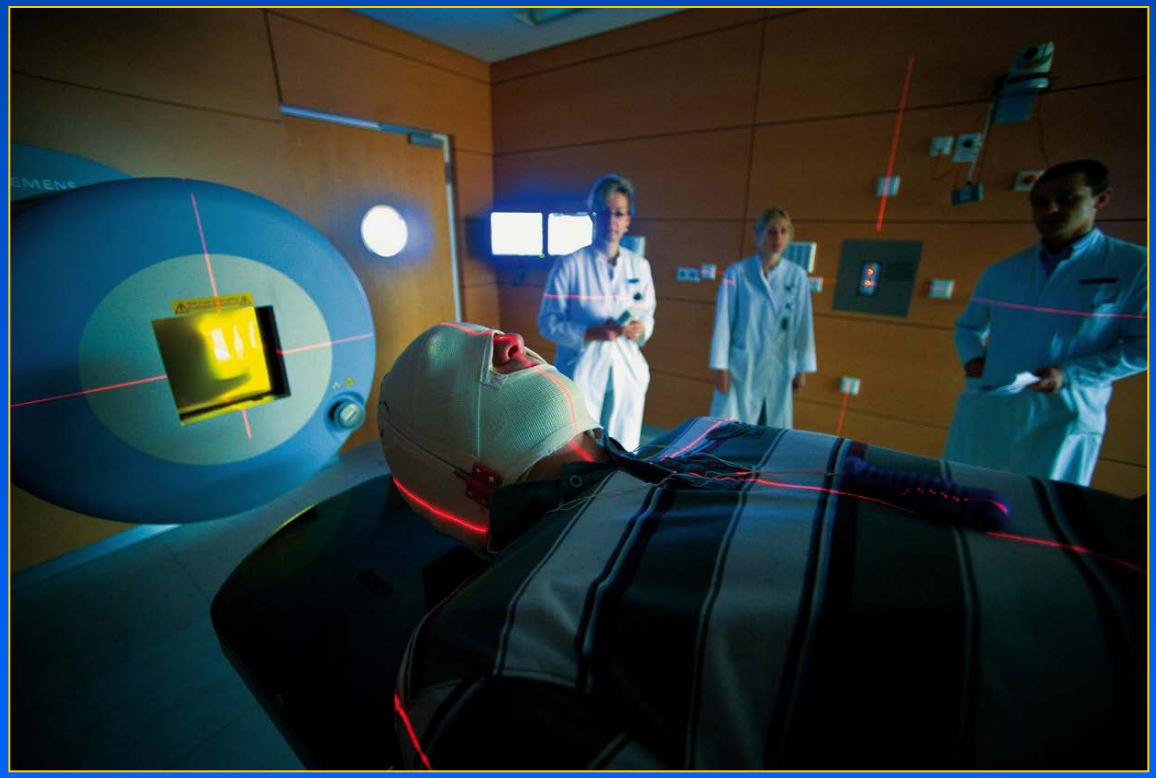
Feedback and Feedforward Systems Improve the Performance and Reliability of the Heidelberg Ion Beam Therapy Center

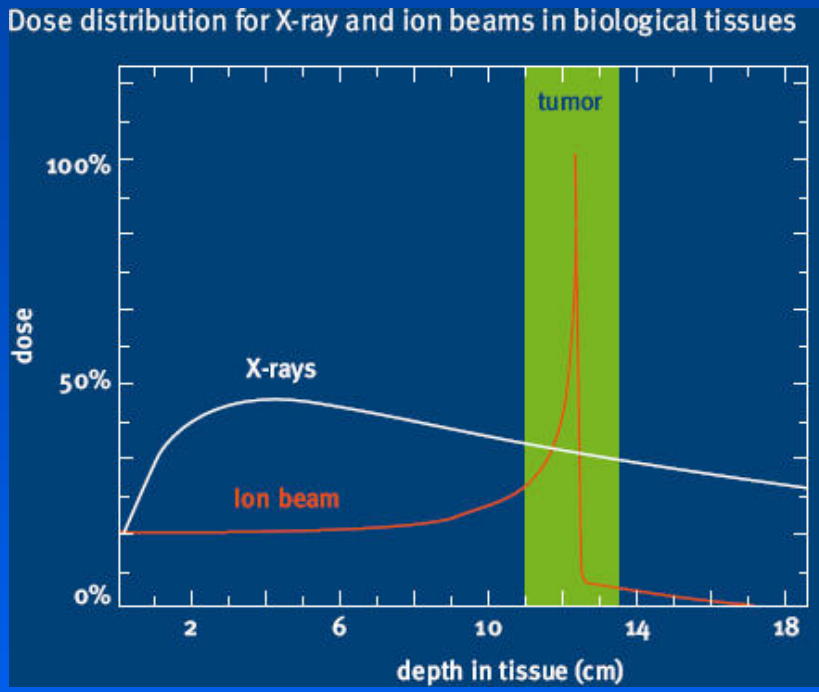


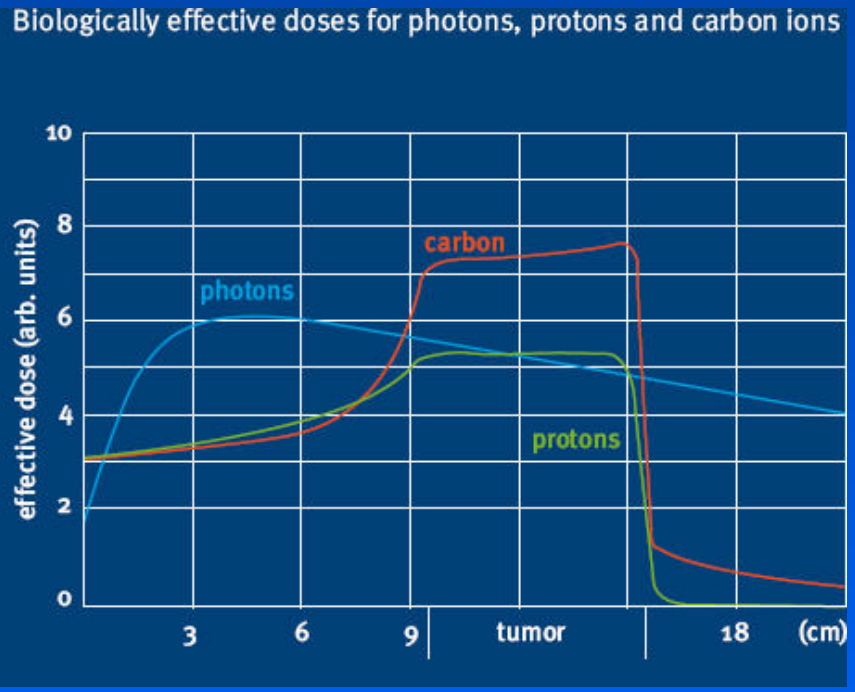
Prof. Dr. Thomas Haberer

Science -Technical Director

Heidelberg Ion Beam Therapy Center

Rationale

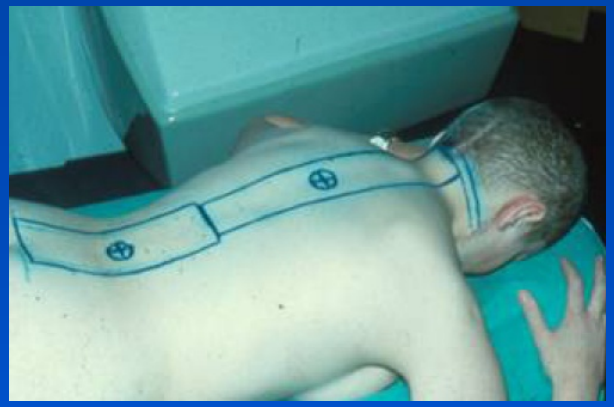




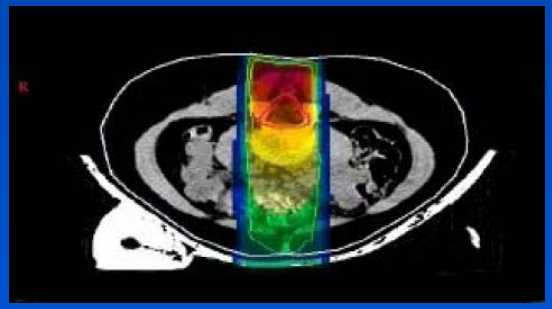
- inverted depth-dose distribution
- mild lateral scattering
- improved cell-killing efficiency (Z > 1)

Medulloblastoma

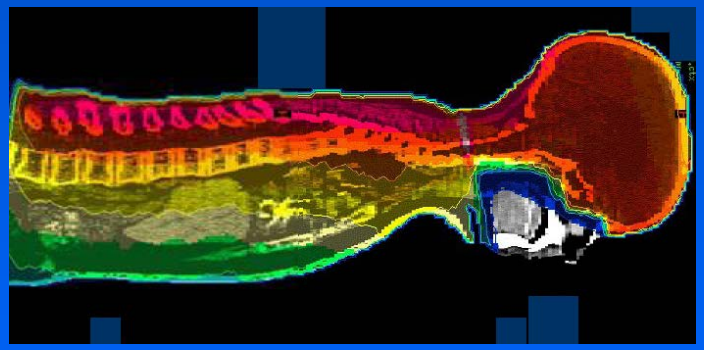
conventional

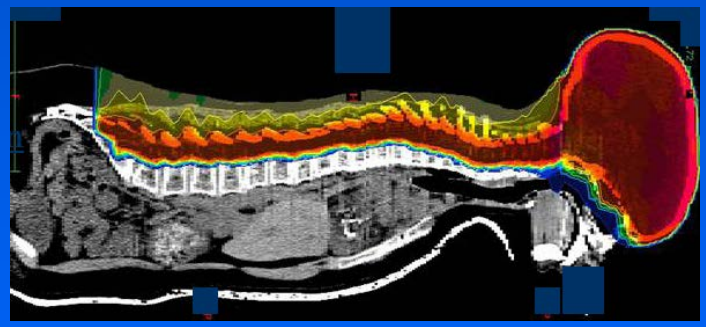


charged particles



Target dose 32 Gy/GyE

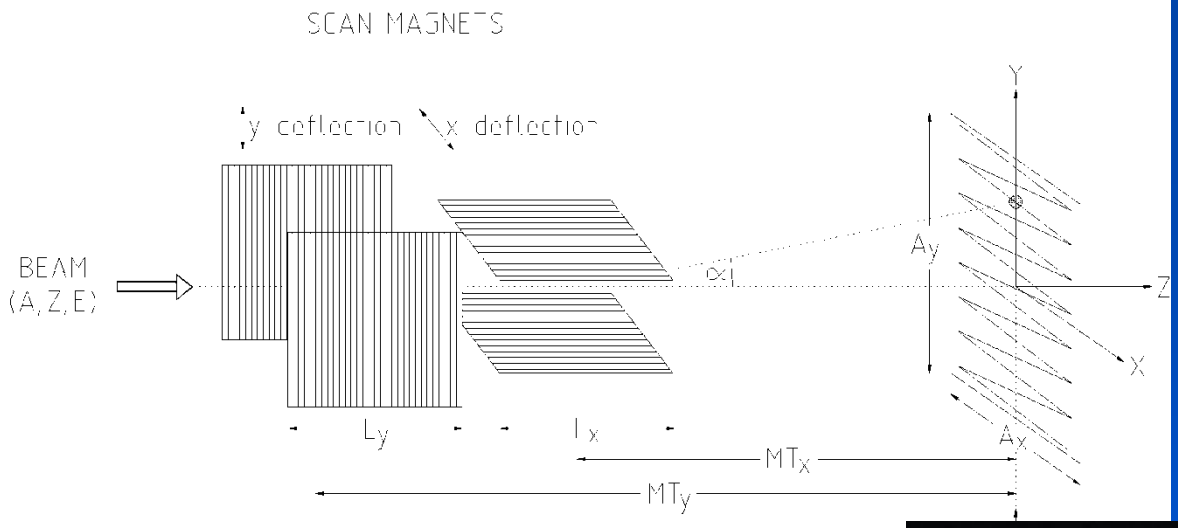




Dose comparison

22 Gy	bone marrow	< 1 GyE
18 Gy	heart	<.5 GyE
20 Gy	intestinal	<.5 GyE

HIT
Heidelberg Ionenstrahl-Therapie Centrum



Haberer et al., NIM A , 1993

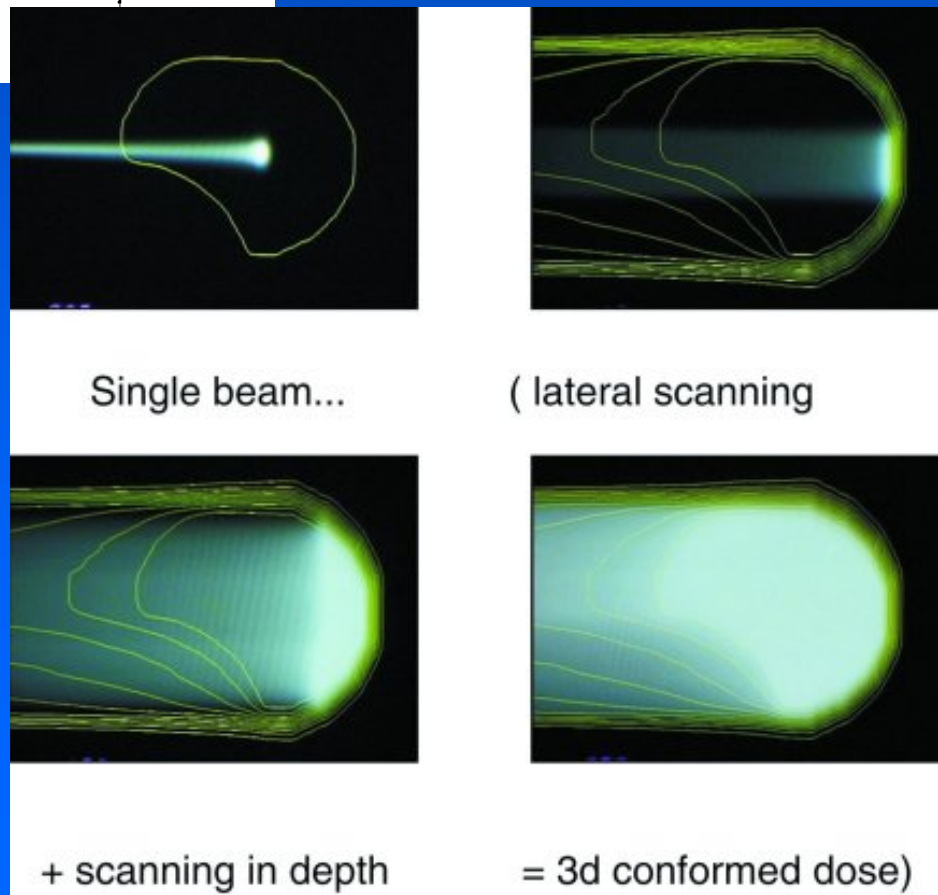
Protons @ cyclotron
Pedroni et al., PSI

spot scanning gantry
1D magnetic pencil beam scanning
plus
passive range shifting

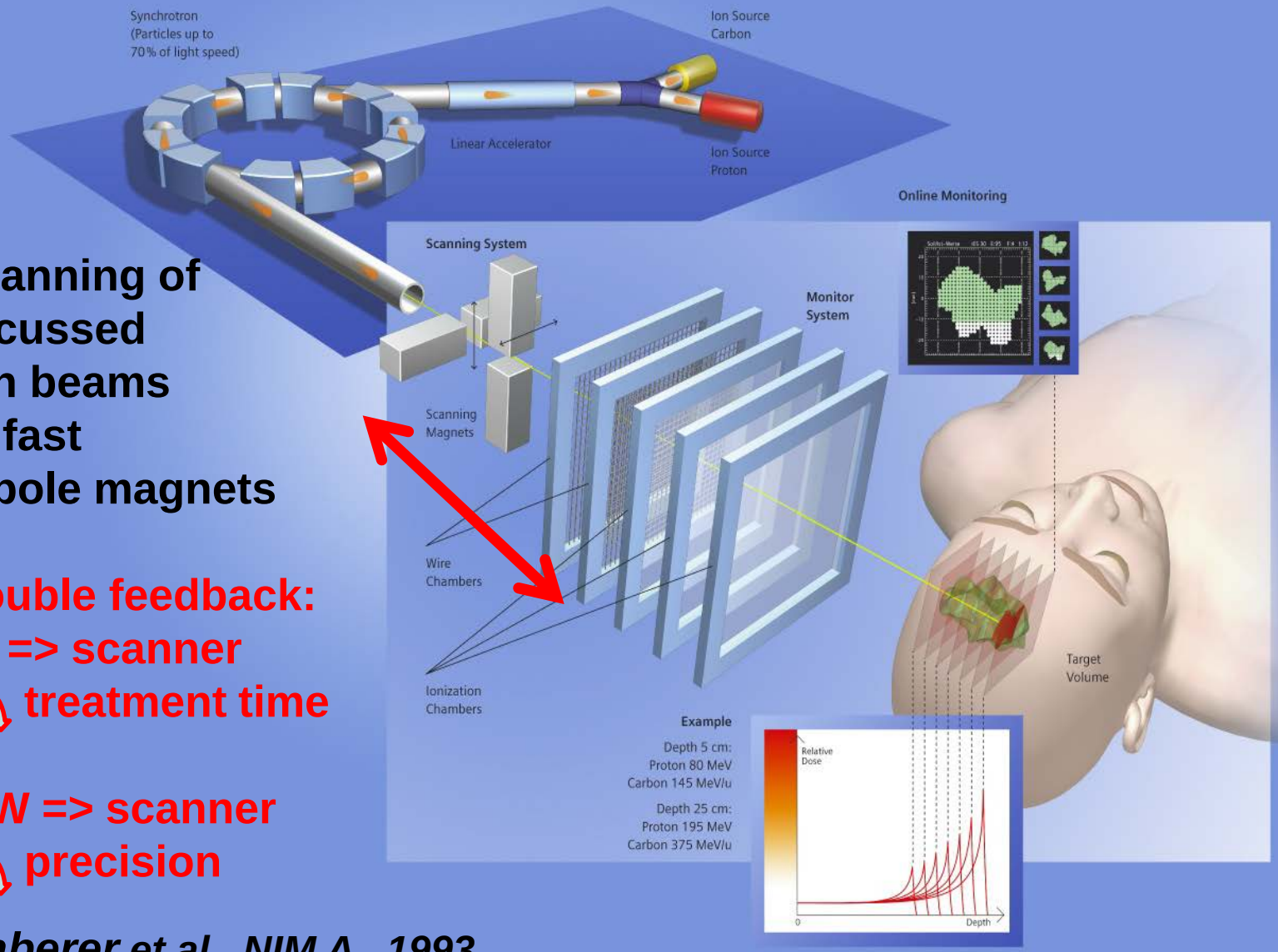
Ions @ synchrotron
Haberer et al., GSI

raster scanning, 3D active,
2D magnetic pencil beam scanning
plus
active energy variation in the accelerator

Beam Scanning



Rasterscan Method



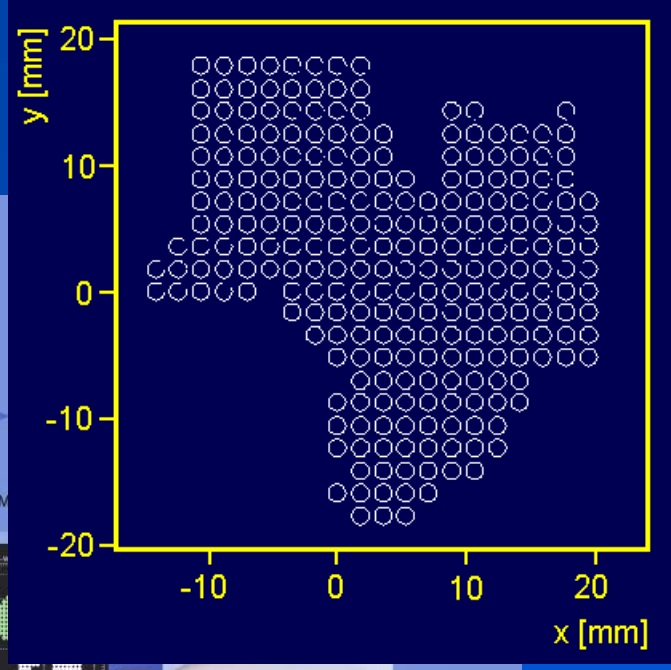
scanning of focussed ion beams in fast dipole magnets

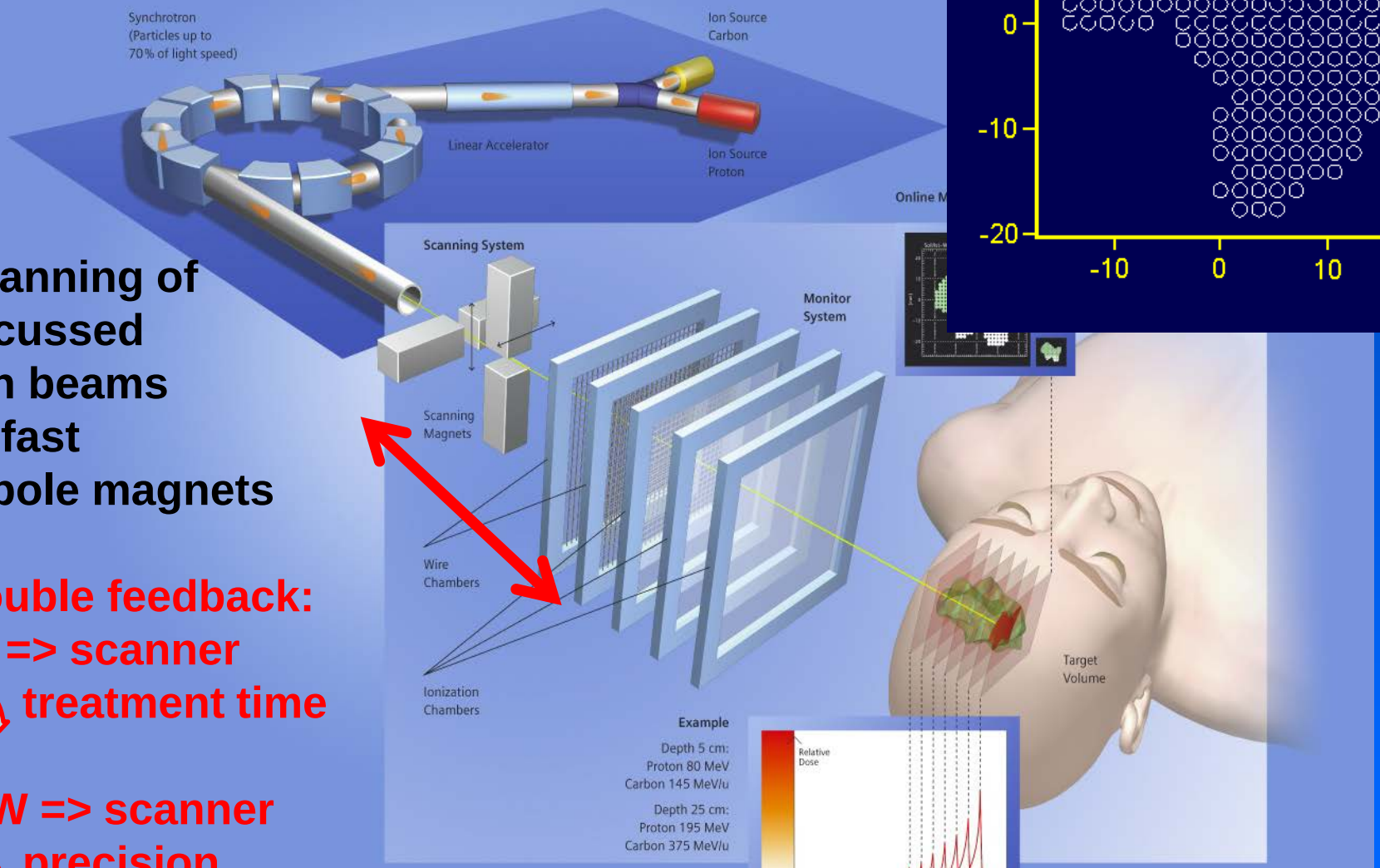
double feedback:
IC => scanner
⋂ treatment time

MW => scanner
⋂ precision

Haberer et al., NIM A , 1993

Rasterscan Method





scanning of focussed ion beams in fast dipole magnets

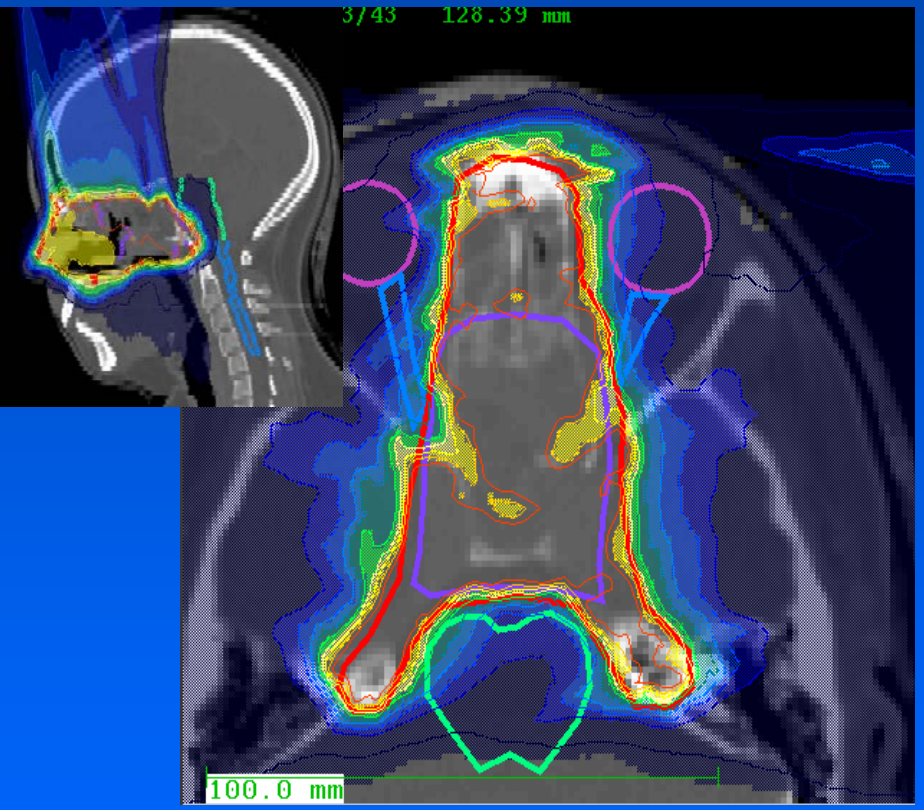
double feedback:
IC => scanner
⋂ treatment time

MW => scanner
⋂ precision

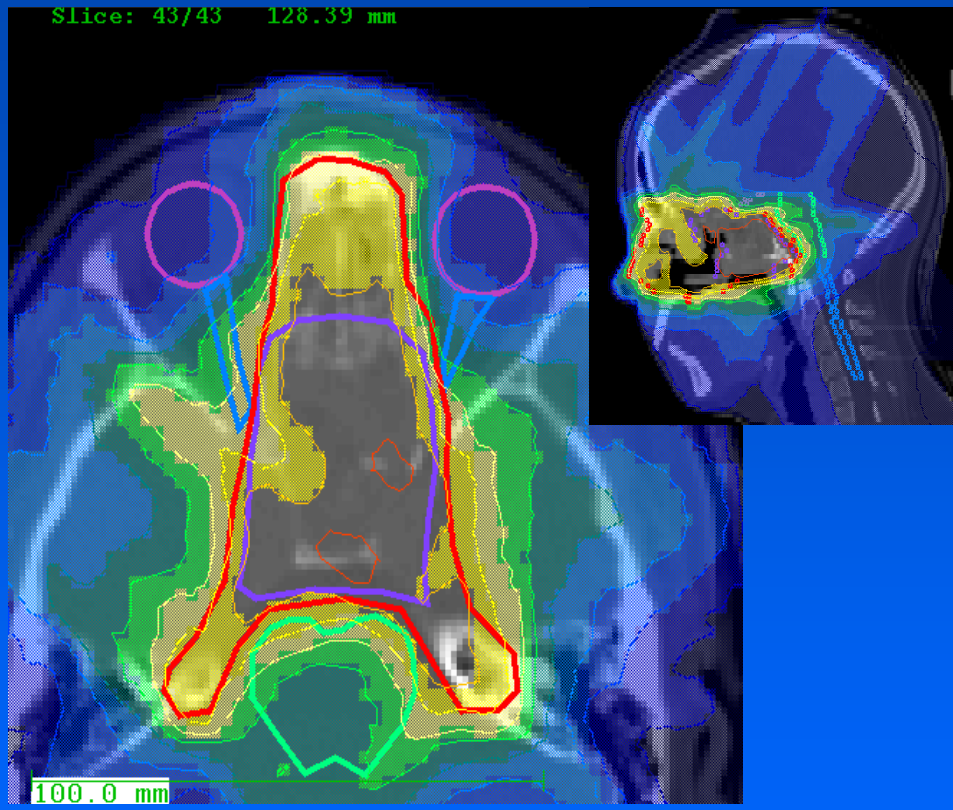
Haberer et al., NIM A , 1993

Scanned Carbon vs. Intensity Modulated Photons

scanned carbon 3 fields



IMRT 9 fields



reduced integral dose
steeper dose gradients
less fields
increased biological effectiveness

courtesy O. Jäkel, HIT

HIT
Heidelberg Ionenstrahl-Therapie Centrum

Carbon Ion Therapy @ GSI 1997 - 2008

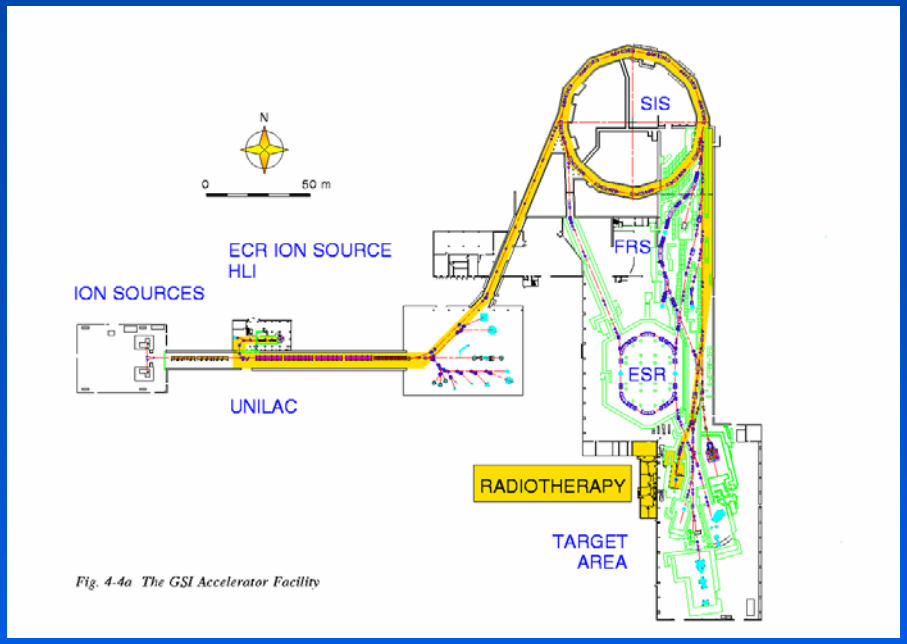
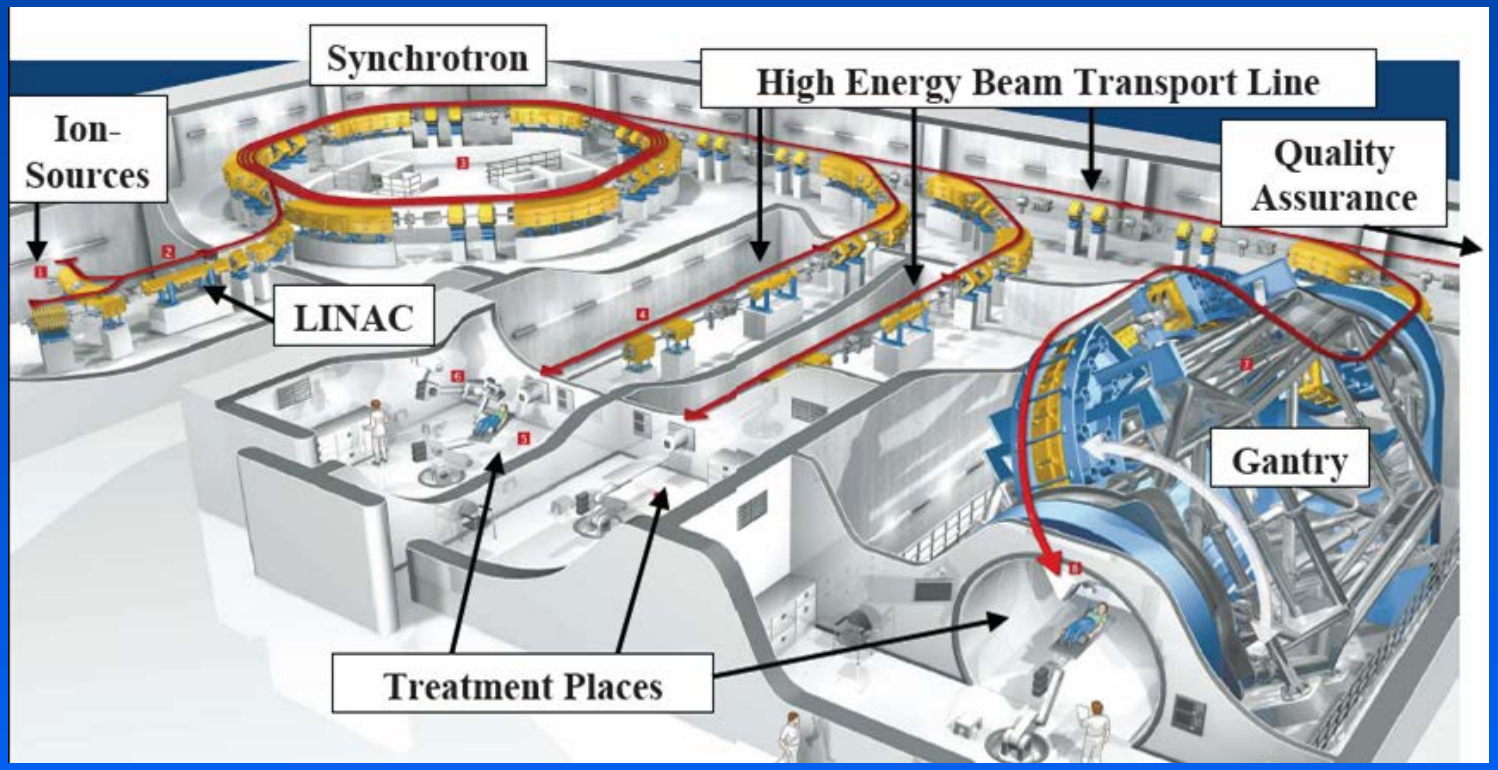


Fig. 4-4a The GSI Accelerator Facility

Heidelberg Ion Therapy Center

„Flexibility and Precision“



- compact design 60m x 70m
- full clinical integration
- rasterscanning only
- world-wide first ion gantry
- > 1000 patients and > 15.000 fractions/yr

- low-LET modality: Protons (Helium)
- high-LET modality: Carbon (Oxygen)
- ion selection within minutes
- R+D in a broad range

HIT Pencil Beam Library

Parameter	
ions	protons and carbon (**2 ion sources**); planned: helium, oxygen (3 ion sources)
intensity	2 x 10^6/s to 8 x 10^7/s for carbon intensity upgrade in progress 8 x 10^7/s to 4 x 10^8/s for protons **10 steps**; maximum extraction time 5 s
energy	88-430 MeV/u for carbon 50-221 MeV/u for protons **255 steps**, 1-1.5 mm spacing, 2-30 cm range in water
focus	3.5-13 mm FWHM 11-33 mm FWHM **4 steps**

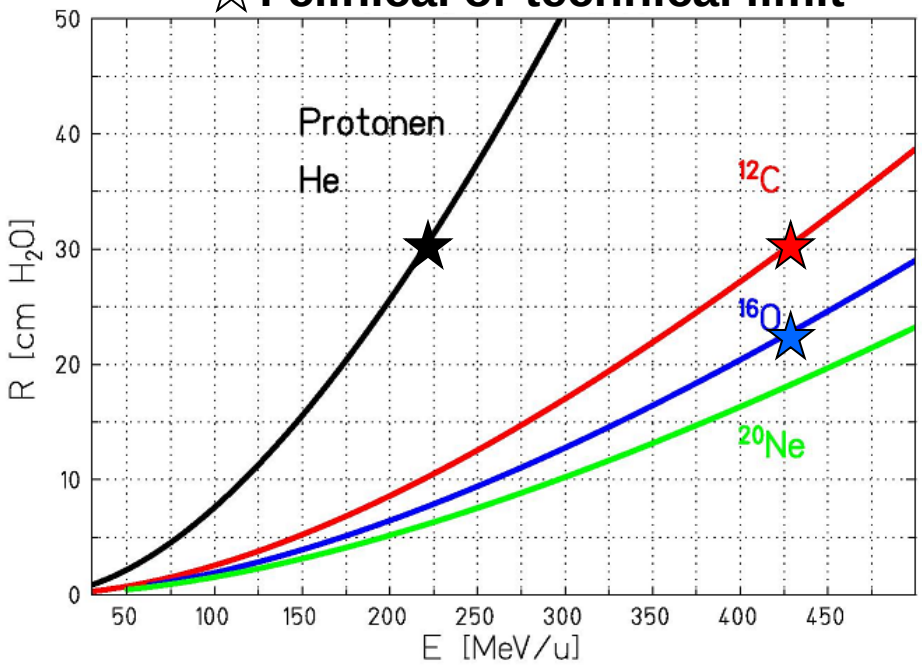
protons and carbon: clinically used

helium and oxygen: under commissioning

→ a total of 2 x 10 x 255 x 4 = 20400 settings per room!

… the gantry (0.1° steps) adds something …

☆: clinical or technical limit

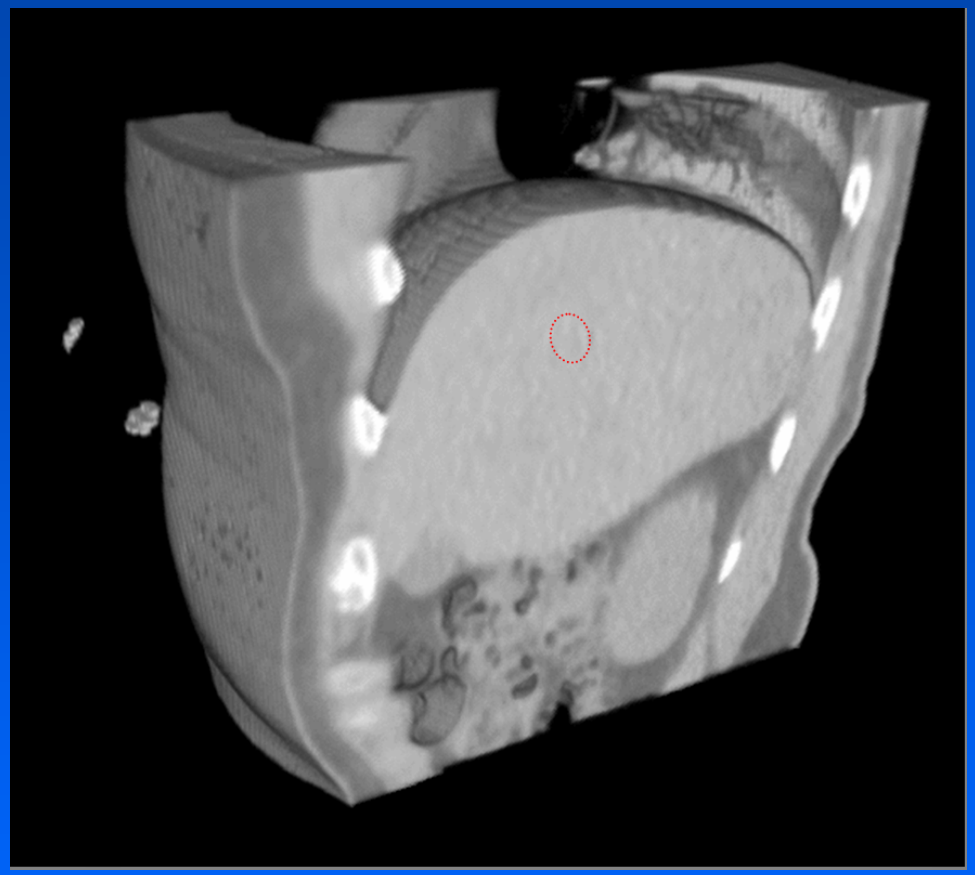


1st Patient @ HIT

15. November 2009

HIT
Heidelberg Ionenstrahl-Therapie Centrum

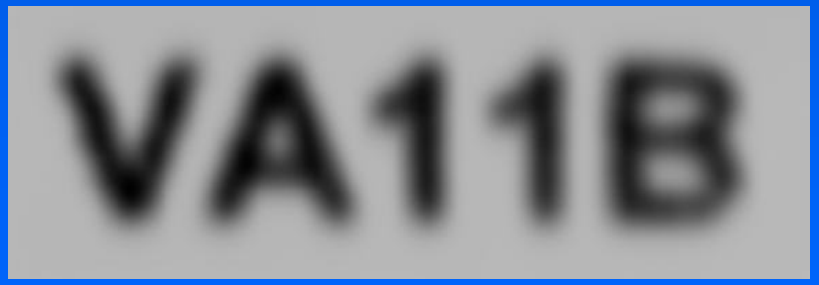
Gating / Moving Organs



Martin von Siebenthal, Phillipe Cattin, Gabor Szekely, Tony Lomax, ETH, Zurich and PSI, Villigen

static target

moving target

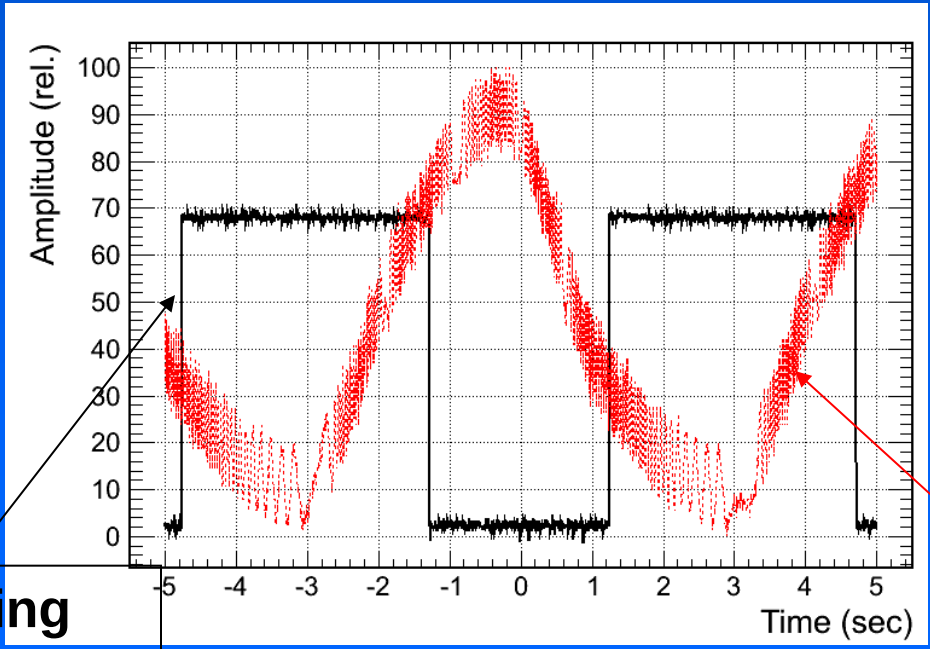


moving target + gating

Gating @ HIT

- **Breathing signal recorded with an Anzai gating belt**
- **4D-CT from each breathing cycle of the patient**
- **Gating signal used to trigger the beam extraction**

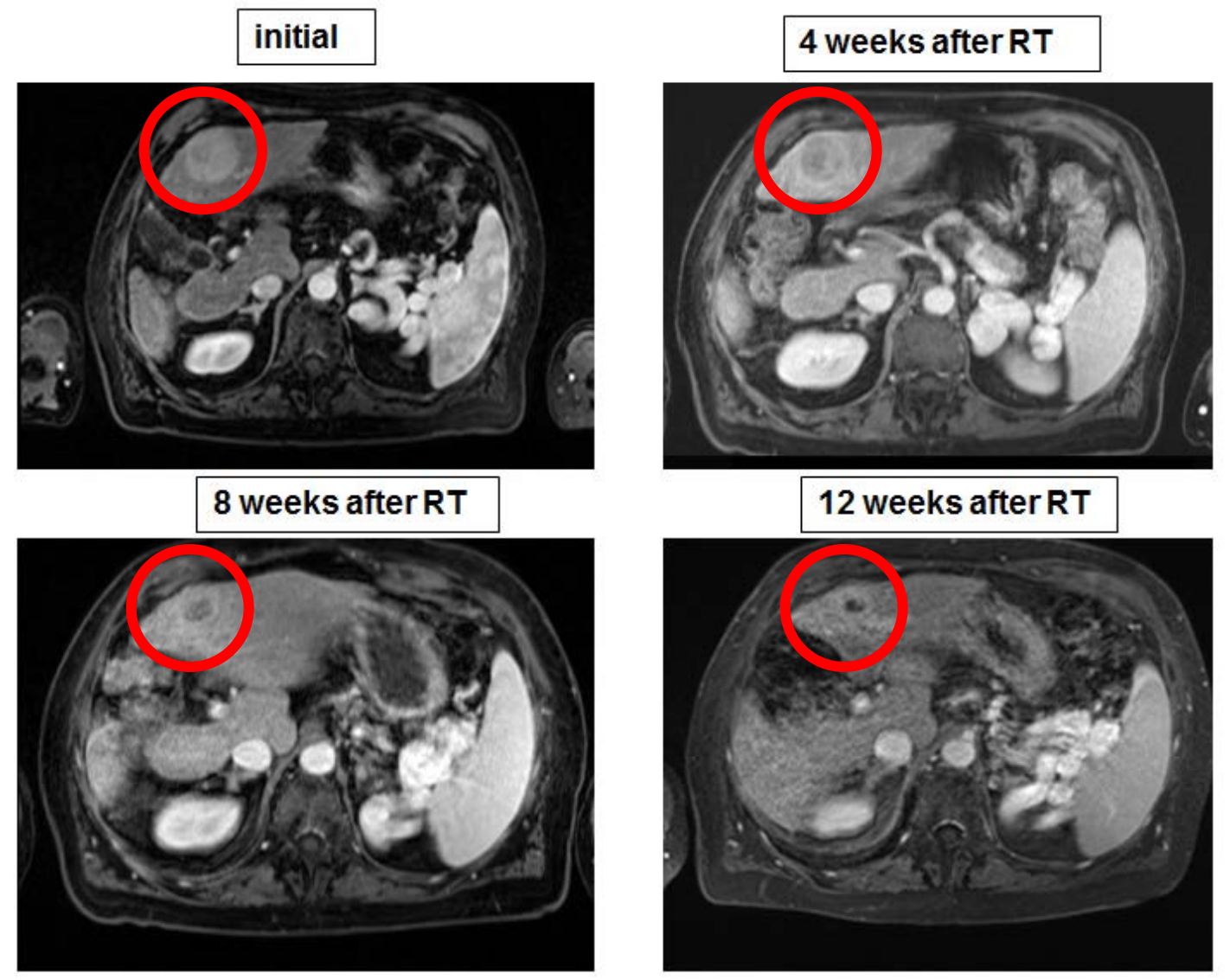
Example of a breathing cycle 30EX-70IN:



Gating window

Breathing signal

Carbon Radiotherapy for Liver Cancer: Response



Habermehl D, .., Combs SE, Radiation Oncology 2013

Advantages of a synchrotron

- It works and fulfills all requirements.

- proven technology
- stable & reliable operation
- built-in flexibility
  (particle types, energy, timing)
- active energy variation
  - maximum beam purity
  - minimum radiation protection effort

Disadvantages of a synchrotron

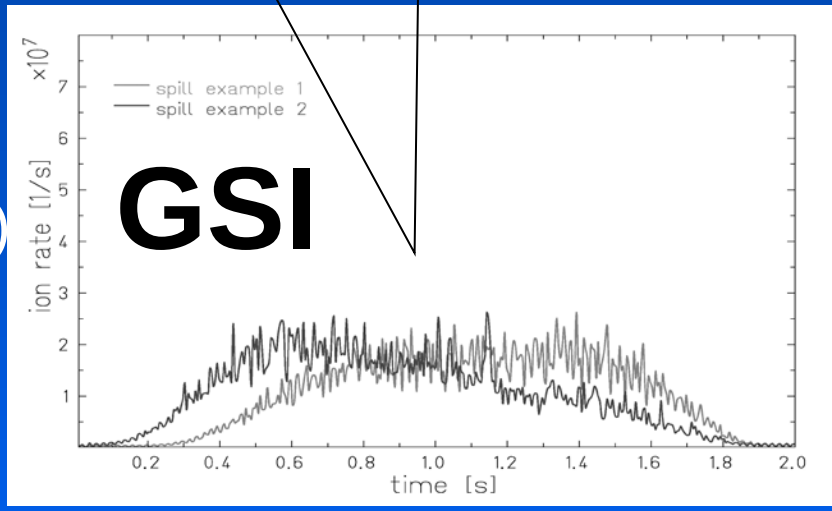
<u>Particle therapy facility</u>

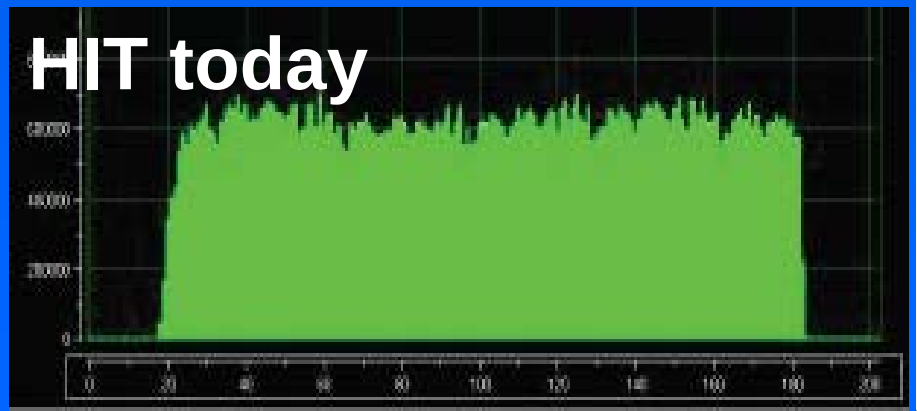
- size of foot print
- initial cost
- (several treatment rooms required)

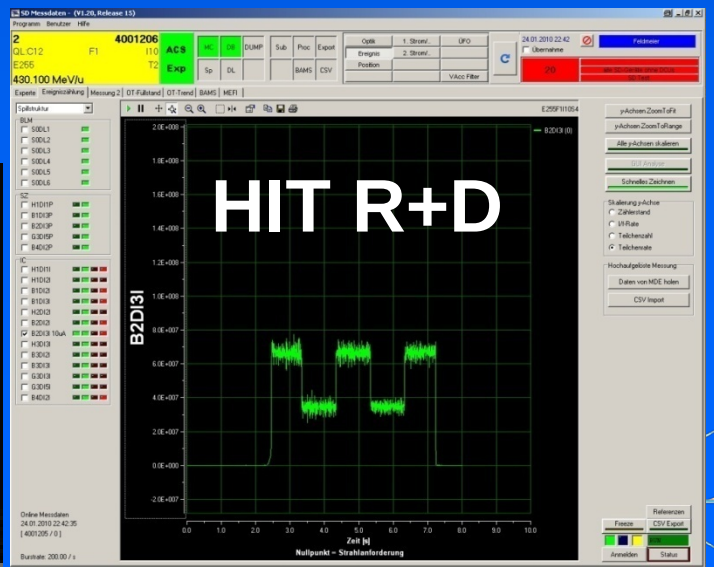
<u>Objections (no real disadvantages)</u>

- current uniformity
- repetition rate

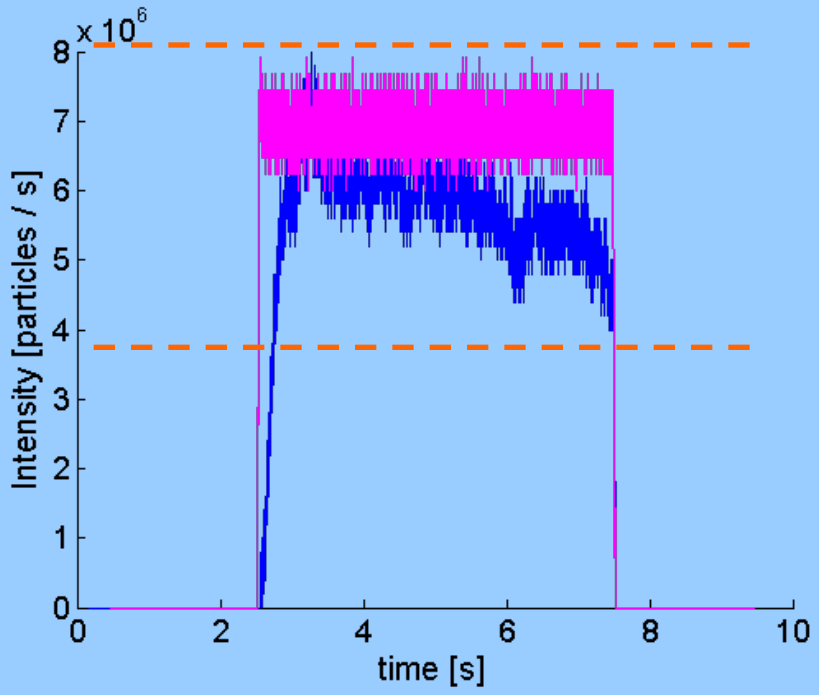
- **440 patients**
- **each field verified**







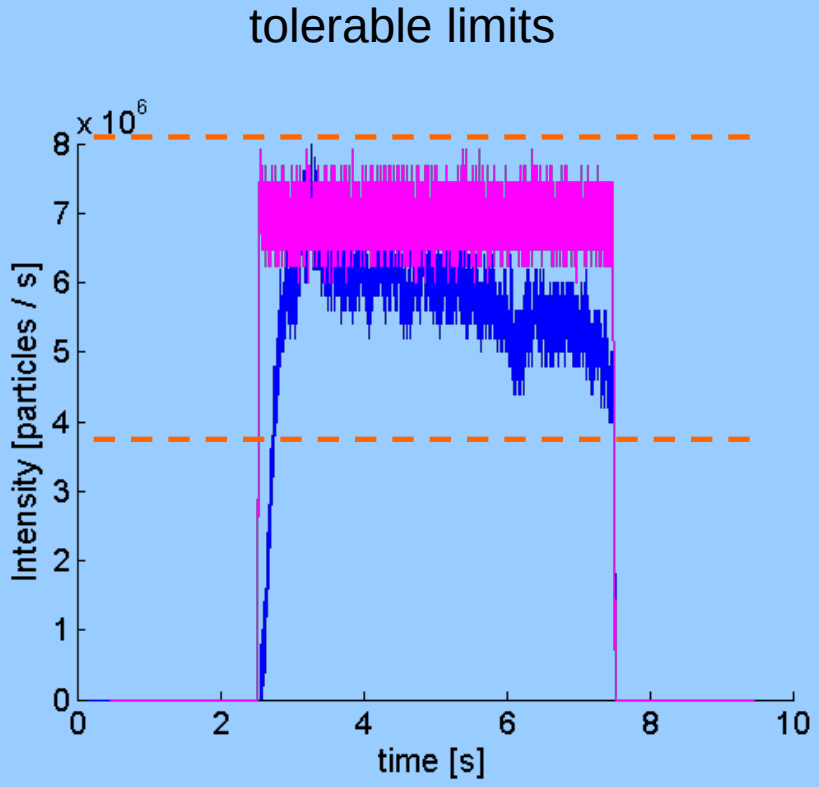
Potential of Spill Feedback



- beam-on time reduction up to 25% / 45%!
  - reduced patient stress
  - higher throughput
- higher acc operational stability
- dose delivery at increased precision (S/N – ratio)
- less interlocks

Christian Schömers, Ph.D. student
U-Frankfurt and HIT Heidelberg

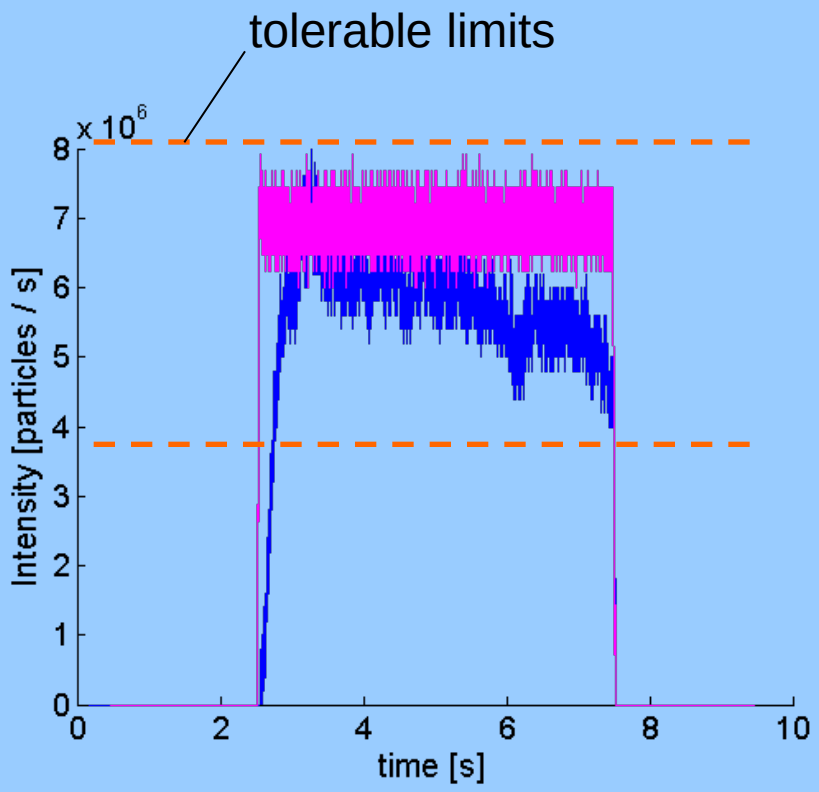
Potential of Spill Feedback



- beam-on time reduction up to 25% / 45%!
  - reduced patient stress
  - higher throughput
- higher acc operational stability
- dose delivery at increased precision (S/N – ratio)
- less interlocks

Christian Schömers, Ph.D. student
U-Frankfurt and HIT Heidelberg

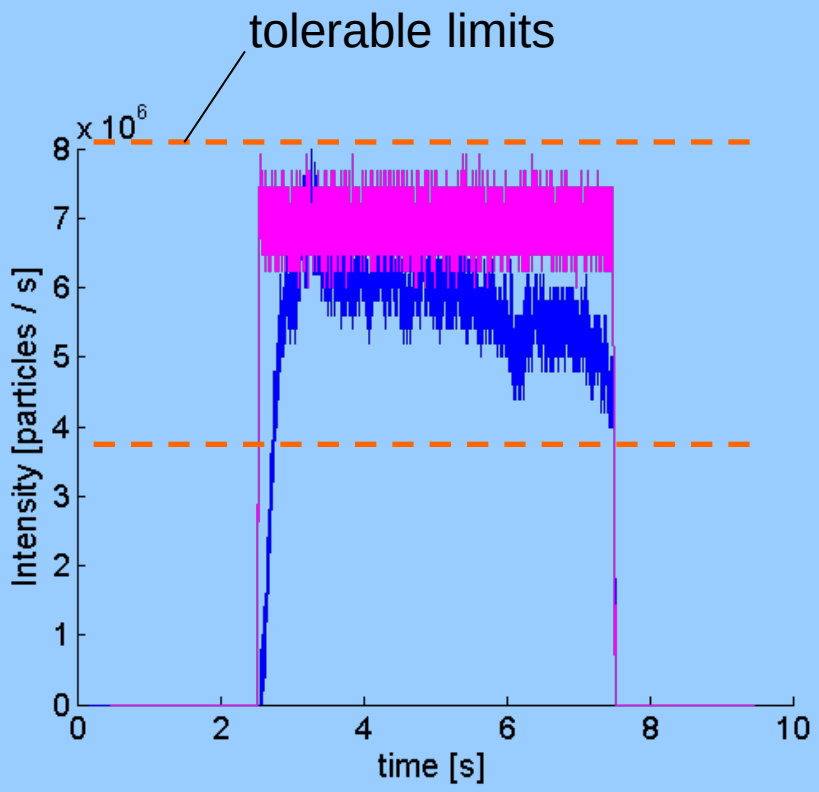
Potential of Spill Feedback



- beam-on time reduction up to 25% / 45%!
  - reduced patient stress
  - higher throughput
- higher acc operational stability
- dose delivery at increased precision (S/N – ratio)
- less interlocks

Christian Schömers, Ph.D. student
U-Frankfurt and HIT Heidelberg

Potential of Spill Feedback



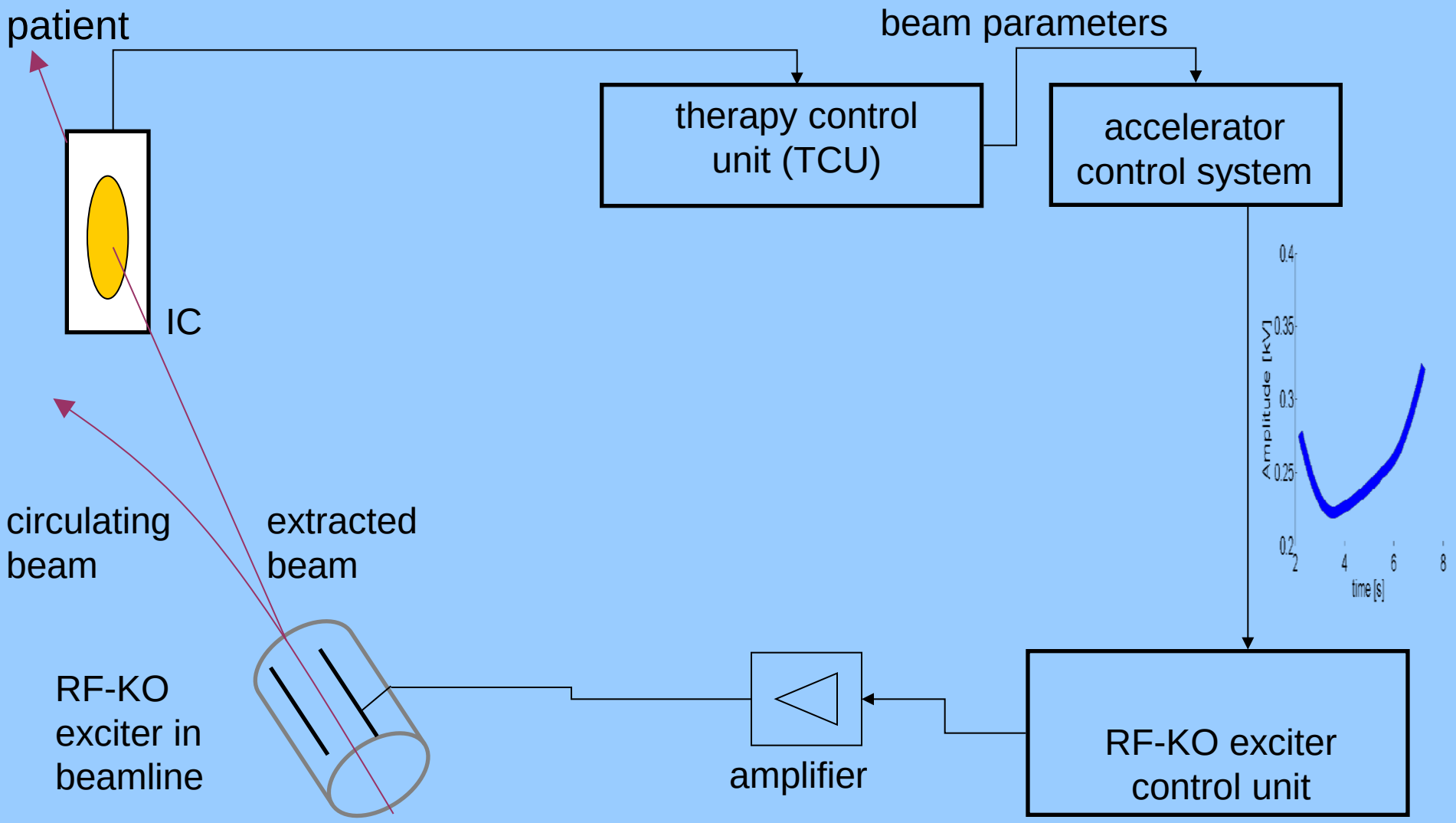
- beam-on time reduction up to 25% / 45%!
  - reduced patient stress
  - higher throughput
- higher acc operational stability
- dose delivery at increased precision (S/N – ratio)
- less interlocks

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

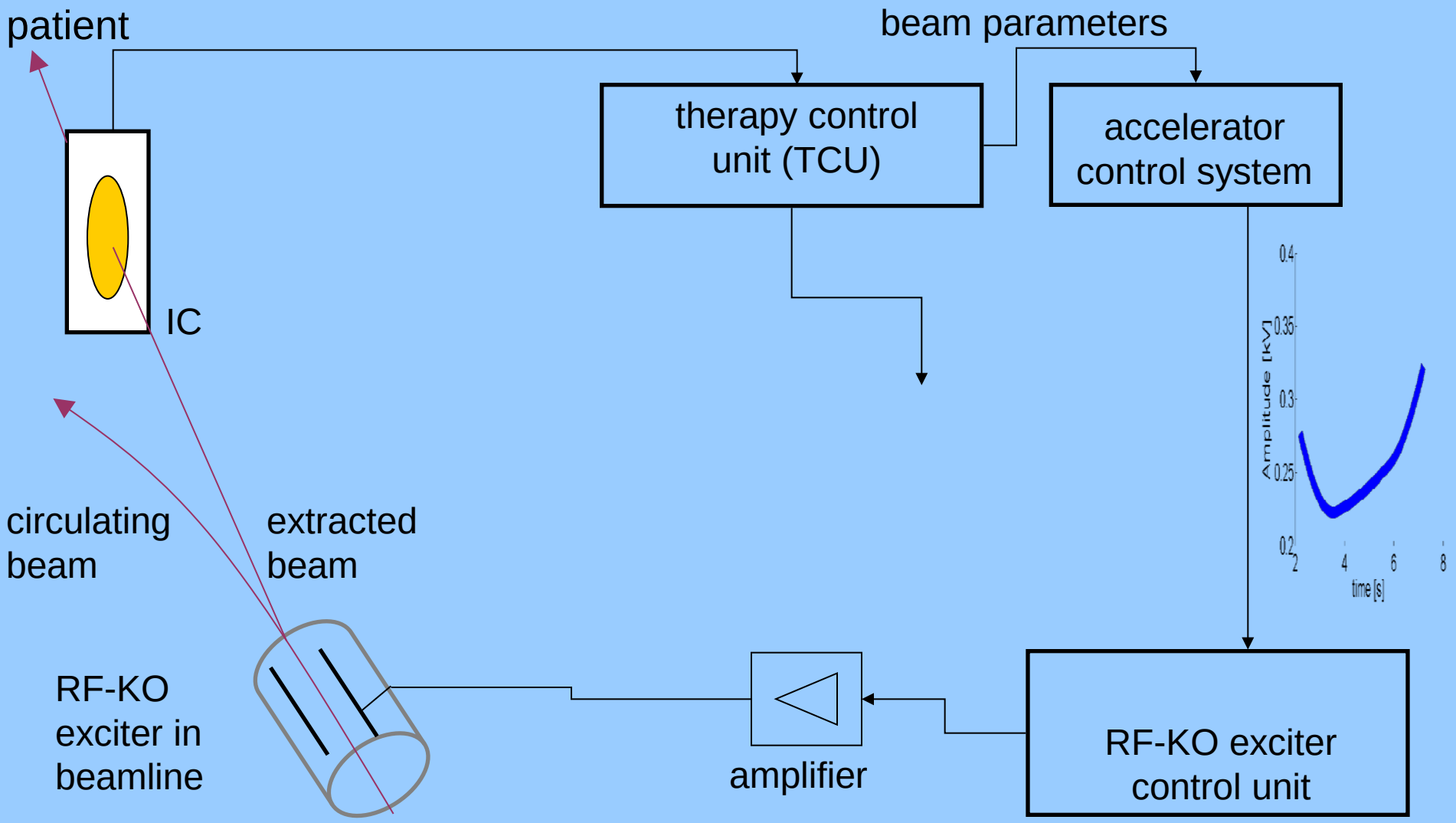
Christian Schömers, Ph.D. student
U-Frankfurt and HIT Heidelberg

HIT Heidelberg Ionenstrahl-Therapie Centrum

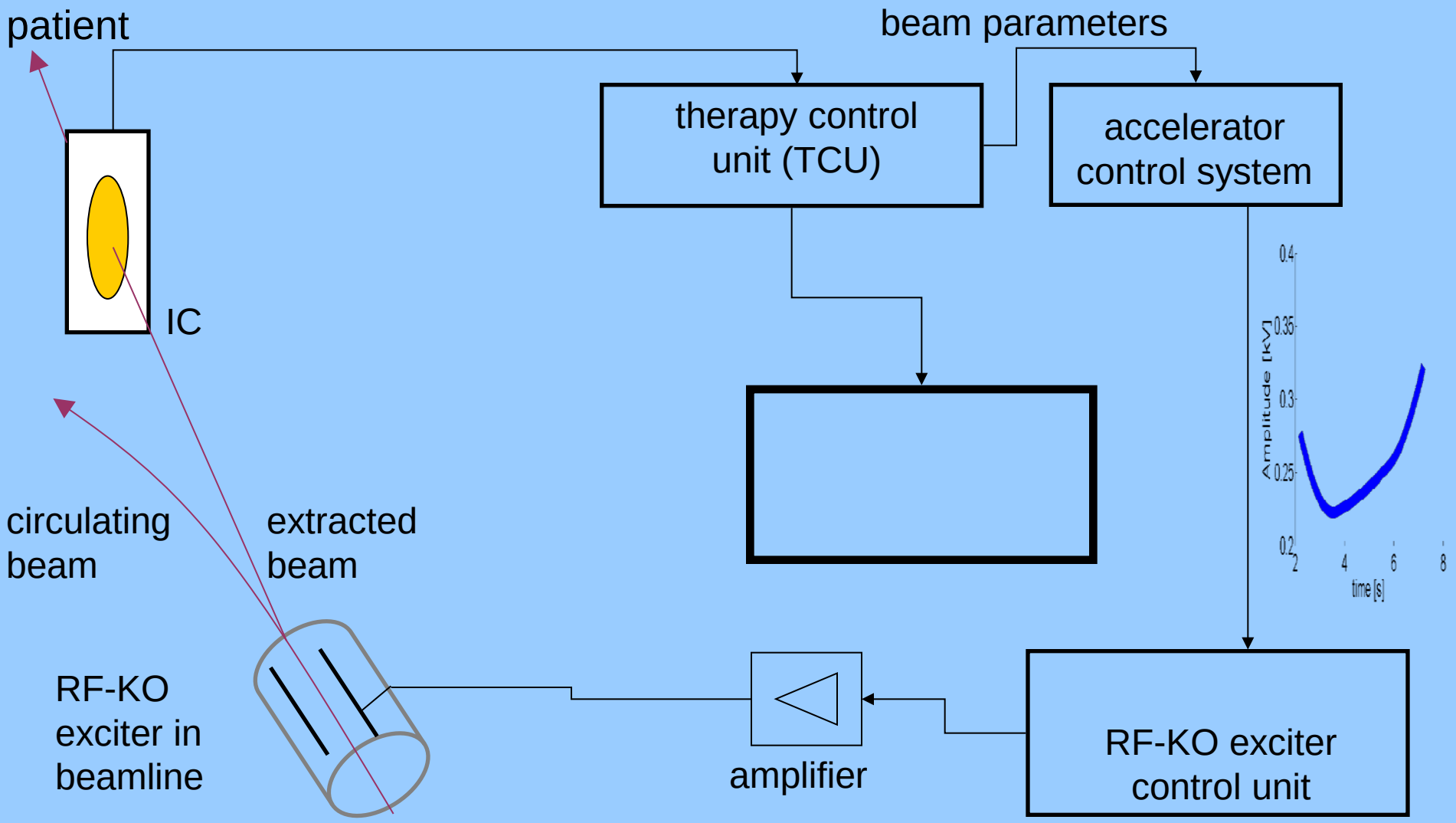
Spill Feedback System Overview



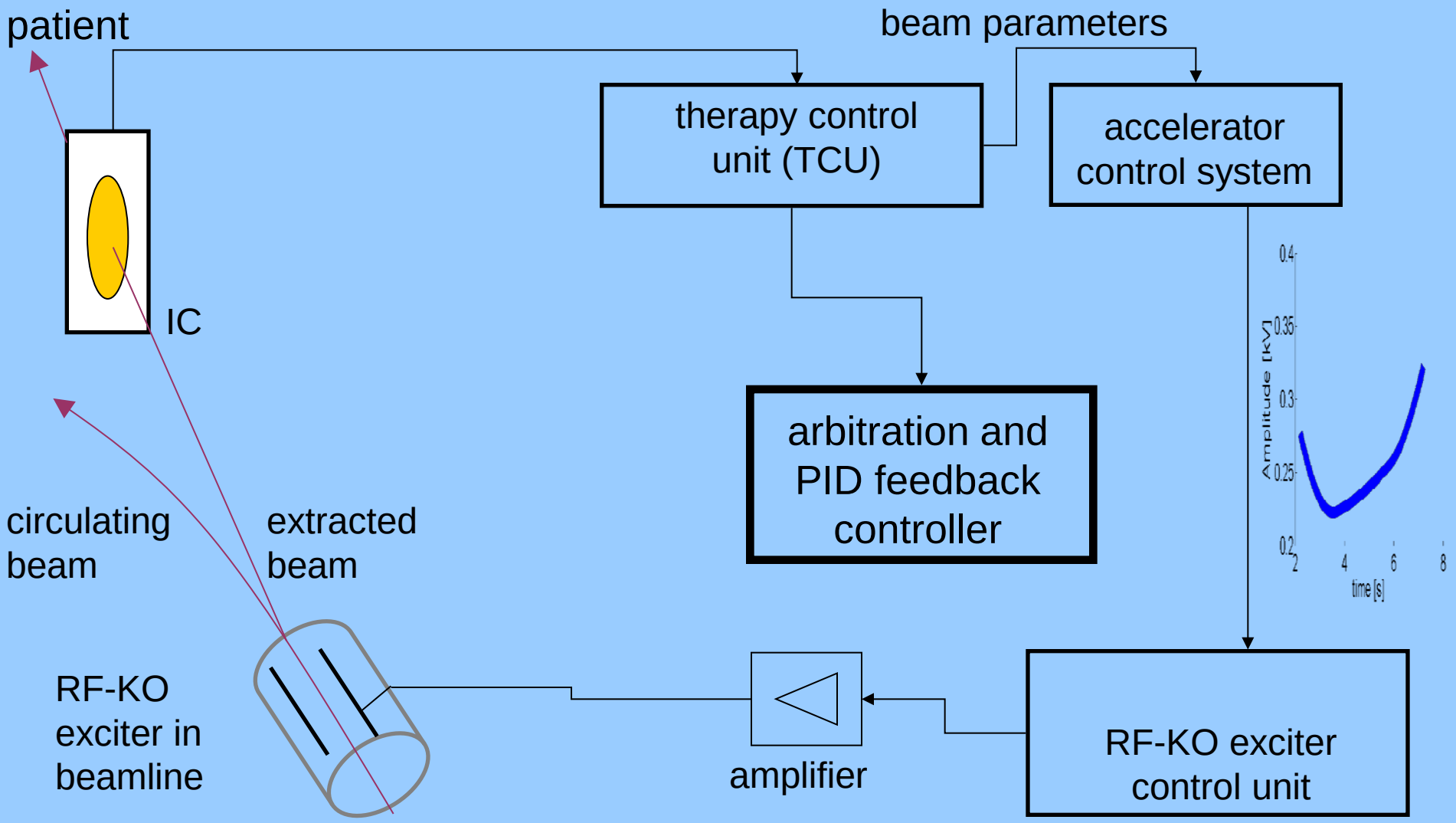
Spill Feedback System Overview



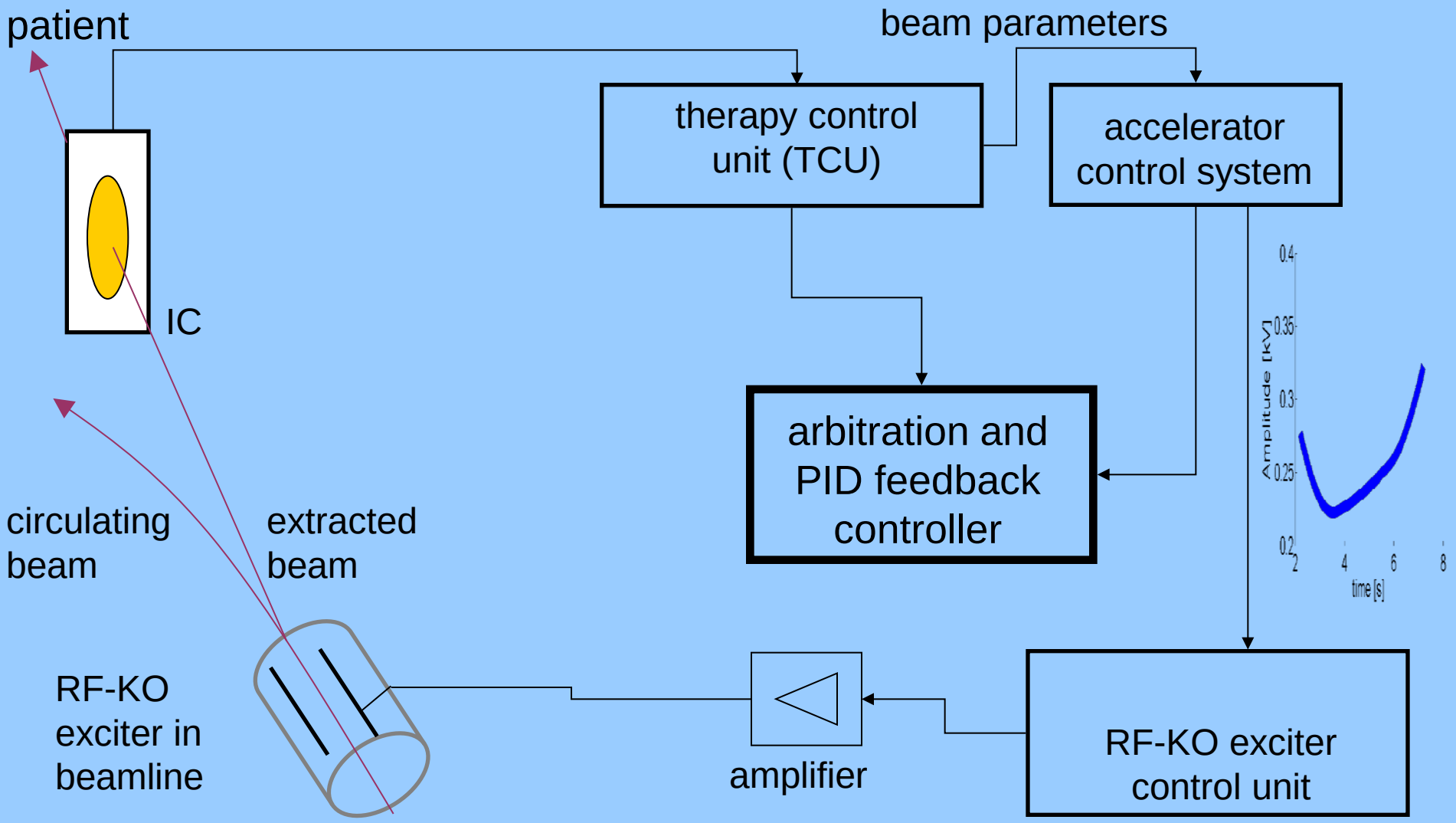
Spill Feedback System Overview



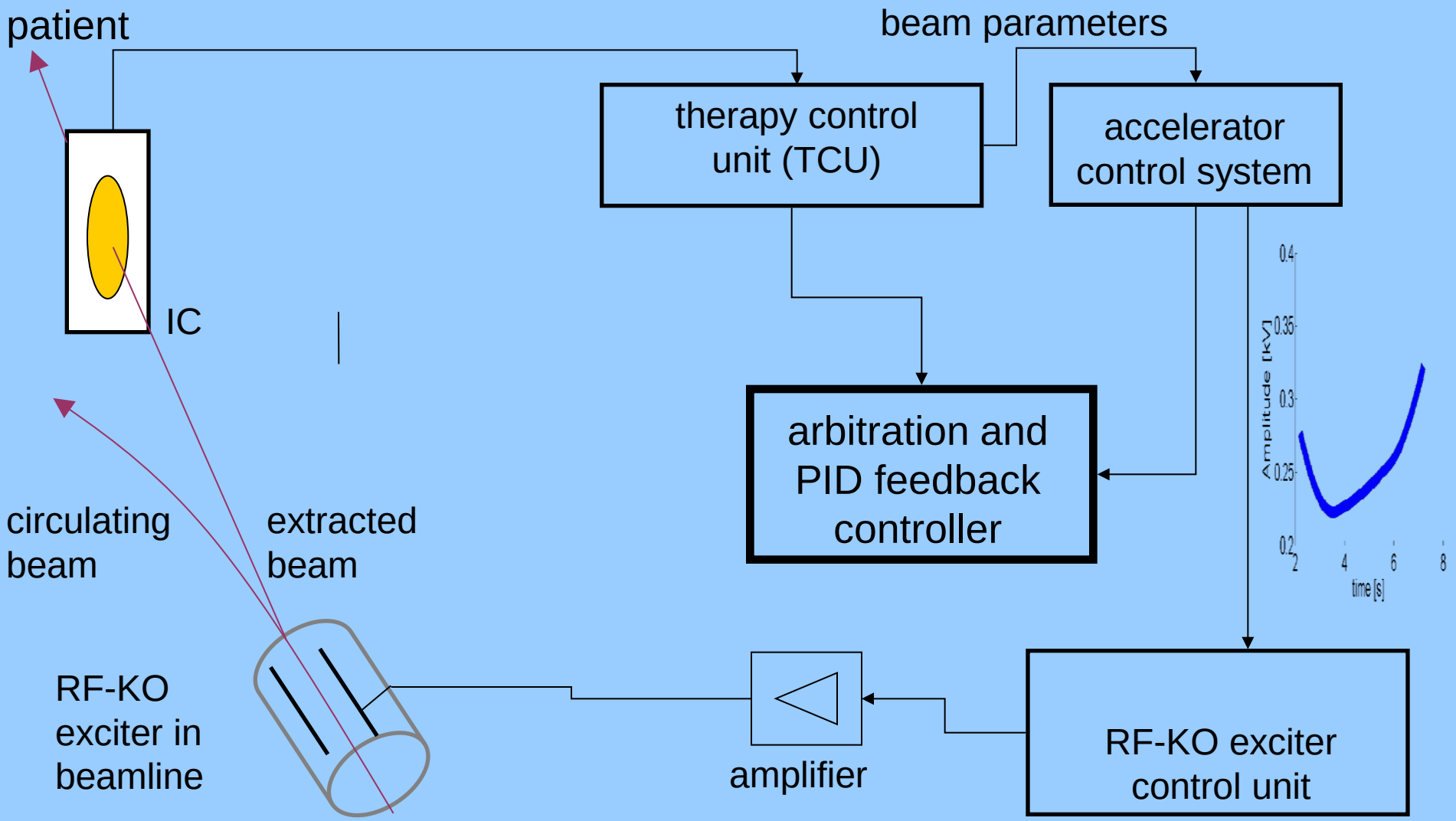
Spill Feedback System Overview



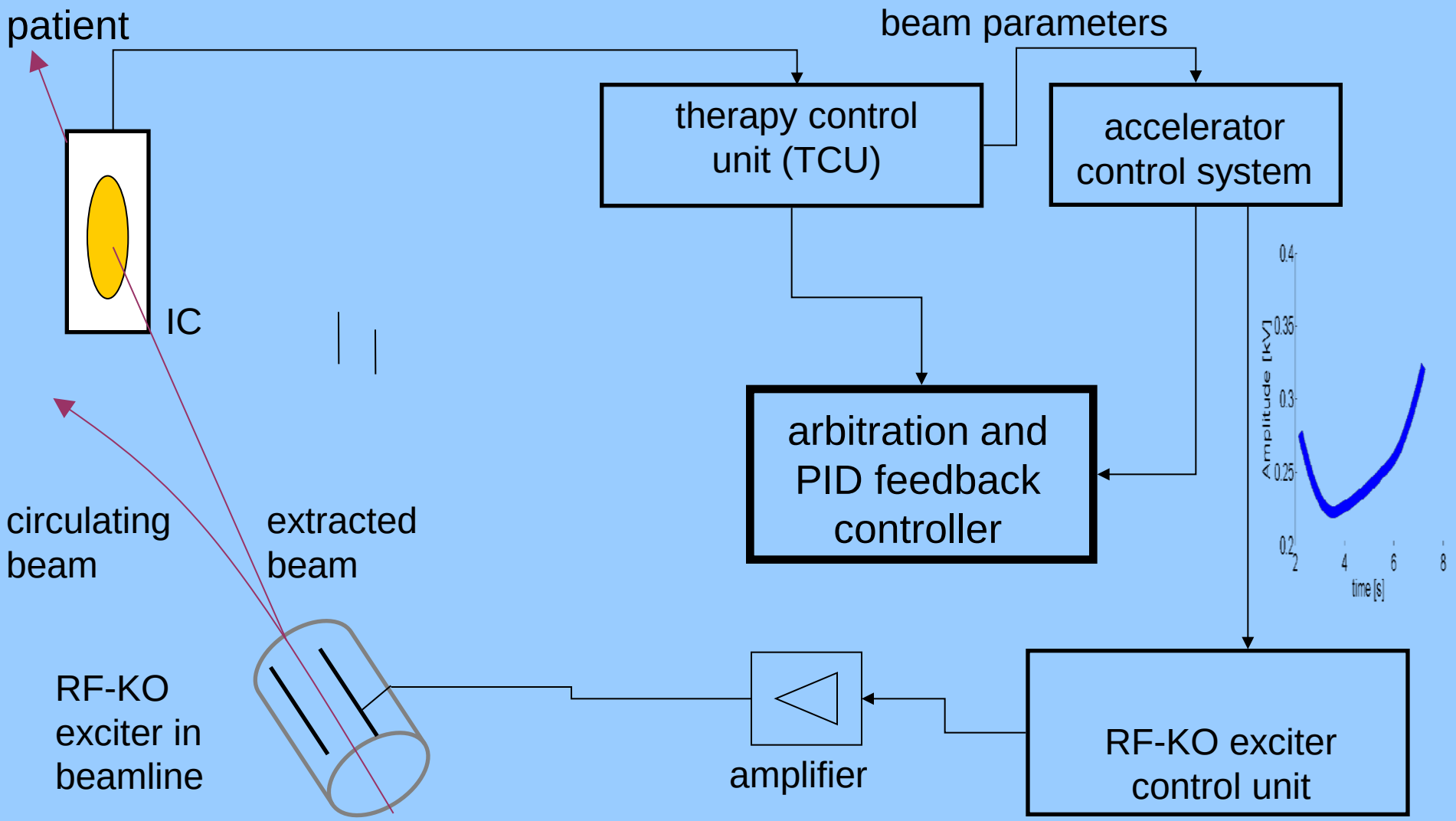
Spill Feedback System Overview



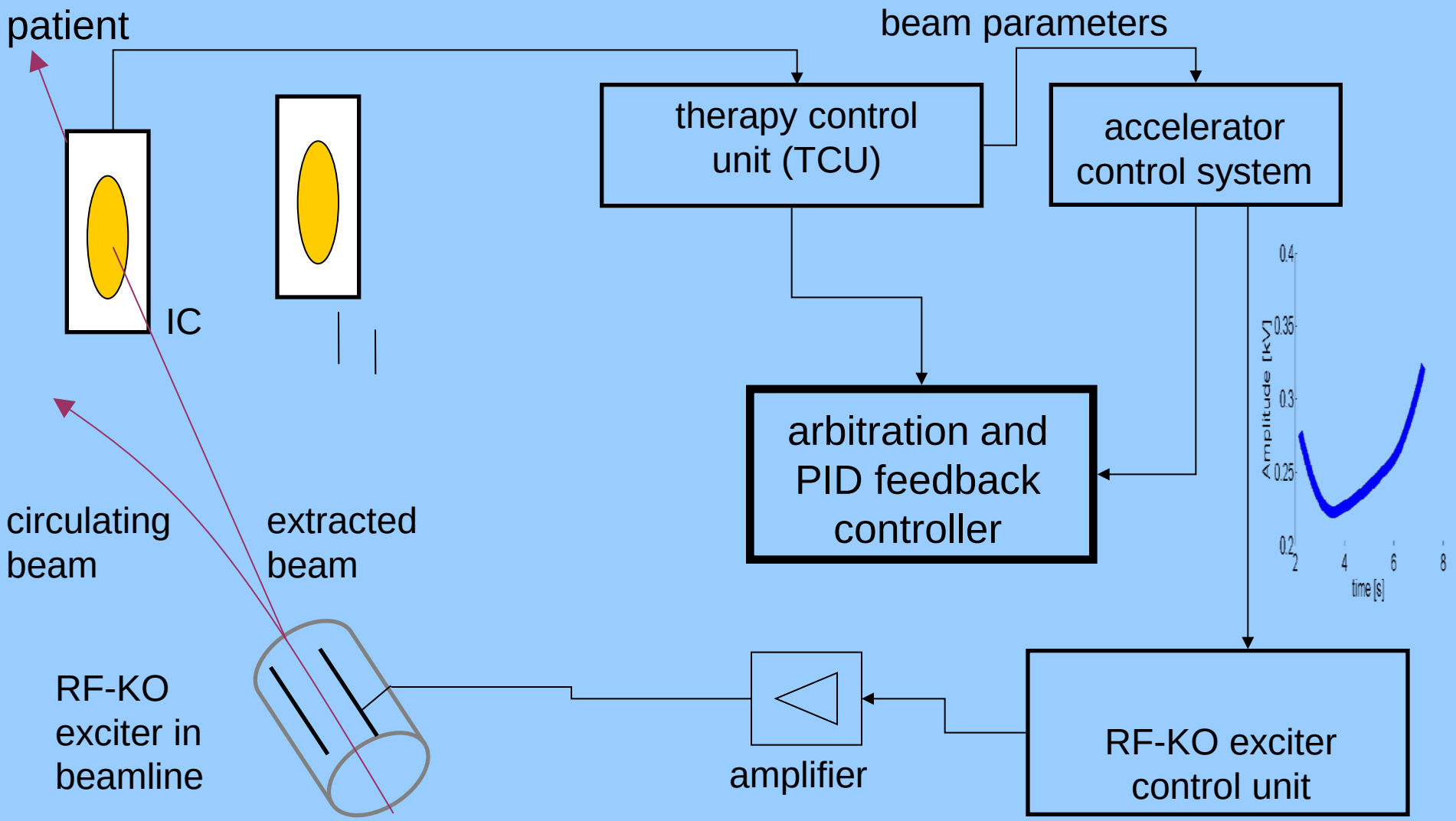
Spill Feedback System Overview



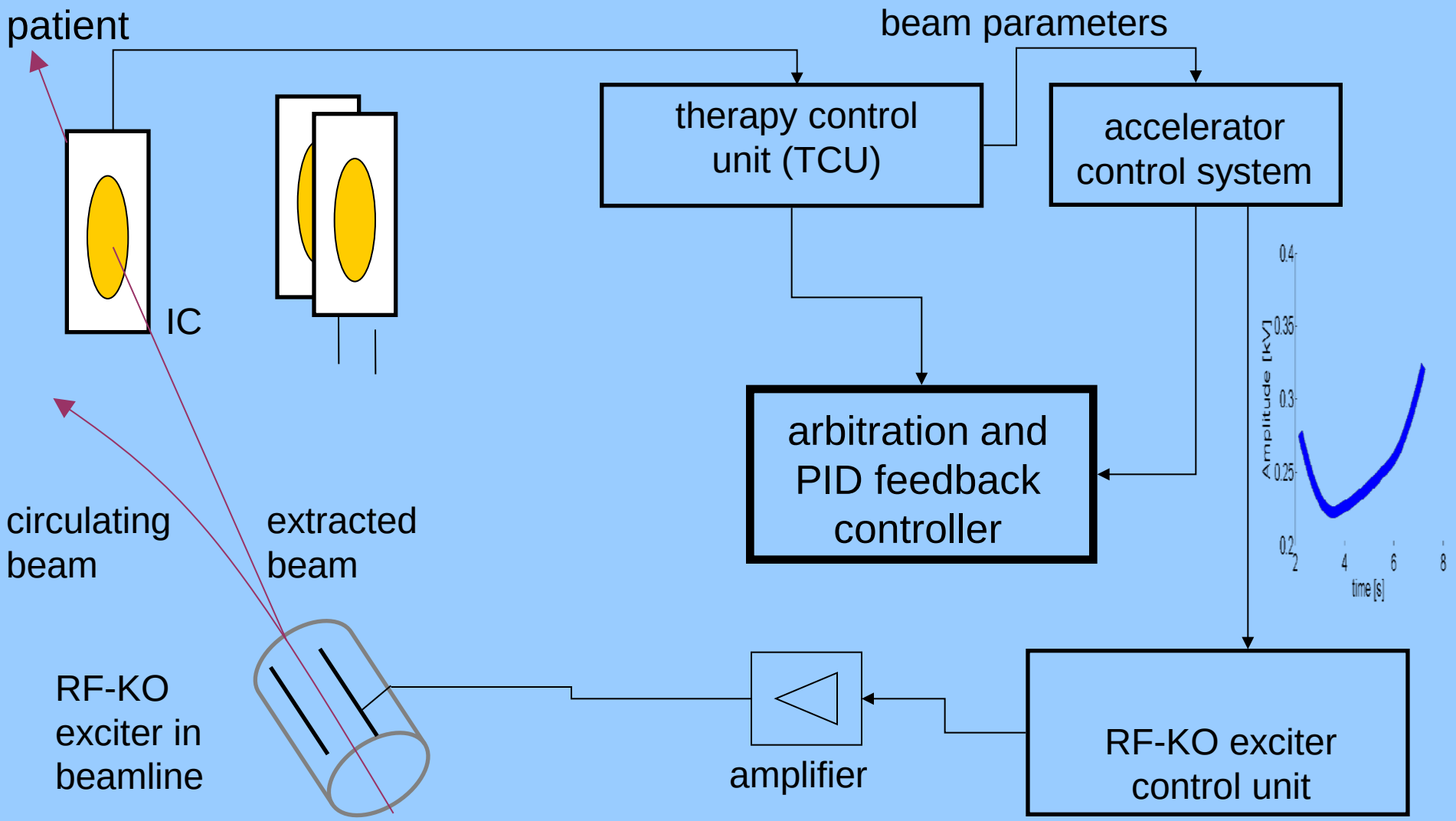
Spill Feedback System Overview



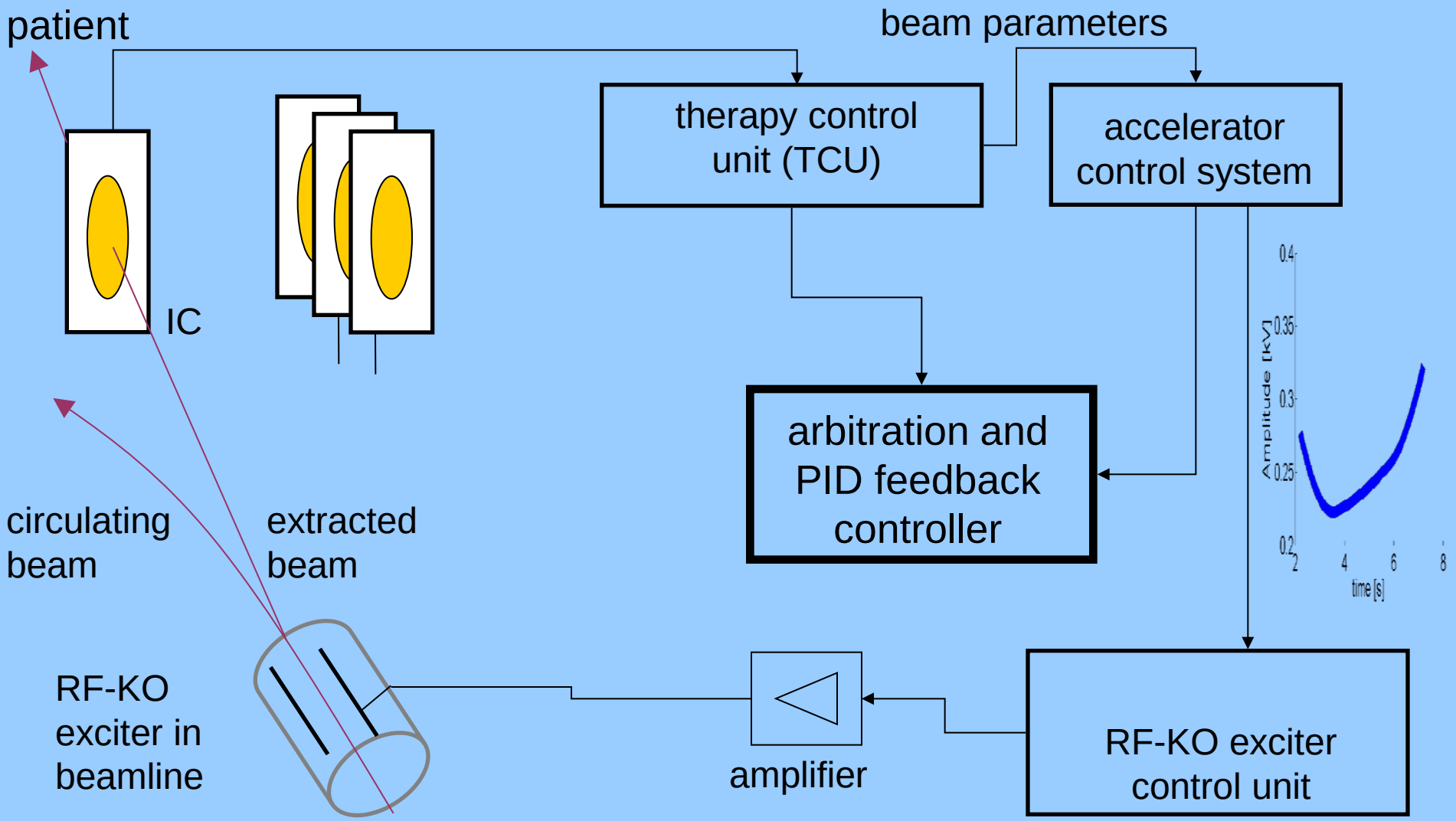
Spill Feedback System Overview



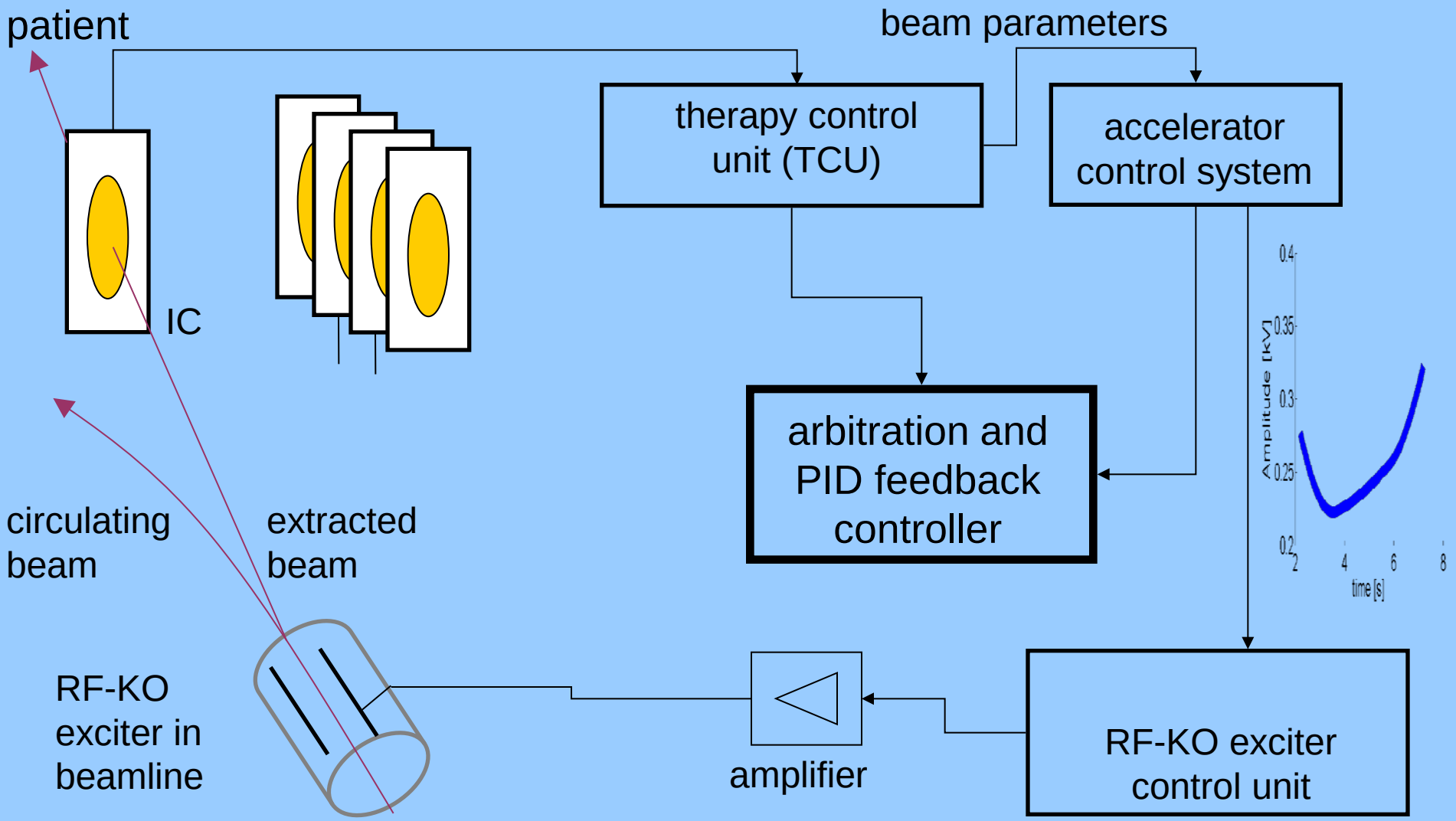
Spill Feedback System Overview



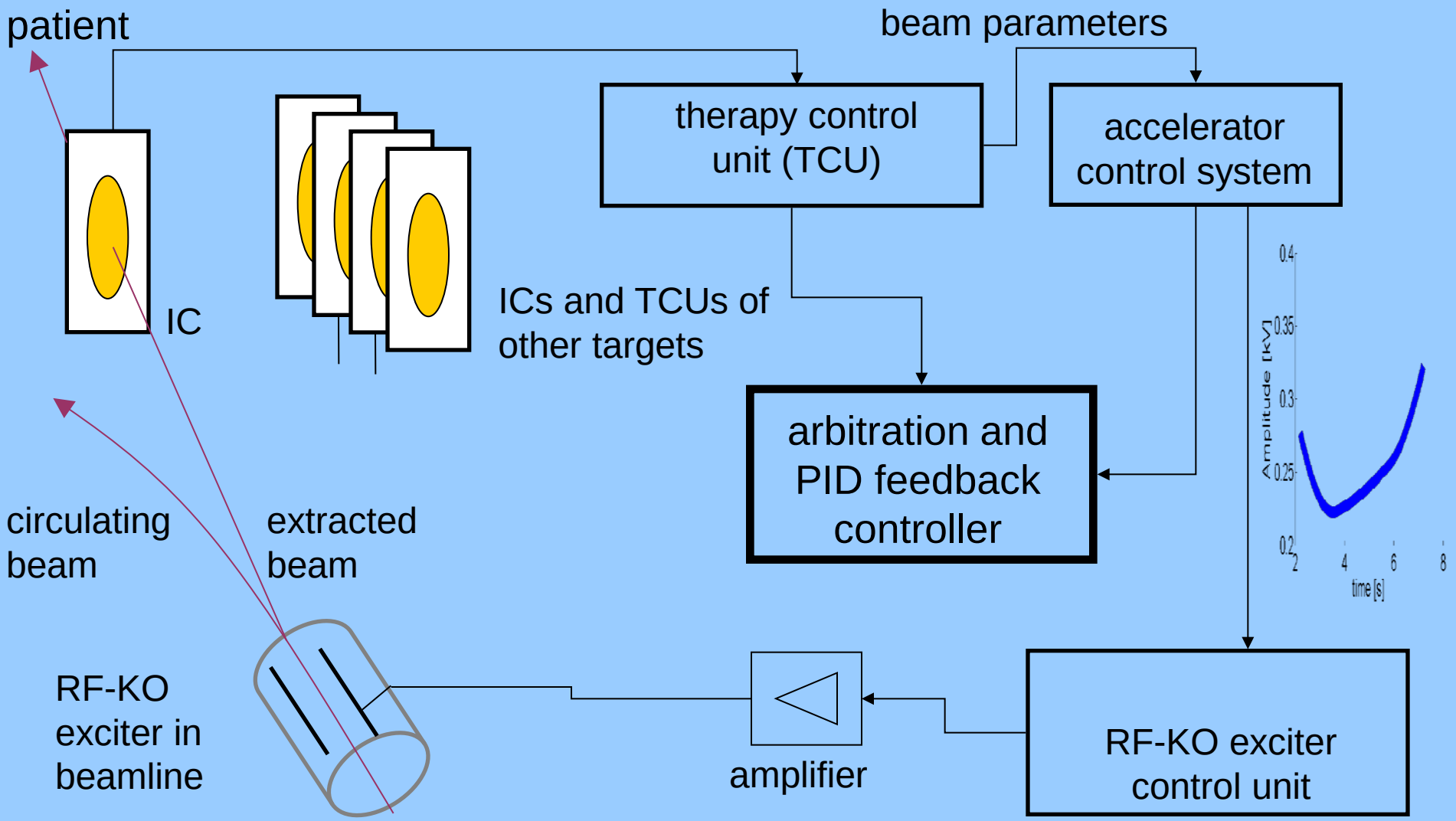
Spill Feedback System Overview



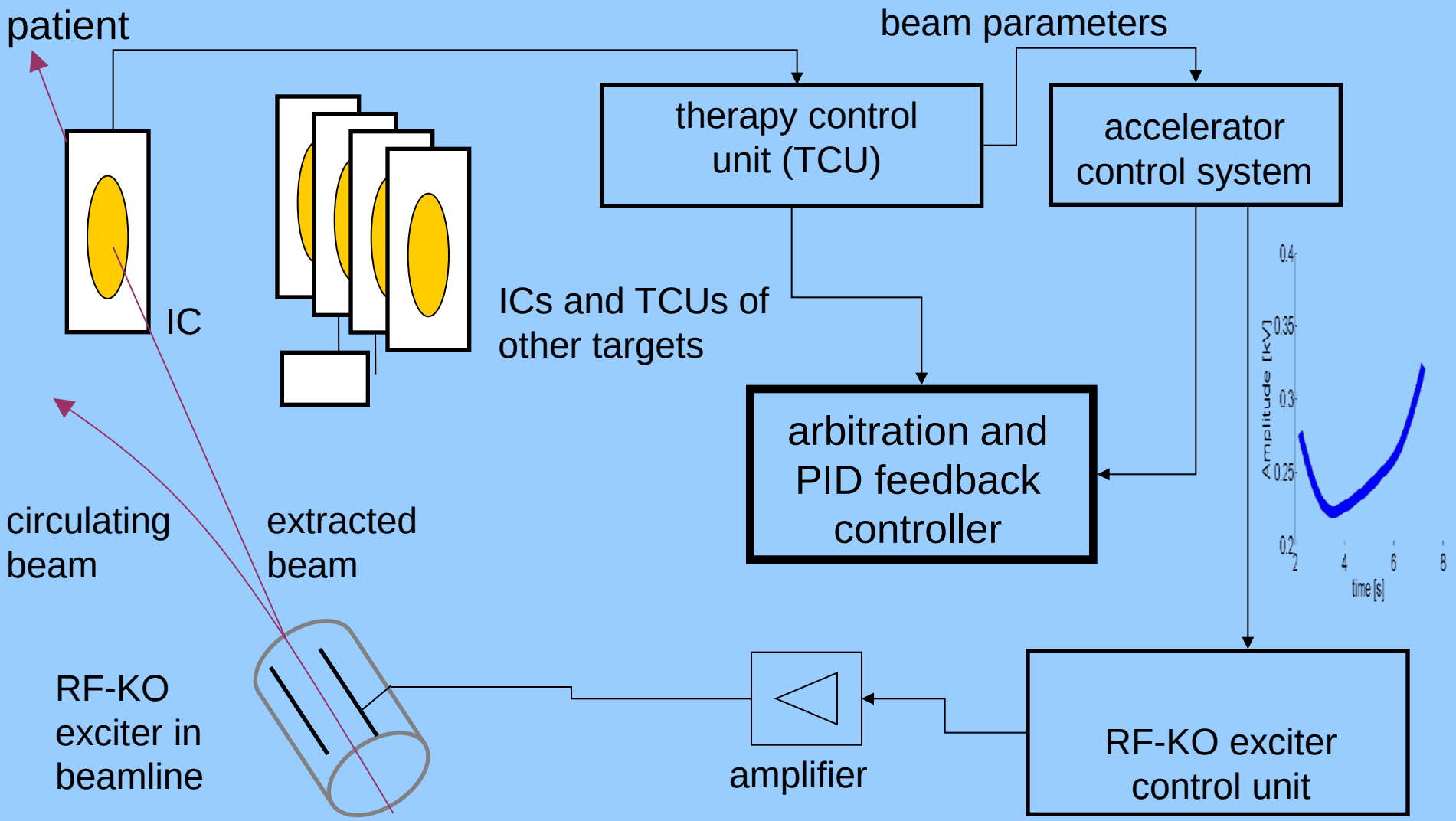
Spill Feedback System Overview



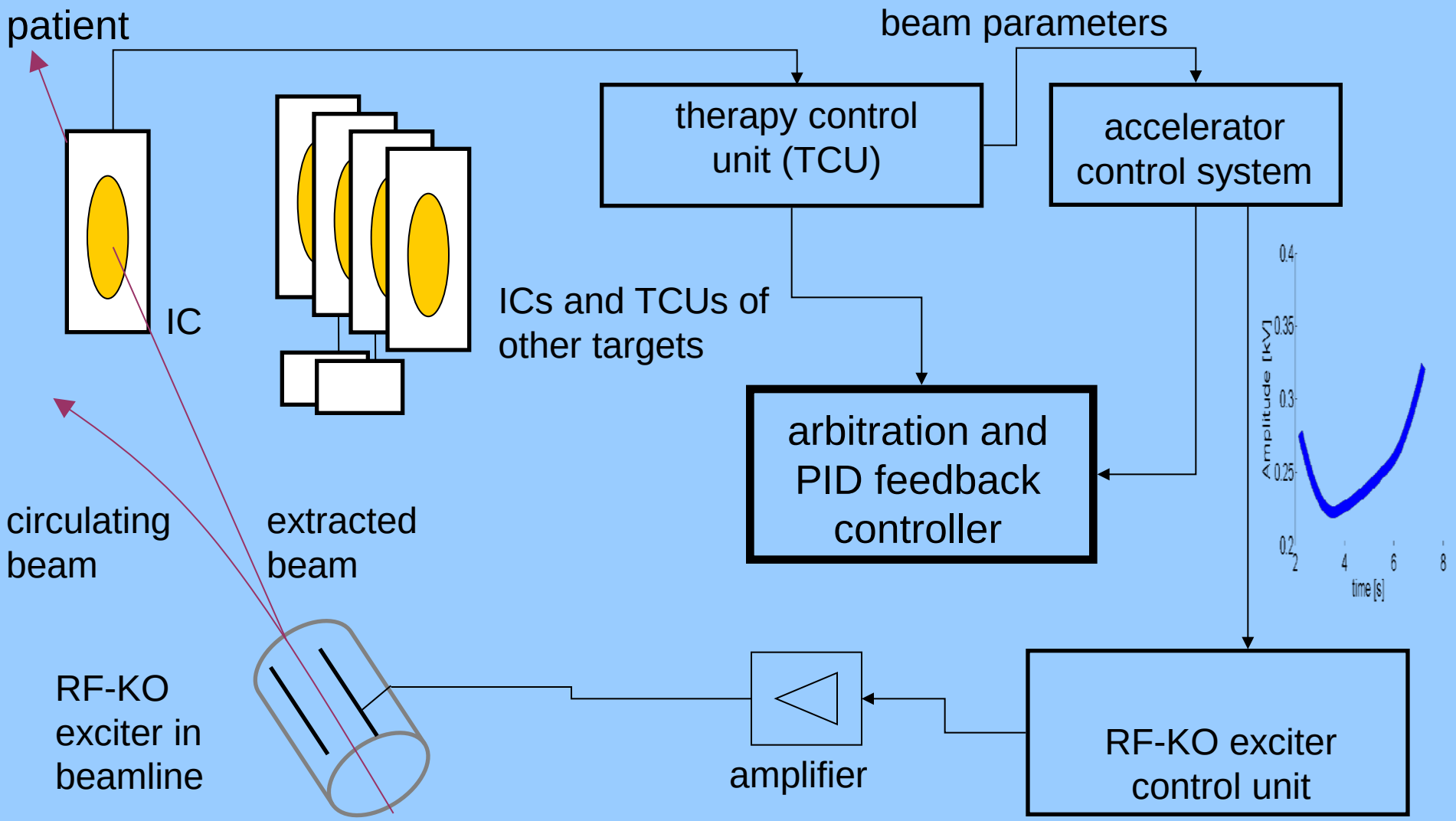
Spill Feedback System Overview



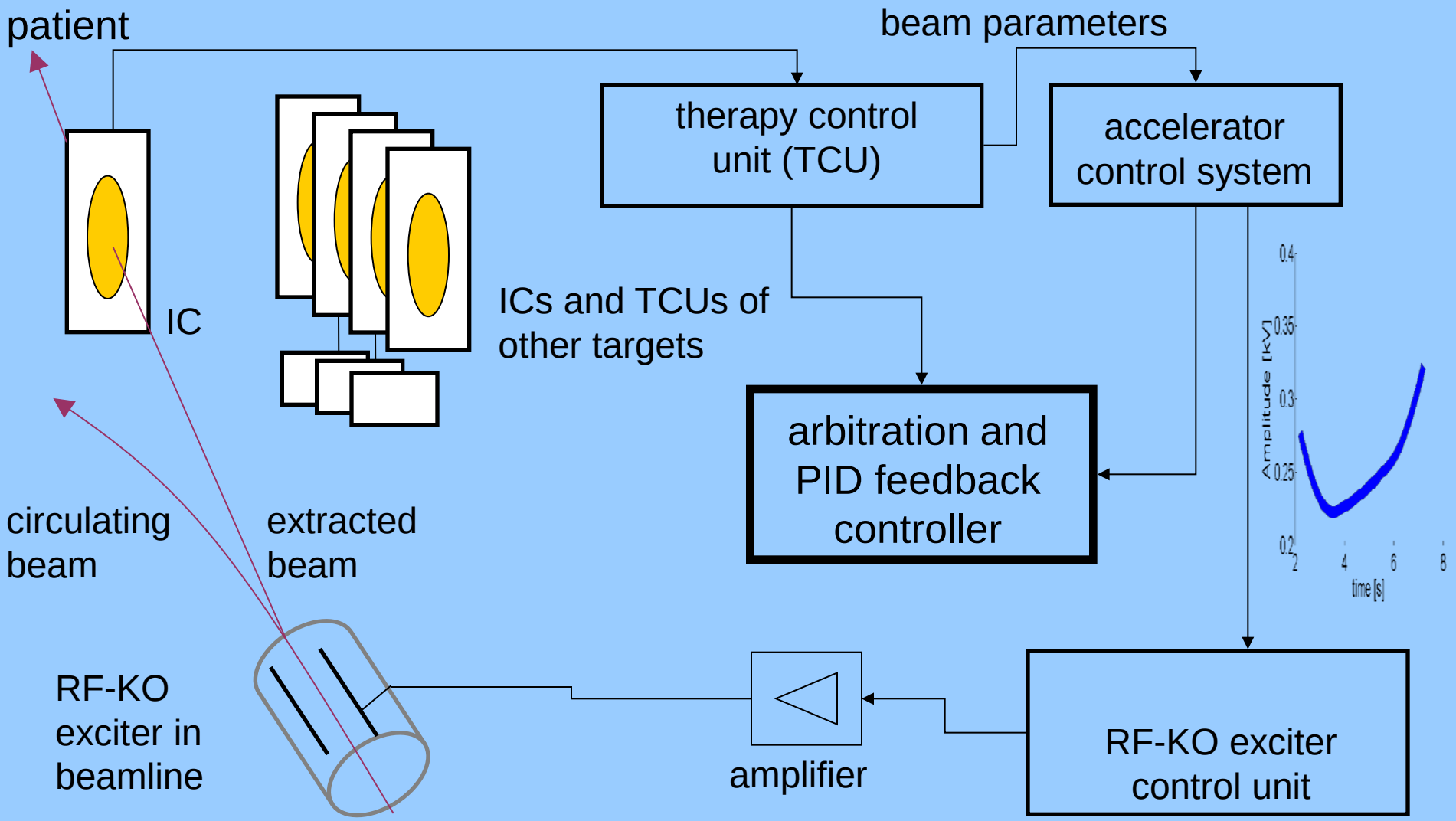
Spill Feedback System Overview



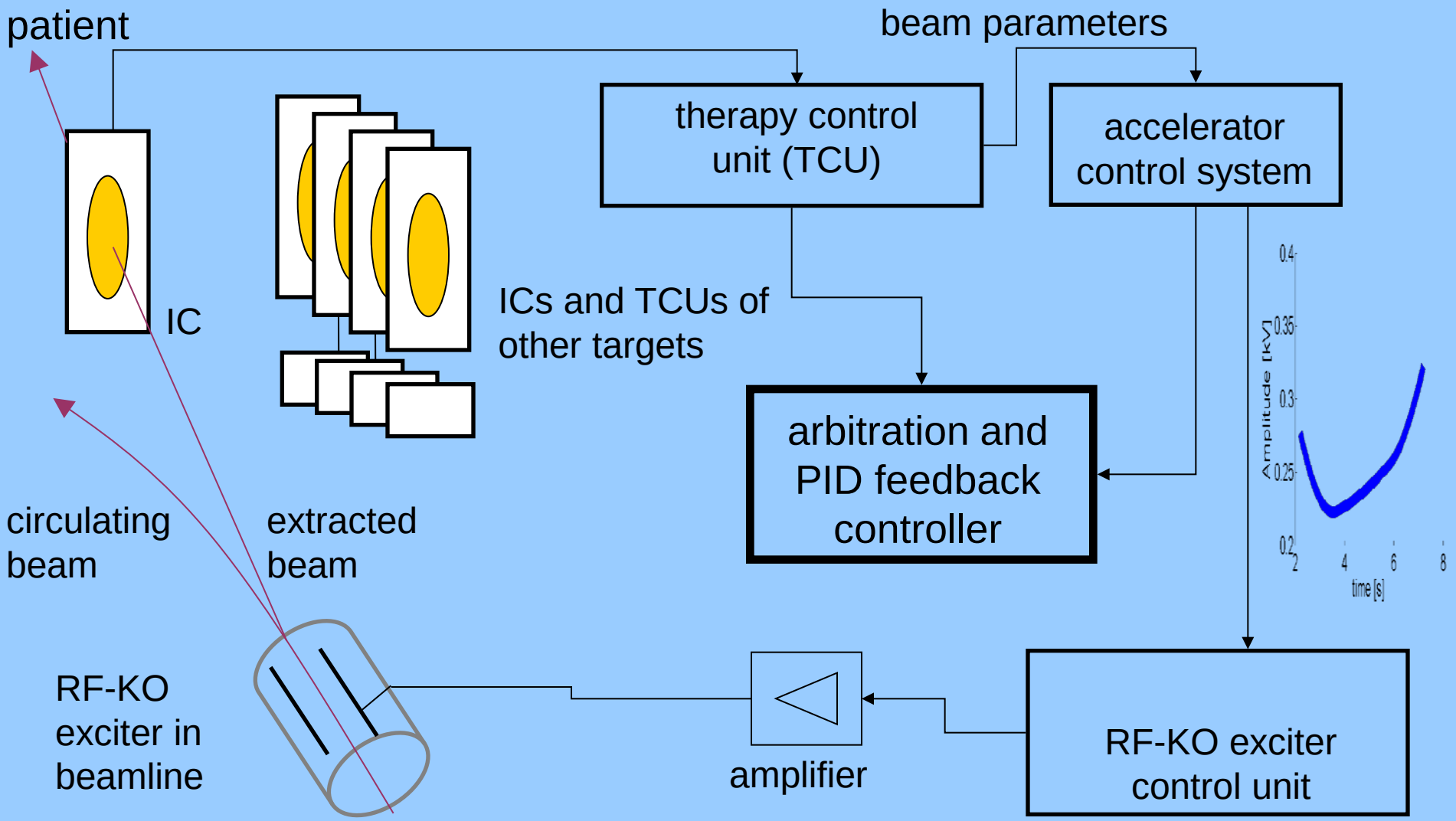
Spill Feedback System Overview



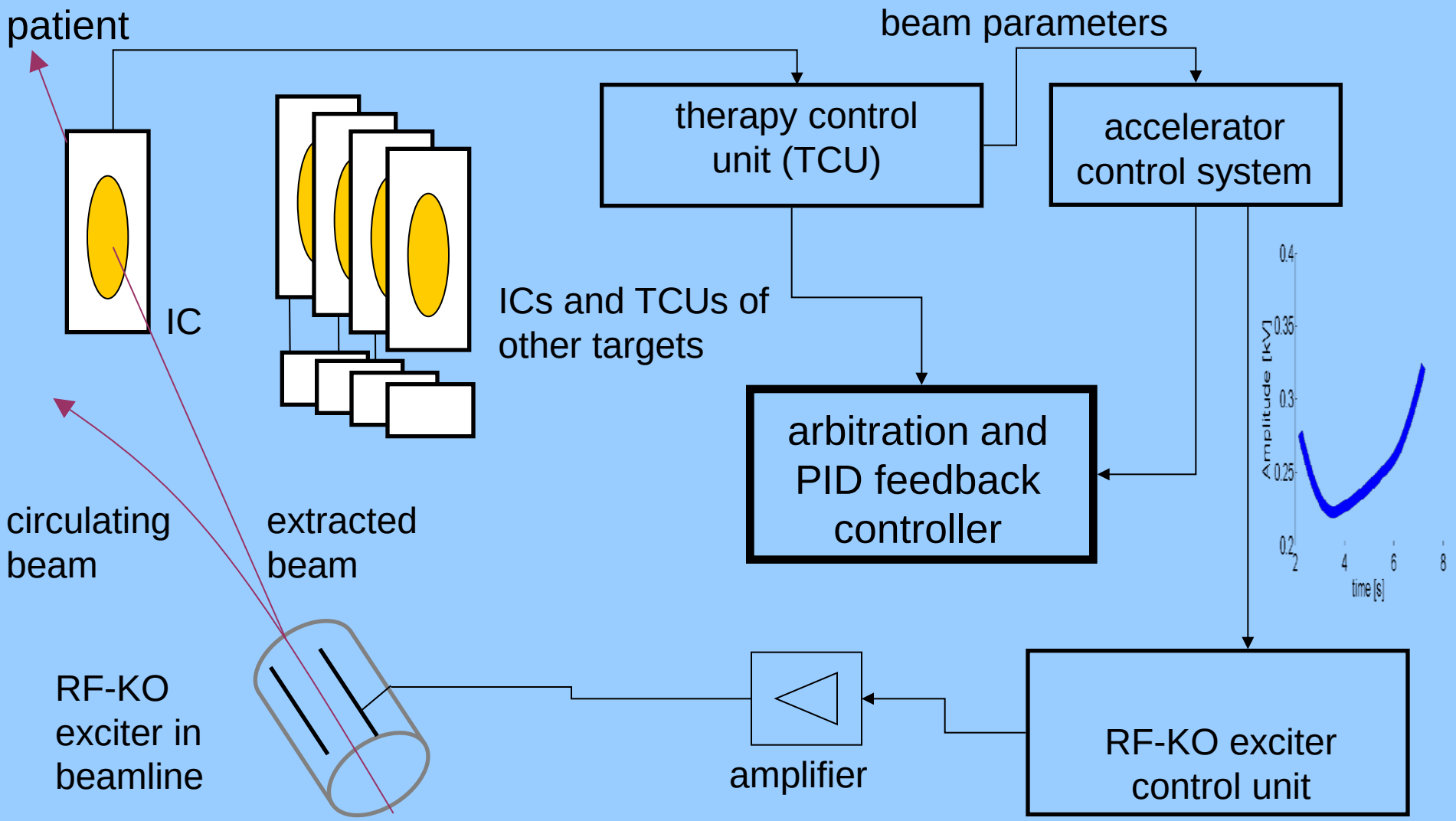
Spill Feedback System Overview



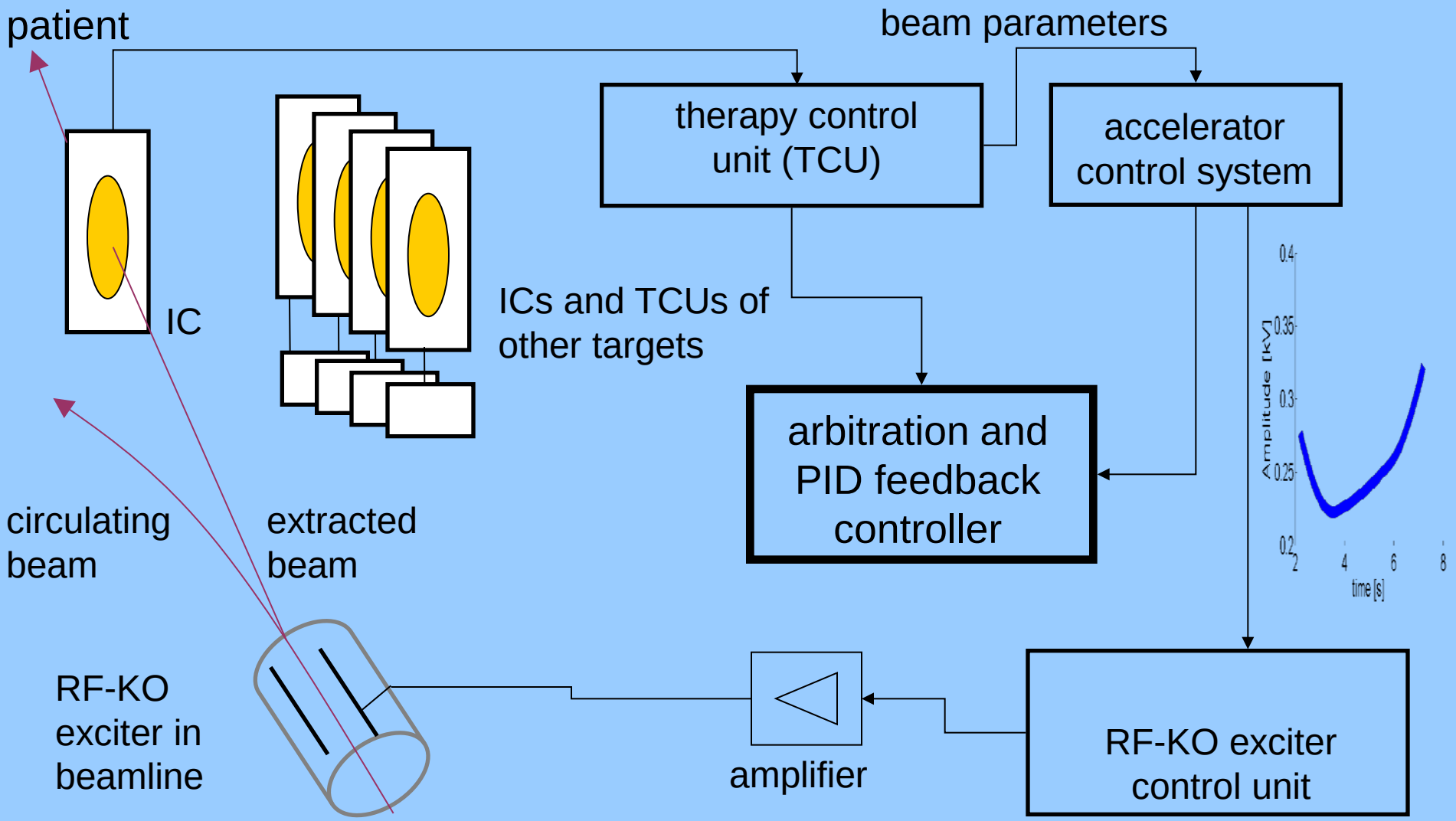
Spill Feedback System Overview



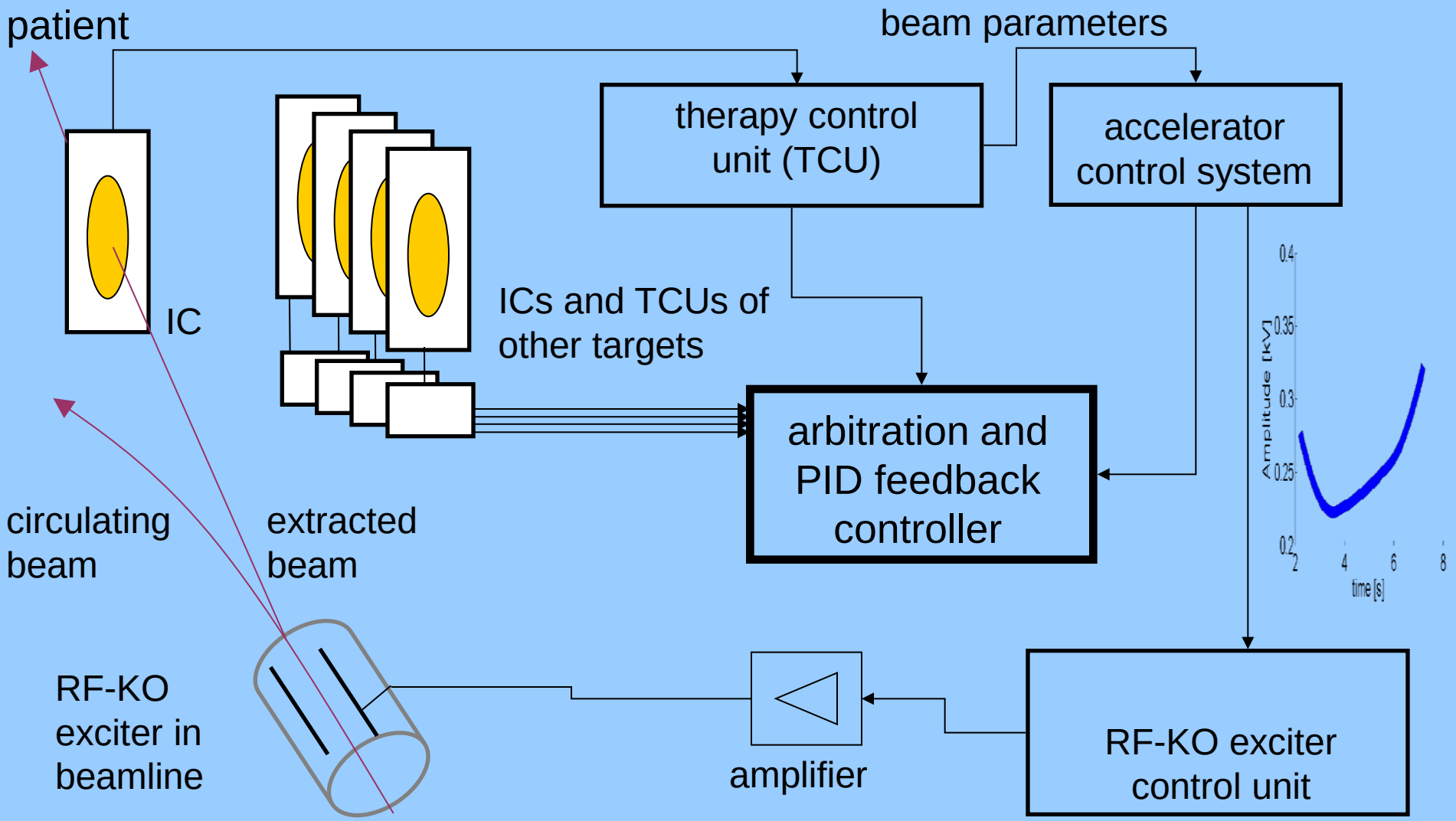
Spill Feedback System Overview



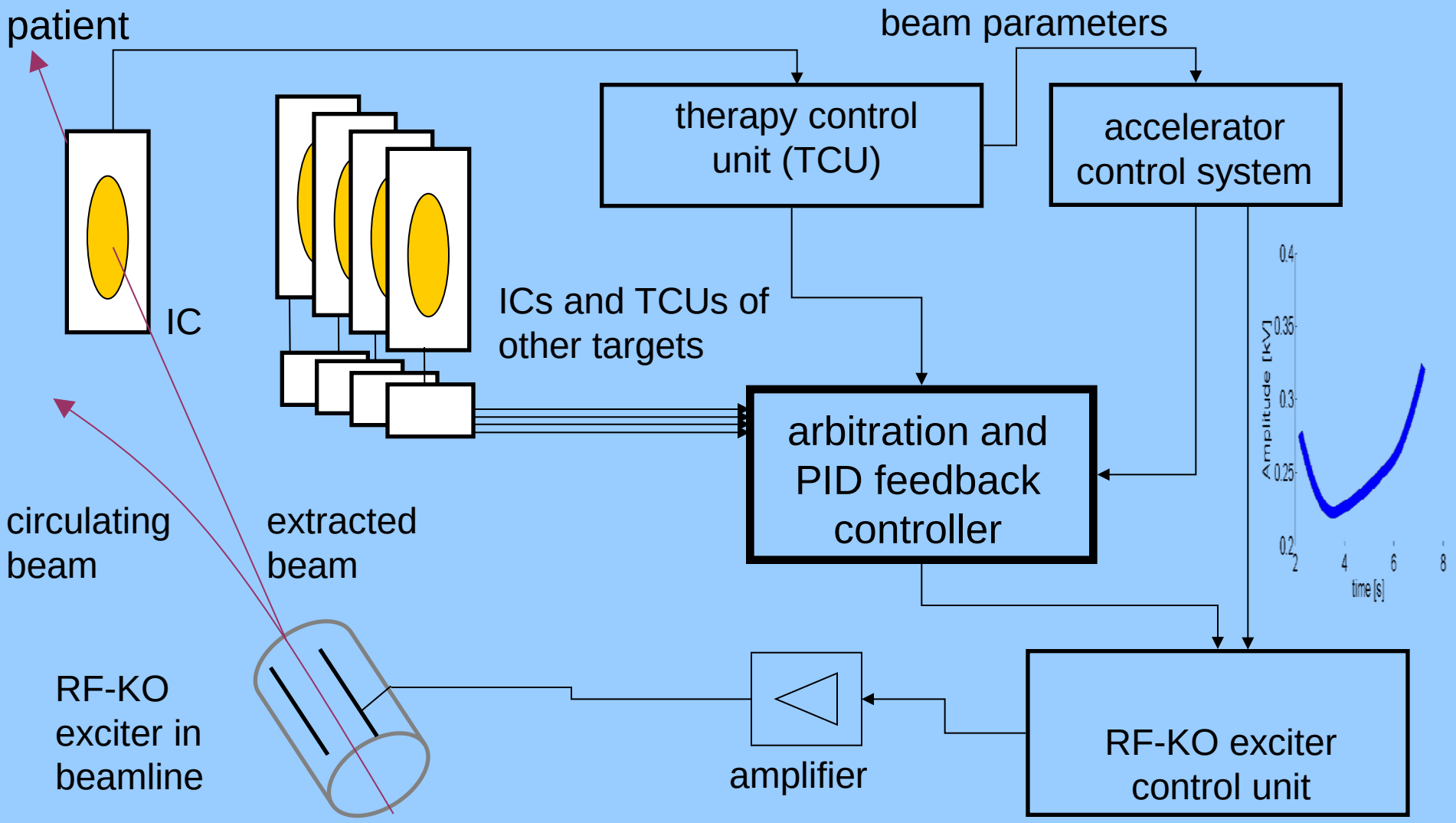
Spill Feedback System Overview



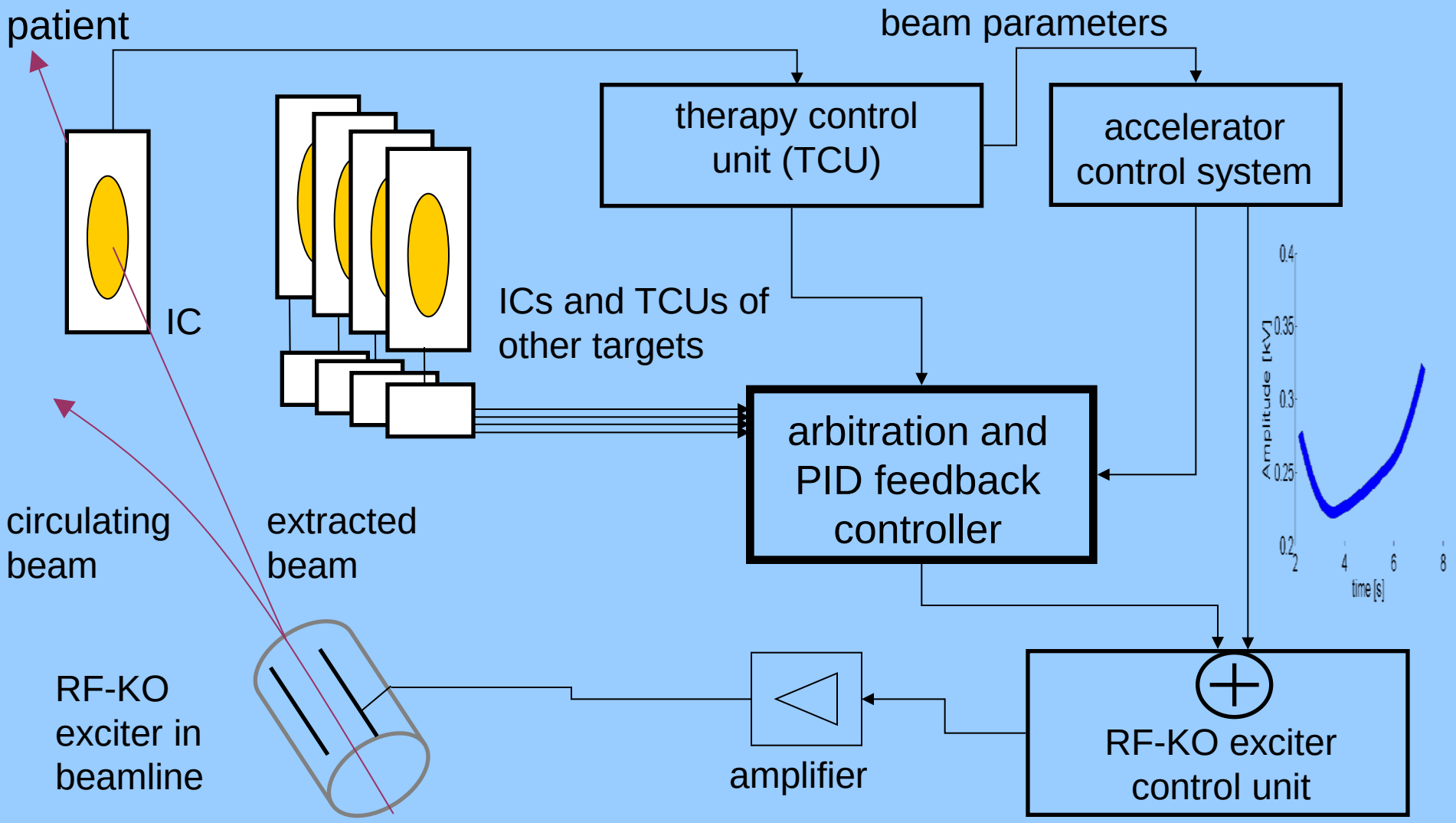
Spill Feedback System Overview



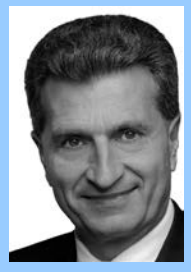
Spill Feedback System Overview



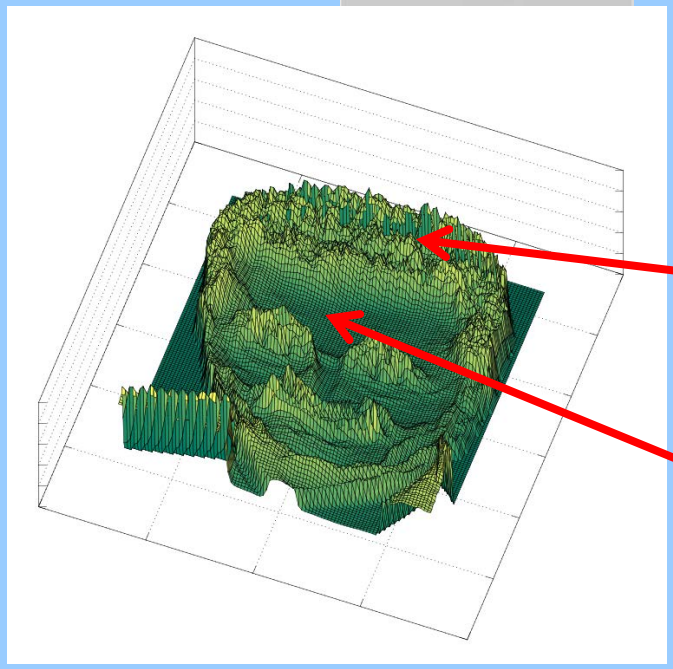
Spill Feedback System Overview



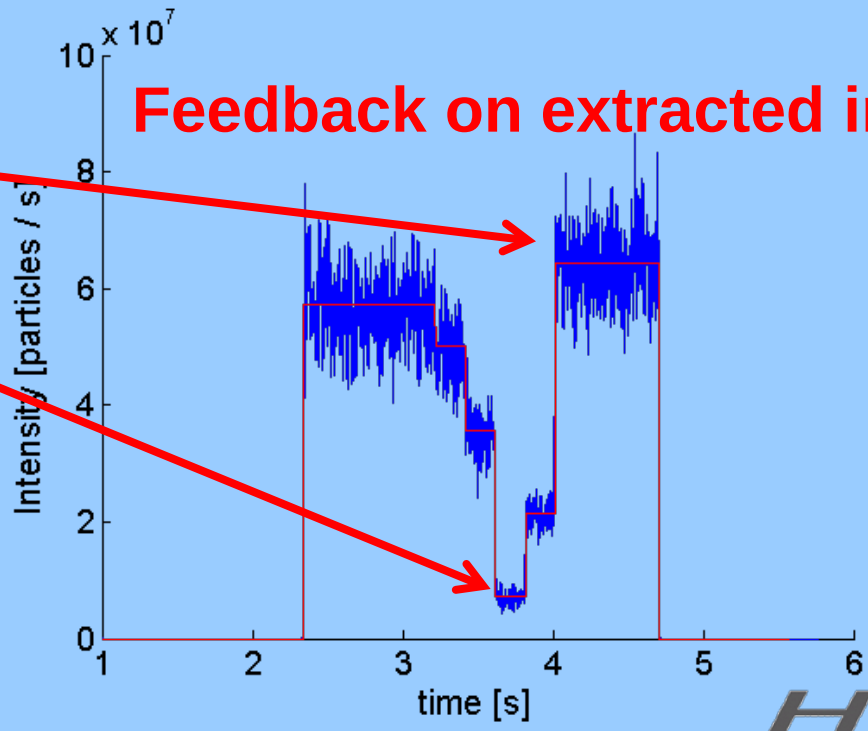
Treatment-plan-specific Feedback



- Extracted intensity varies from rasterpoint to rasterpoint
- Each raster point is irradiated by an individual particle rate: up to 45% time saving
- Intensity can be increased within < 1ms, decrease is relevantly slower => process data!

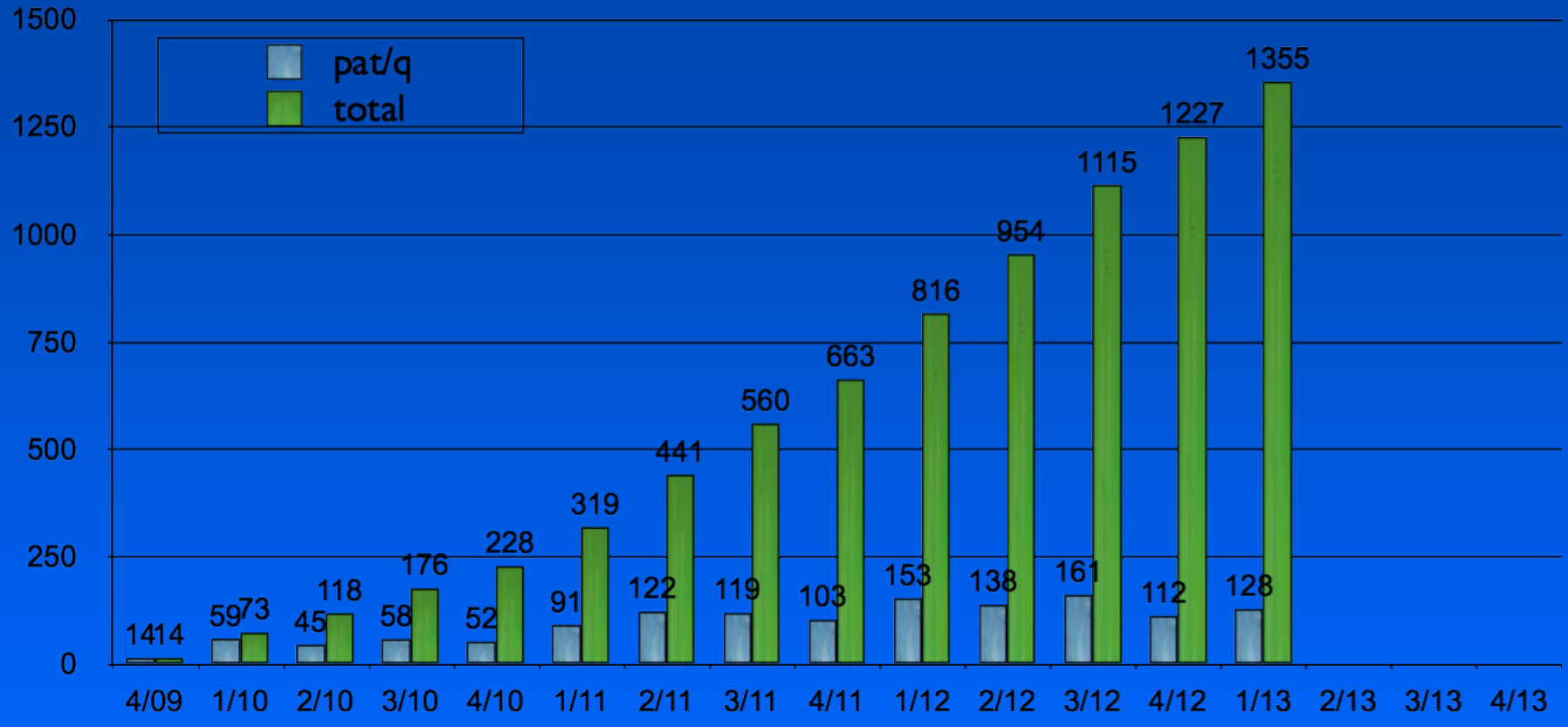


fluence map
range: 1 … 100



Feedback on extracted intensity

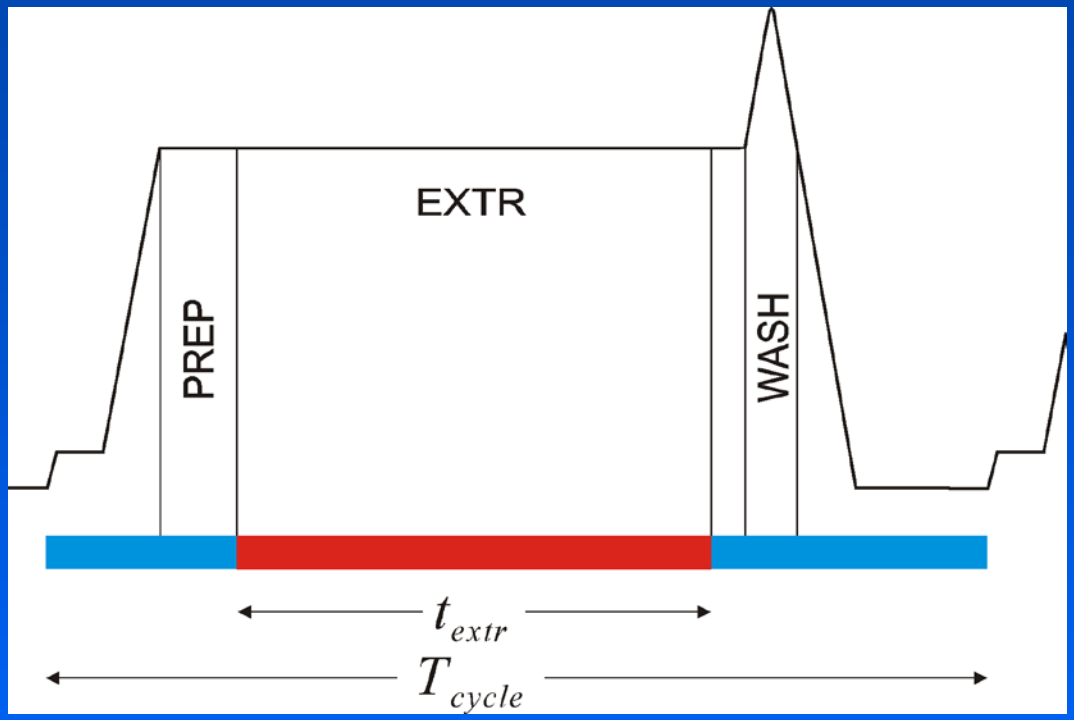
Patients @ HIT



2009	2010	2011	2012	2013*
14	214	435	564	128

* 28.2.2013

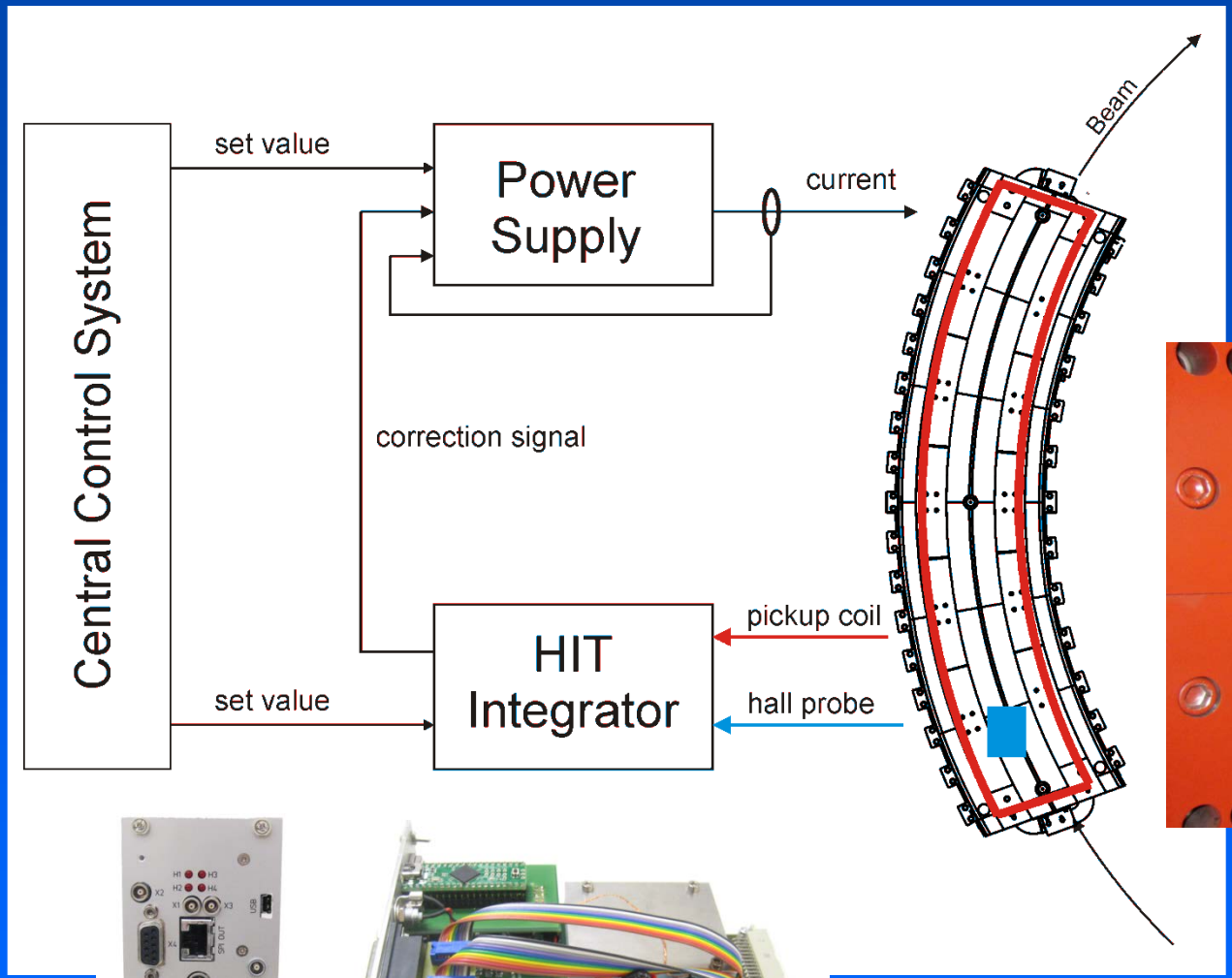
Synchrotron Duty Cycle

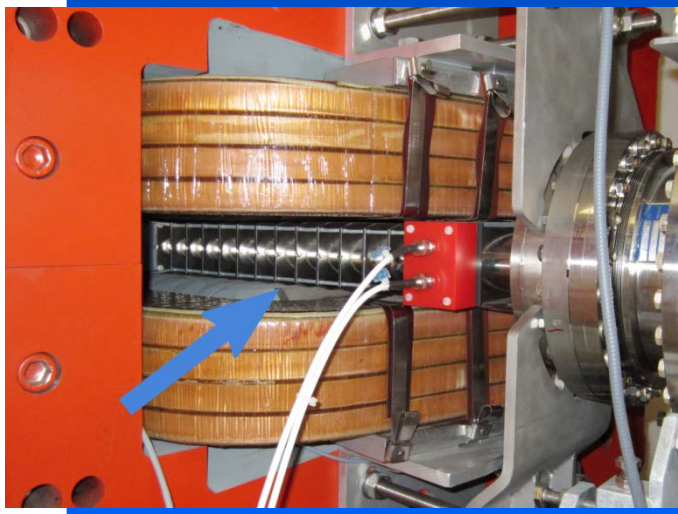


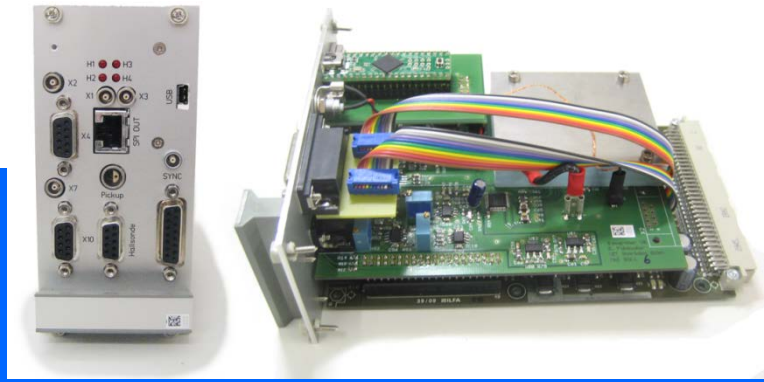
$$\text{duty cycle} = \frac{t_{extr}}{T_{cycle}} = \frac{t_{extr}}{t_{extr} + t_{acc} + \cdots + t_{\text{zwischenzyklus}}}$$

[courtesy of E. Feldmeier]

Dynamic Magnetic Field Feedback

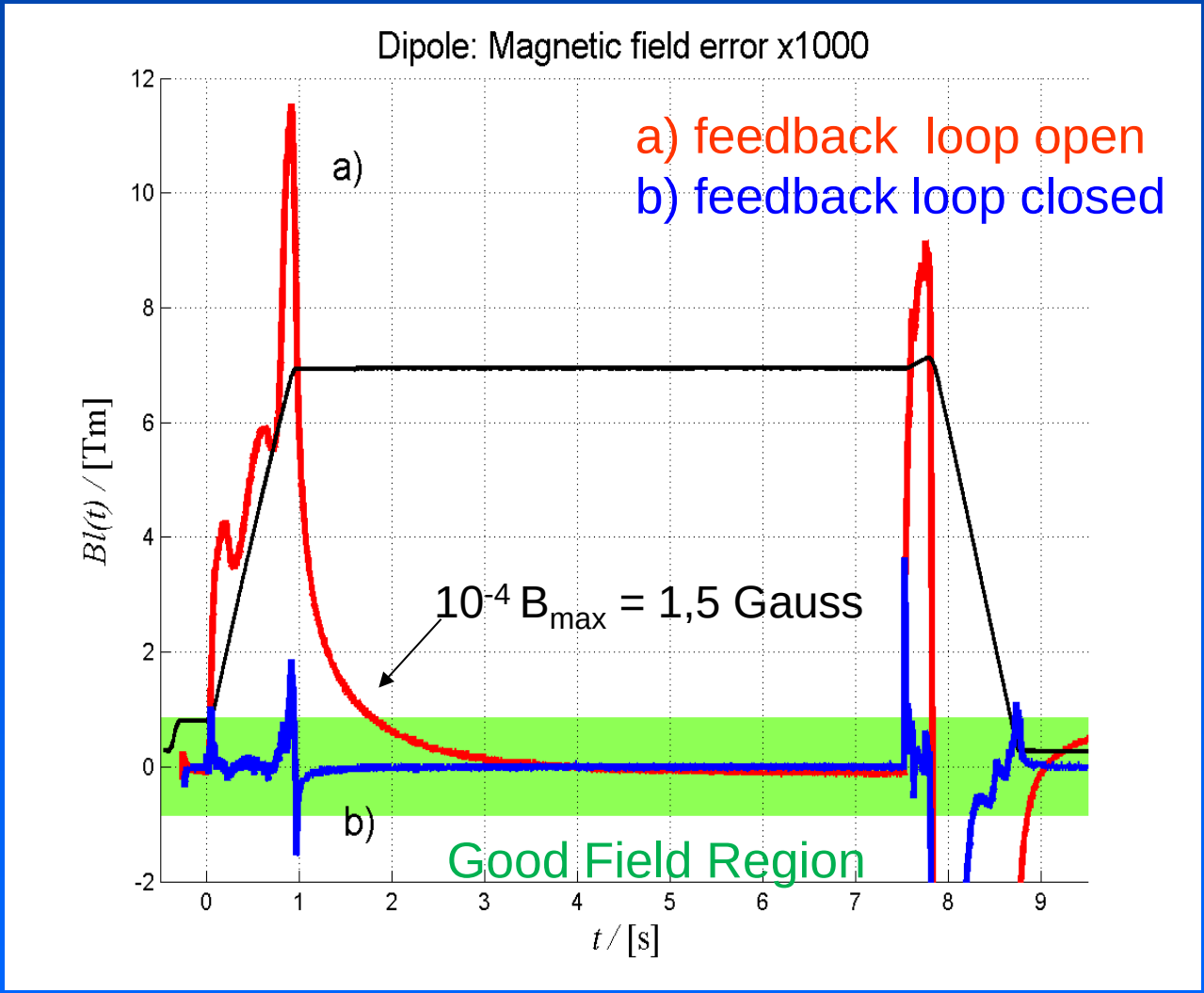






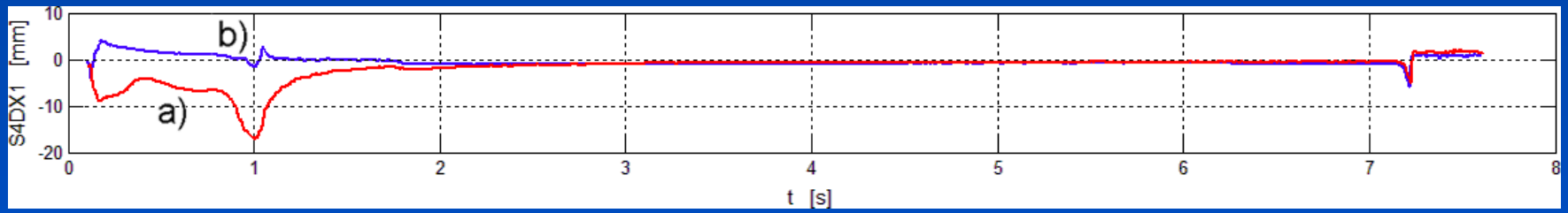
$$BL_{meas}(t) = g_{\text{hall}} U_{\text{hall}}(t=0) + g_{\text{ind}} \int_0^t U_{\text{ind}}(\tau)\, \mathrm{d}\tau$$

Dynamic Magnetic Field Feedback

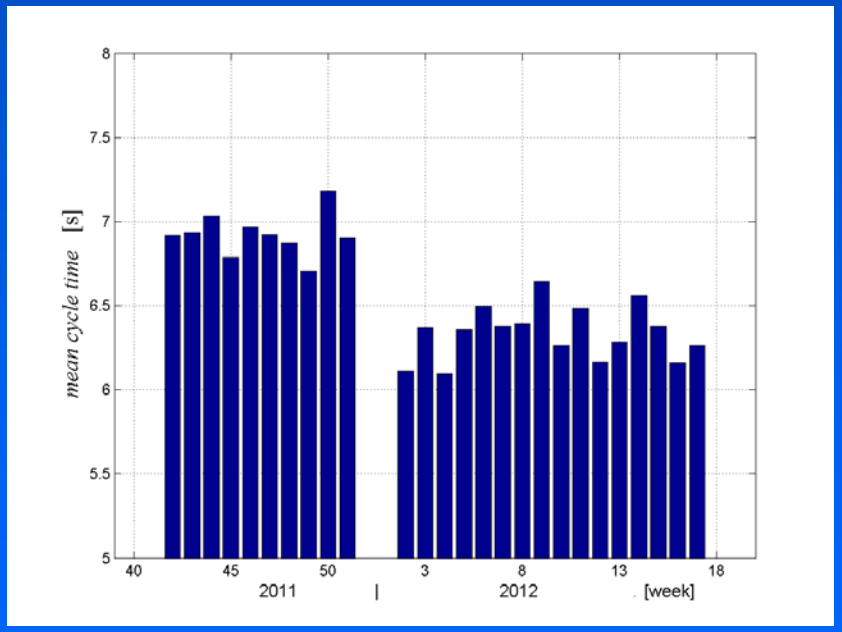


[courtesy of E. Feldmeier / HIT]

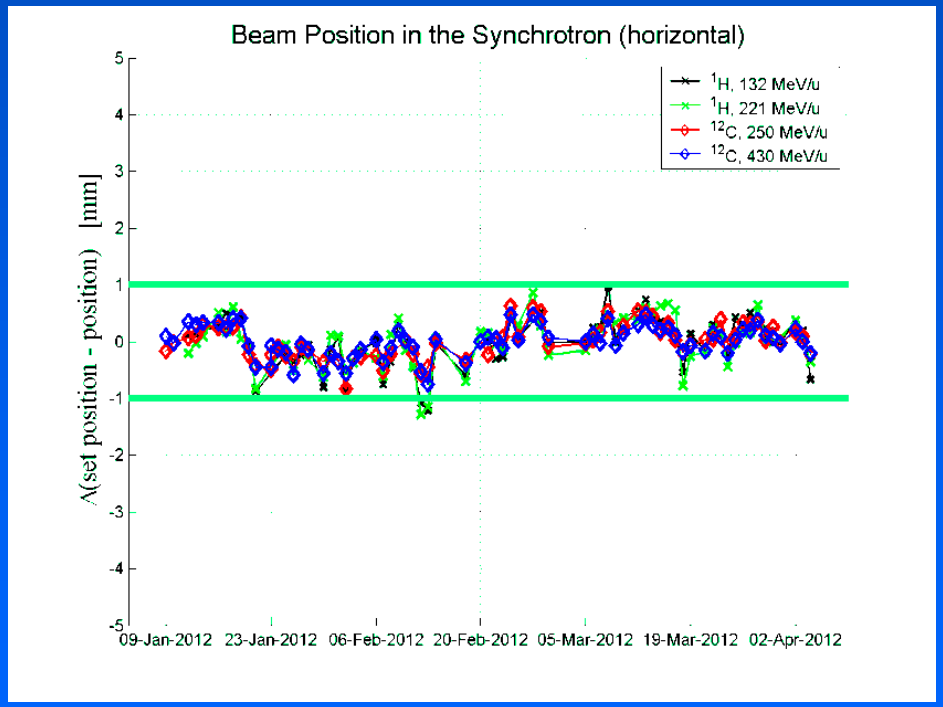
Reduction of Irradiation Duration



horizontal beam position in the synchrotron



saving: 600 ms per cycle



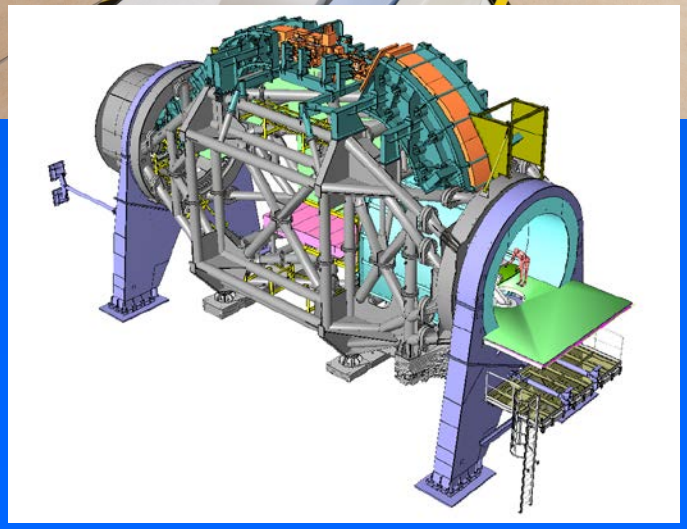
Beam position long term stability

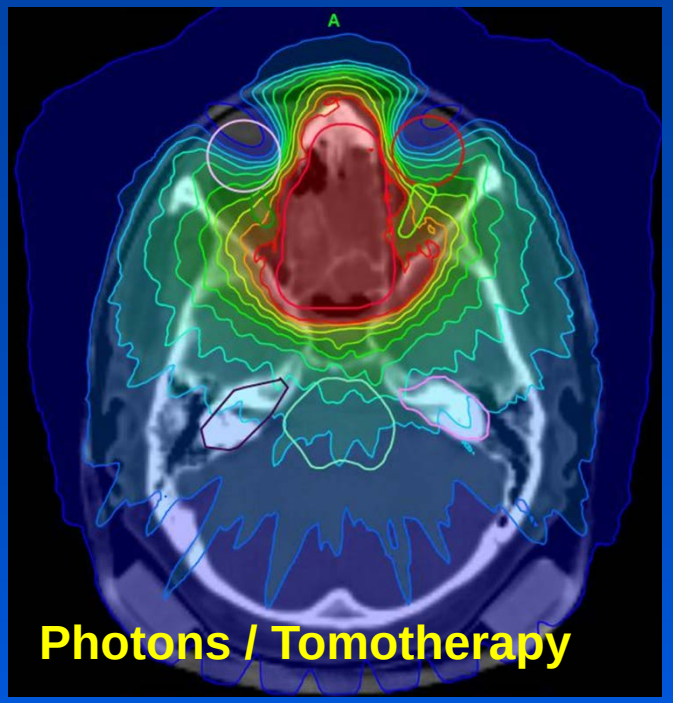
3 months

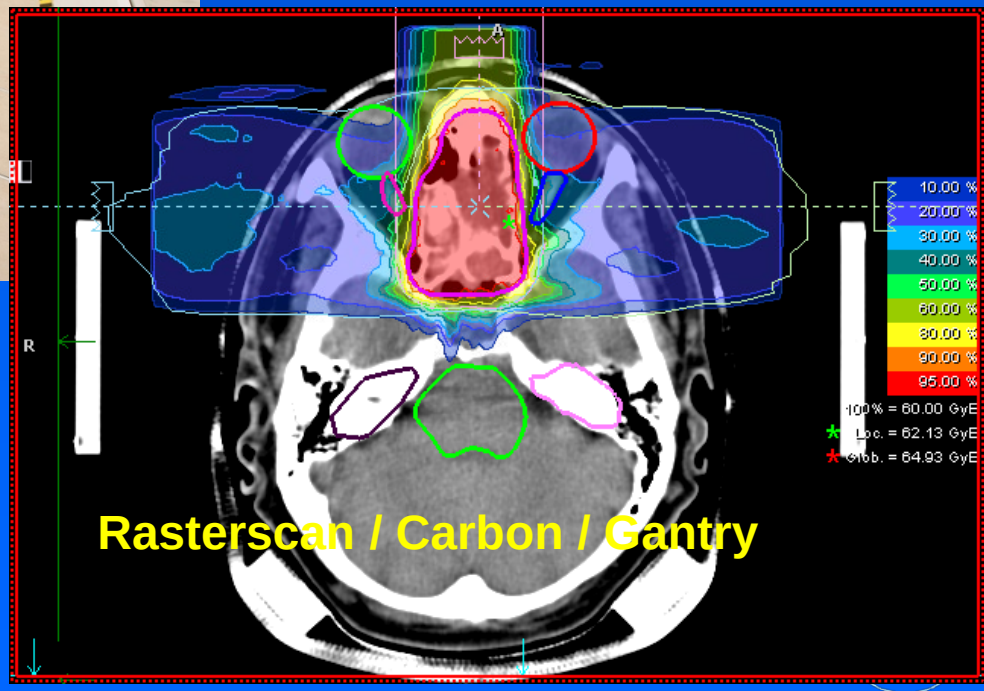
[courtesy of E. Feldmeier]

Heidelberg Ionenstrahl-Therapie Centrum

1st treatment at HIT‘s world-wide only scanning ion gantry







I would like to thank the numerous experts providing the information presented in this talk!

www.hit-heidelberg.com

HIT

IN SCIENTIA SALUS

Rasterscan@HIT/H1 Carbon 430 MeV/u

E. Feldmeier, C. Schömers, K. Höppner, A. Peters, J. Naumann, R. Panse, …

HIT
Heidelberg Ionenstrahl-Therapie Centrum