PRELIMINARY INVESTIGATION FOR DEVELOPING REPAINTED BEAM SCANNING ON THE PSI GANTRY 2

Silvan Zenklusen
E. Pedroni, D. Meer
Paul Scherrer Institut (PSI)
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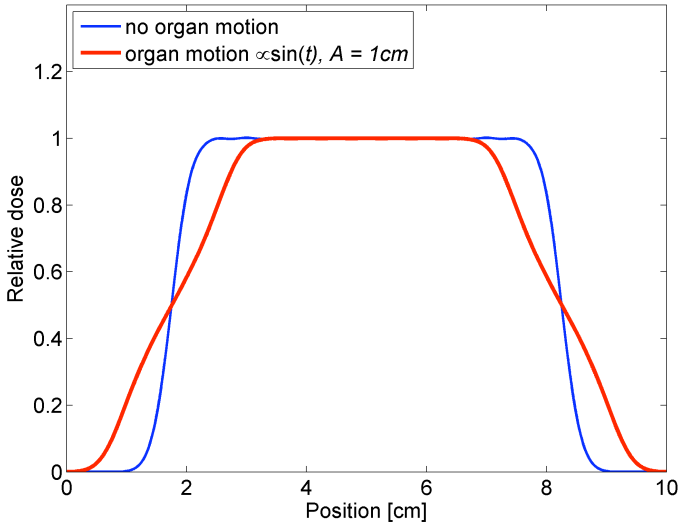
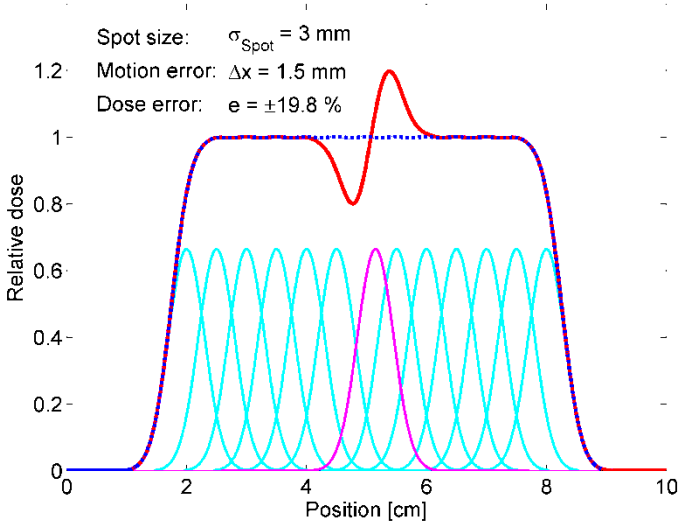
Motivation: Beam scanning and organ motion

The effect of organ motion:

- The lateral dose conformation can not be guaranteed (scattering and scanning)
- Disturbance of the dose homogeneity (only scanning)
  This makes spot scanning very sensitive to organ motion during beam delivery
  - With Gantry 1 we can treat only immobile lesions, e.g. tumors in
    - head
    - spinal chord
    - low pelvis
  - We accept only movements <1-2mm with full fractionation





Importance of fast scanning

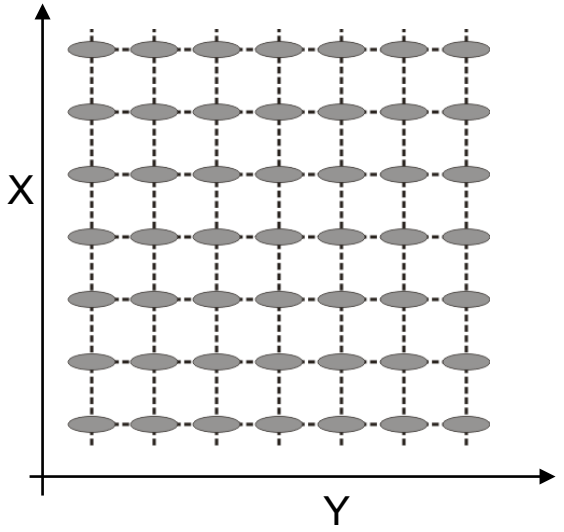
A faster dose delivery allows for target repainting and reduces local interference effects.

→ Statistical error is reduced by $\frac{1}{\sqrt{N}}$

Fast change of energy allows to rescan the volume (volumetric repainting)

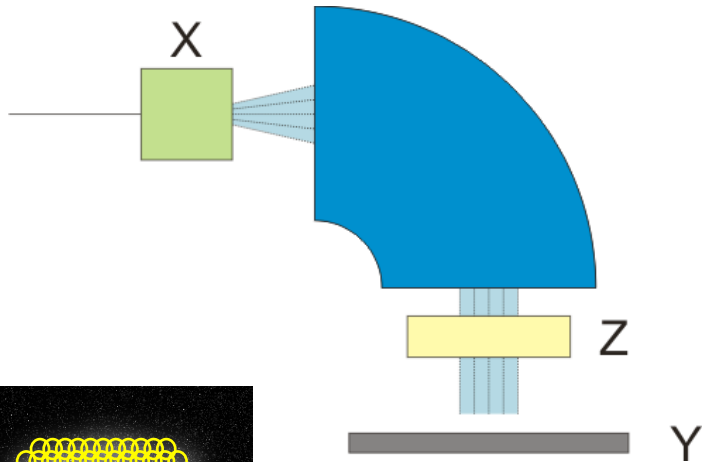
→ inherent advantage of scattering

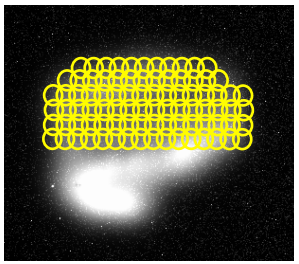
Repainting smears out the spot over the motion amplitude.



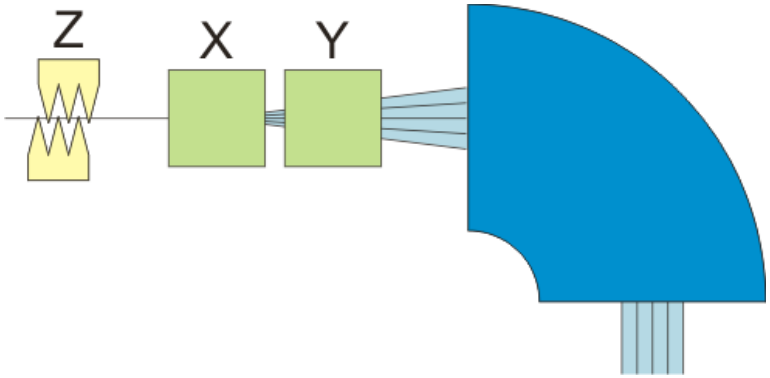
Pencil beam scanning methods at PSI

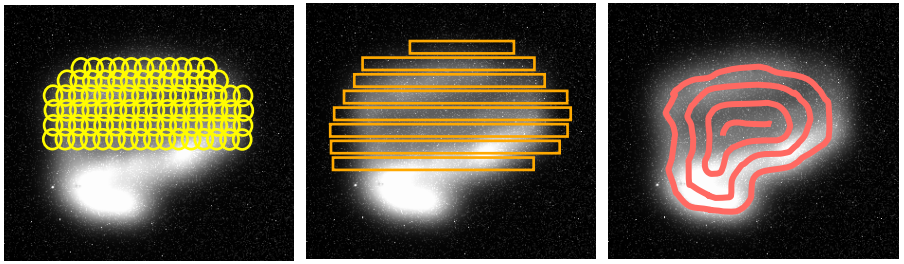
Gantry 1 - *spot scanning*





Gantry 2 - *spot & line scanning*





	inner loop	medium loop	outer loop
Gantry 1	X: 5 ms/step (sweeper)	Z: 50 ms (range shifter)	Y: 1000 ms/step (table)
Gantry 2	X: 4 ms/step (sweeper)	Y: 4 ms/step (sweeper)	Z: 150 ms/step (degrader)
slow dE	X: 4 ms/step (sweeper)	Y: 4 ms/step (sweeper)	Z: 1000 ms/step

A framework for simulations of the different dose delivery strategies on PSI's Linux cluster

A framework allowing a systematic study over the phase space of the motion parameters was built.

"Phase space" consists of:
- 50 respiration frequencies (1-50 per minute)
- 12 start phase (each 30°)
- 1 direction of motion
- 1 motion amplitude

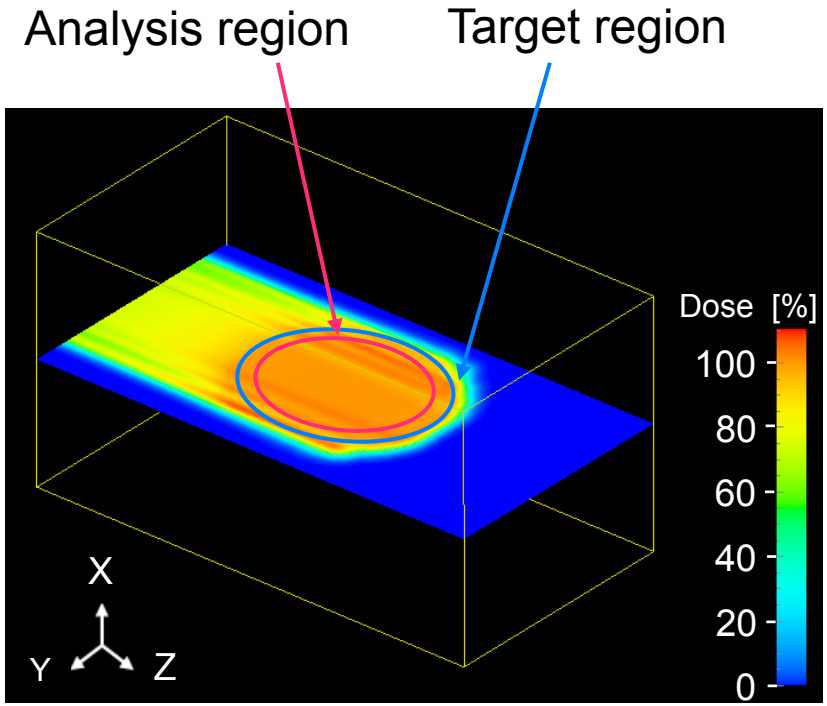
Typical run:
→ 9000 (= 50 ·12 ·15) dose calculations

Would take about 60 days on a standard PC, but approximately 1 day on the cluster!

Repainting strategies
- Number of repaintings N=1, 2, …, 15 (15)

PSI – Linux - Cluster:
- 24 compute nodes (two dual core AMD Opteron 2.4 GHz CPUs, 8GB RAM)
- Equivalent to 96 single-CPU PC's
- 12 TByte disk space

Analysis method

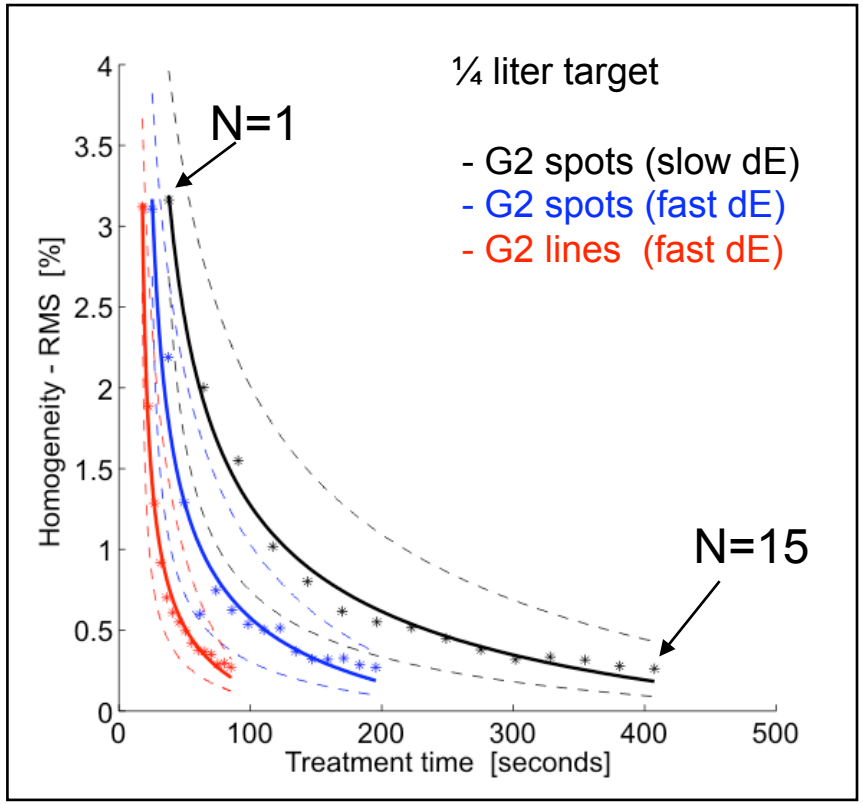


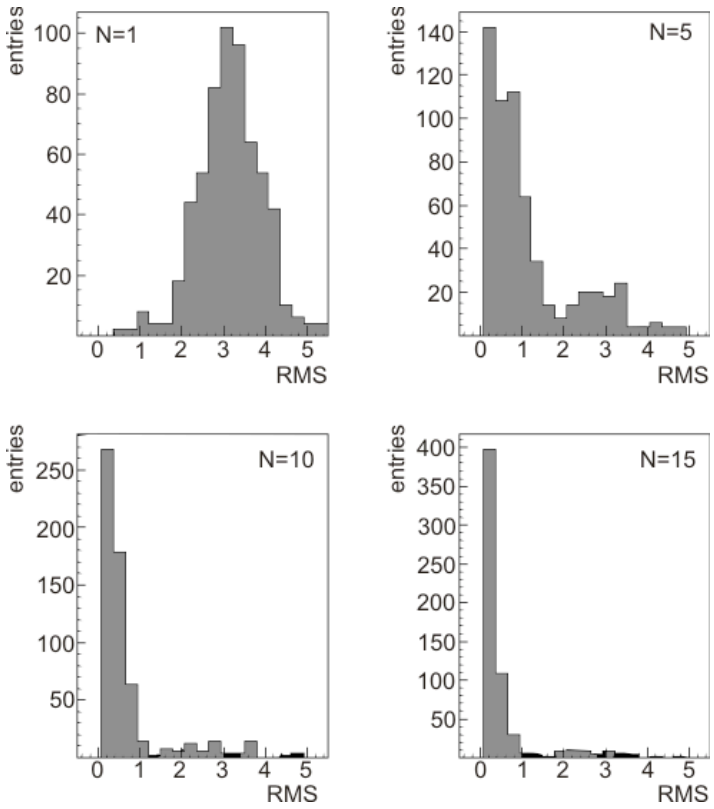
Dose distribution without repainting, motion along X-axis

- Cos^4-motion to simulate respiration
  - 5 mm amplitude
  - Motion along X - direction
  - Constant respiration frequency
  - Fixed start phase
- Beam size σ = 3mm
- Homogeneous spherical targets (¼, ½ and 1 liter) in water.
- For each dose distribution the homogeneity is expressed as the **R**oot **M**ean **S**quare of the difference to the prescribed dose for each voxel.
- Spectrum of RMS of typically 600 dose calculations

Results: Comparison of different delivery techniques

(12 start-phases, 50 frequencies, N = 1-15 repaintings)



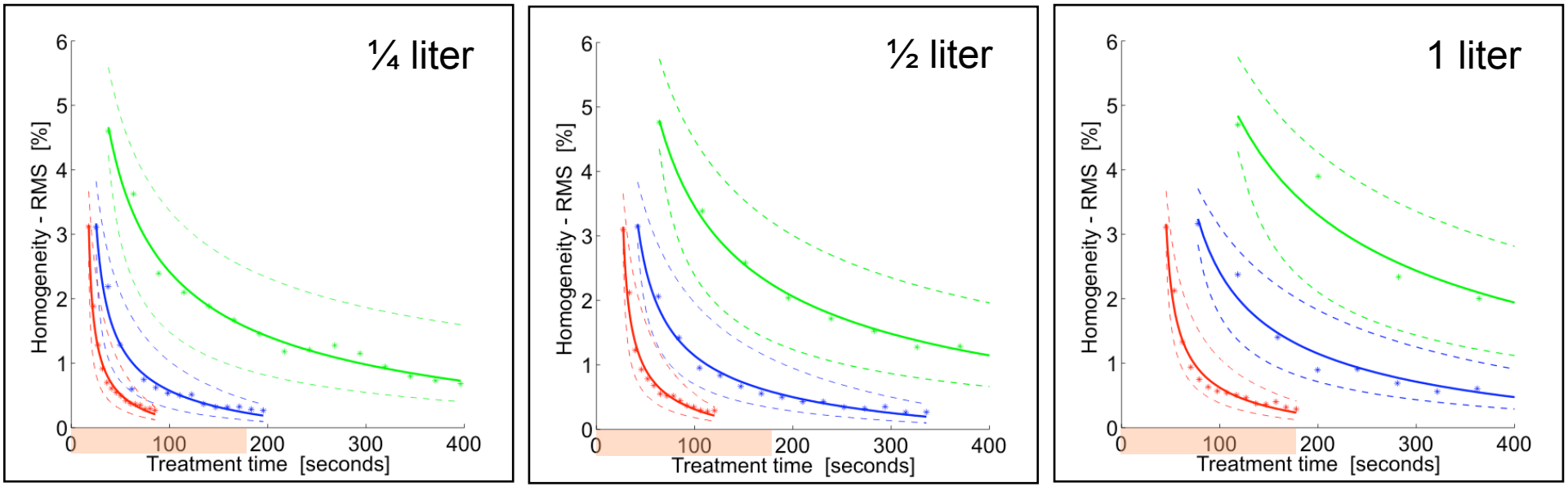


— median of the RMS spectrum
--- 75 % of the dose distributions are below upper dashed line.
--- 25 % of the dose distributions are below lower dashed line.

Results: Comparison of different volumes

(12 start-phases, 50 frequencies, N = 1-15 repaintings)

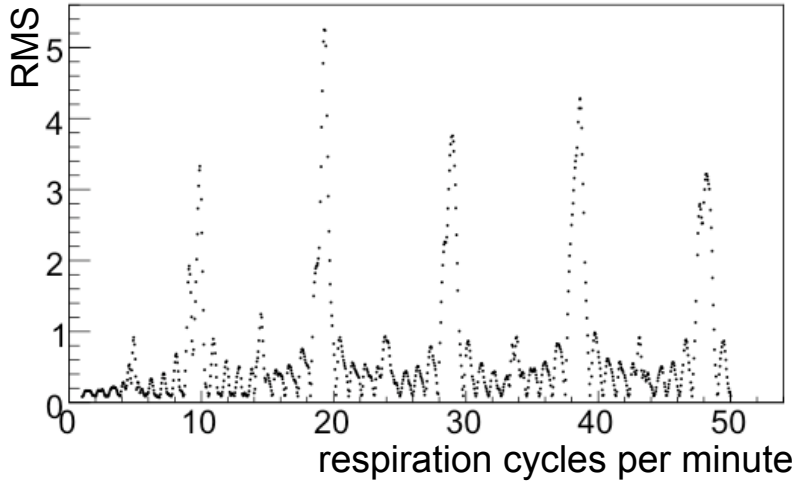
- G1 spots / motion perp. to sweep
- G2 spots
- G2 lines

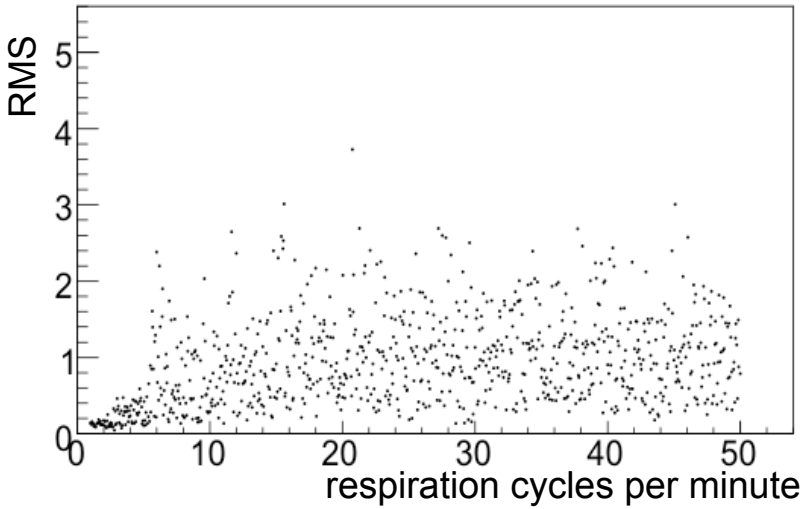


three minutes limits
— median of the distribution
--- 75 % of the dose distributions are below upper dashed line.
--- 25 % of the dose distributions are below lower dashed line.

Interference of scan volume time and motion period

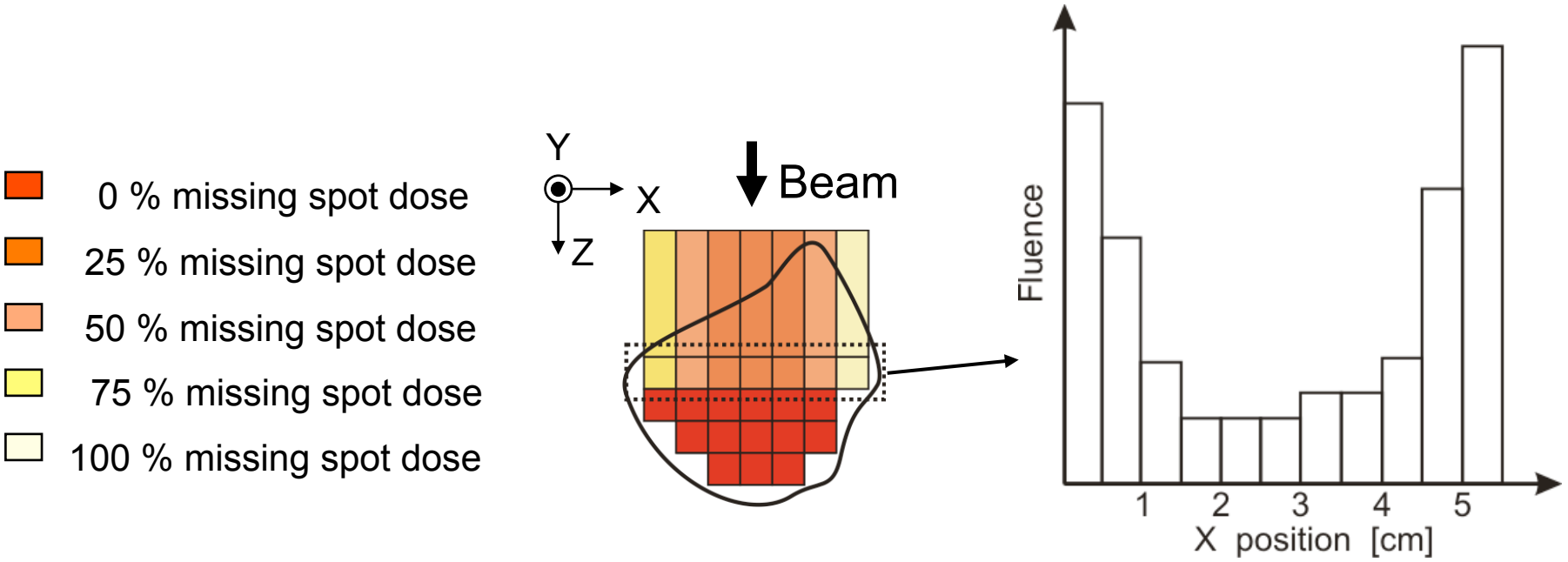
- A potential problem of interference between the volume scan time and the motion period occurs, since scaled repainting is highly repetitive.
- How realistic is this case and what can be done about it?
- Possible improvements:
  - Introduce random pauses between repainting cycles.
  - Other repainting strategy:
    Iso layer repainting





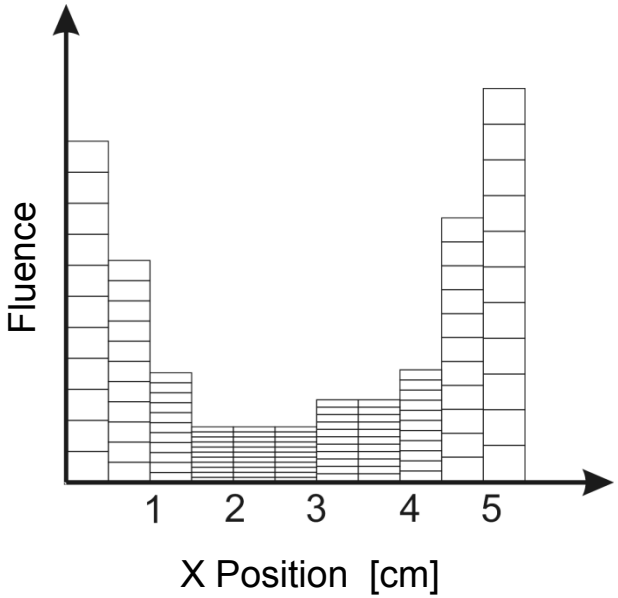
Repainting strategies

- Dose is built up by applying different dose layers at different energies.
- Spots in central region get dose from previous layers.
- In this case boundary regions of layers get higher doses as compared to central regions.

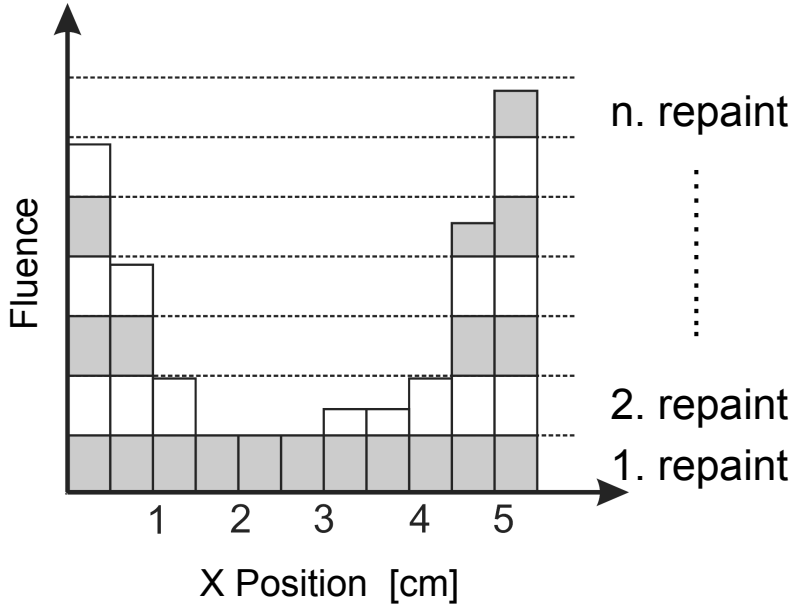


Repainting strategies

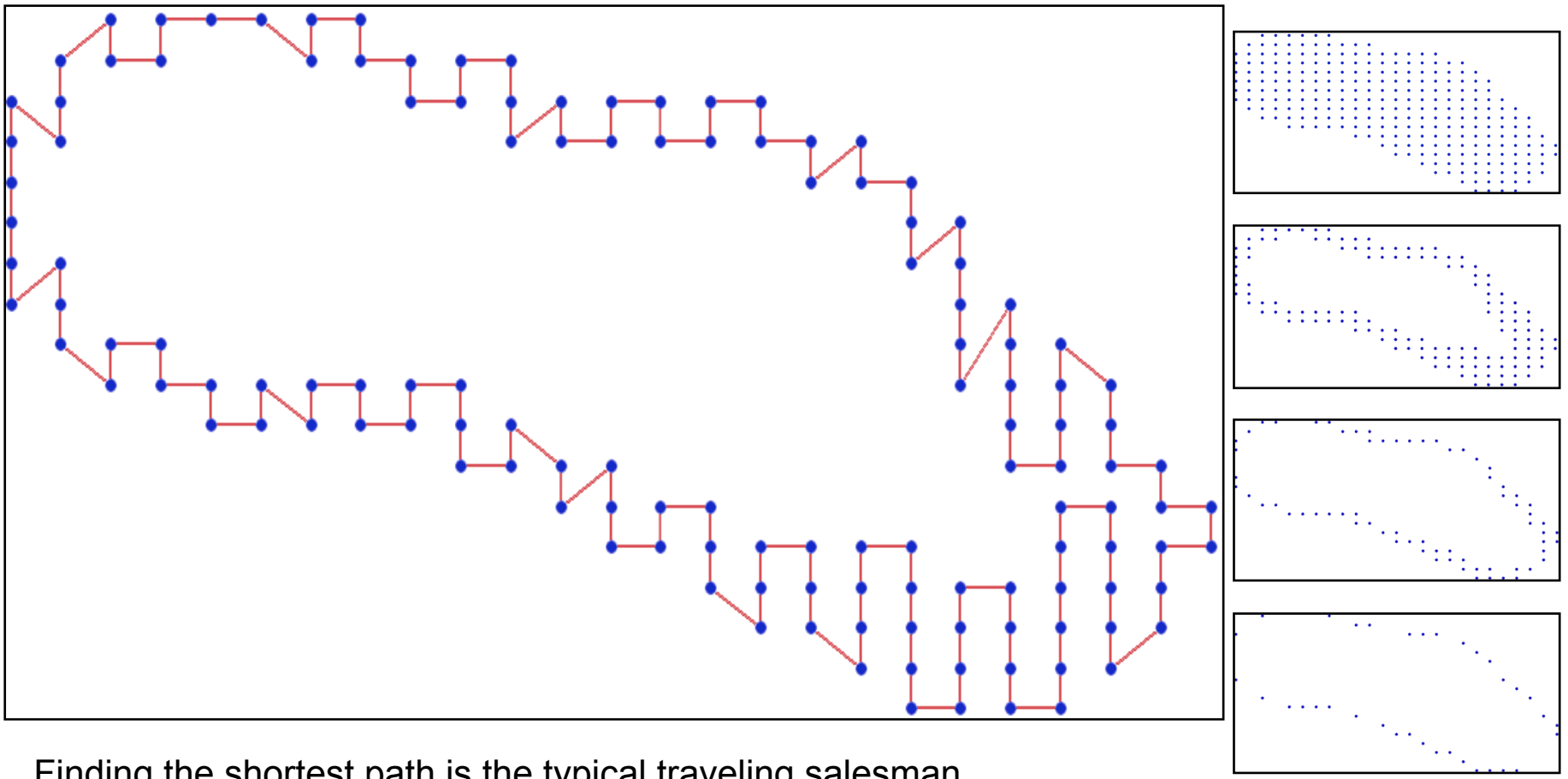
- **Scaled repainting:**
- Dividing the dose by a constant factor N = number of repaintings.
- Leads to very small doses per spot, not efficient, difficult to deliver.
- Simple (just repeat plan).



- **Iso-layer repainting:**
- Setting an upper dose limit per spot per visit via a maximal beam-on-time.
- Efficient (only uncompleted spots are revisited)
- Spots in the middle fall away, more difficult to find an optimal path.



Challenge and benefit of iso-layer repainting



Finding the shortest path is the typical traveling salesman problem that can be solved by a optimization algorithm.

Conclusions and outlook

- A systematic simulation study is ongoing to investigate the problem of motion and beam scanning.
  → Repainting helps reducing dose inhomogeneities within the target volume.
  → A fast scanning system is mandatory to achieve high repainting rates.
  → For volumetric repainting within acceptable treatment time the speed of changing the energy is the limiting parameter.
  → Gantry 2 will allow to irradiate a target using volumetric repainting.
  → Line scanning is superior to spot scanning especially for large target volumes.

- Future studies will be investigating
  → Expected benefits from iso-layer repainting.
  → Simulated scattering with a scanning machine.
  → Repainting in combination with gating/tracking.