# SPILL-CONTROL FOR A HIGHER PERFORMANCE IN ION BEAM THERAPY

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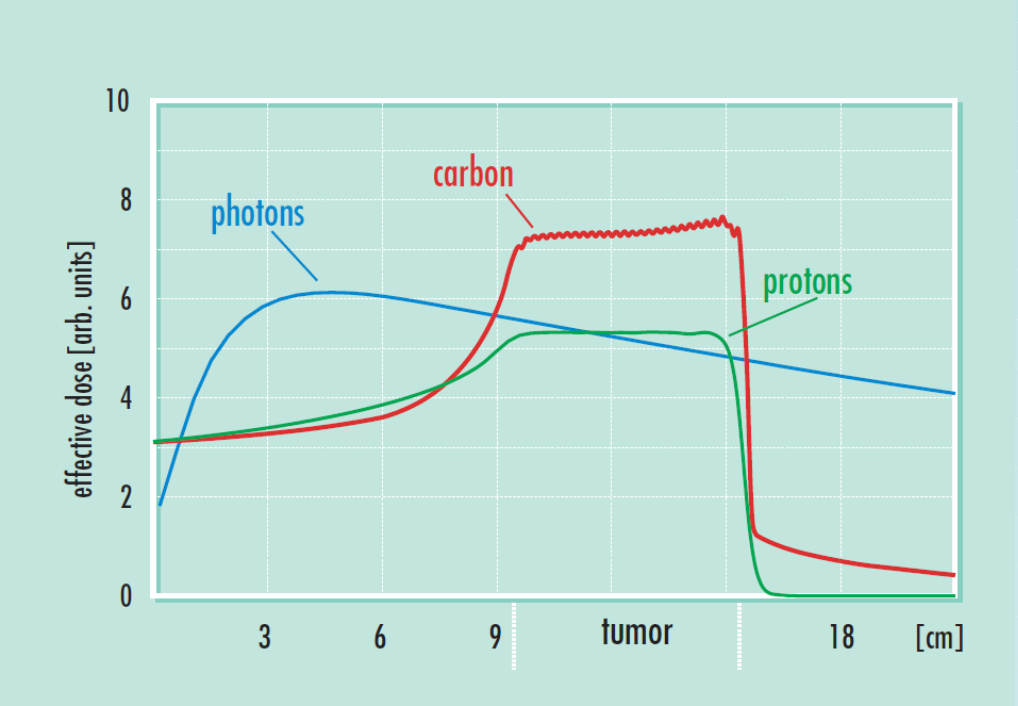
2011/11/04
Seminar Frankfurt

**HIT** Betriebs GmbH am
Universitätsklinikum Heidelberg
mit beschränkter Haftung

http://www.hit-centrum.de

# Why do we need this??

- Particle therapy has advantages compared to conventional radiotherapy (photons)
- Effectiveness is proven

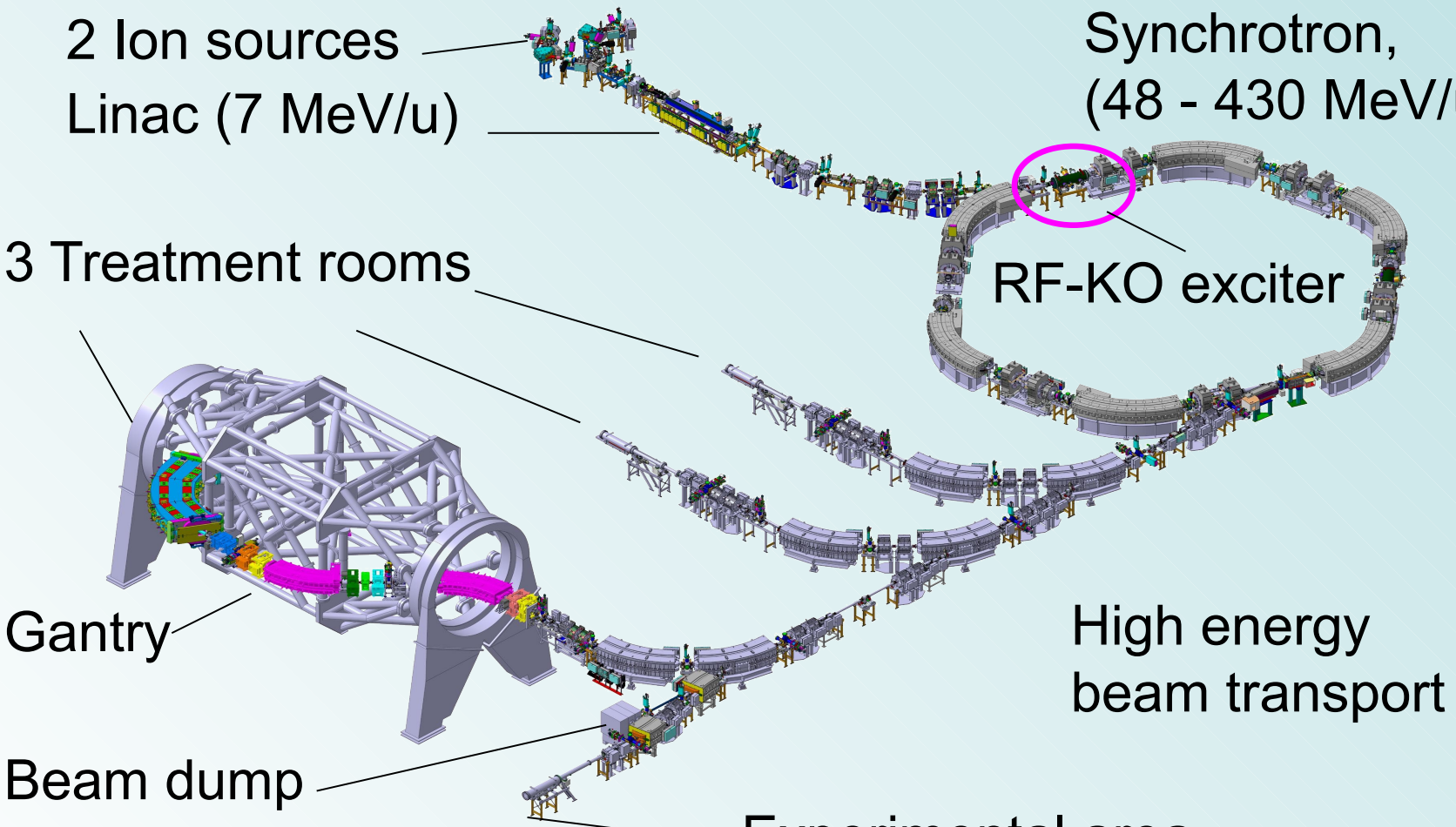



- Goals are to make the therapy...
  - more efficient → more patients!
  - more convenient for the patients

# Outline

- HIT and raster scanning
- Slow extraction with transverse RF-knockout
- Feedback loop design
- Constant spill and its advantages
- Controller in details
- Intensity modulated spill
- Summary and Outlook

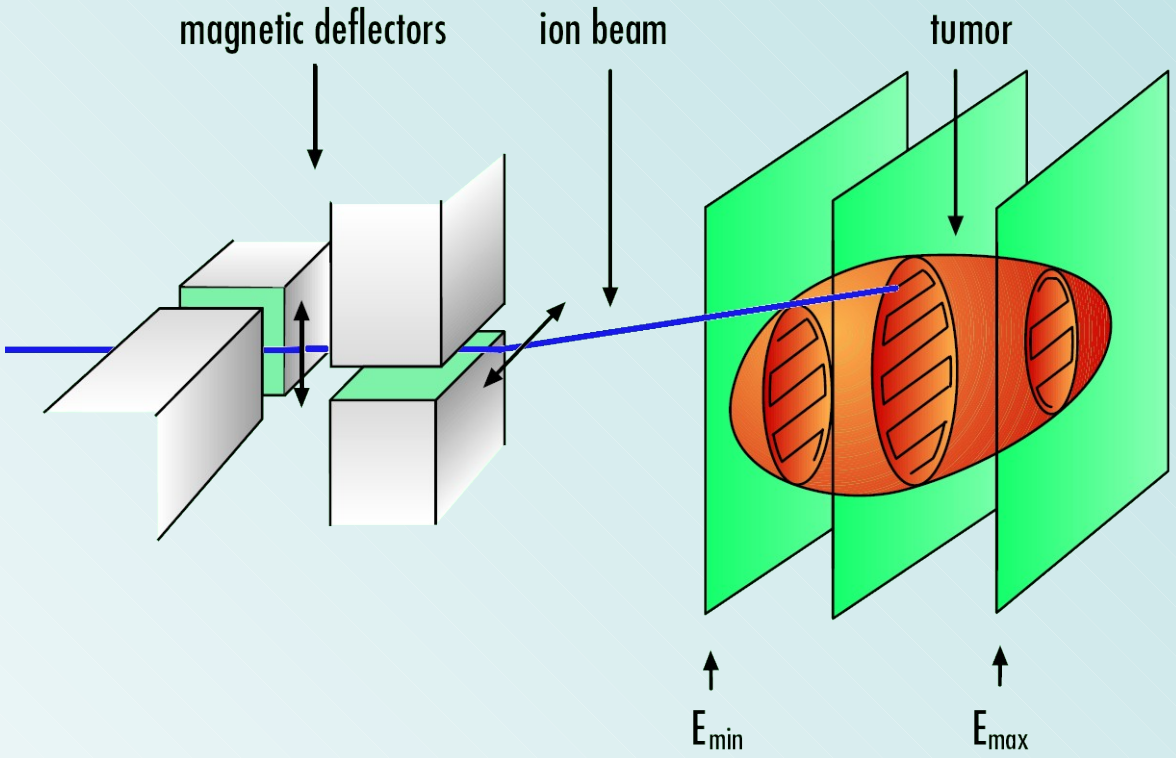
# HIT - Heidelberg Ion Therapy facility



# Raster scanning and requirements

- Tumour is irradiated ‘slice by slice’
- Beam ‘scans’ each slice in raster points

→ Slow extraction is needed



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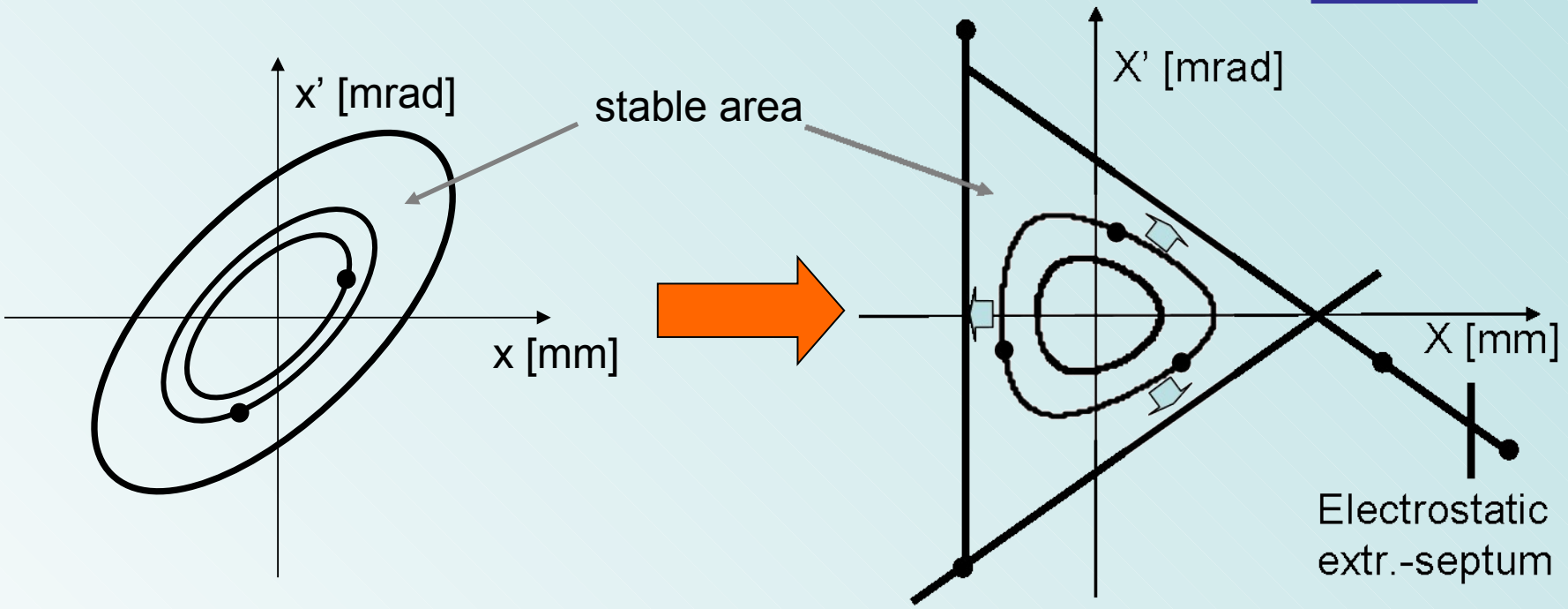
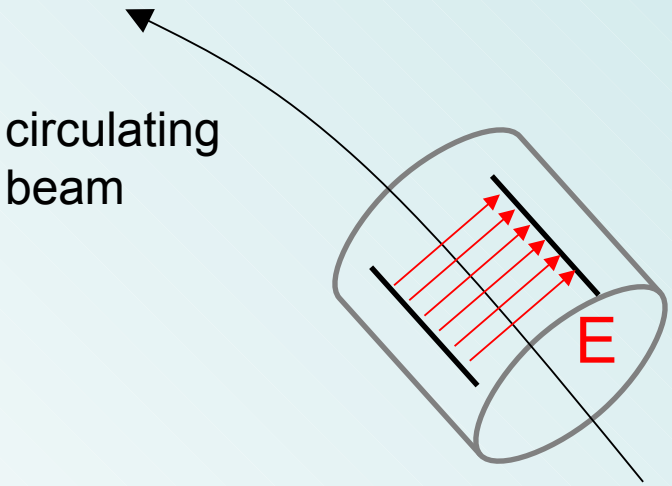
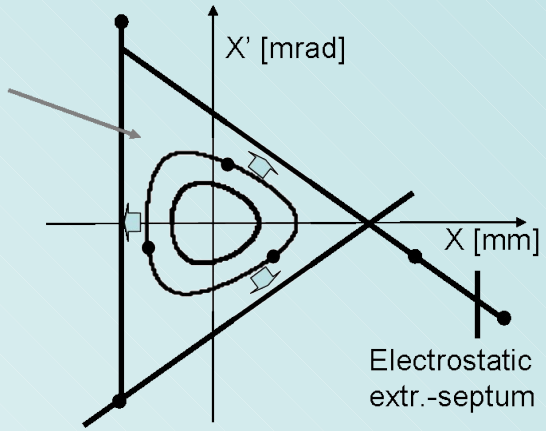
# Third order resonant extraction




- Quadrupoles excite a third order resonance
- Stable phase space ellipse turns into separatrix under the influence of sextupoles
- Beam is blown up by transverse RF knockout exciter

# The RF-knockout exciter



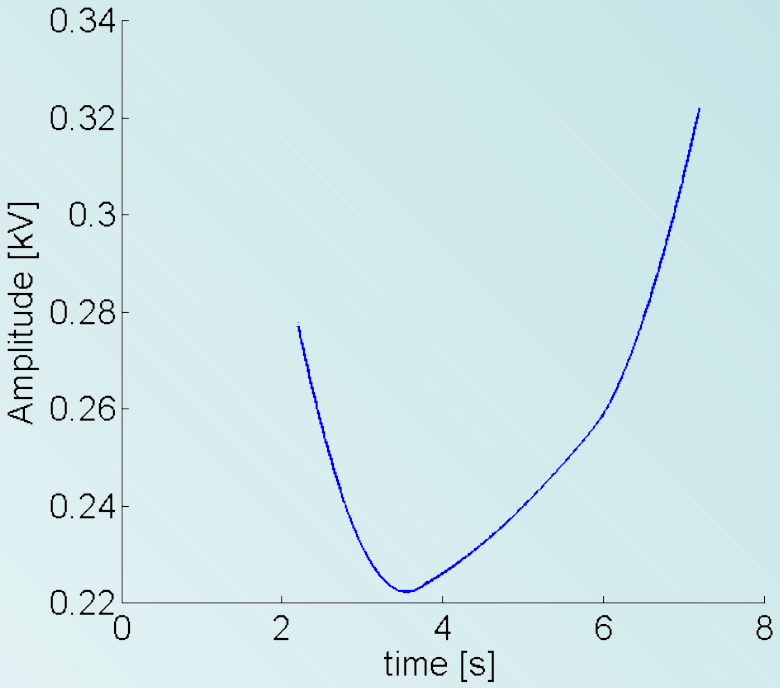

- Applies a transverse electric HF-field
- Resonance condition:

$$f_{ko} = (m + q) \cdot f_{rev} \quad , m \in \mathbb{N}$$

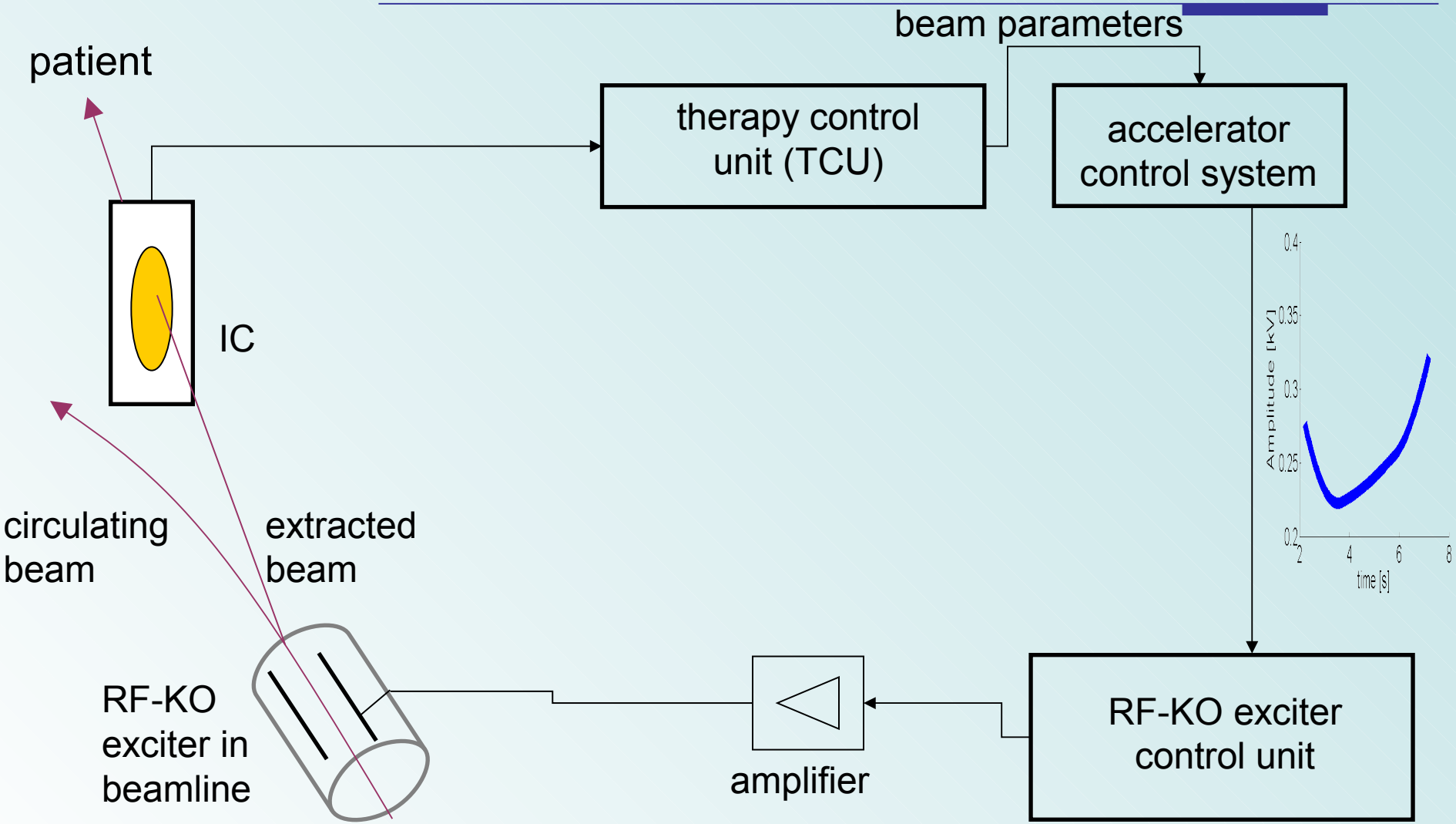
*q* = fractional part of the betatron tune

# RF-KO exciter amplitude curve

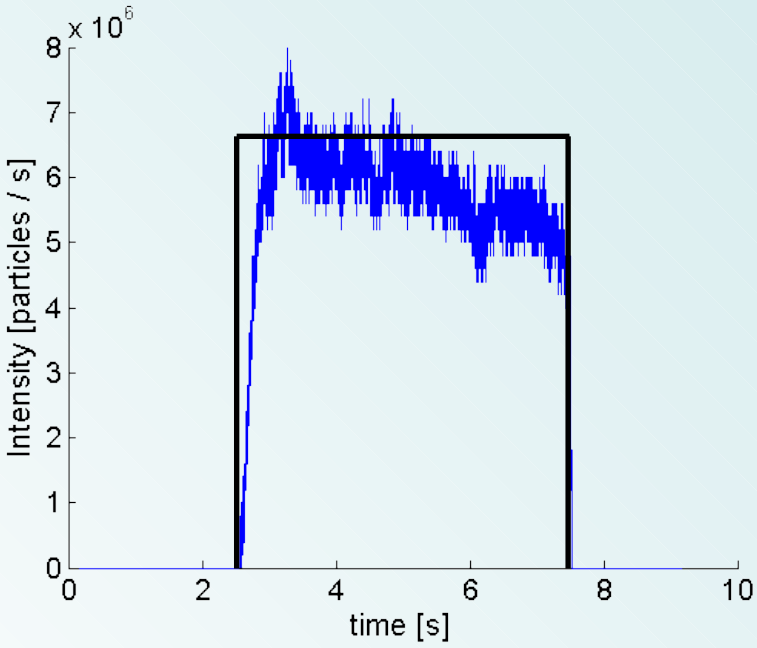
- Predefined amplitude
- Curve is energy dependent (> 250 levels!)
- Only device with non-constant setting during extraction
- Mainly responsible for spill-shape
- Complicated mathematical description
- Sensitive to changes of other synchrotron settings



# System overview without feedback



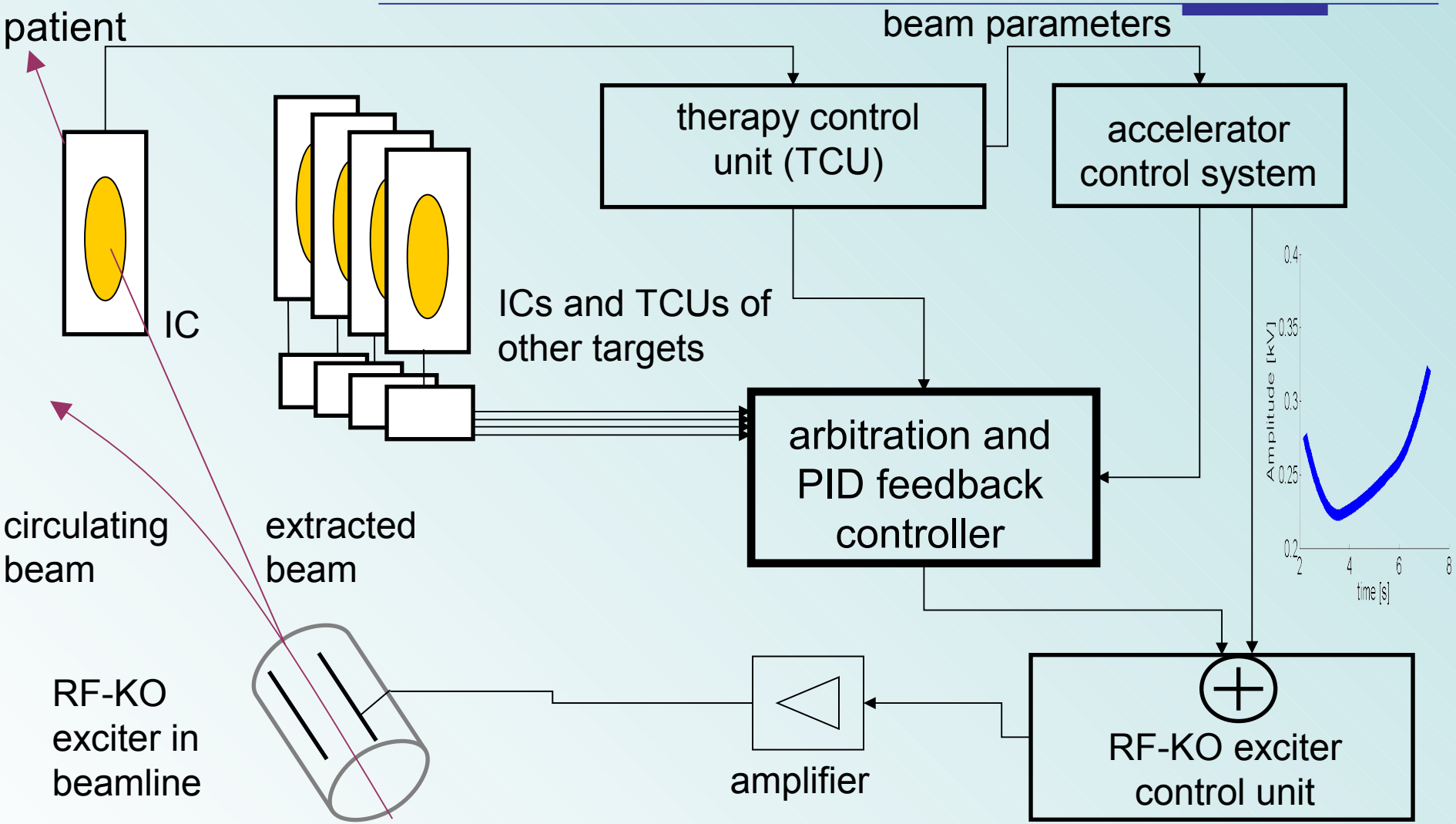
# Present spill shape




- Typically created spill (blue)
  - Not too bad!
- Ideal, constant spill (black)
- Inhomogeneous particle distribution
- Varying injection pulses

Solution: feedback!

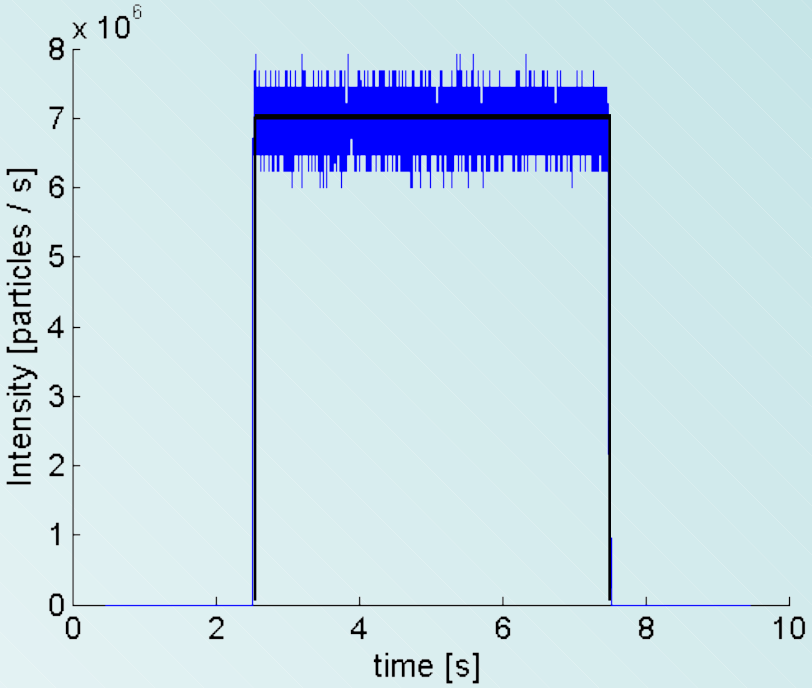
# Spill feedback system overview



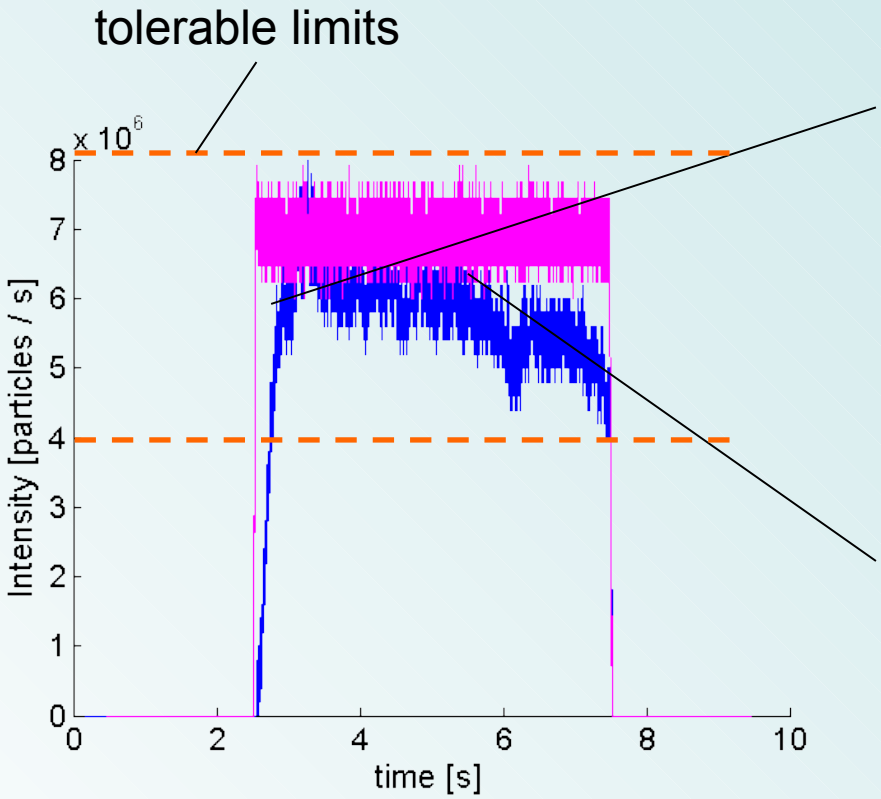
# Spill control: rectangular spill

- Less beam-on time, reduction up to 25% !
  - More comfort for patient
  - Available for more patients
  - Economic facility operation
- Less adjustment time

→ **More patients**



# Advances of spill control




- Effect 1:
  - Fast rise time (some ms compared to some 10ms or 100ms)
  - Significant, often full spill is not needed
  - Dose delivery more accurate
- Effect 2:
  - Flat spill can be tuned to upper limit without producing interlocks

# How to realise the controller

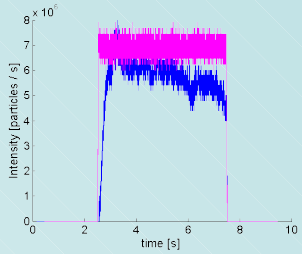
Different possibilities of realisation:

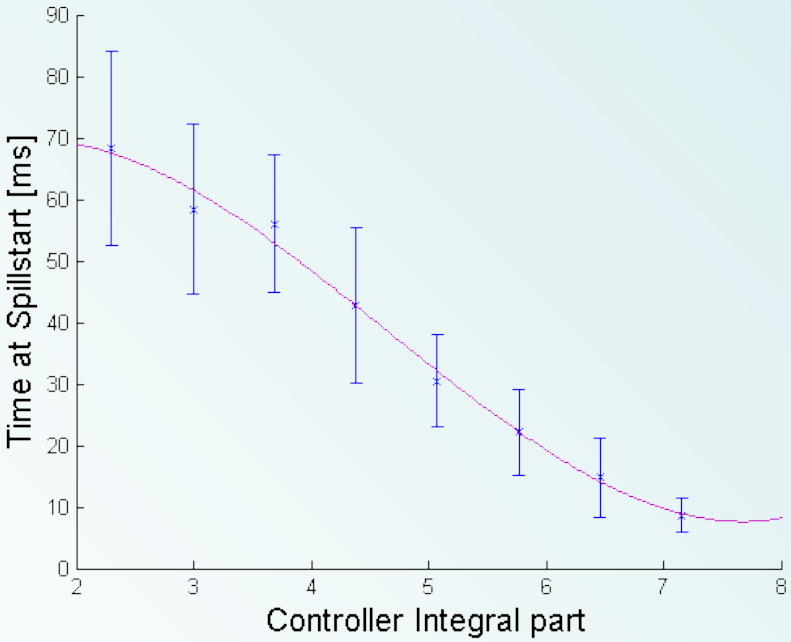
- 1st approach: software solution, real time PLC
  - Good for tests
  - Not good enough for permanent use
- Final version: FPGA based hardware solution
  - Integrated in the accelerator control system
  - Integrated in the therapy control system
  - Fast
  - Reliable

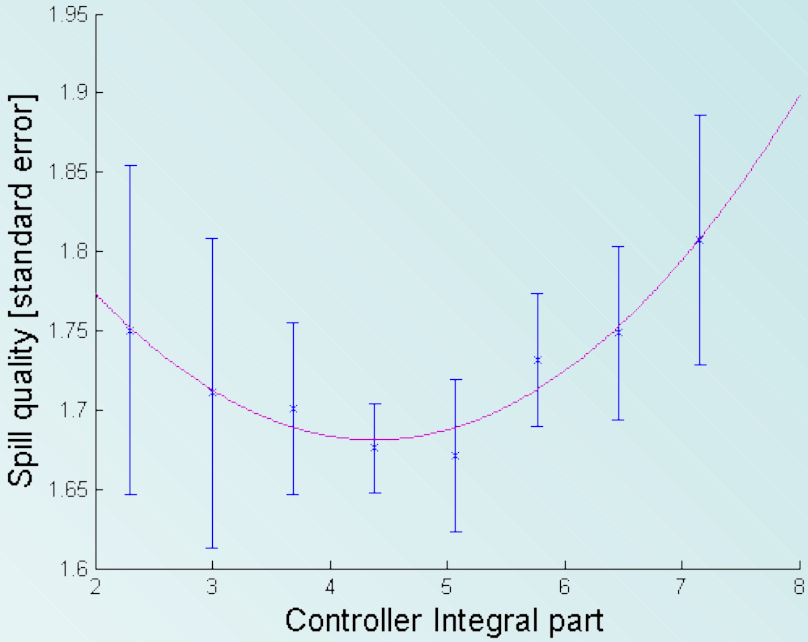
# Controller characteristics

- PID transfer function
- Rise time and spill quality were investigated
- Feedback parameters are energy and intensity dependent

Plots for Carbon, 88 MeV/u, $10^6$ particles/s



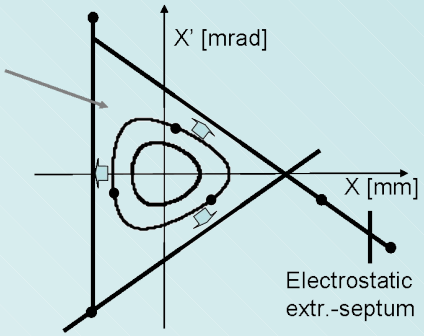



# Controller characteristics II

- Different behaviour during one spill
- Reaction-time at the beginning (≈ 2 ms)
- Particles make some $10^3$ turns before extracted

→ Determines the controller

- Fast controller during the rest of the spill

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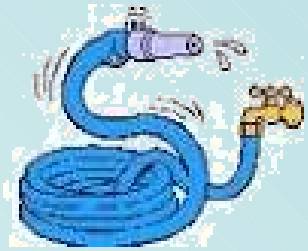

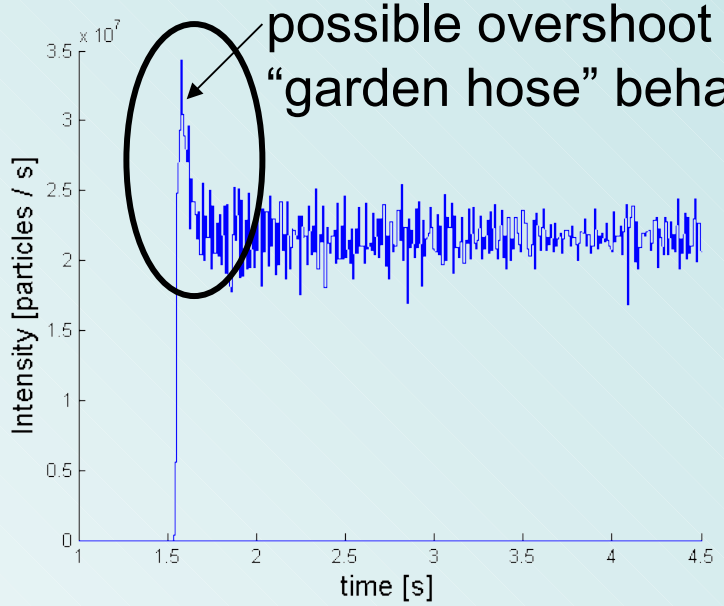




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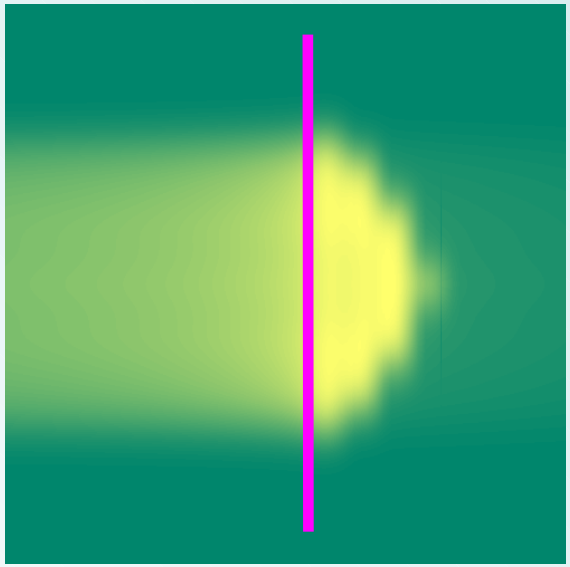
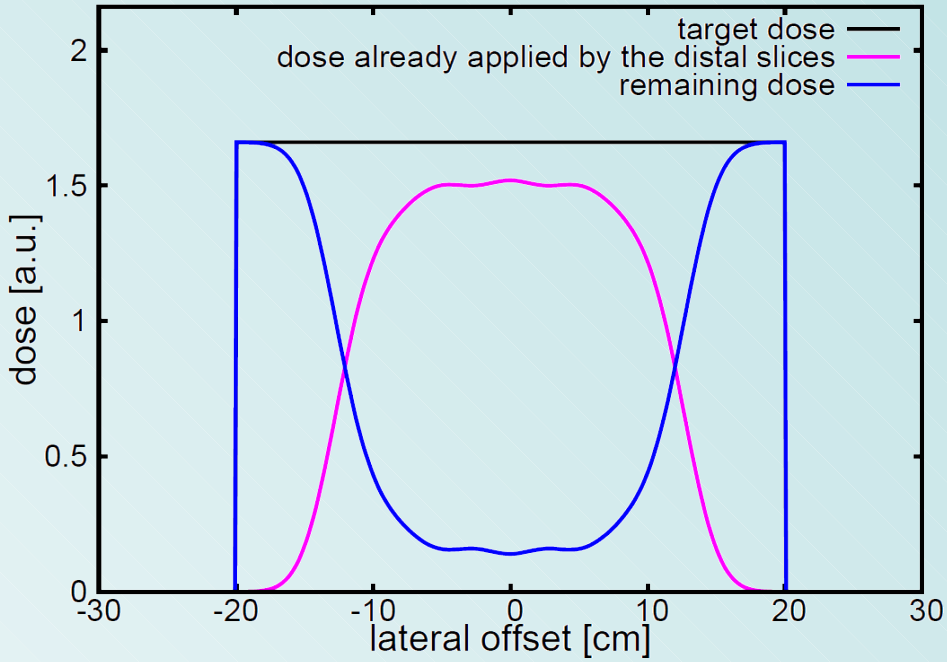
# Dose distribution



Distal part of the tumour

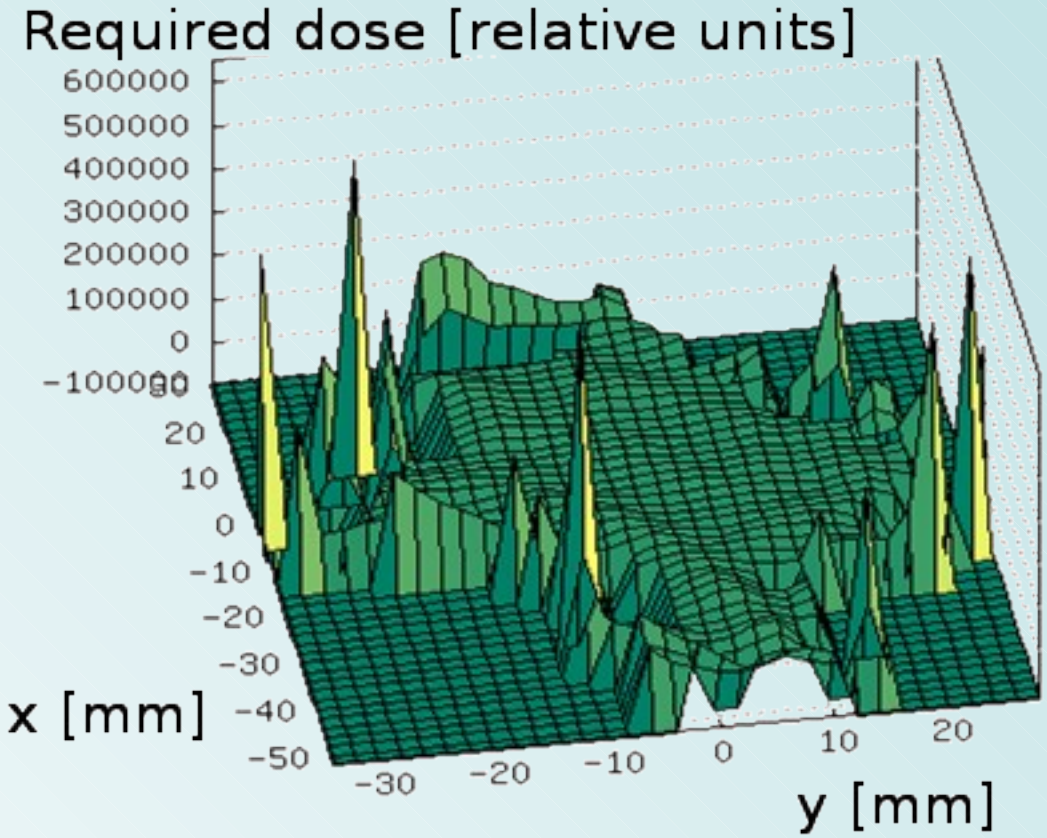



Ratio of applied and remaining dose

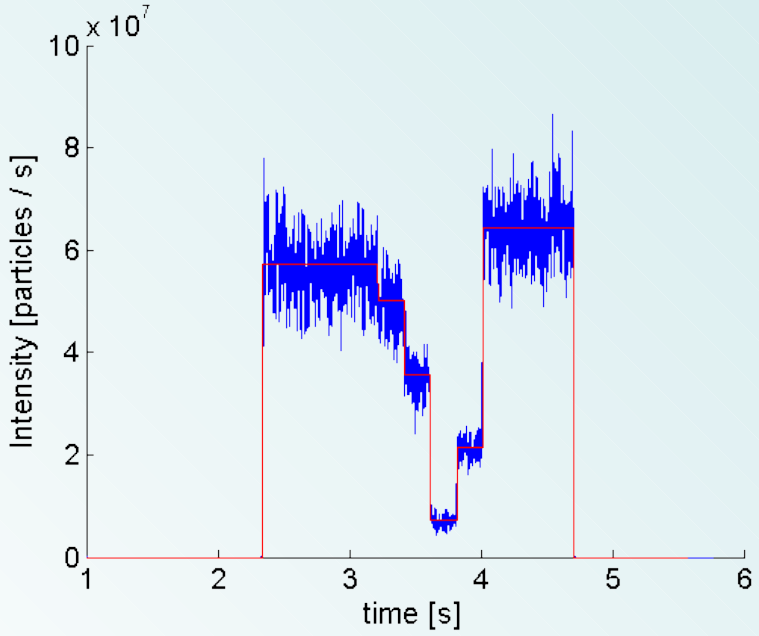
# Dose distribution II

- Dose variation per raster point of factor 100 and more
- Simulation: ideal, individual intensity compared to flat spill

→ beam-on time can be reduced by 50%!



# Intensity-modulated spill




- Alternating reference value
- Each raster point is irradiated by an individual particle rate
- Intensity can be changed within < 1ms

→ Smaller scale than time for one raster point

# Summary & Outlook

- Feedback loop for flat spill is in operation for experiments
- Implementation into clinical routine after risk analysis and approval
- Treatment plan specific dynamic intensity is available for further tests
- Extended real time connection to therapy system required for individual raster point intensity

# Thank you for your attention!

...and to these people for their support and collaboration:

- E. Feldmeier, Th. Haberer, J. Naumann, R. Panse, A. Peters (HIT)
- Dr. Martin Bräuer (Siemens AG)



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