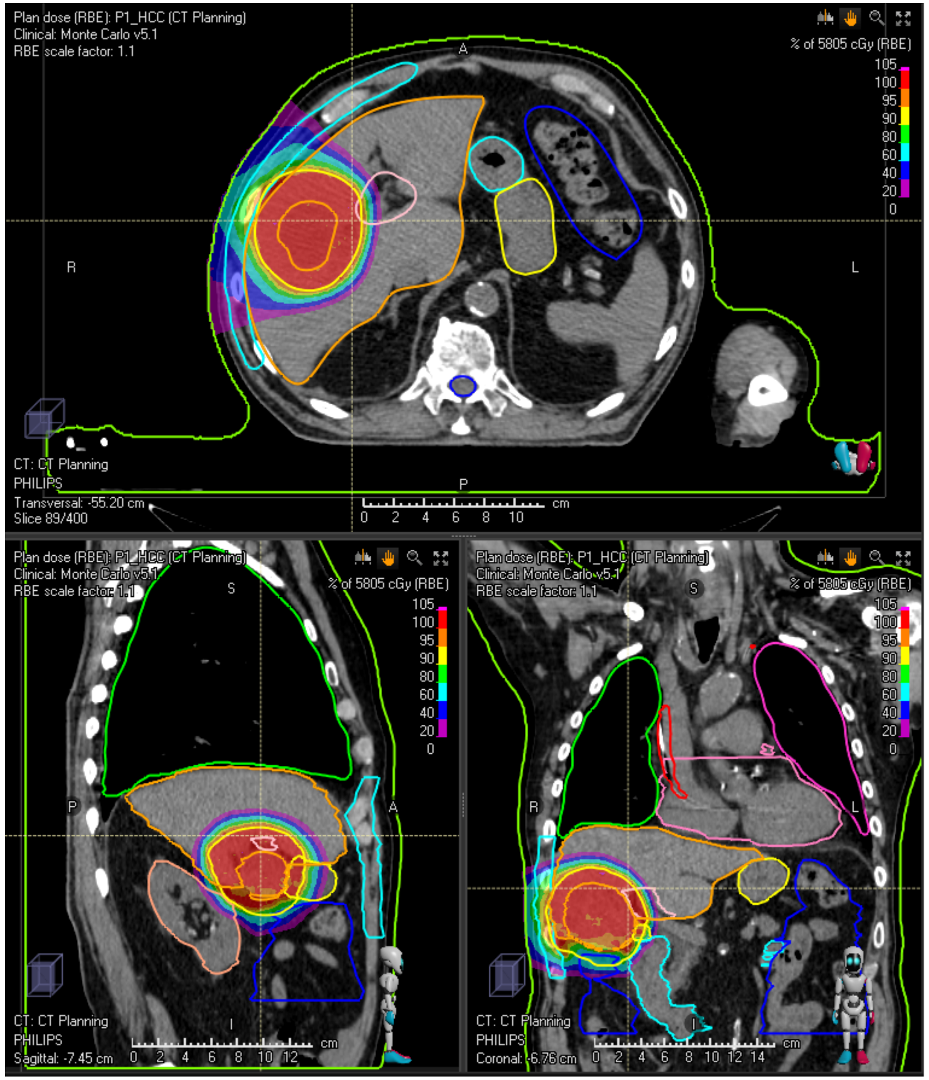
Range Modulators for proton beams

F. Tommasino
(most slides from R. Cristoforetti)

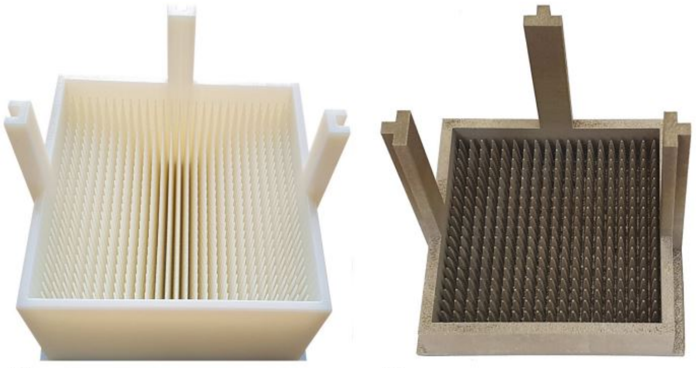
Case study: liver cancer

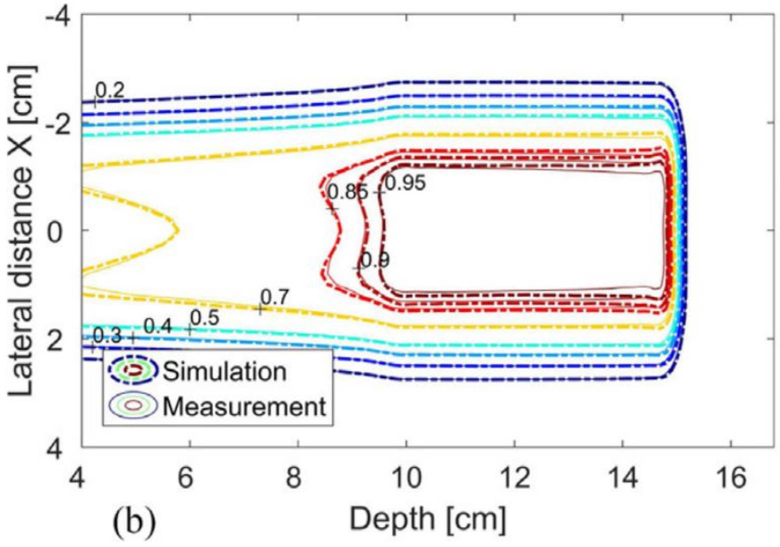


- Energy change requires times in the order of **seconds**
- Up to **30** energy layers per field...
- ... and more than one field
- Severely affected by **target motion**, so breath hold techniques need to be exploited

The use of Range Modulators (RMs) avoids the energy selection process

2D vs 3D Range Modulators

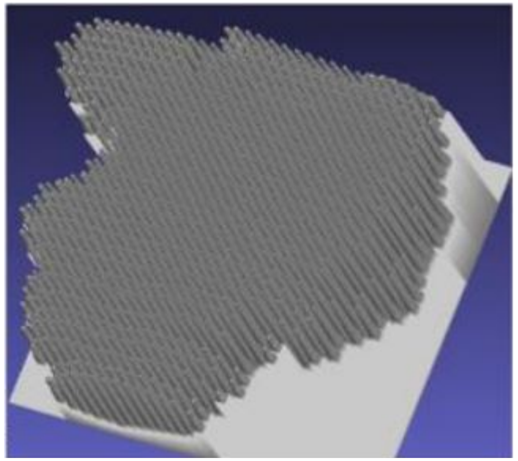


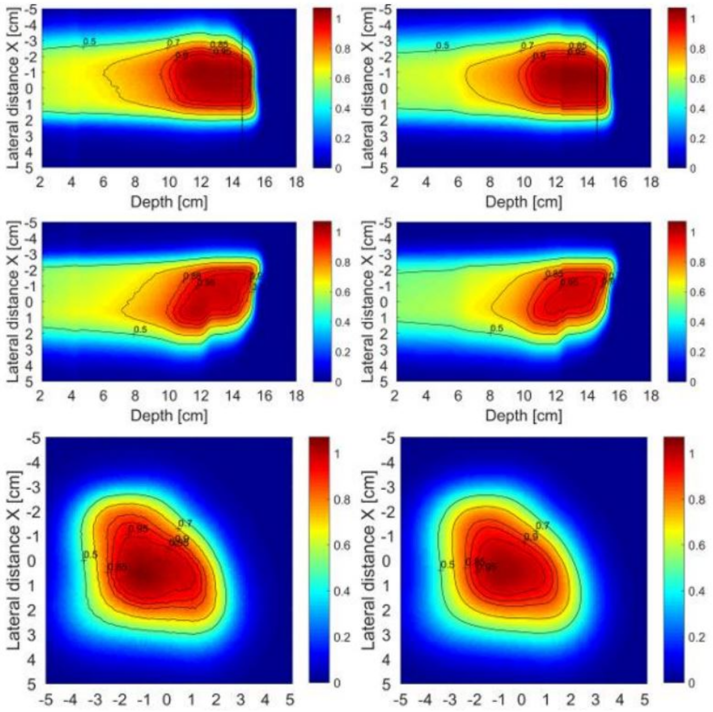


- Pins are all **identical**
- Dose distribution controlled only on the **depth-dose profile**
- **Not** useful for clinical applications

Simeonov et al. Monte Carlo simulations and dose measurements of 2-D range modulators for scanned particle beams.

2D vs 3D Range Modulators





Simeonov et al. MC simulations and dose measurements of a patient-specific 3D range modulator for proton therapy.

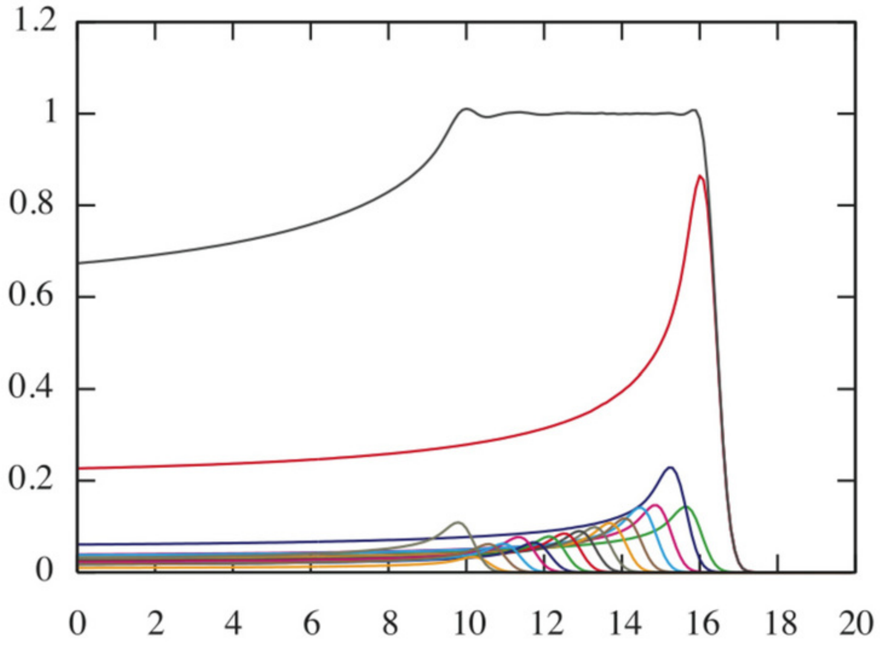
- All pins need to be **different** in order to exploit all available **degrees of freedom**
- Objective dose distribution is **conformal** to arbitrary shape
- **Scattering** becomes relevant
- Increased level of **complexity**

Numerical description

$$D_{SOBP}(i) = \sum_{j=1}^{N_S} w(j) D(i,j)$$

⇓

$$\begin{bmatrix} D[1] & \cdots & D[N_s] \\ \vdots & \ddots & \vdots \\ D[N_z] & \cdots & D[N_s + N_z] \end{bmatrix} \cdot \begin{bmatrix} w[1] \\ \vdots \\ w[N_s] \end{bmatrix} = \begin{bmatrix} D_{SOBP}[1] \\ \vdots \\ D_{SOBP}[N_z] \end{bmatrix}$$



- D_{SOBP} = SOBP profile
- D = Single BP
- N_s = Number of BPs
- w = fluence weights
- N_z = Number of sampled depths

Workflow

For 2DRMs

Numerical Optimization

→

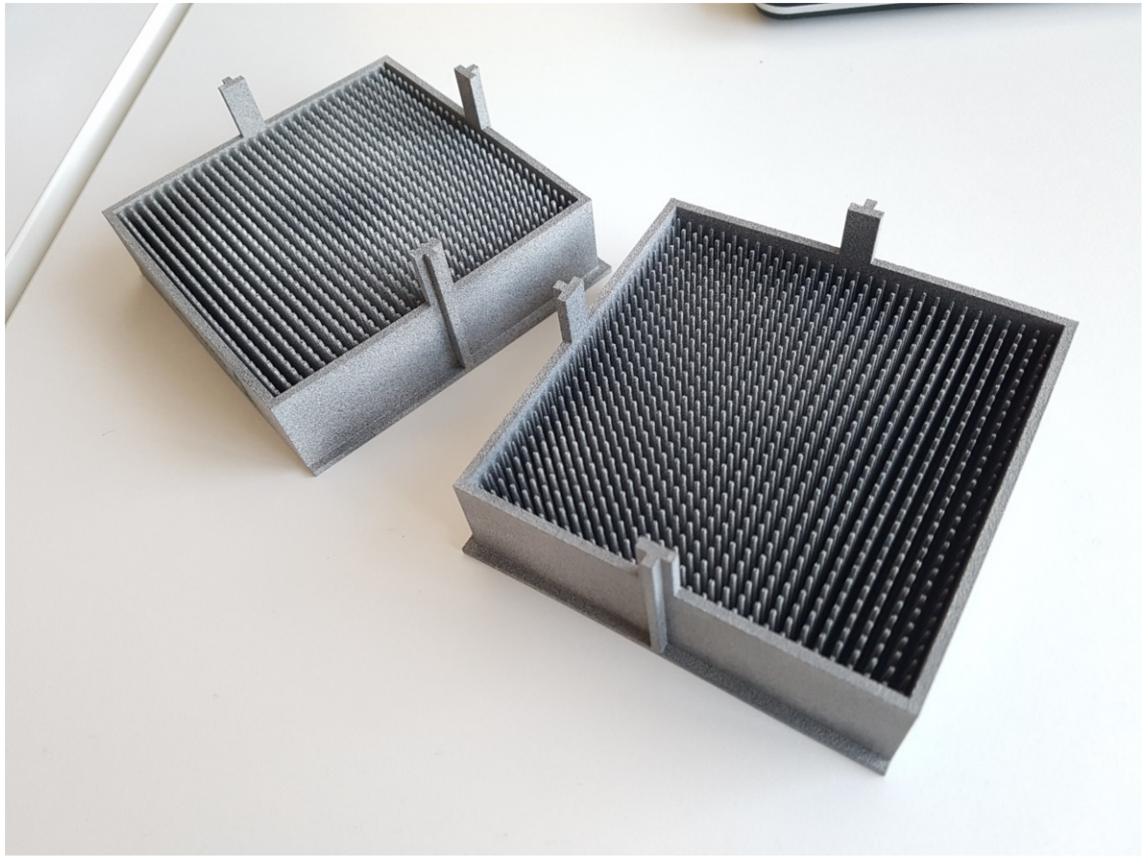
Monte Carlo Simulation

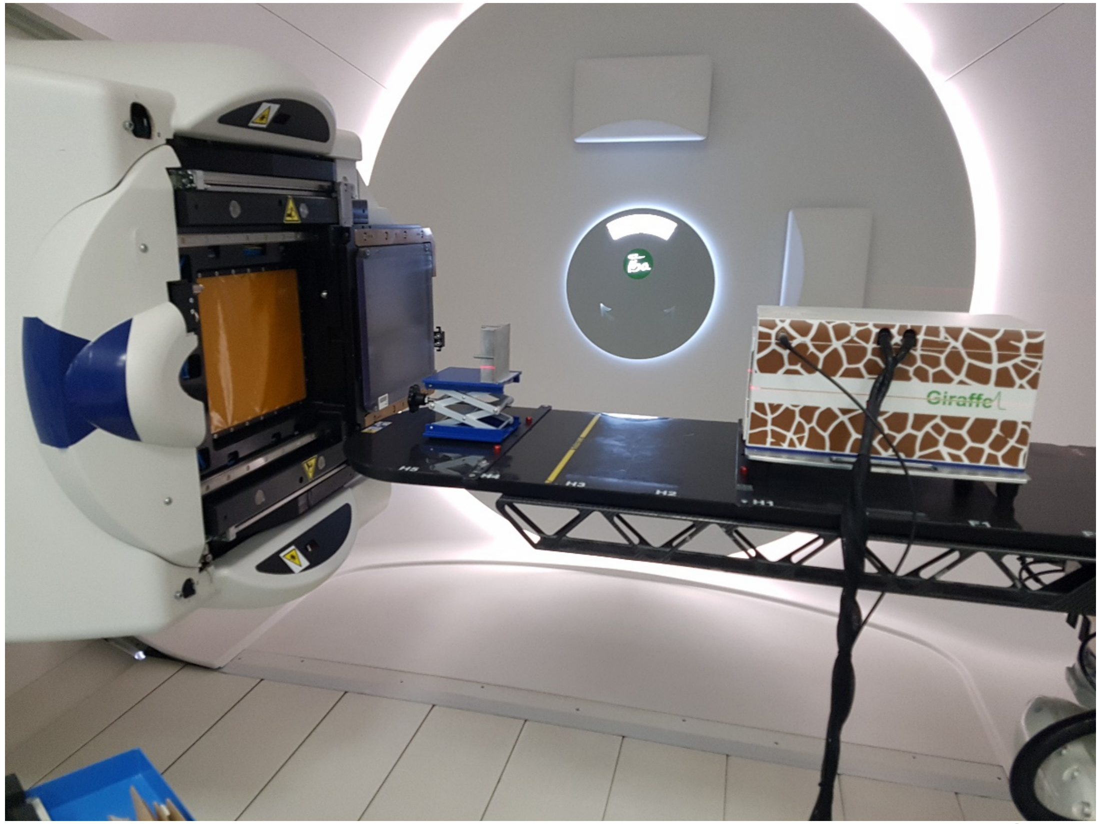
→

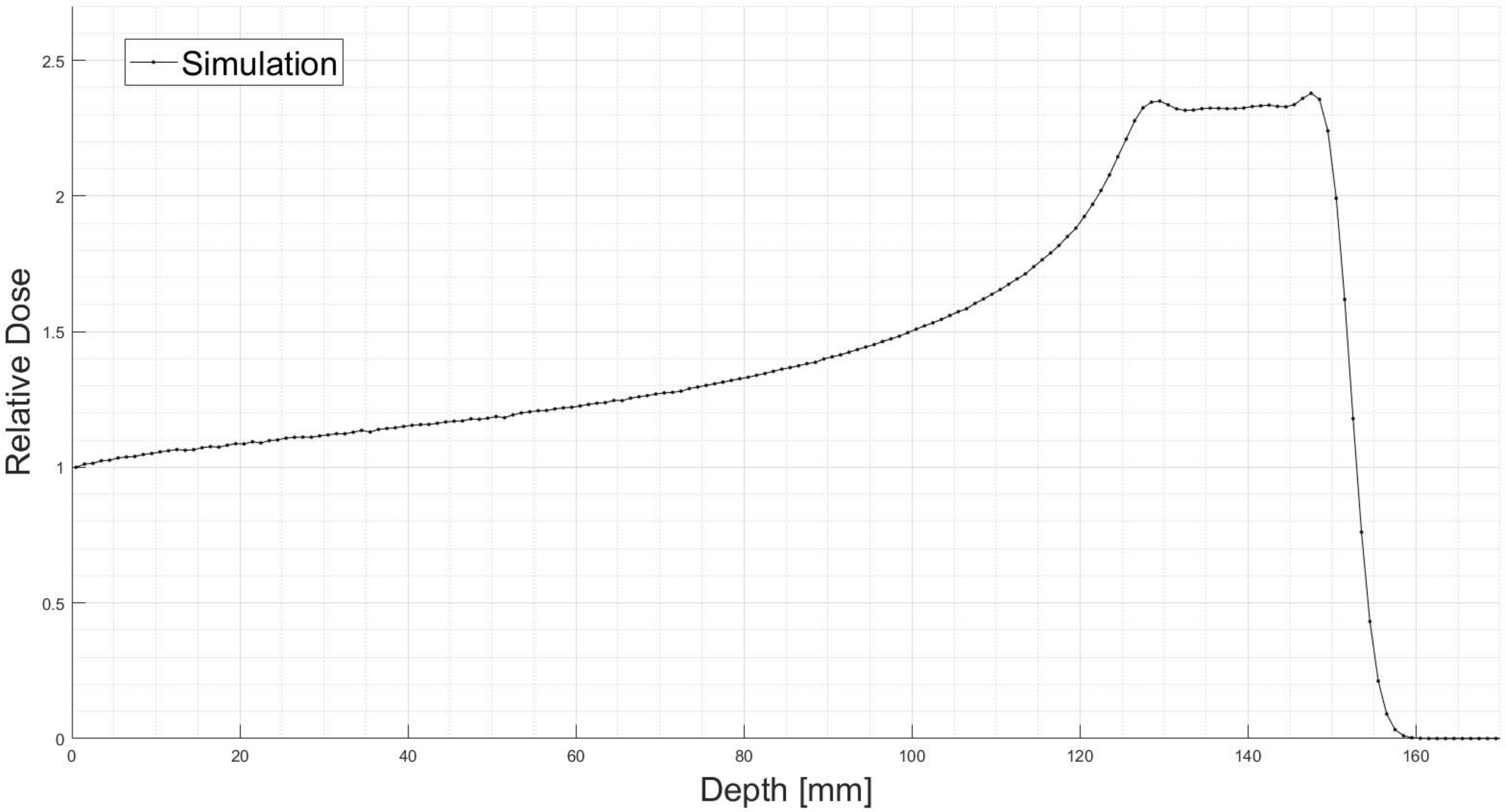
Printing & Validation

REALIZATION AND EXPERIMENTAL VALIDATION

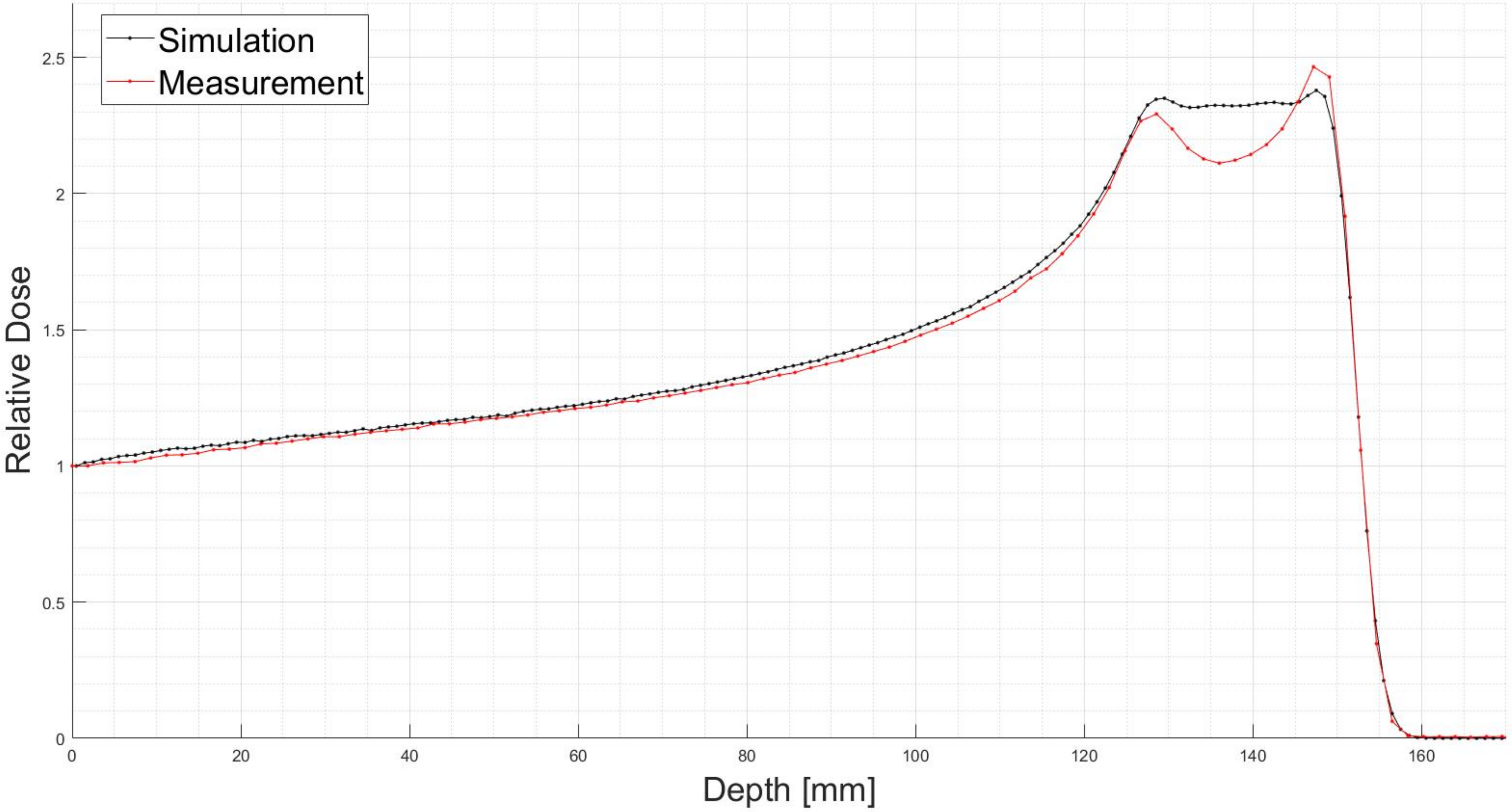
First prototypes: PA12 Range Modulators







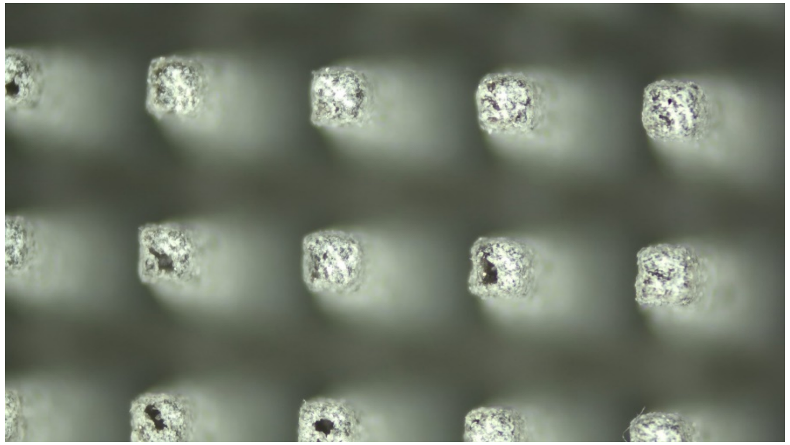
Simulation
Relative Dose
Depth [mm]
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
120
140
160

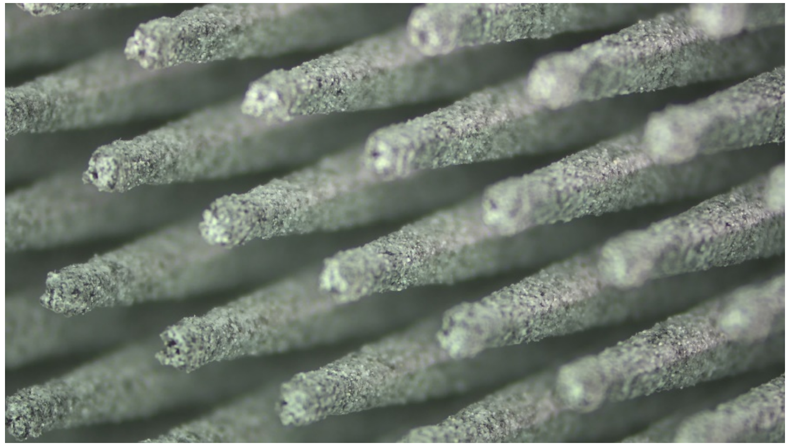


Simulation
Measurement
Relative Dose
Depth [mm]
0
0.5
1
1.5
2
2.5
0
20
40
60
80
100
120
140
160

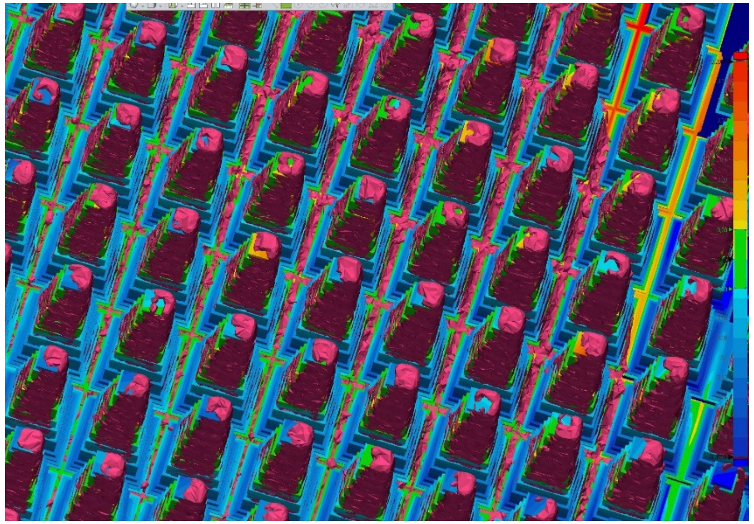
Stereo Microscope
(Visual Inspection)

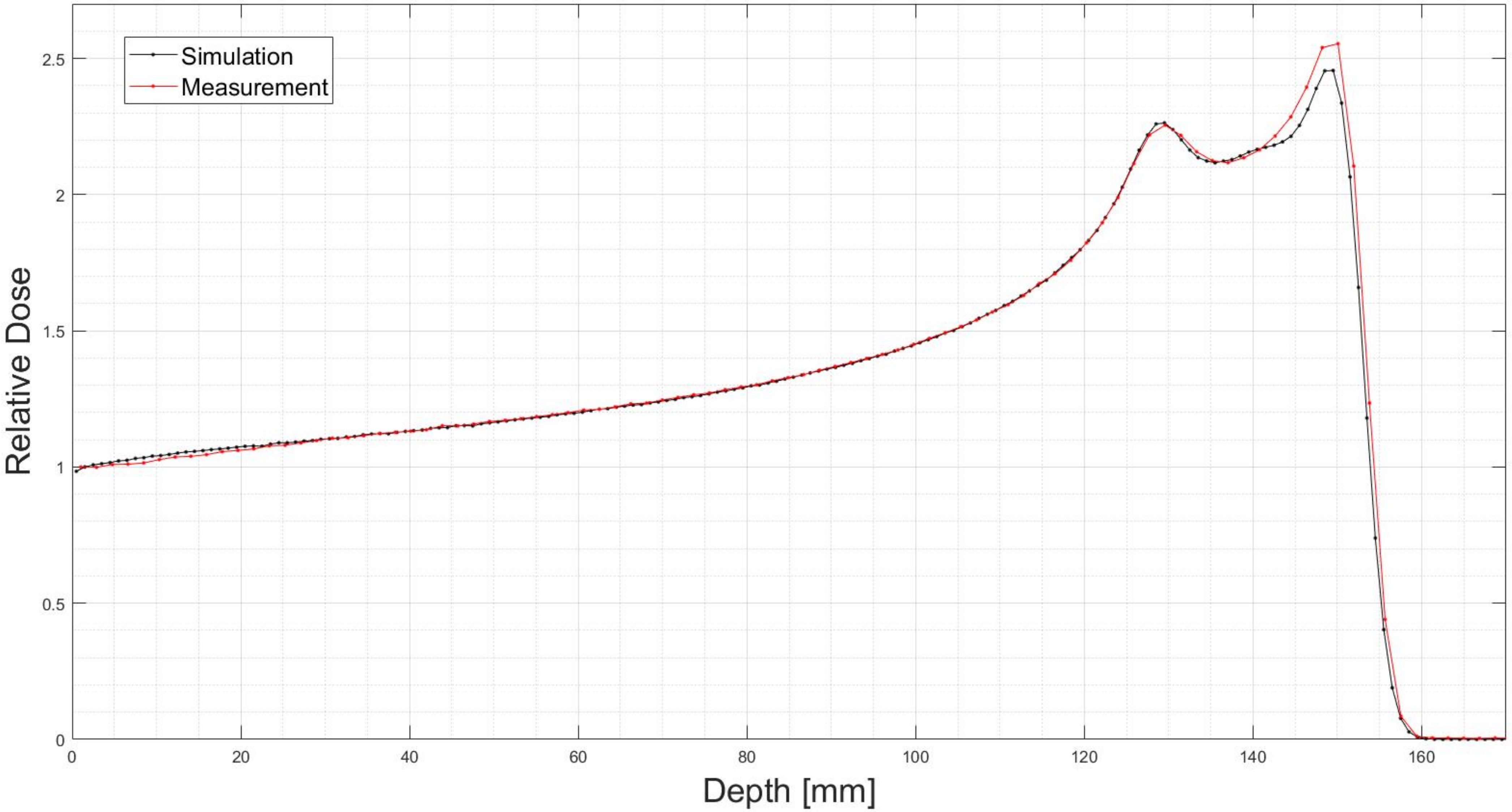
Industrial Tomograph
(Quantitative estimation)



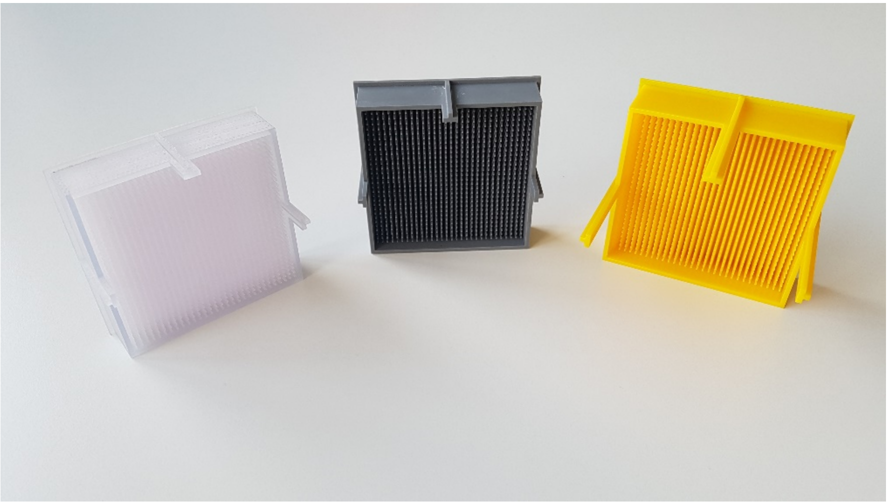


- Porosity
- Irregularities
- **Systematic deviations**




Simulation
Measurement
Relative Dose
Depth [mm]
0
0.5
1
1.5
2
2.5
0
20
40
60
80
100
120
140
160

Solution: change material and printing technique

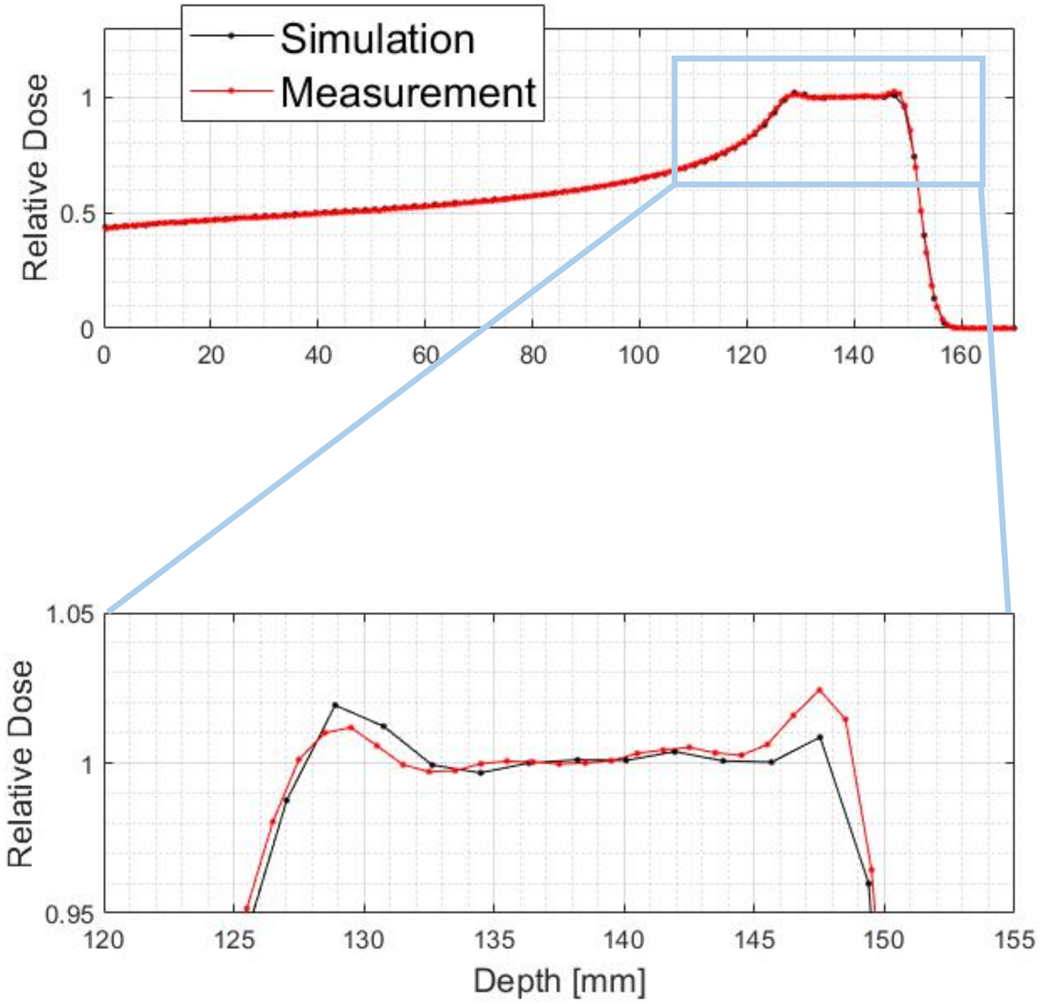


Stereolitography with three different resins:

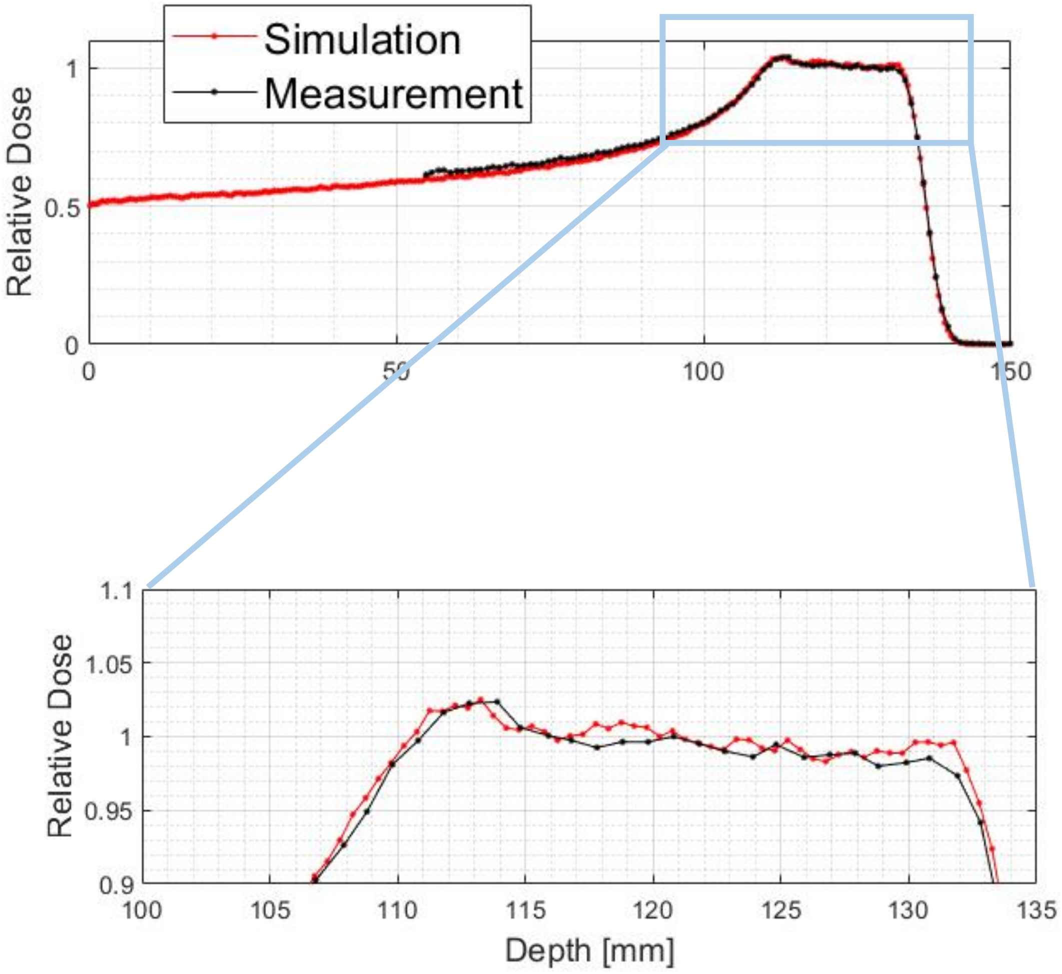
- Vitra
- DWS
- Vero Yellow

Results

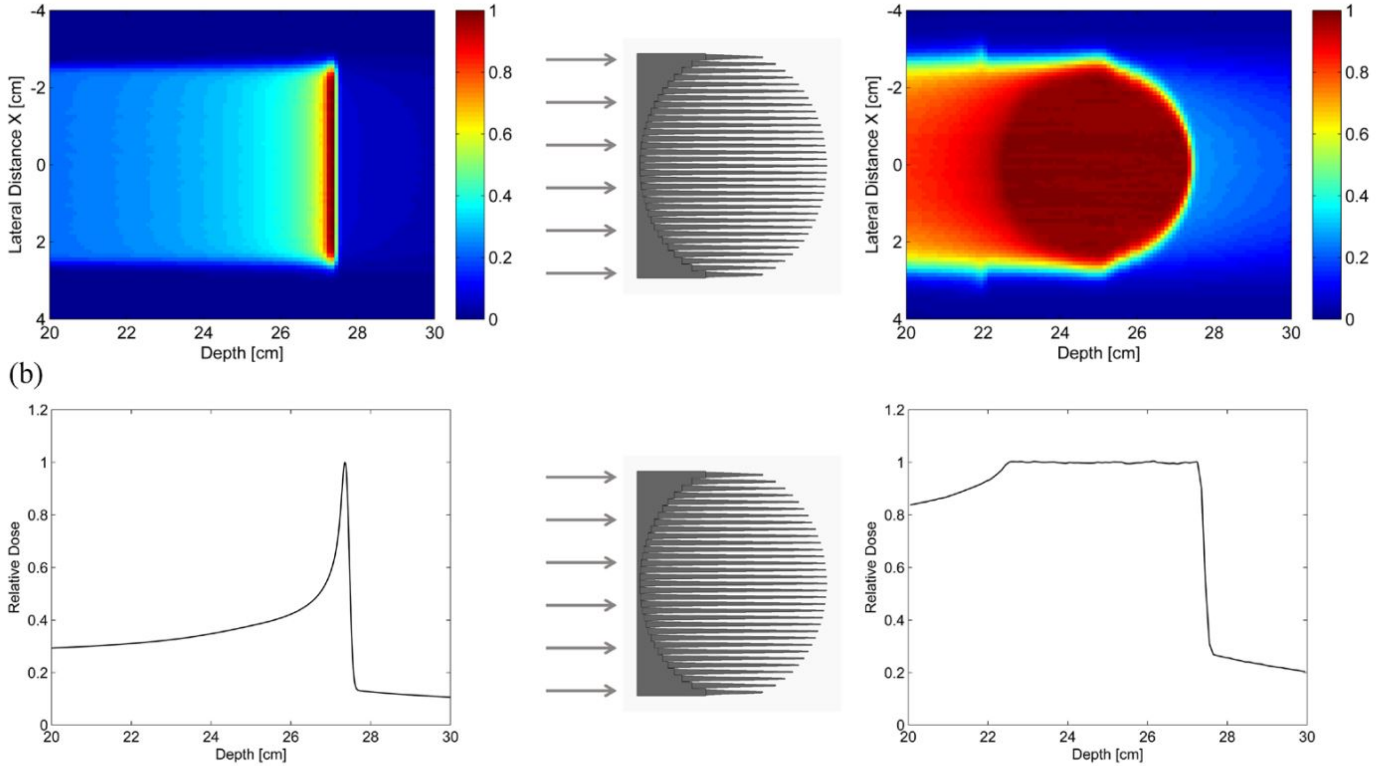
Gantry



Research Area



3D Range Modulators



Y. Simeoneov et al, 3D range-modulator for scanned particle therapy: development, Monte Carlo simulatons and experimental validation

- All pins need to be **optimized**
- Increased number of degrees of freedom required
- Need to control **beam scattering** and **optical divergence**
- Up to several thousands of optimization variables
- Linear combination of **full dose distributions** instead of single depth dose profiles

Workflow

For 3DRM

Plan Setup

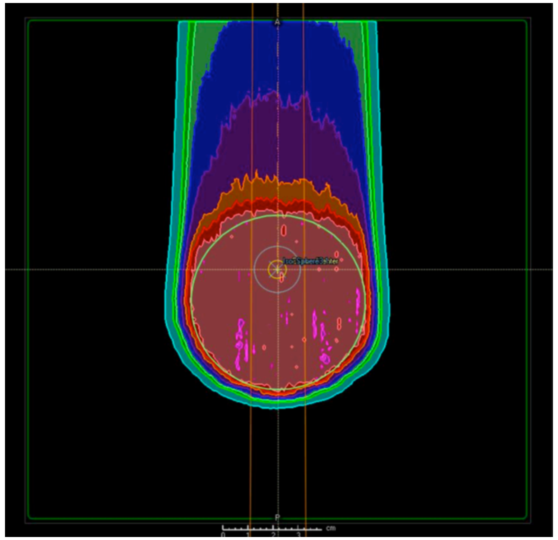
Optimization

Simulation

Printing & Validation

3D Range Modulators: spherical target in water

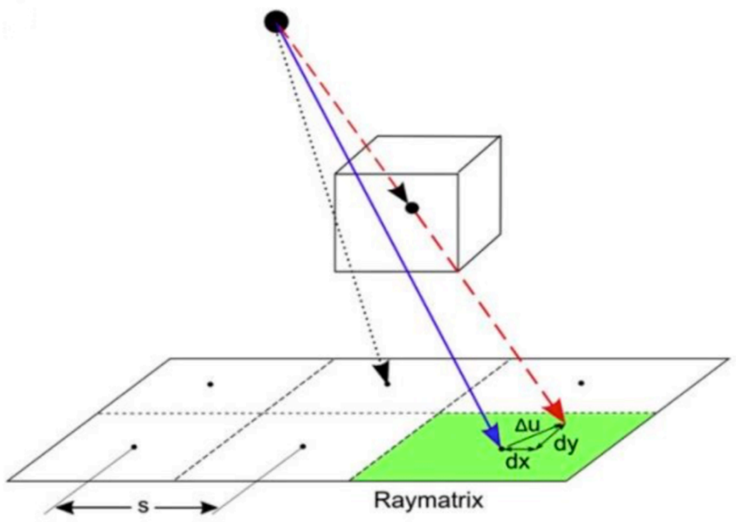
1. Target definition and RS plan



Export DICOM RP, RD, RS

Switch to Matlab/matRad

2. RM "macroscopic" geometry definition



At this stage, we get how many pins we need and "where"

3D Range Modulators

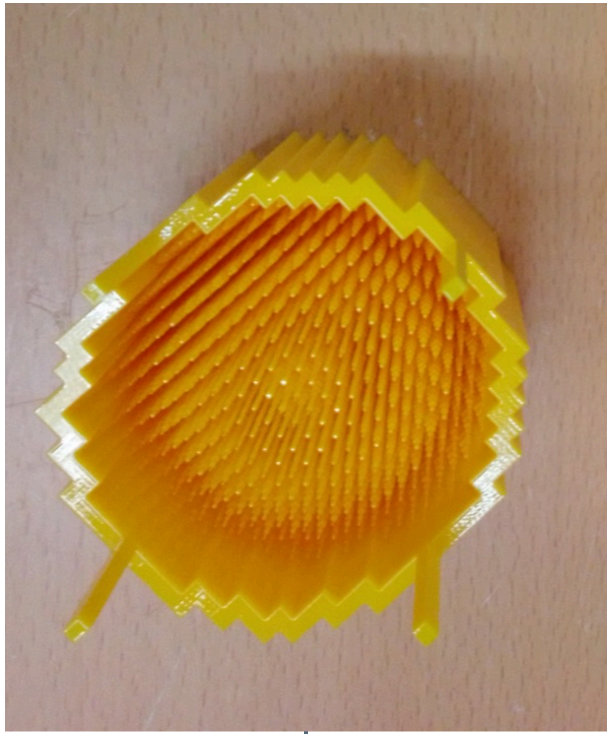
4. Weights converted into pin geometry and sent to printer

3. Pre-computed Dose Influence Matrix

$$D[i] = \sum_{j=1}^{N_s} d[i][j]w[j]$$

i –> voxel
j –> spot

Optimization to get weights

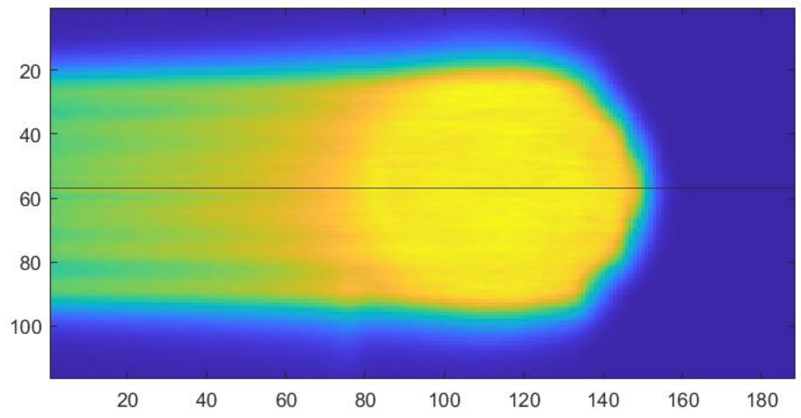


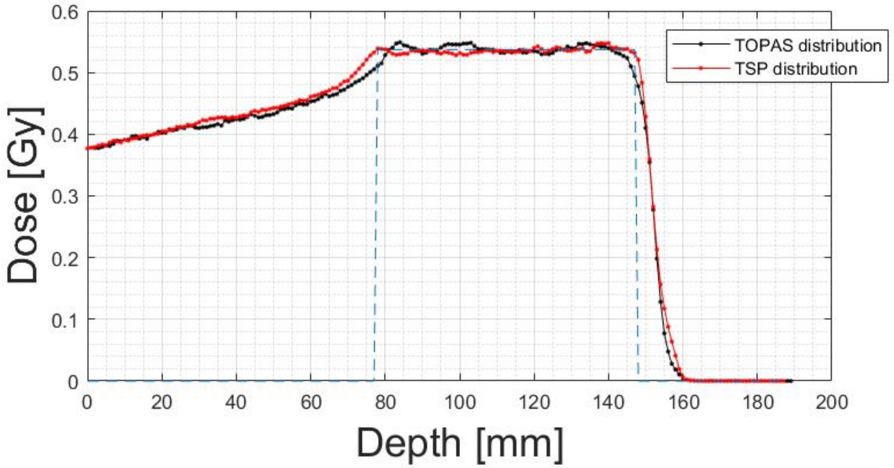
6. Fluence map optimization

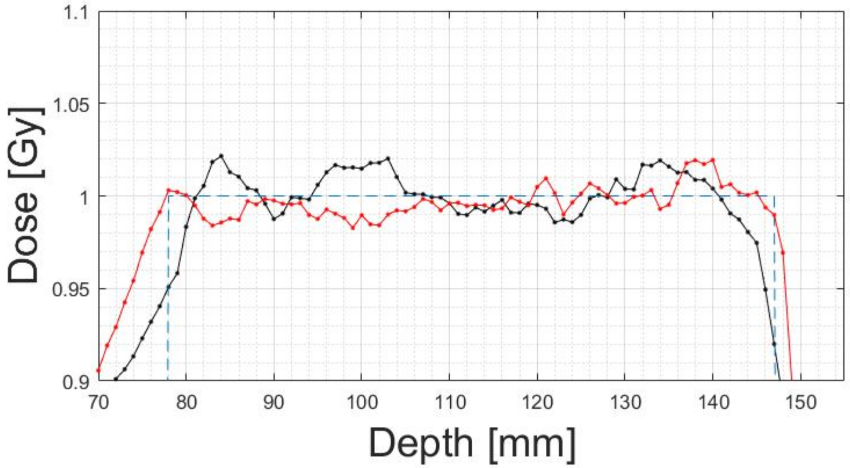
5. Monte Carlo (TOPAS) re-calculation of D(i)

Simulation

Simulation

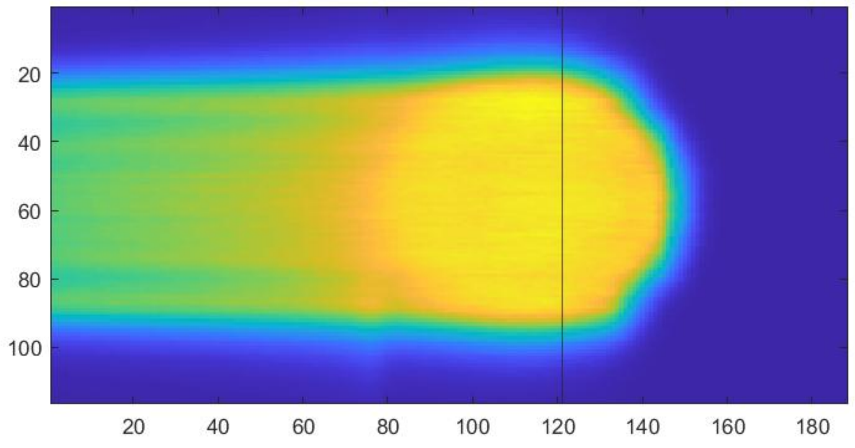


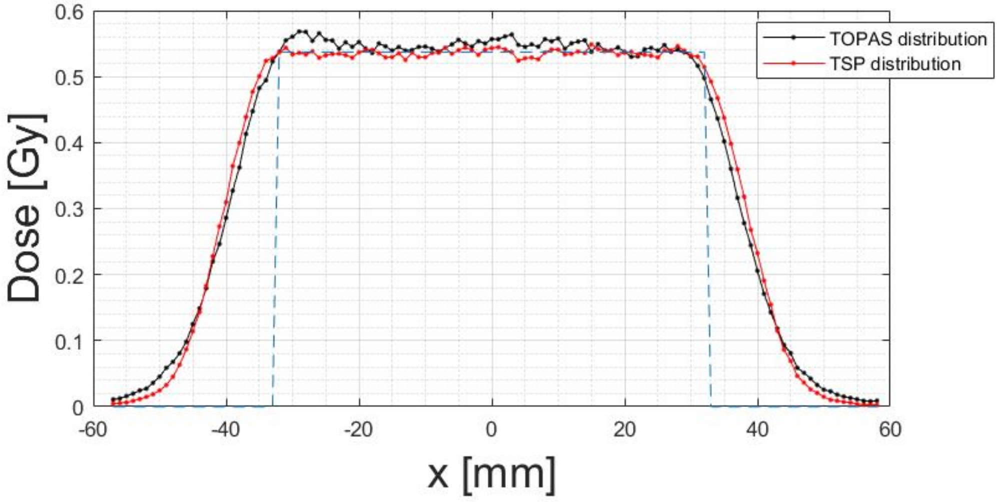


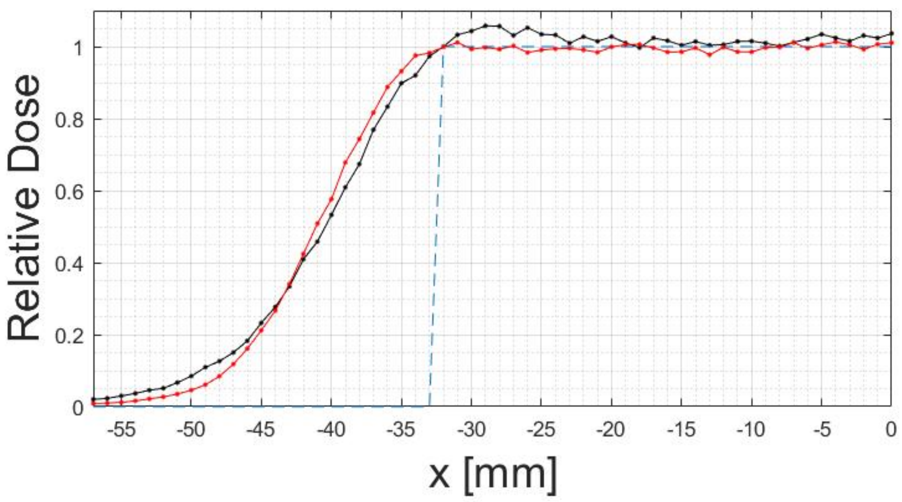


Simulation

Simulation





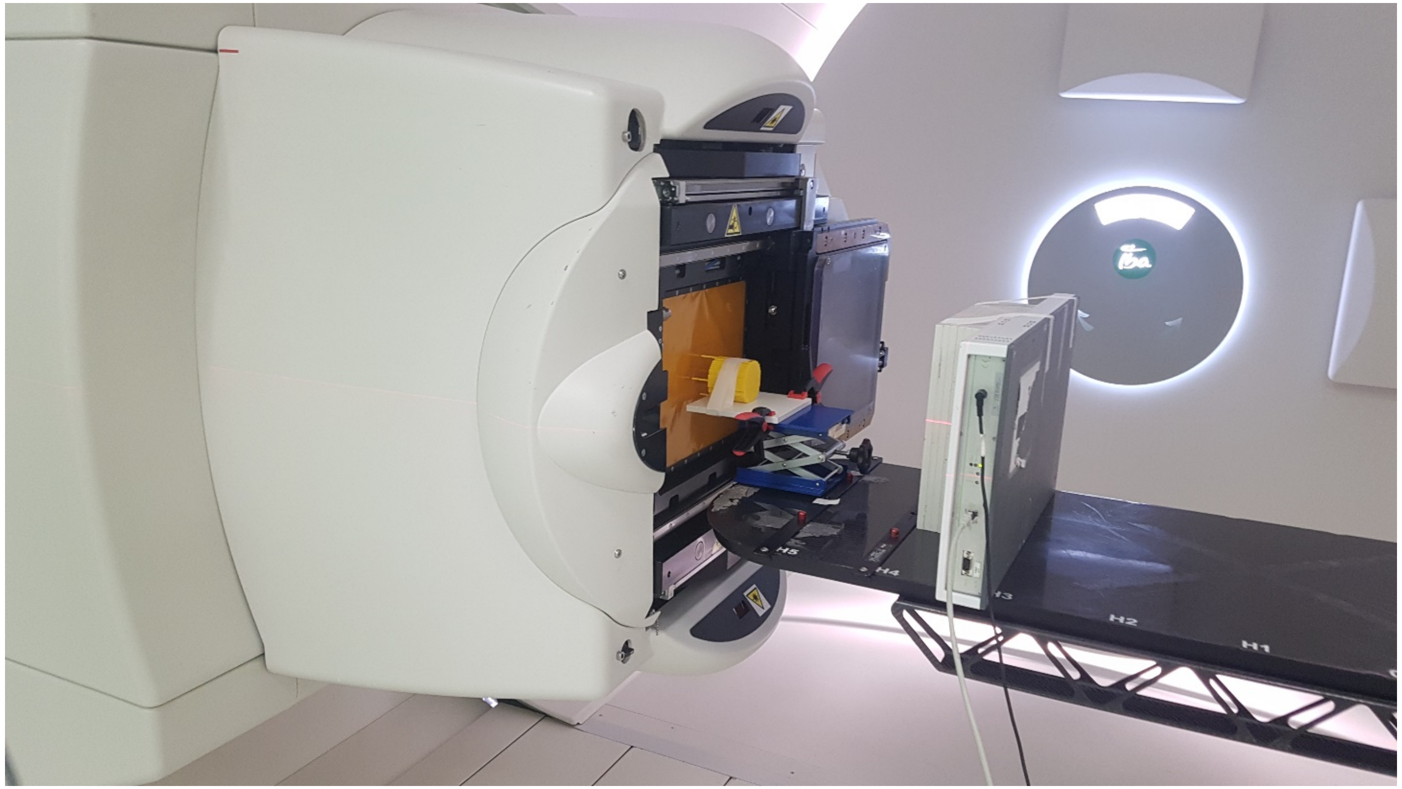


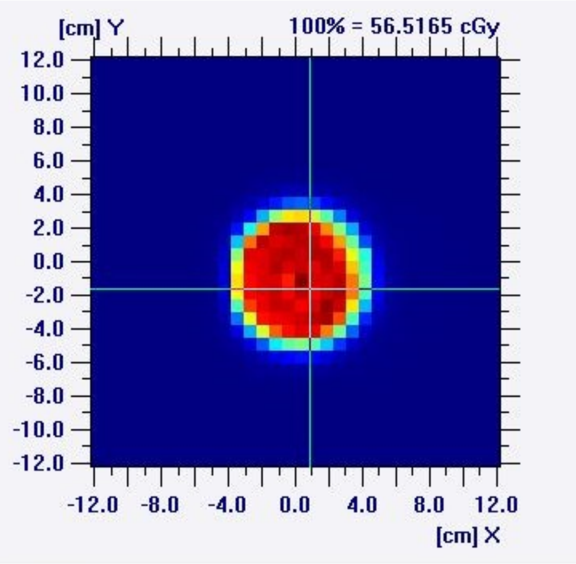
First prototype

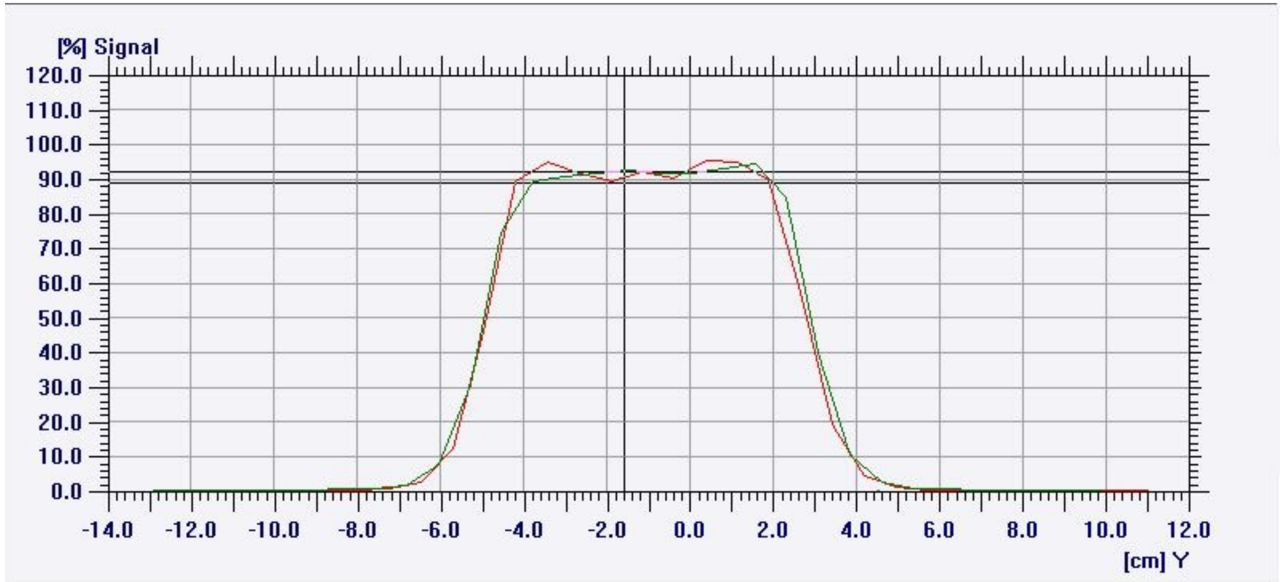
Printing & Validation

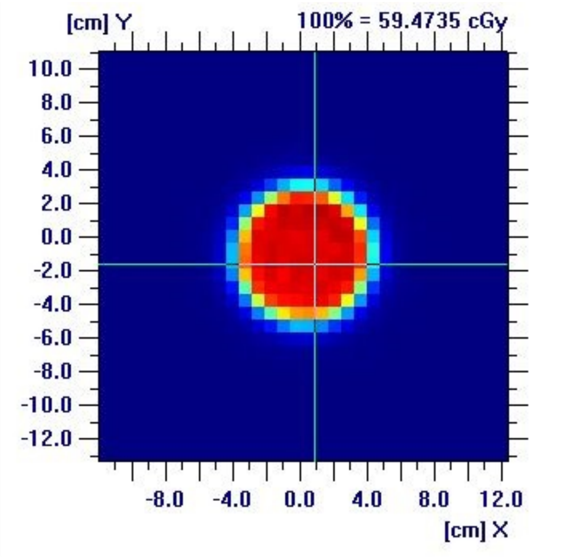
POLO MECCATRONICA

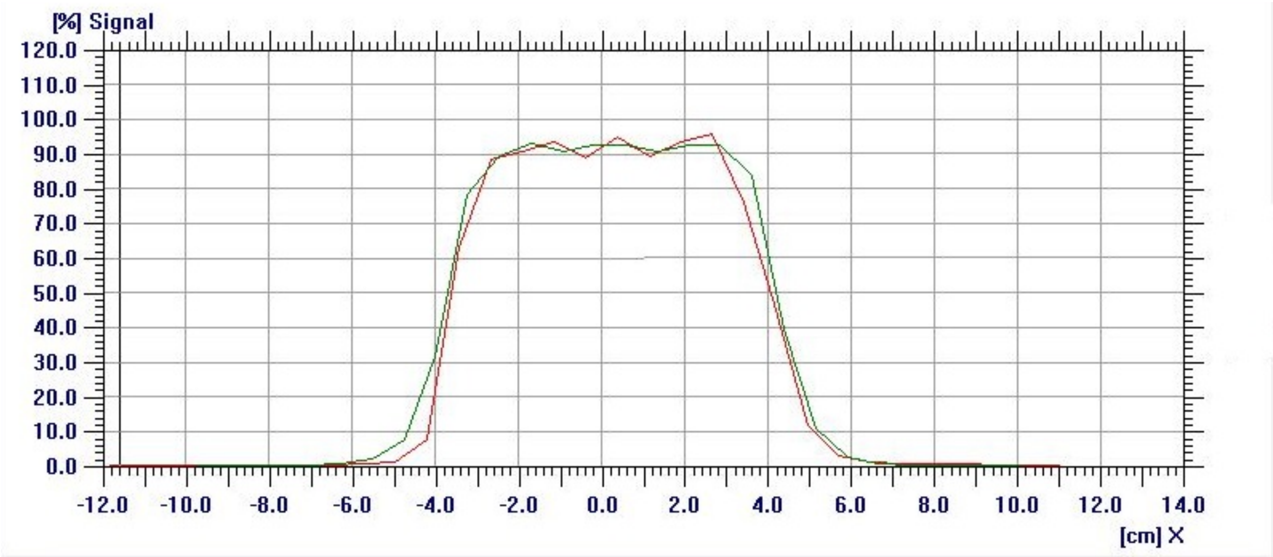
[Pro]M MECHATRONICS PROTOTYPING FACILITY




[cm] Y
100% = 56.5165 cGy
[cm] X


[%] Signal
[cm] Y


[cm] Y
100% = 59.4735 cGy
[cm] X


[%] Signal
[cm] X

Outlook

- Further **testing** of the 3DRM prototype (on the short term)
- Best setup for 3D RM implementation?
- Improvement of the 3DRM optimization **procedure**
- Evaluation of dose rate distributions
- Implementation of DMF and SDDRO