean dose =  0.19 Gy +/-  0.47 Gy (Max dose
=  2.40 Gy, Min dose =  0.00 Gy)
                          D2% =  1.86 Gy, D5% =  1.27 Gy, D50% =
0.00 Gy, D95% =  0.00 Gy, D98% =  0.00 Gy,
                          V0Gy = 100.00%, V0.4Gy =  14.73%, V0.9Gy =
12.06%, V1.4Gy =   3.76%, V1.9Gy =   1.27%, V2.3Gy =   0.11%,

 9      Lt femoral head - Mean dose =  0.68 Gy +/-  0.53 Gy (Max dose
=  1.54 Gy, Min dose =  0.00 Gy)
                          D2% =  1.37 Gy, D5% =  1.31 Gy, D50% =
0.91 Gy, D95% =  0.00 Gy, D98% =  0.00 Gy,
                          V0Gy = 100.00%, V0.4Gy =  62.28%, V0.9Gy =
50.44%, V1.4Gy =   1.23%, V1.9Gy =   0.00%, V2.3Gy =   0.00%,

  2.277559510950275
```



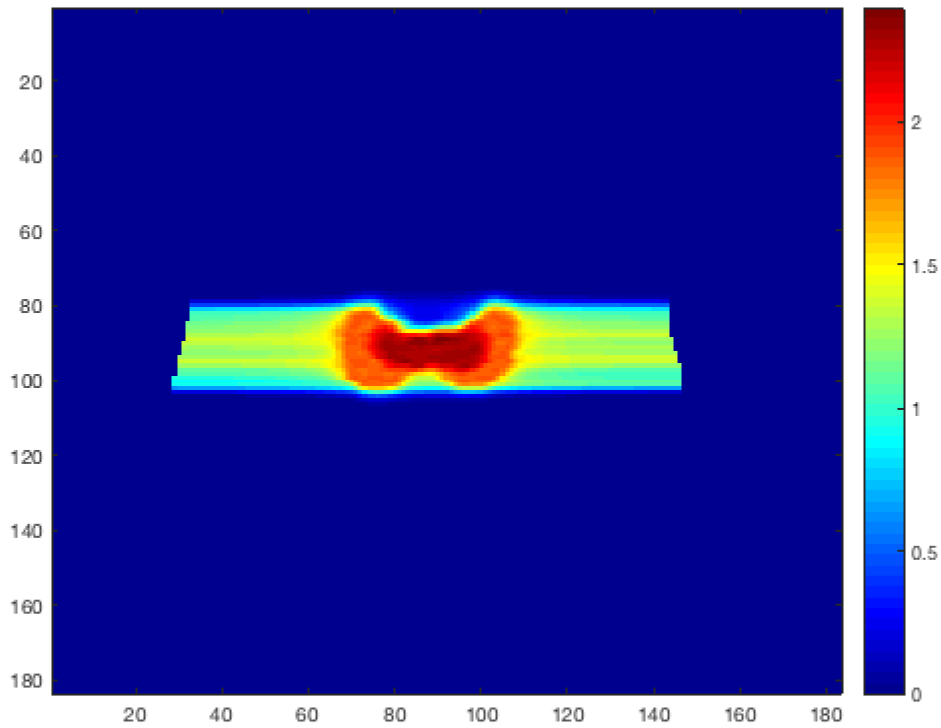


	mean	std	max	min
Rectum	0.8744	0.6804	2.3519	
Penile_bulb	0.0423	0.0591	0.1784	
Lymph Nodes	1.8980	0.0996	2.3295	1.79
Rt femoral head	0.6604	0.5258	1.5142	
prostate_bed	2.2642	0.0173	2.3402	2.19
PTV_68	2.2556	0.0568	2.3997	1.85

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.RBExDose(:,:,slice)),colorbar, colormap(jet)
```



Now let's simulate a range undershoot by scaling the relative stopping power cube by 3.5% percent

```
ct_manip         = ct;
noise            = ct.cube{1} .* 0.035;
ct_manip.cube{1} = ct_manip.cube{1} + noise;
```

Recalculate Plan

Let's use the existing optimized pencil beam weights and recalculate the RBE weighted dose

```
resultGUI_noise =
 matRad_calcDoseDirect(ct_manip,stf,pln,cst,resultGUI.w);
```

```
matRad: Using a constant RBE of 1.1
Warning: Surface for SSD calculation starts directly in first voxel of
 CT
matRad: Particle dose calculation...
```

```
Beam 1 of 2:
matRad: calculate radiological depth cube...done.
matRad: calculate lateral cutoff...done.
Progress: 100.00 %
Beam 2 of 2:
matRad: calculate radiological depth cube...done.
matRad: calculate lateral cutoff...done.
Progress: 100.00 %
matRad: applying a constant RBE of 1.1
```

Visual Comparison of results

Let's compare the new recalculation against the optimization result.

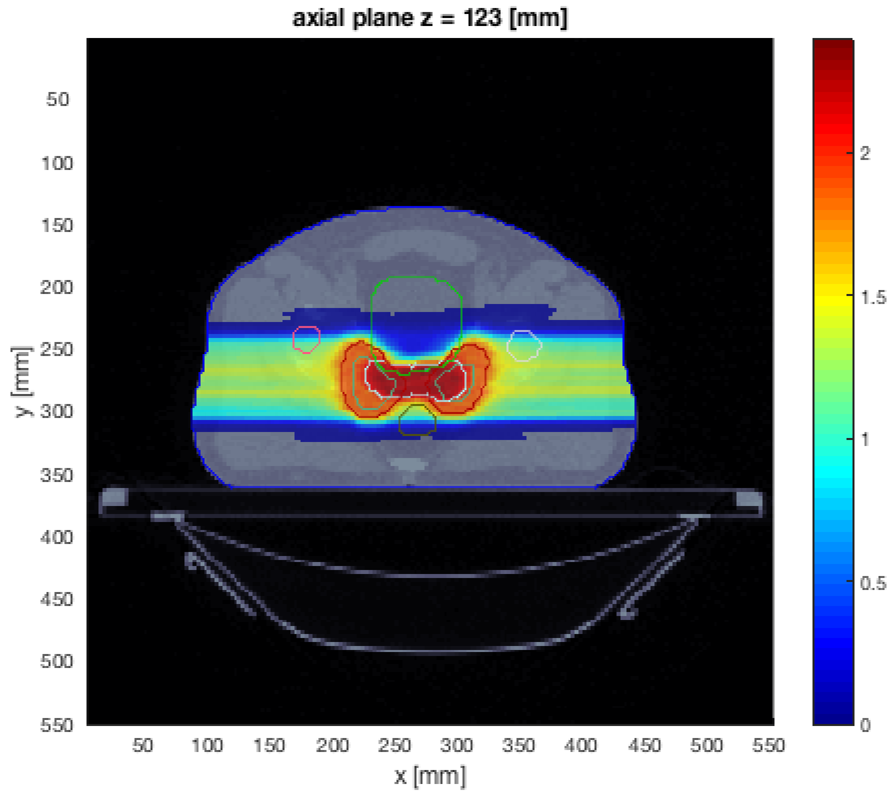
```
plane      = 3;
doseWindow = [0 max([resultGUI.RBExDose(:);
 resultGUI_noise.RBExDose(:)])];

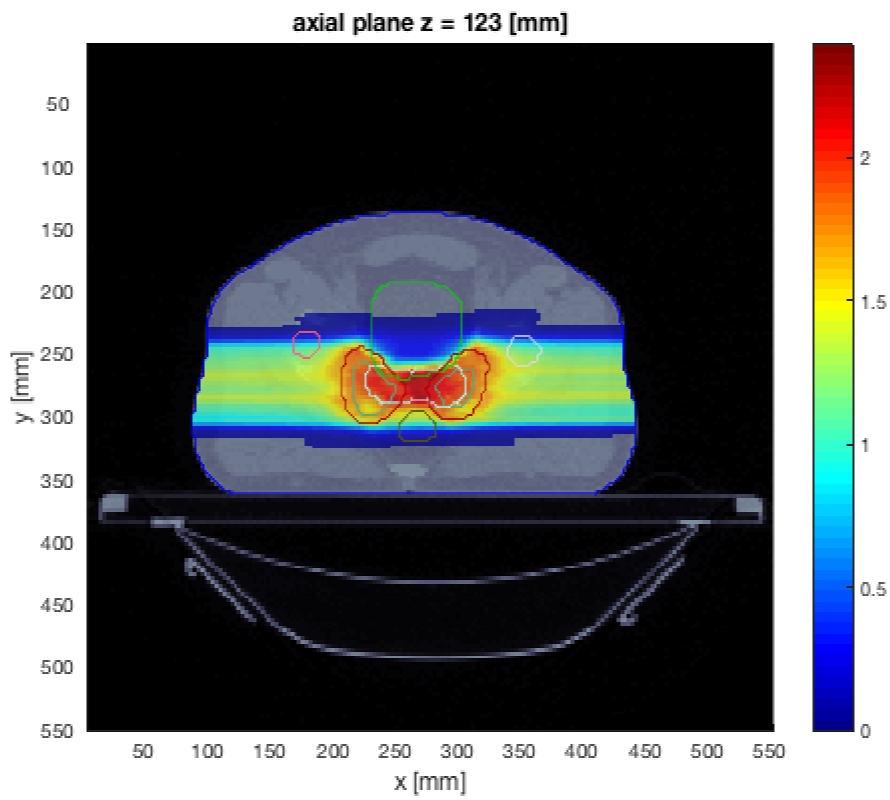
figure,title('original plan')
matRad_plotSliceWrapper(gca,ct,cst,1,resultGUI.RBExDose,plane,slice,
[],0.75,colorcube,[],doseWindow,[]);
figure,title('manipulated plan')
matRad_plotSliceWrapper(gca,ct_manip,cst,1,resultGUI_noise.RBExDose,plane,slice,
[],0.75,colorcube,[],doseWindow,[]);

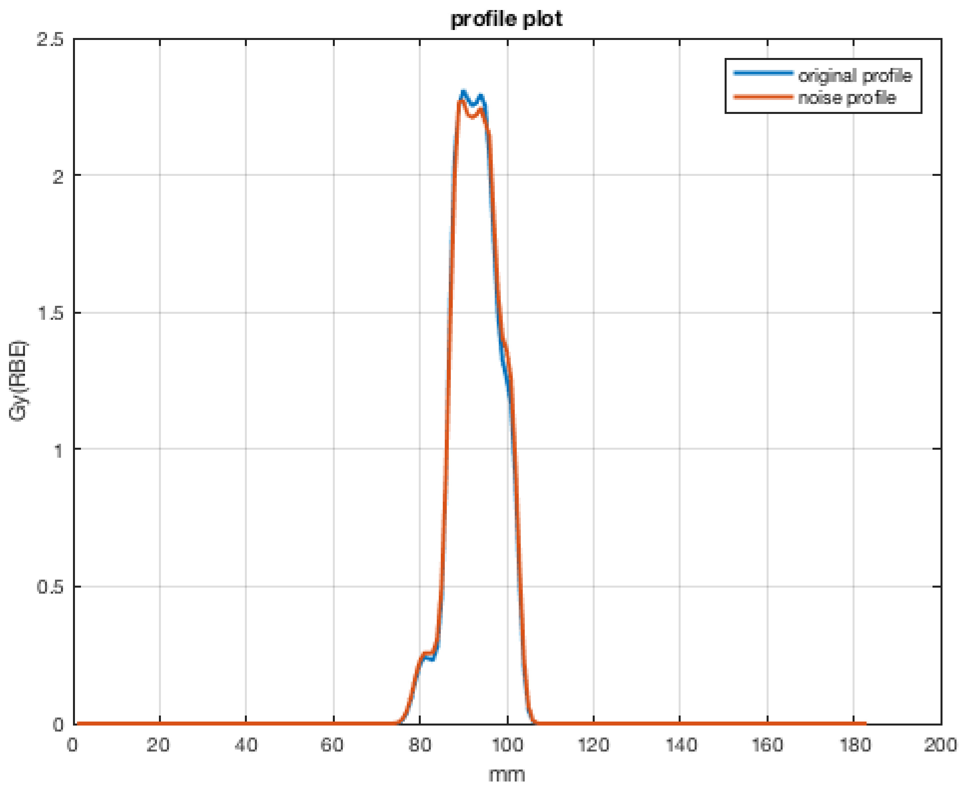
% Let's plot single profiles along the beam direction
ixProfileY = round(pln.propStf.isoCenter(1,1)./ct.resolution.x);

profileOrginal = resultGUI.RBExDose(:,ixProfileY,slice);
profileNoise   = resultGUI_noise.RBExDose(:,ixProfileY,slice);

figure,plot(profileOrginal,'LineWidth',2),grid on,hold on,
       plot(profileNoise,'LineWidth',2),legend({'original
 profile','noise profile'}),
       xlabel('mm'),ylabel('Gy(RBE)'),title('profile plot')
```


axial plane z = 123 [mm]
y [mm]
x [mm]
50
100
150
200
250
300
350
400
450
500
550
0
0.5
1
1.5
2


axial plane z = 123 [mm]
y [mm]
x [mm]
50
100
150
200
250
300
350
400
450
500
550
0
0.5
1
1.5
2



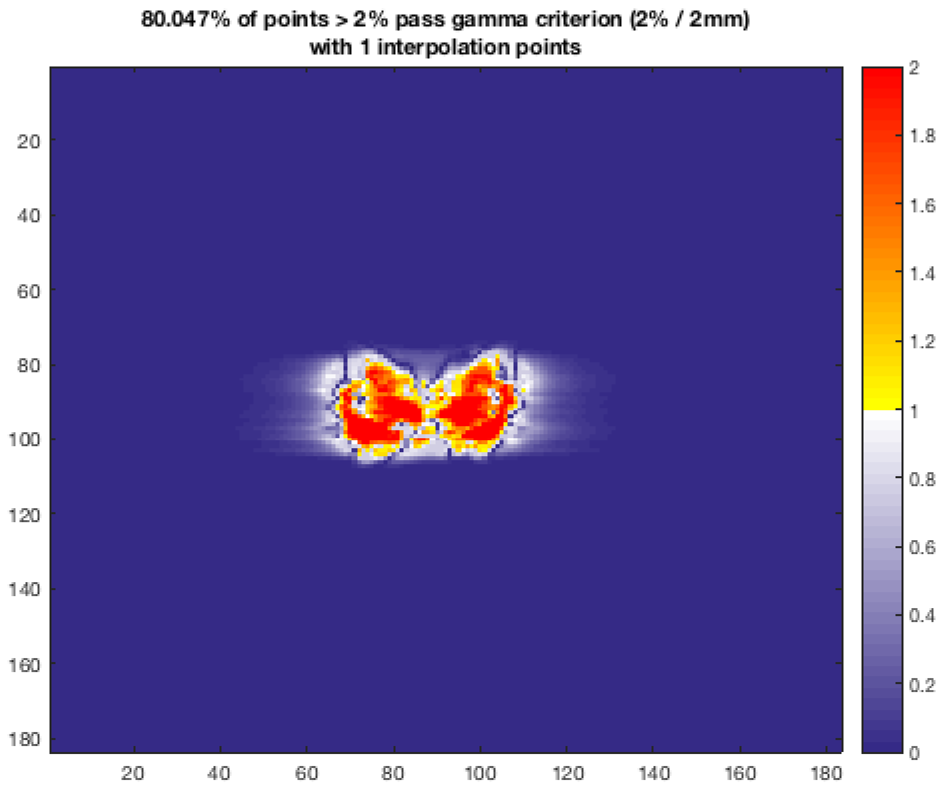
Quantitative Comparison of results

Compare the two dose cubes using a gamma-index analysis.

```
% add tools subdirectory
addpath([fileparts(fileparts(mfilename('fullpath')))
 filesep 'tools']);

doseDifference   = 2;
distToAgreement  = 2;
n                = 1;

[gammaCube,gammaPassRateCell] = matRad_gammaIndex(...
    resultGUI_noise.RBExDose,resultGUI.RBExDose,...
    [ct.resolution.x, ct.resolution.y, ct.resolution.z],...
    [doseDifference distToAgreement],slice,n,'global',cst);
```



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