Novel Techniques and Challenges in Hadron Therapy

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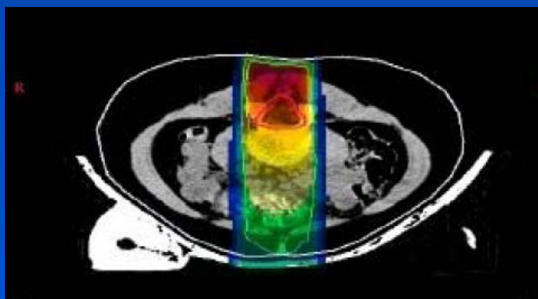
GOETHE UNIVERSITÄT FRANKFURT AM MAIN

IAP

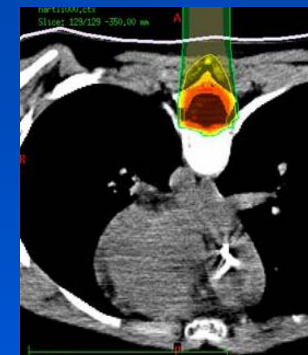
HIT Heidelberg Ionenstrahl-Therapie Centrum

Reduction of the Normal Tissue Dose

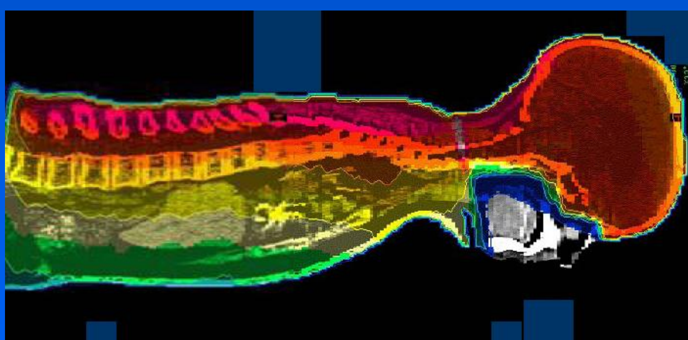
conventional

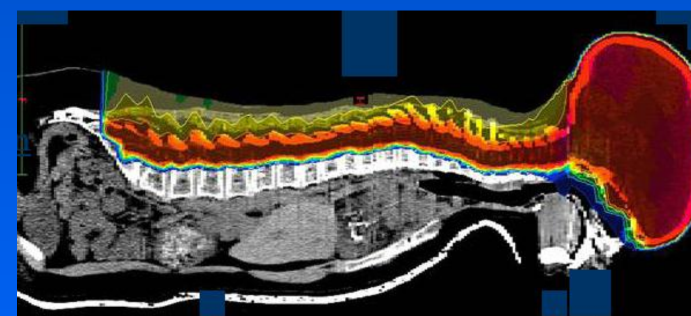


charged particles



Target dose 32 Gy/GyE





Dose comparison

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

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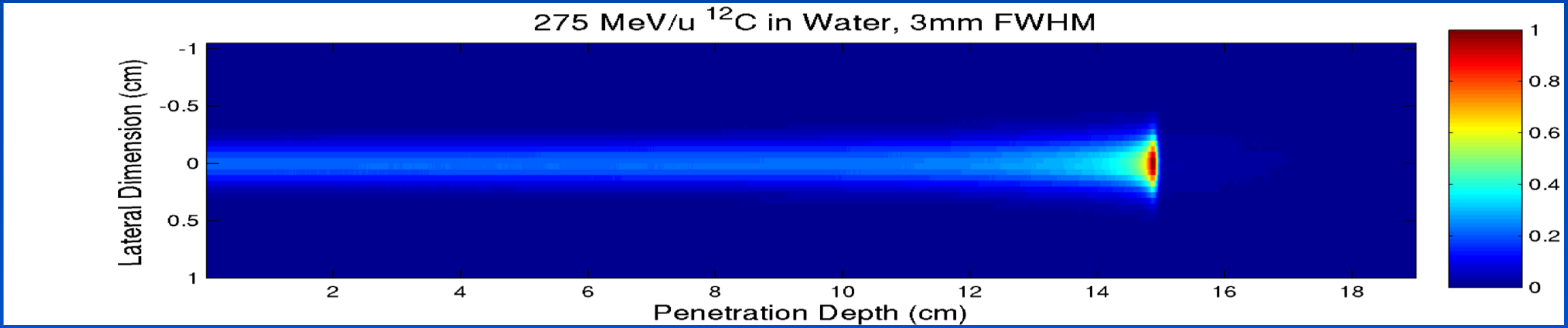
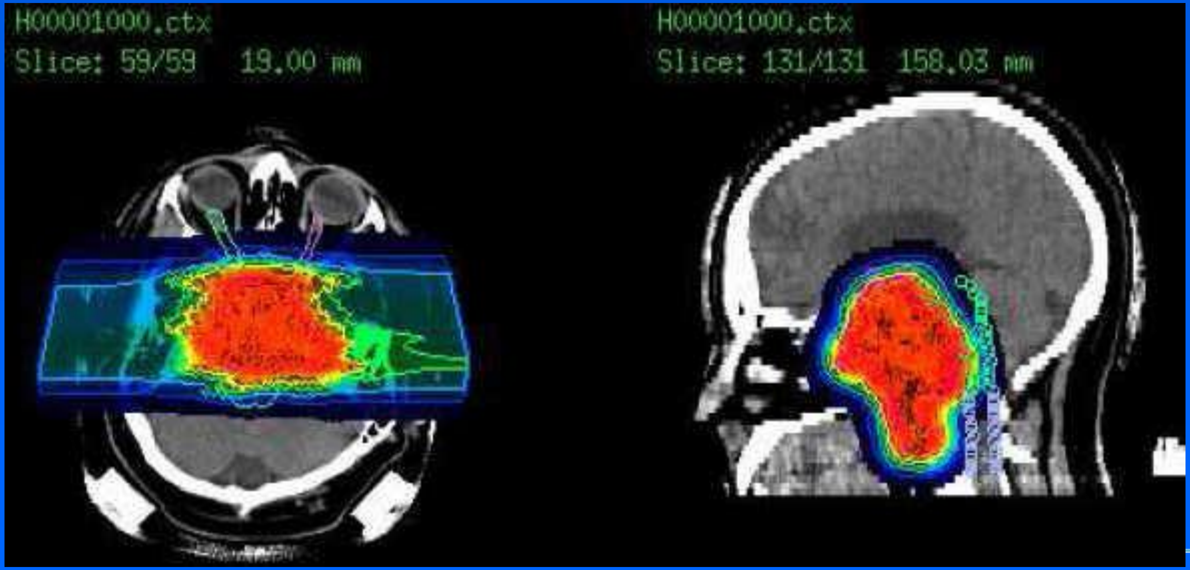
Pencil Beam vs. Dose Distribution



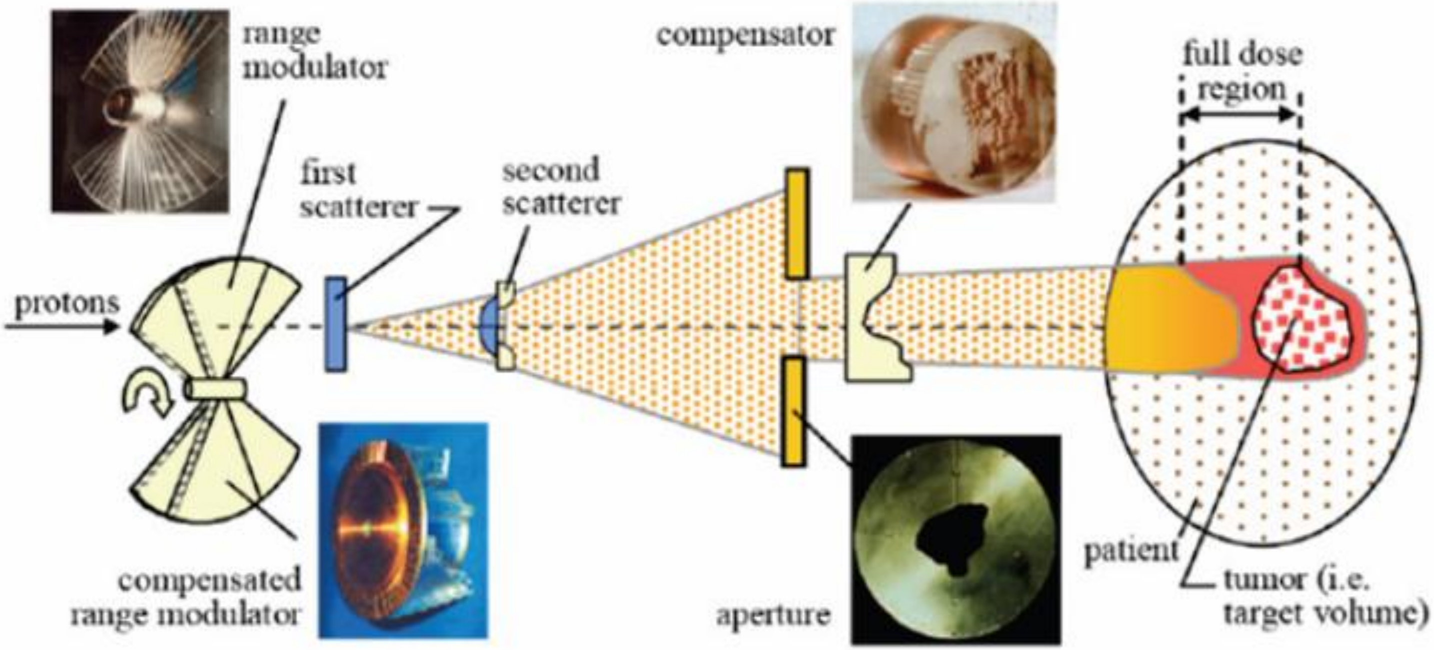
entrance channel:
- low physical dose
- low rel. biol. effiency

tumour:
- high physical dose
- high rel. biol. effiency

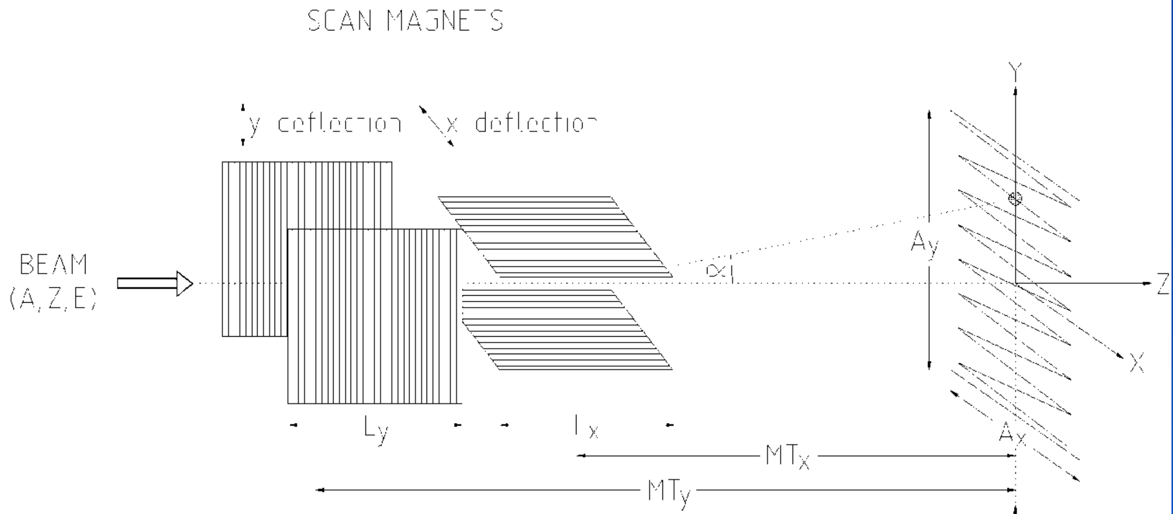


Passive Dose Delivery

Treatment nozzle for a passive scattering proton therapy beamline



MASSACHUSETTS GENERAL HOSPITAL
RADIATION ONCOLOGY

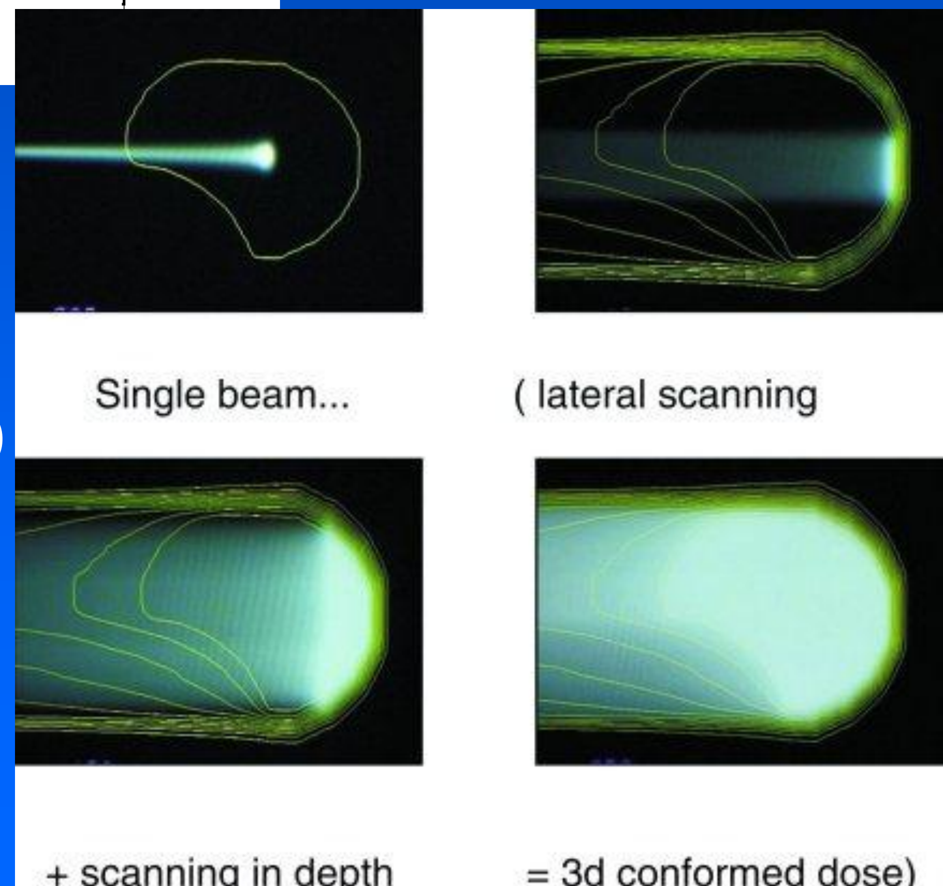


Haberer et al., NIM A , 1993

Protons (Pedroni et al., PSI):
spot scanning gantry
1D magnetic pencil beam scanning
plus
passive range stacking (digital range shifter)

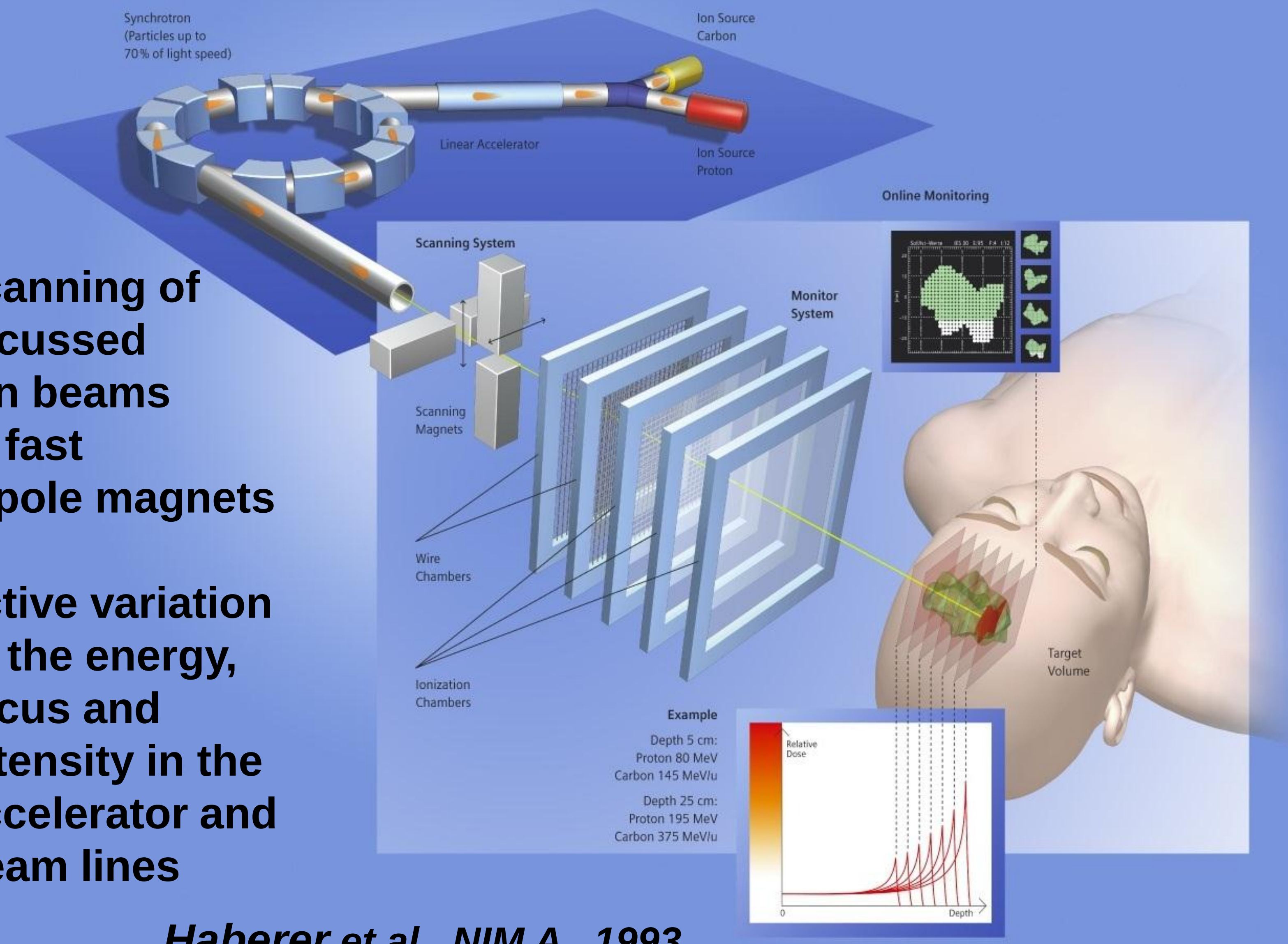
Ions (Haberer et al., GSI):
raster scanning, 3D active,
2D magnetic pencil beam scanning
plus
active range stacking (spot size, intensity) in the accelerator

Beam Scanning



Th. Haberer, Heidelberg Iontherapy Center

Rasterscan Method

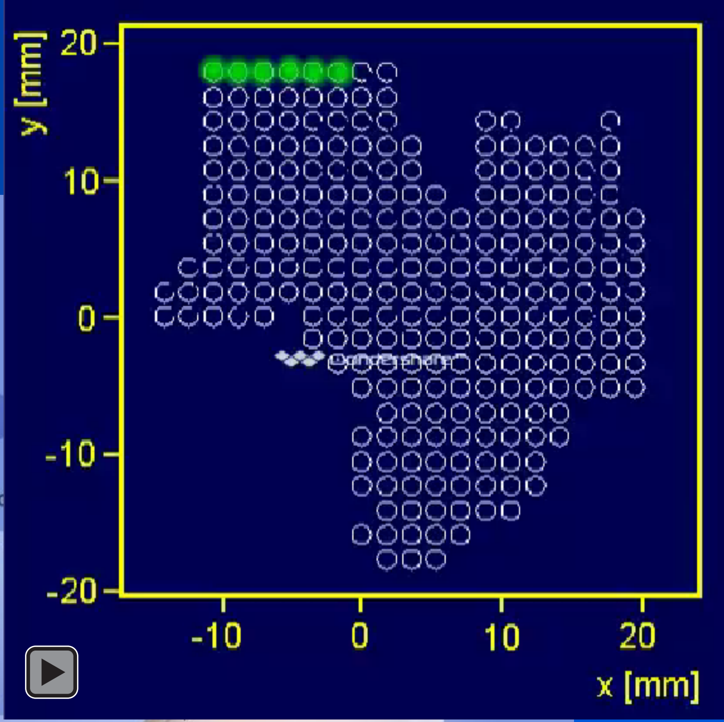


scanning of focussed ion beams in fast dipole magnets

active variation of the energy, focus and intensity in the accelerator and beam lines

Haberer et al., NIM A , 1993

Rasterscan Method



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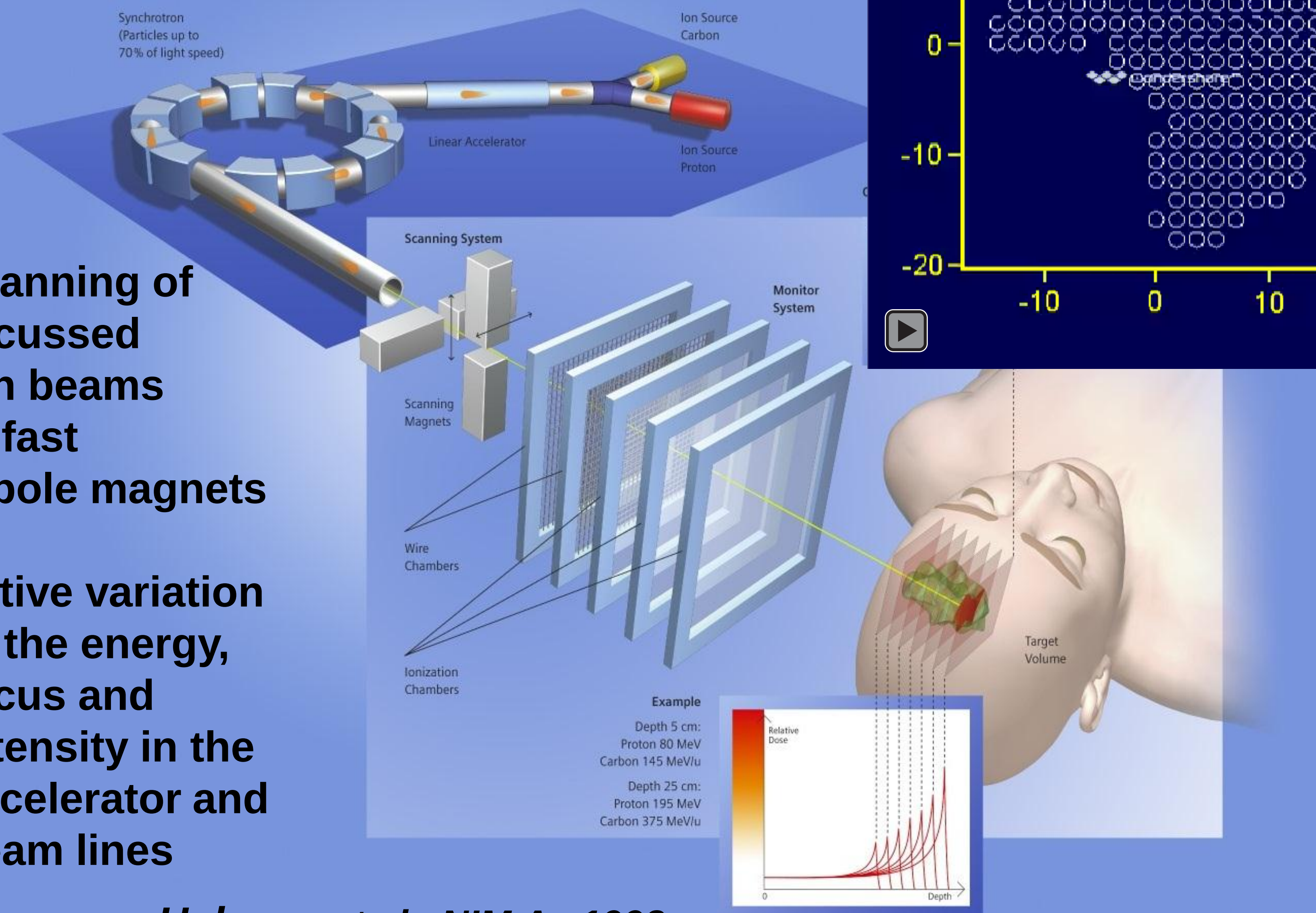
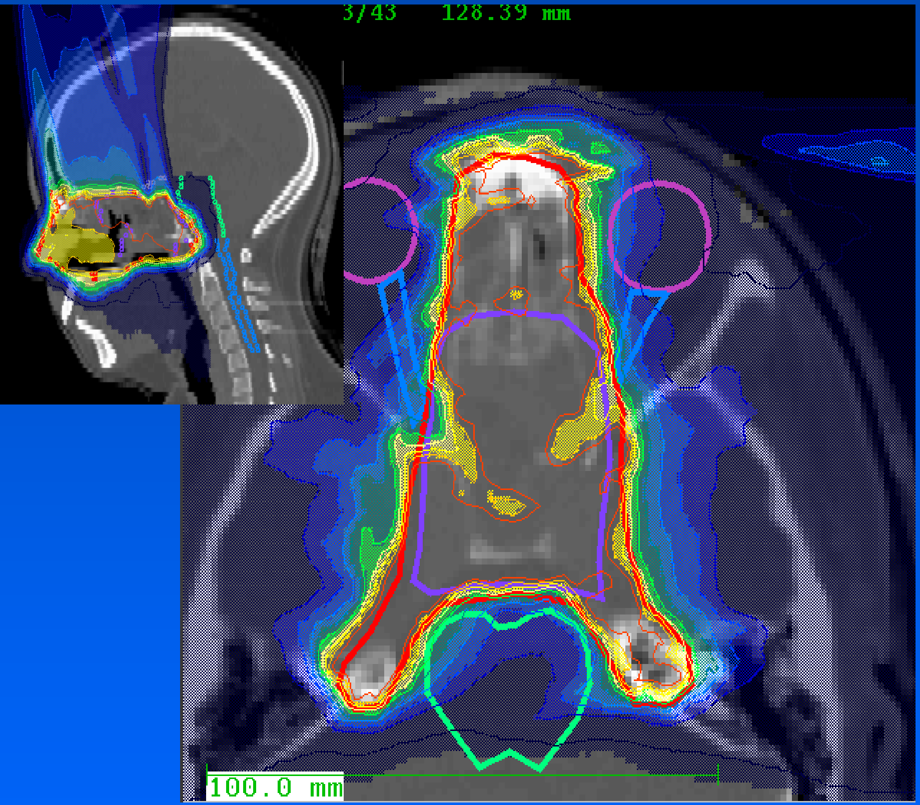


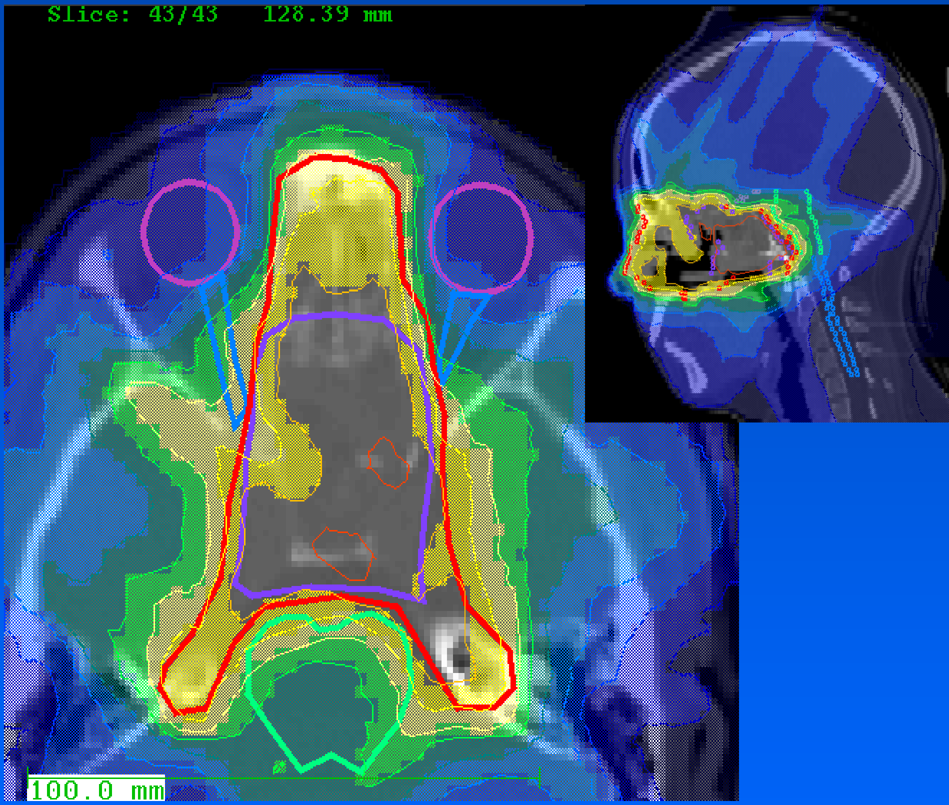
Haberer et al., NIM A , 1993

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

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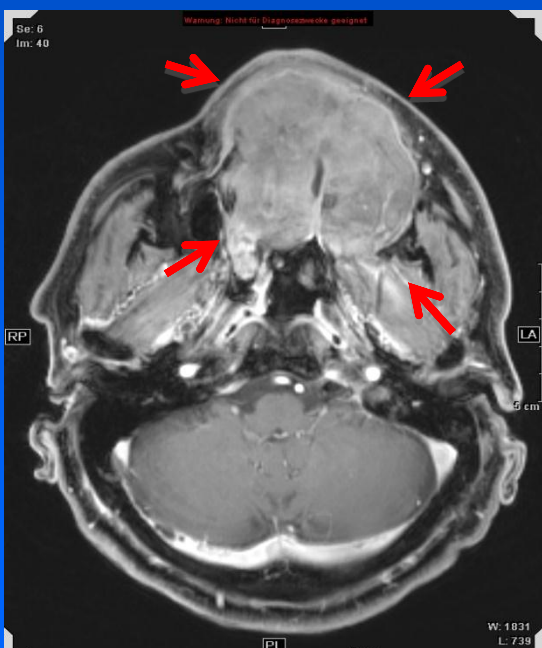
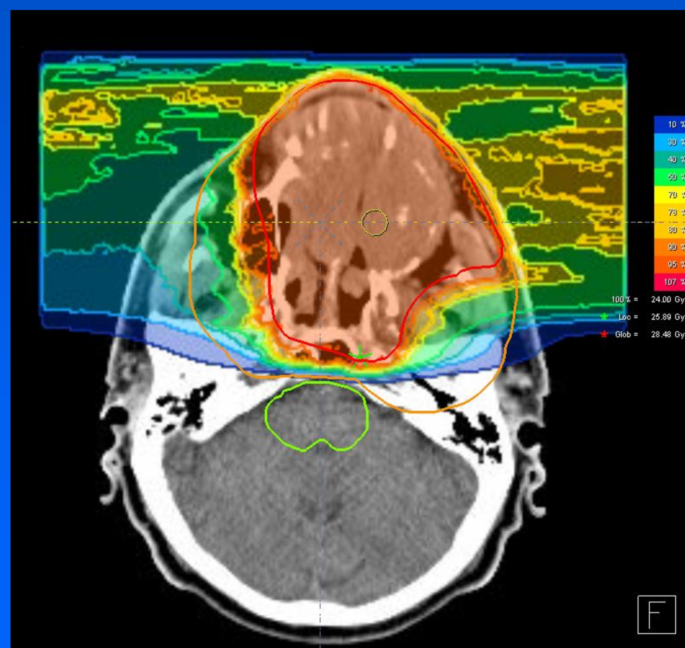
Iontherapy – established for adenoidcystic carcinomas (salivary glands)

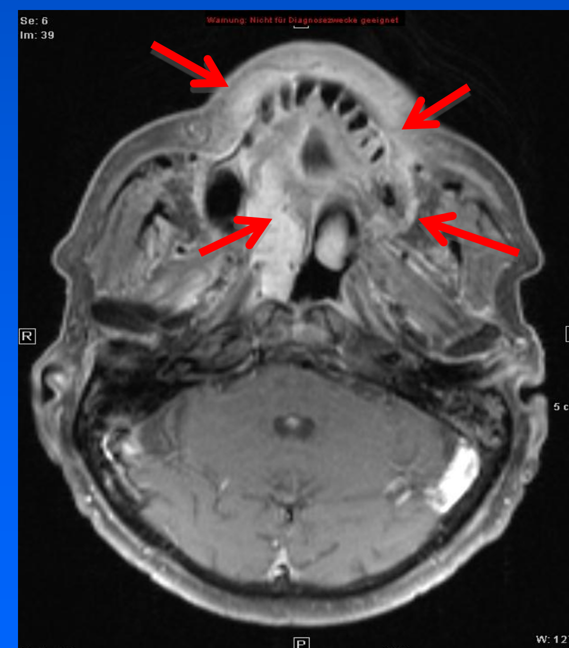
Fast tumor response



pre ion-RT



Treatment plan



6 weeks post RT

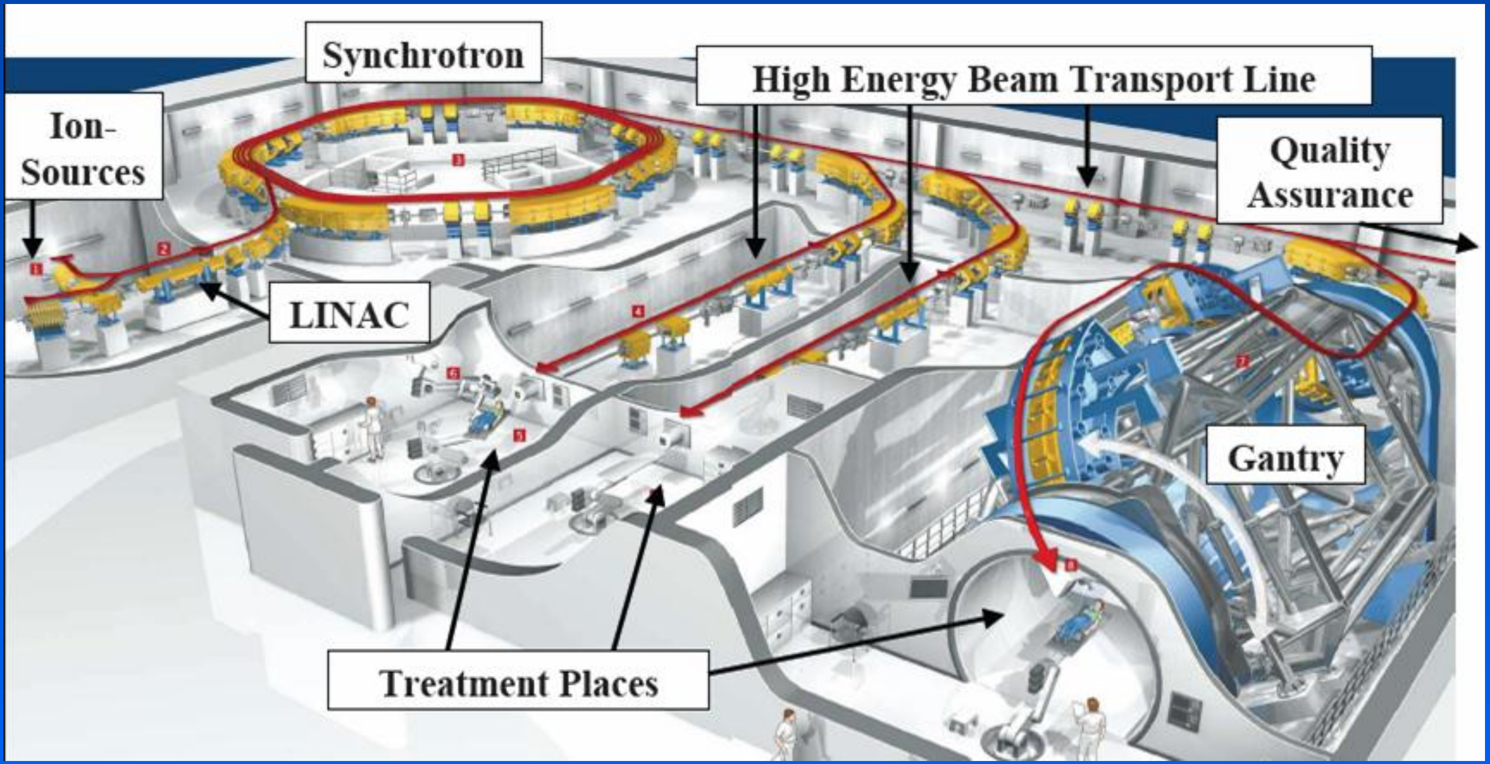
Hospital-based Facilities

- typically run at university hospitals treating high patient numbers in a multitude of disciplines
- major investment, business plan requires high patient throughput
- particle accelerator feeds several treatment vaults
- beam scanning is now state-of-the-art
- anyhow, many existing facilities use scattering systems to shape the dose distribution
- reimbursement for proton treatments in the US
- reimbursement for proton and carbon treatments in the EC and Japan

Heidelberg Ion Therapy Center (HIT)

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

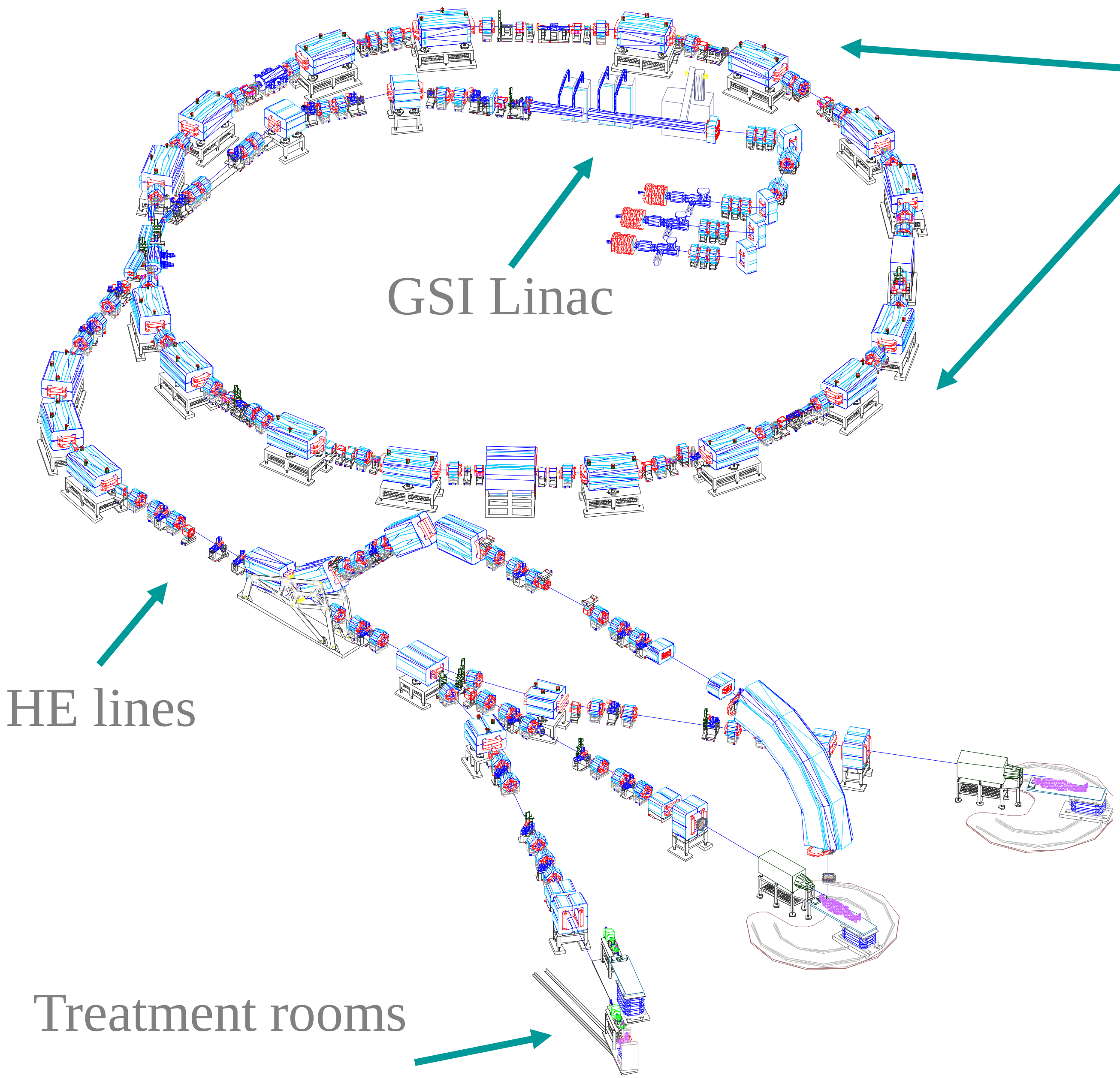
CNAO - Pavia

First patient: September 2011
(first with C-ions: 13 Nov. ’12)

So far about 80 patients

Courtesy Sandro Rossi
CNAO

The heart of CNAO



SYNCHROTRON

OPTIMIZED
for an hospital based facility (all Ion-therapy centres existing in the World adopt it):
- Safety
- Efficiency
- Reliability
- Maintainability

-Designed by

PIMMS/TERA

Heidelberg Ionenstrahl-Therapie Centrum

IBA Proton Facility

ACC

Fictitious Accounting

Investment	**~ 100M€**
Reimbursement	**~ 20k€ (EC) / ~ 50k€ (US)**

Running costs / a

Staff	**~ 5 M€ (~ 70 FTEs)**
Investment costs	**~ 8 M€**
Maintenance	**~ 5 M€**
Energy	**~ 2 M€**
Reinvestment	**~ 1 M€**
Total	**~ 21 M€**

=> More than 1000 treatments per year needed!

Challenges

Multi-vault design only adequate for large clinical centers

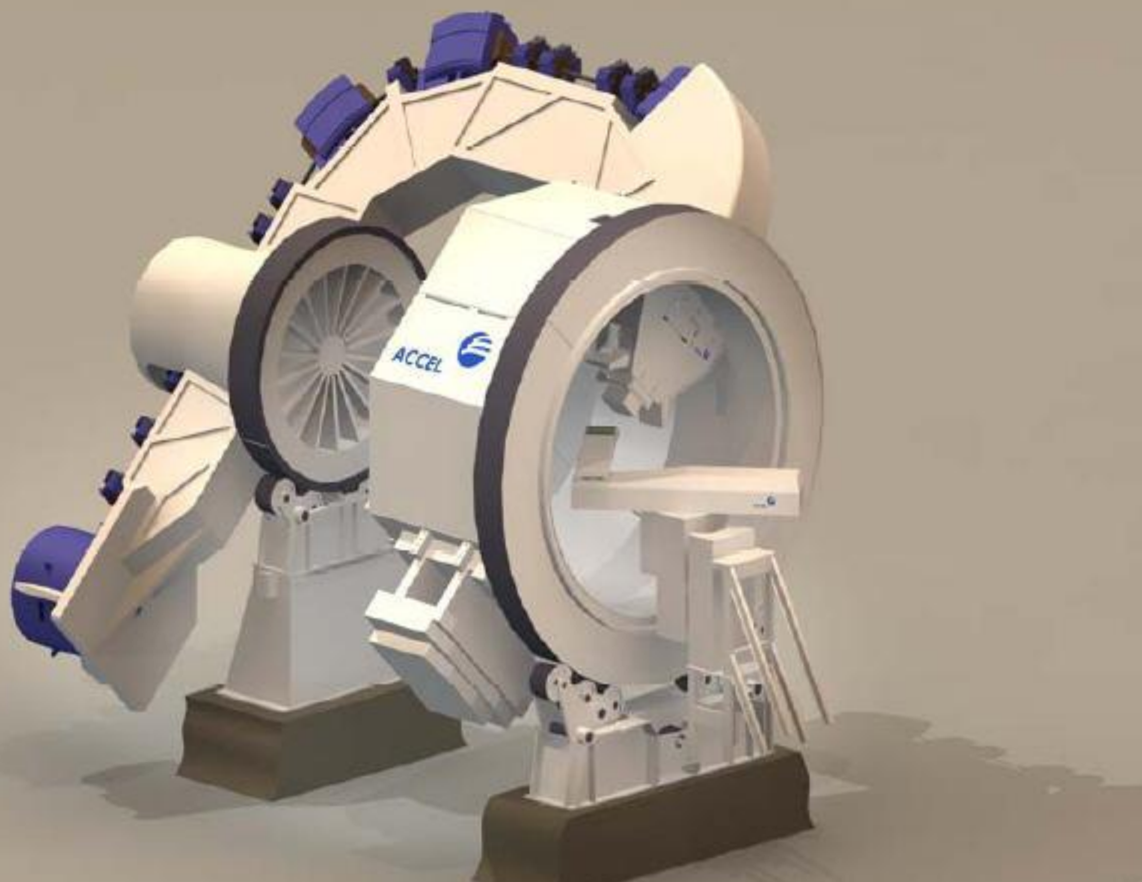
Single or two-room designs would open a new market

Cut investment via compact design (acc, beamlines, gantry) would help. To really change this setting magnetic fields need to be more than doubled .

Anyhow, the beam quality (lateral scattering, fragmentation, …) and finally the conformity of the dose distribution (typically via beam scanning) must not be compromised!

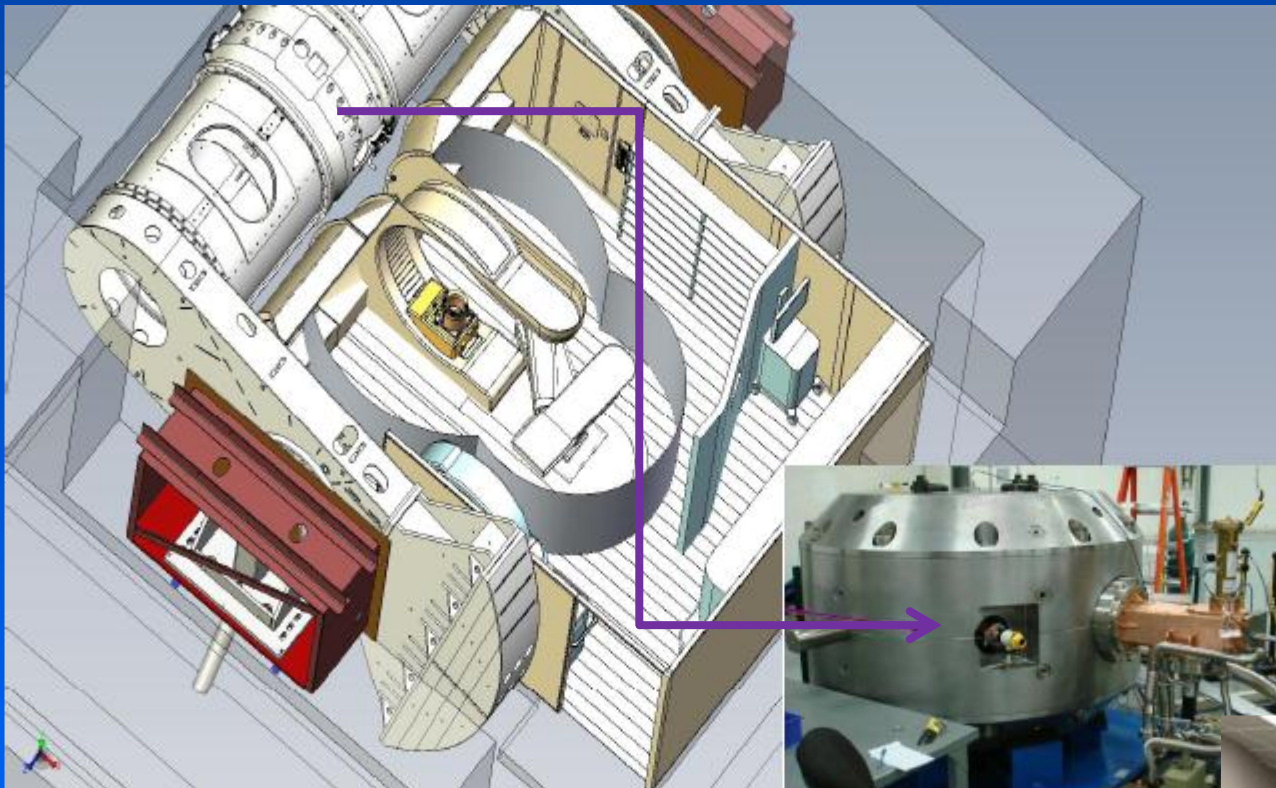
Compact SynchroCyclotrons

VARIAN medical systems / ACCEL



Schirrmeister, Varian medical, designstudy, Erice 2009

Compact SynchroCyclotrons



The MEVION S250 Proton Therapy System is USFDA 510(k) cleared and complies with MDD/CE requirements.

www.mevion.com

s.c. 9 T Nb3Sn , 250 MeV + energy degrader passive dose delivery

Installation at Washington University School of Medicine in St. Louis (2012)

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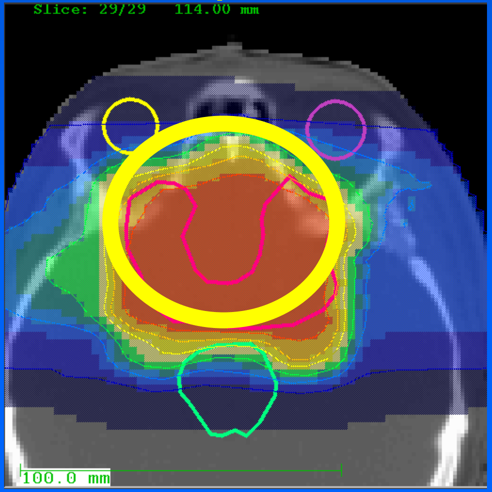
Two-Room Proton Solution

Questions

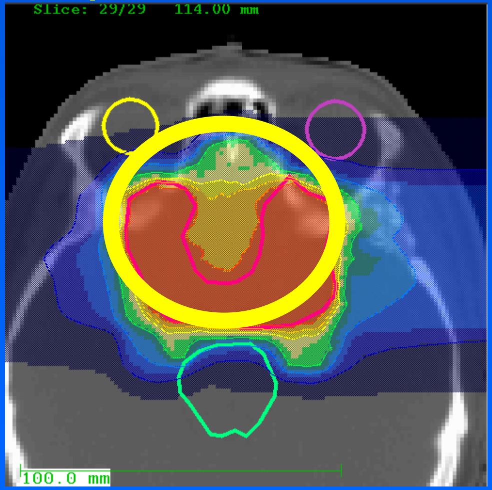
Will single-room systems allow for pencil-beam scanning? (beam quality and dose conformity)

Costly accelerators may run idle while patients are immobilized. Two-room facilities may offer an attractice cost-benefit-ratio.

protons, passive
ithemba, 2 fields



rasterscanned carbon
GSI, 2 fields



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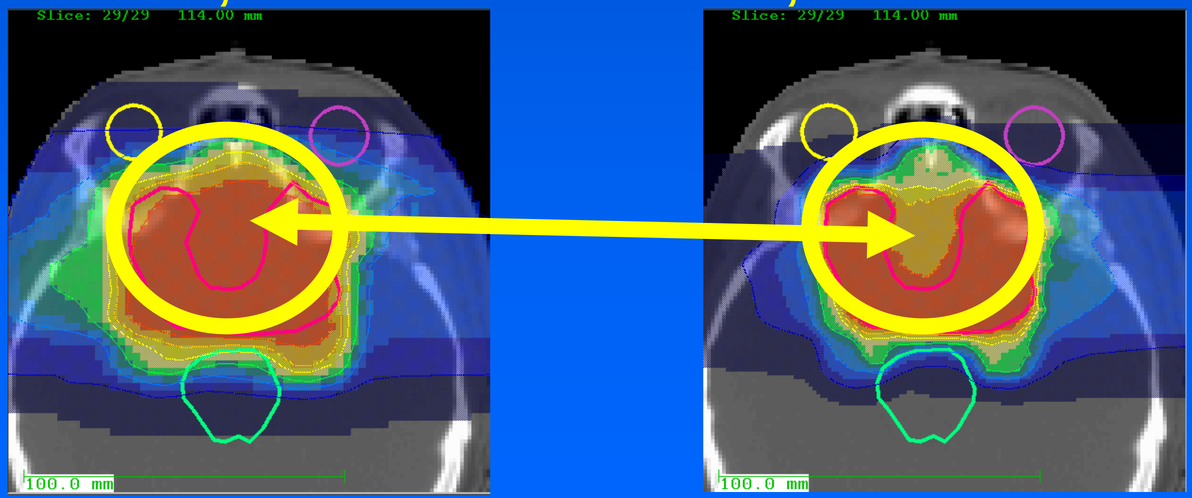
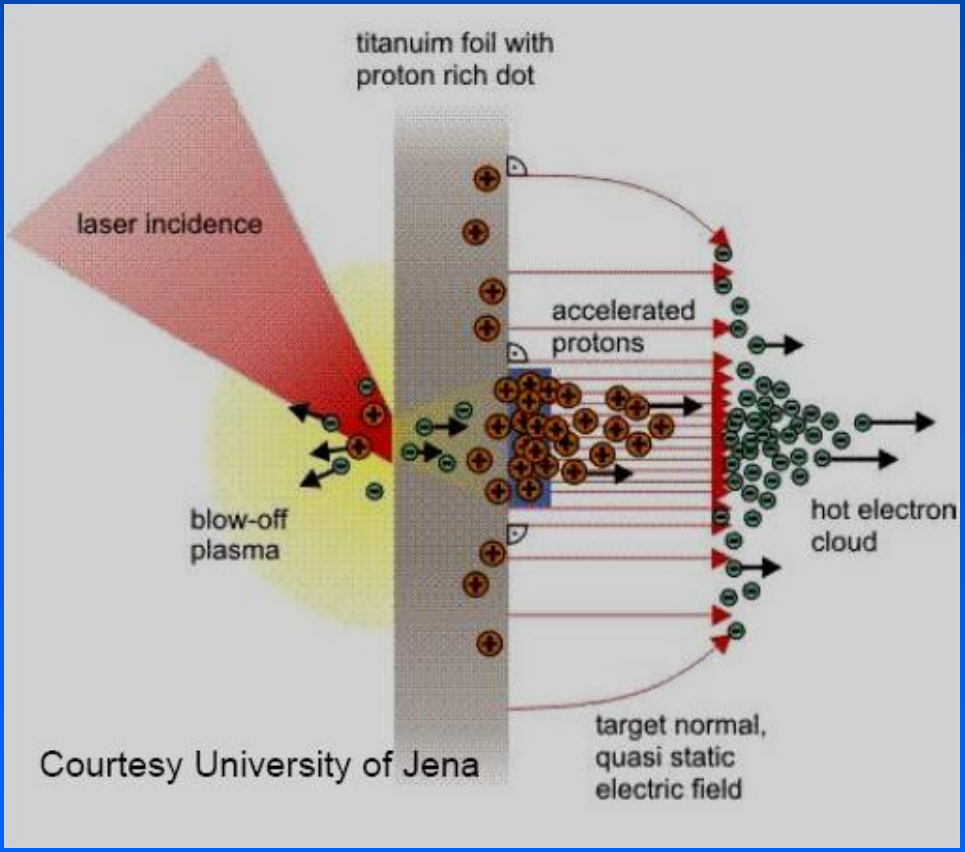


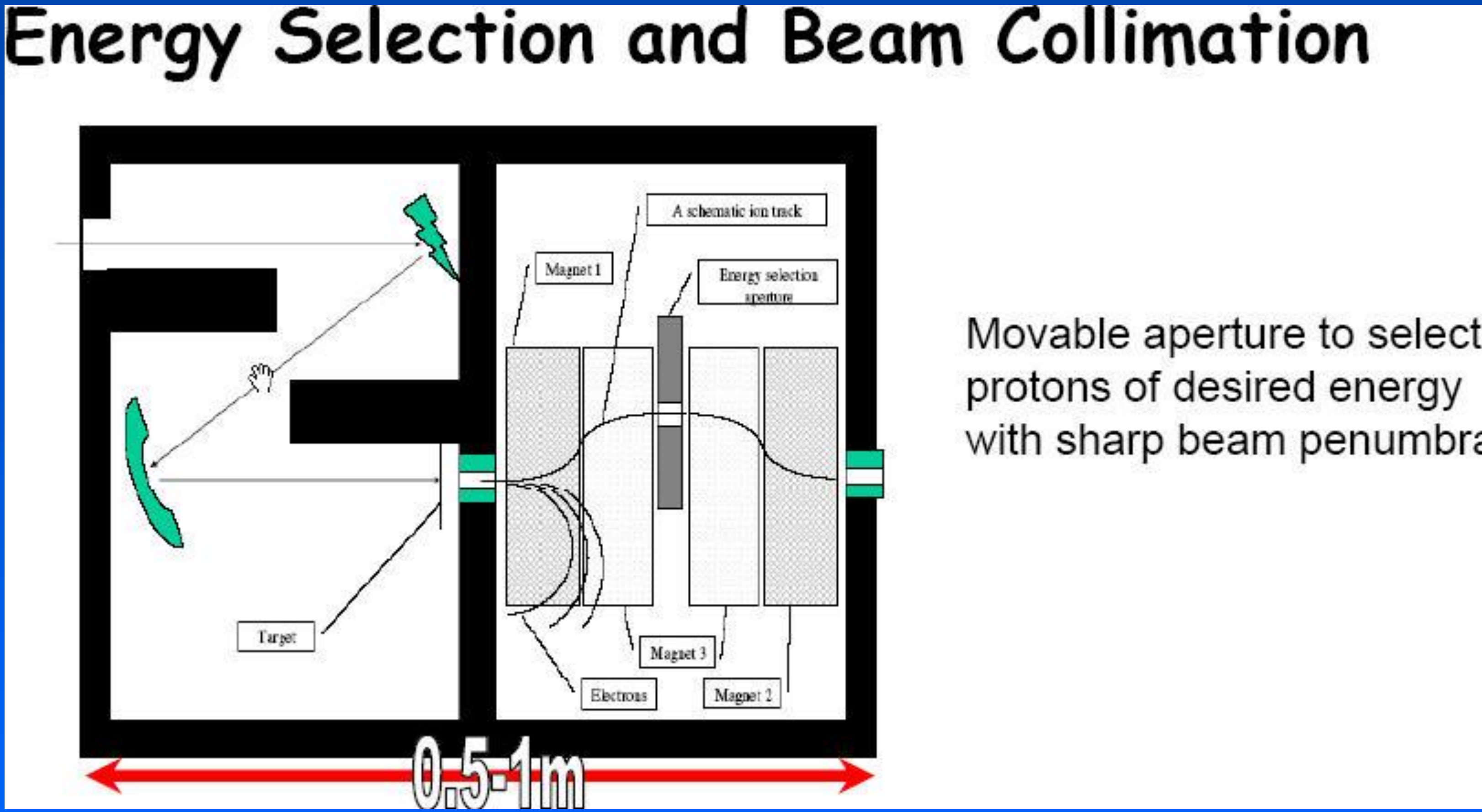
Laser Ion Acceleration



- **Laser: 50 fs, 50 J (Petawatt!)**
- **I = 10^{21} W/cm^2**
- **10^{11} protons up to 300 MeV should be possible (~ 80 MeV reached)**

Repetition rate?
Intensity control?
Radiation field?
Energy spectrum?
Dose delivery?

Laser Ion Acceleration

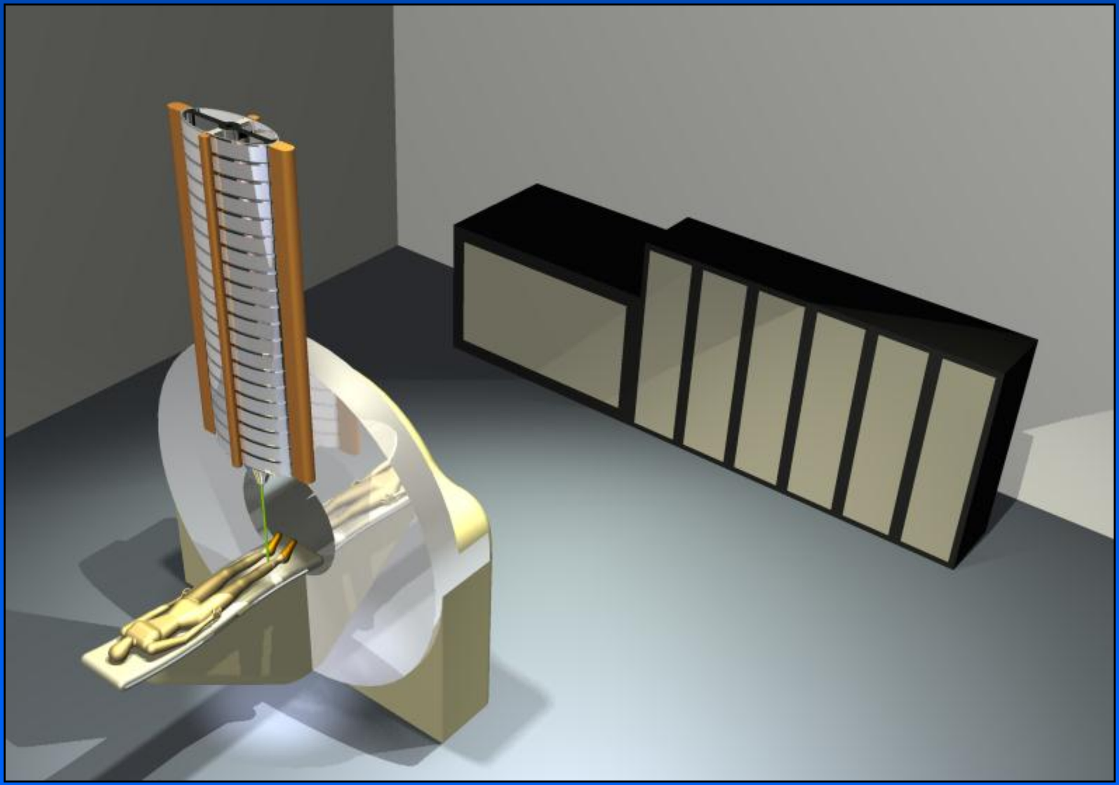


to be integrated in a rotational gantry

courtesy, E.E. Klein, New developments in proton therapy delivery systems

Dielectric Wall Accelerator

The DWA enables protons (ions) to be accelerated at gigantic field gradients. Wide-bandgap optical switches allow for the direct conversion of a light signal to rf.



Dimensions close to conventional photon-therapy systems can be imagined.

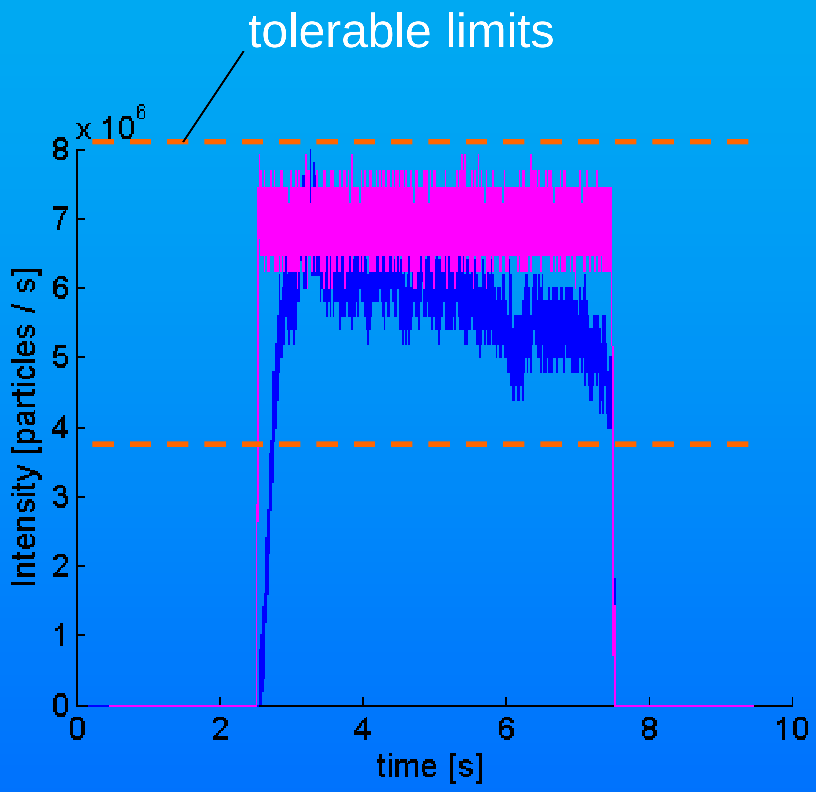
Patient Throughput Optimization in Existing Facilities

Our fictitious business plan asks for 1000 patients per year. This translates into 20000 fractions and 45000 fields per year. A reliable facility may be used clinically at 275 days and about 160 fields per day have to be delivered during a 14 hours period. Finally a single field needs to be delivered in about 5 minutes. (This is by far too optimistic.)

There is a strong need to minimize the dose delivery time!

The accelerator duty-cycle, intensity profile and the scanning beam dose delivery should be optimized.

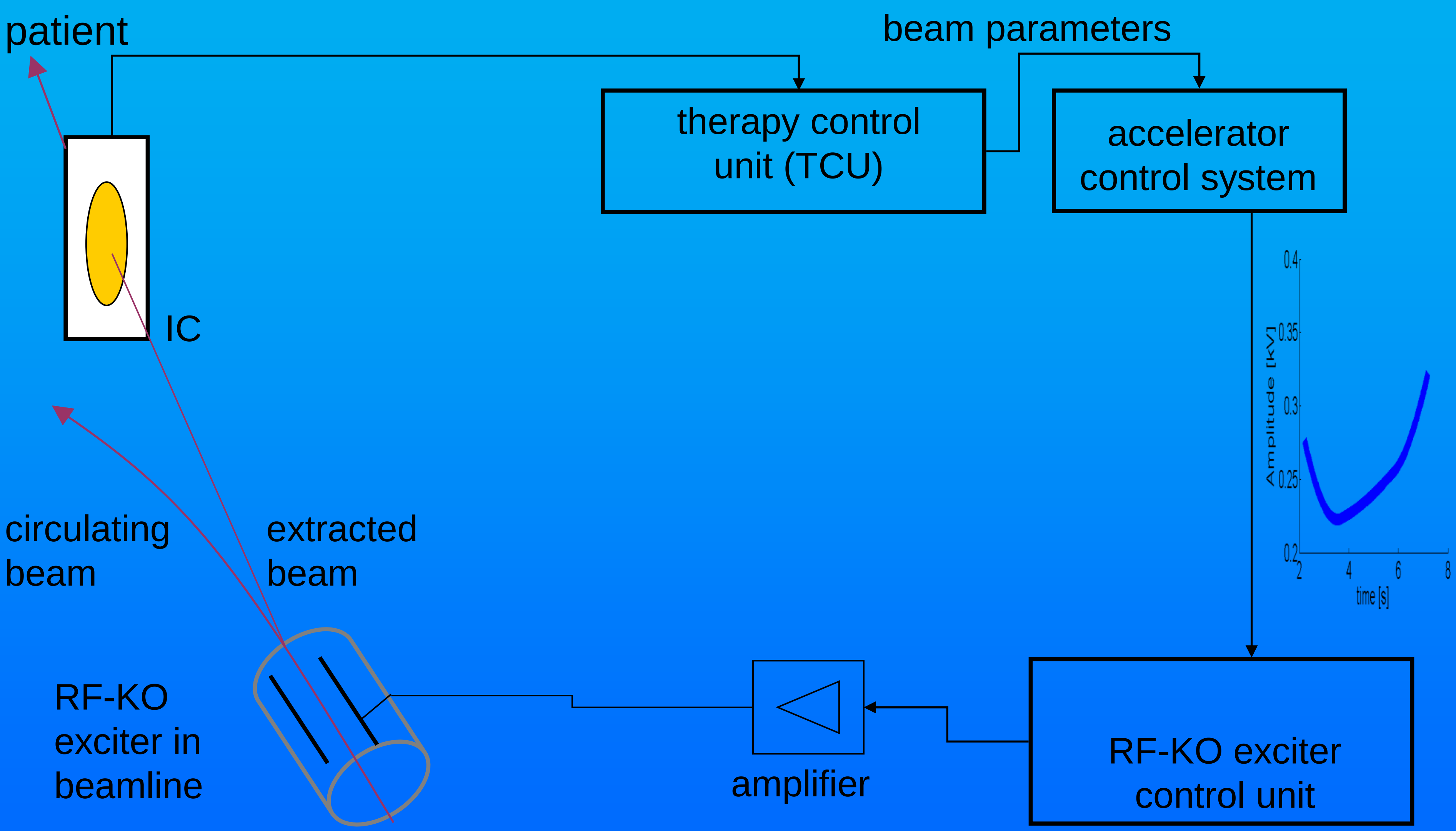
Potential of Synchrotron Spill Feedback



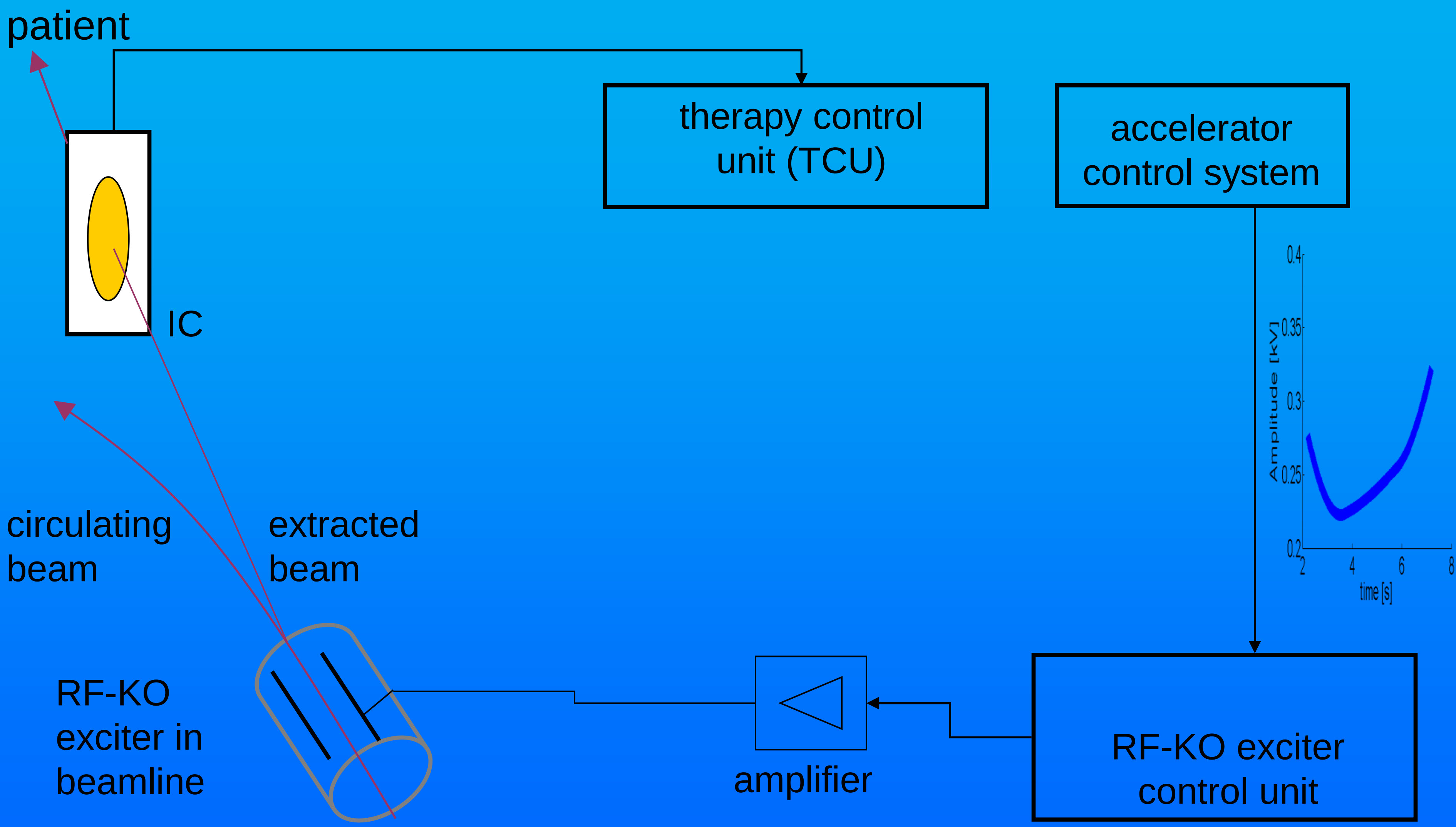
- beam-on time reduction up to 25% / 45%!
  - reduced patient stress
  - higher throughput
- higher acc operational stability
- dose delivery at increased precision (S/N – ratio)
- less interlocks

Christian Schömers, HIT Heidelberg, Poster session

Spill Feedback System Overview



Spill Feedback System Overview



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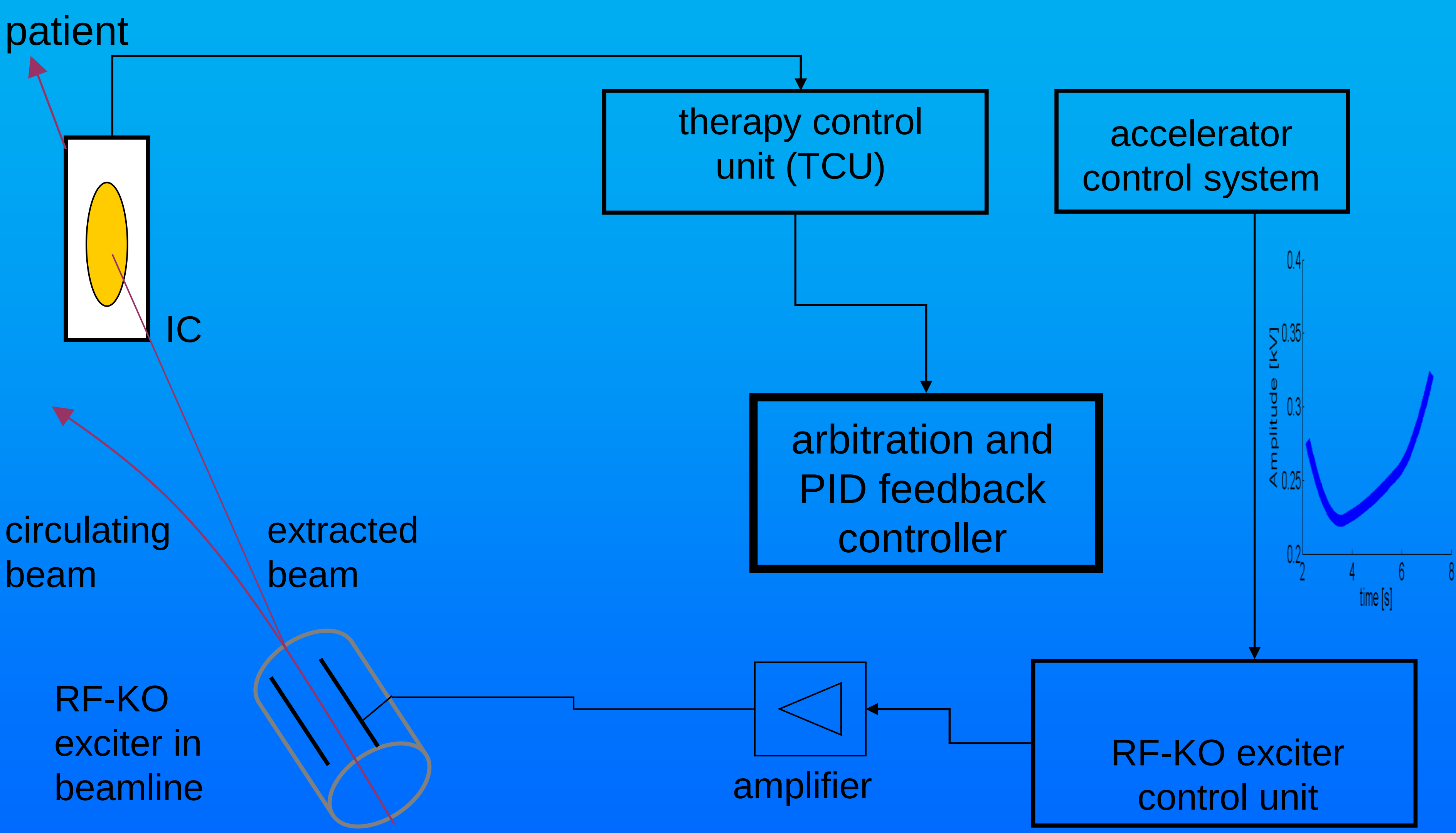

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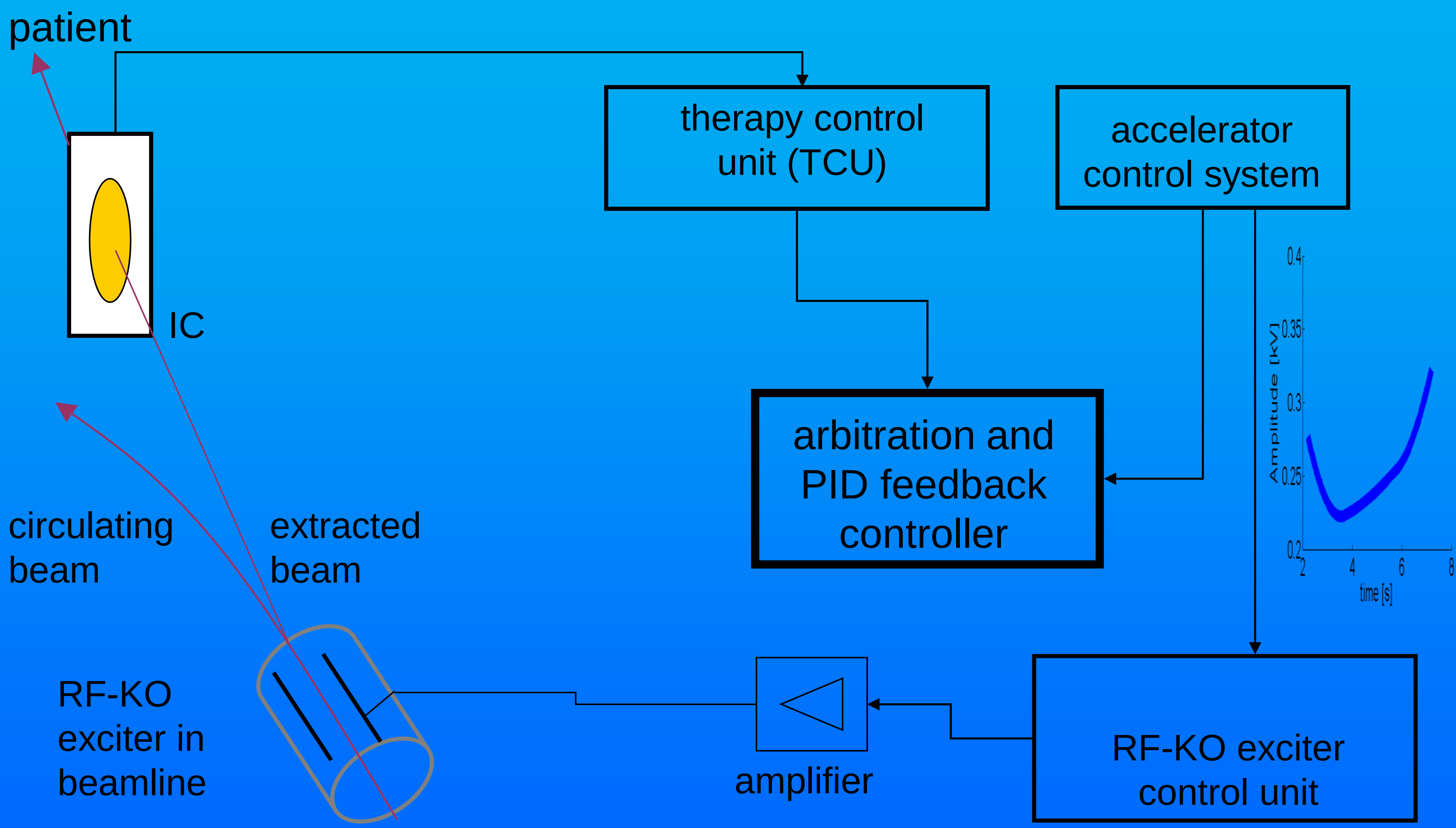

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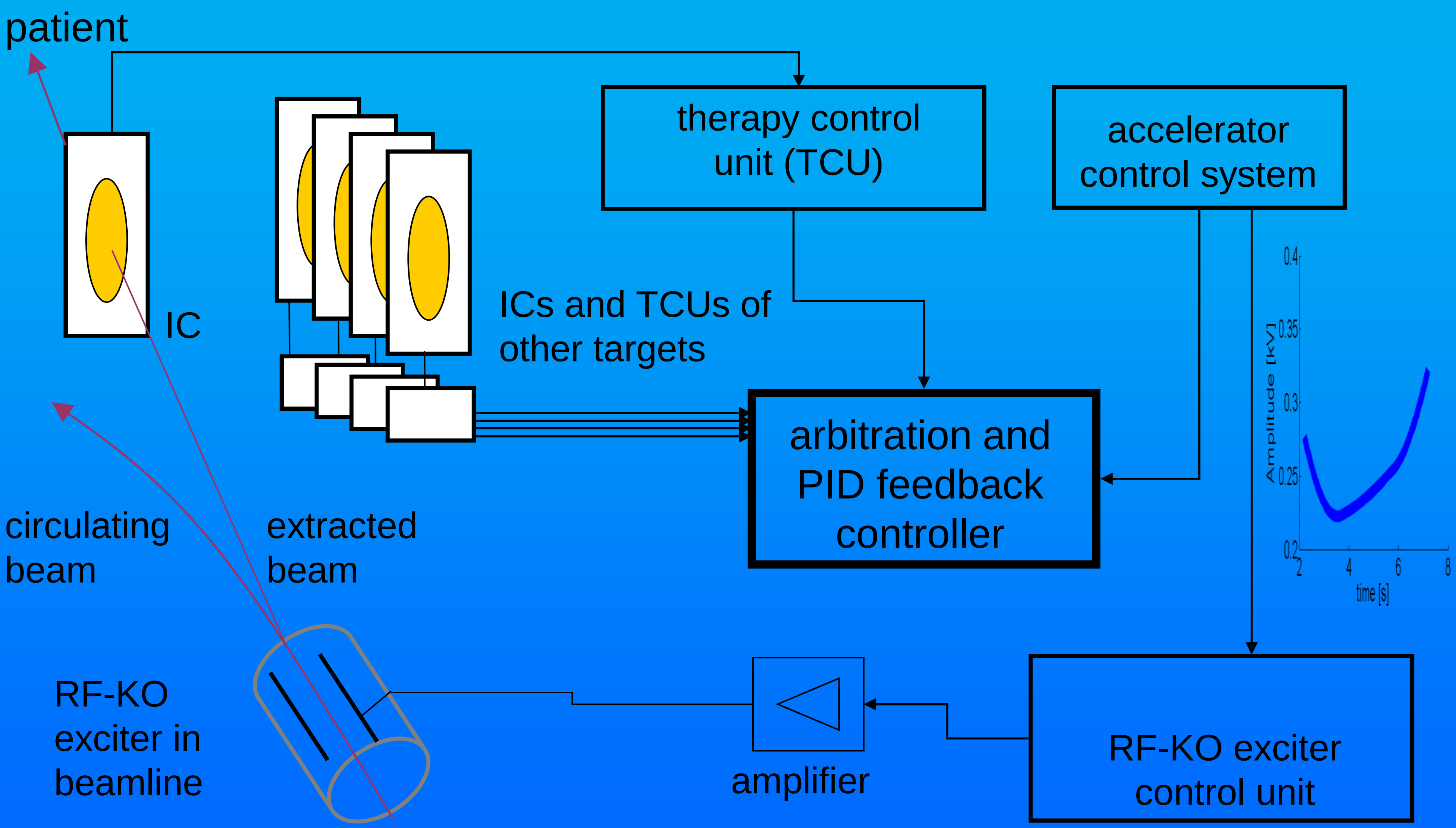

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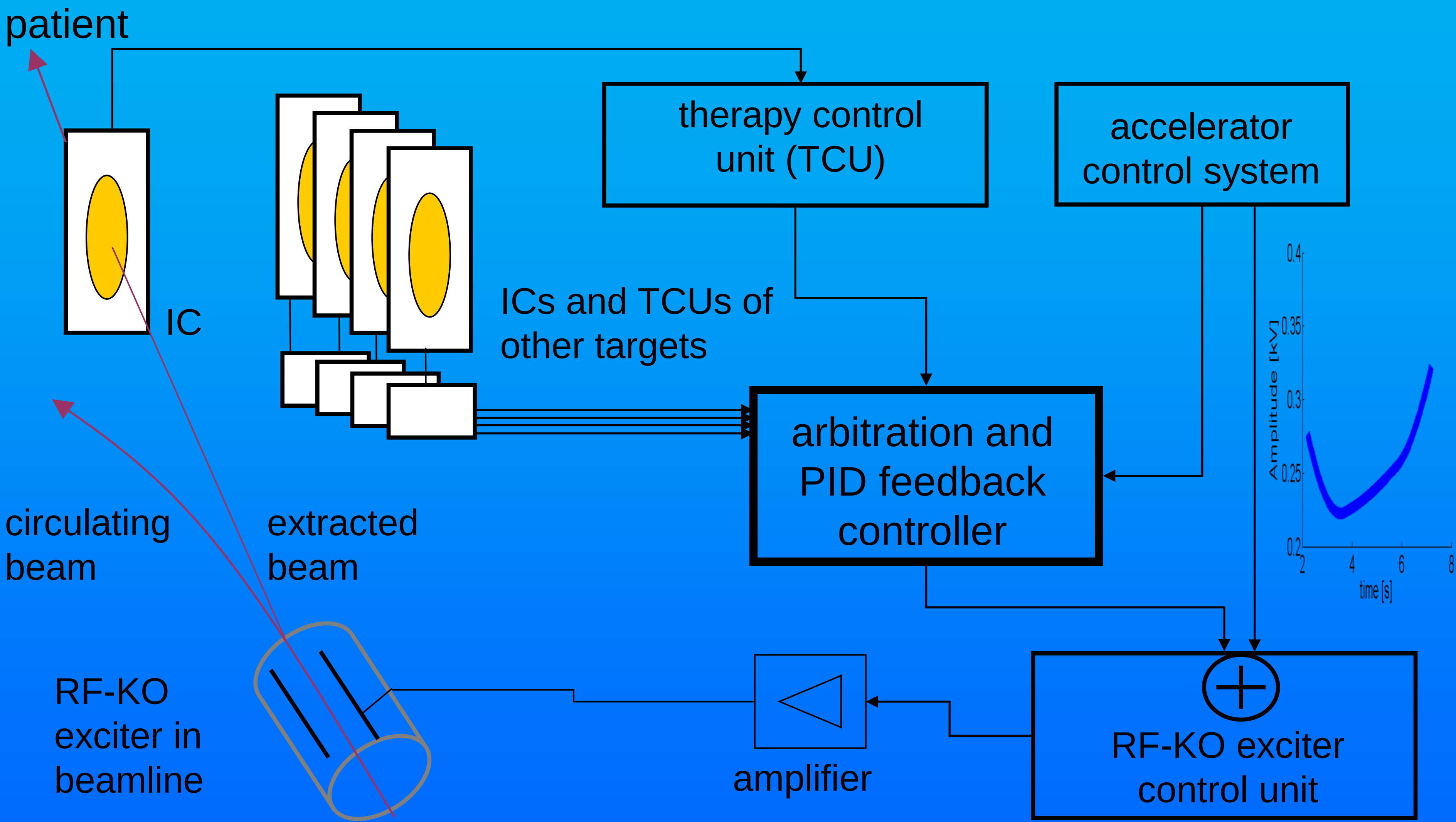

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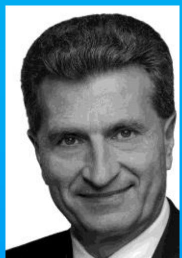
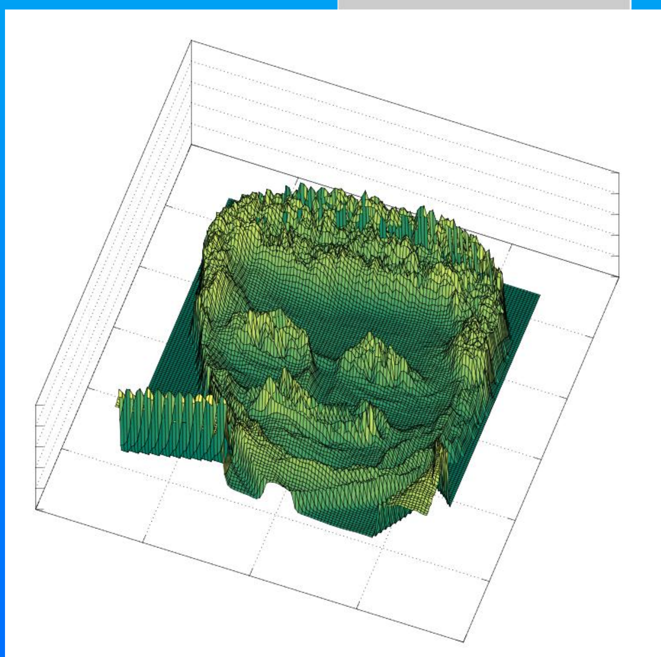
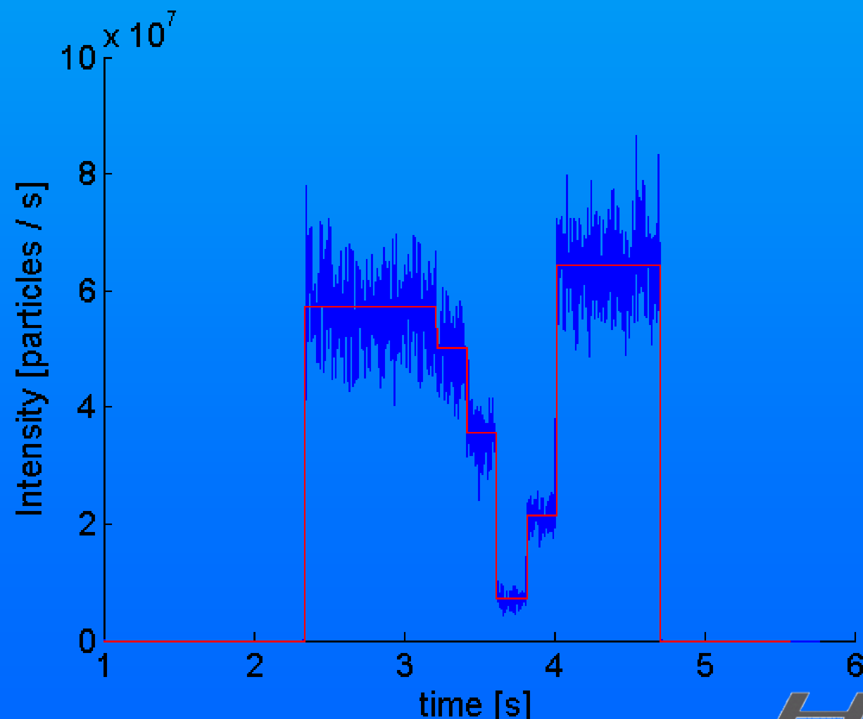
Treatment-plan-specific Feedback



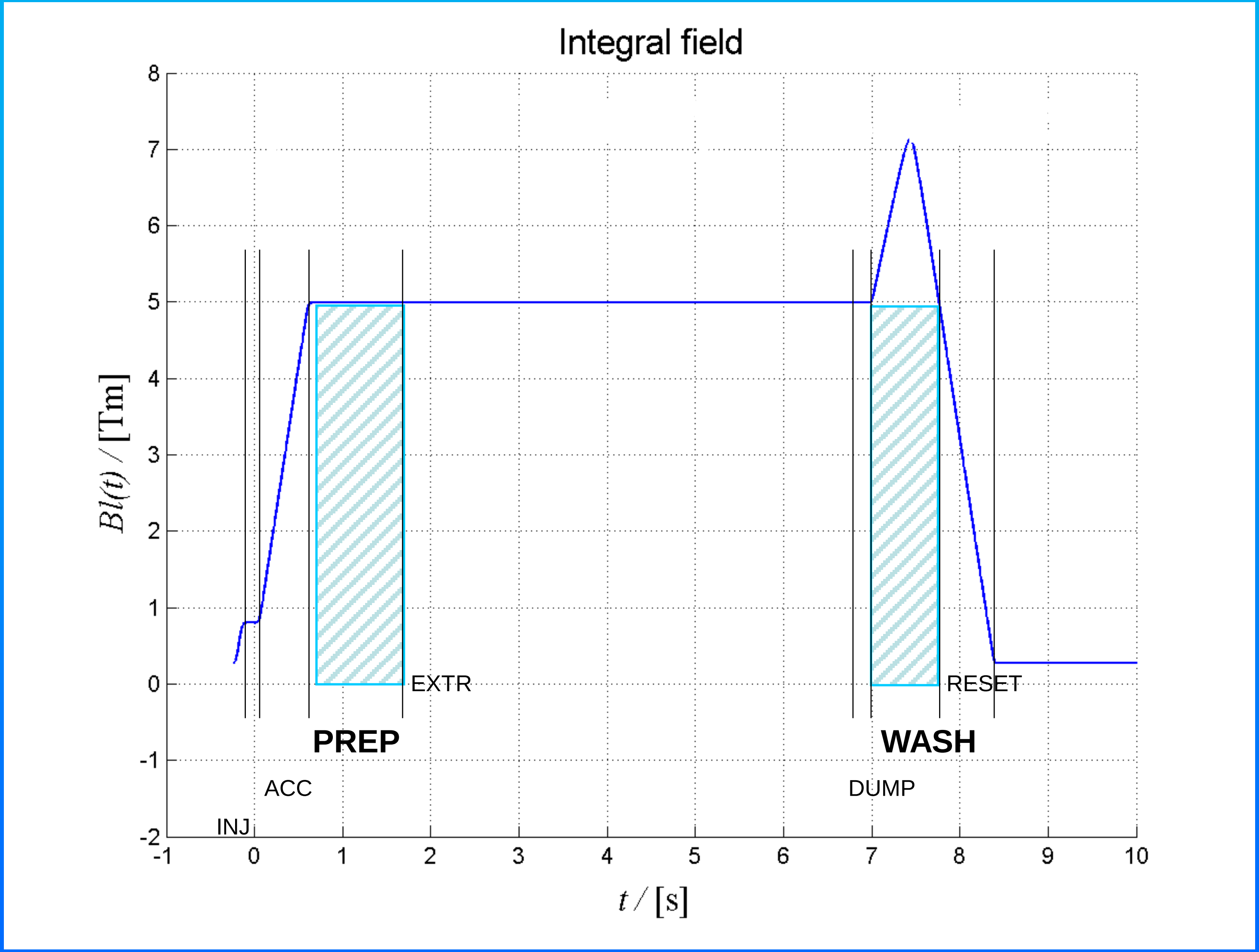


fluence map
range: 1 … 100

- 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!



Faster Irradiation via Feed-Back of Magnetic Fields



Eike Feldmeier, HIT Heidelberg, Poster session

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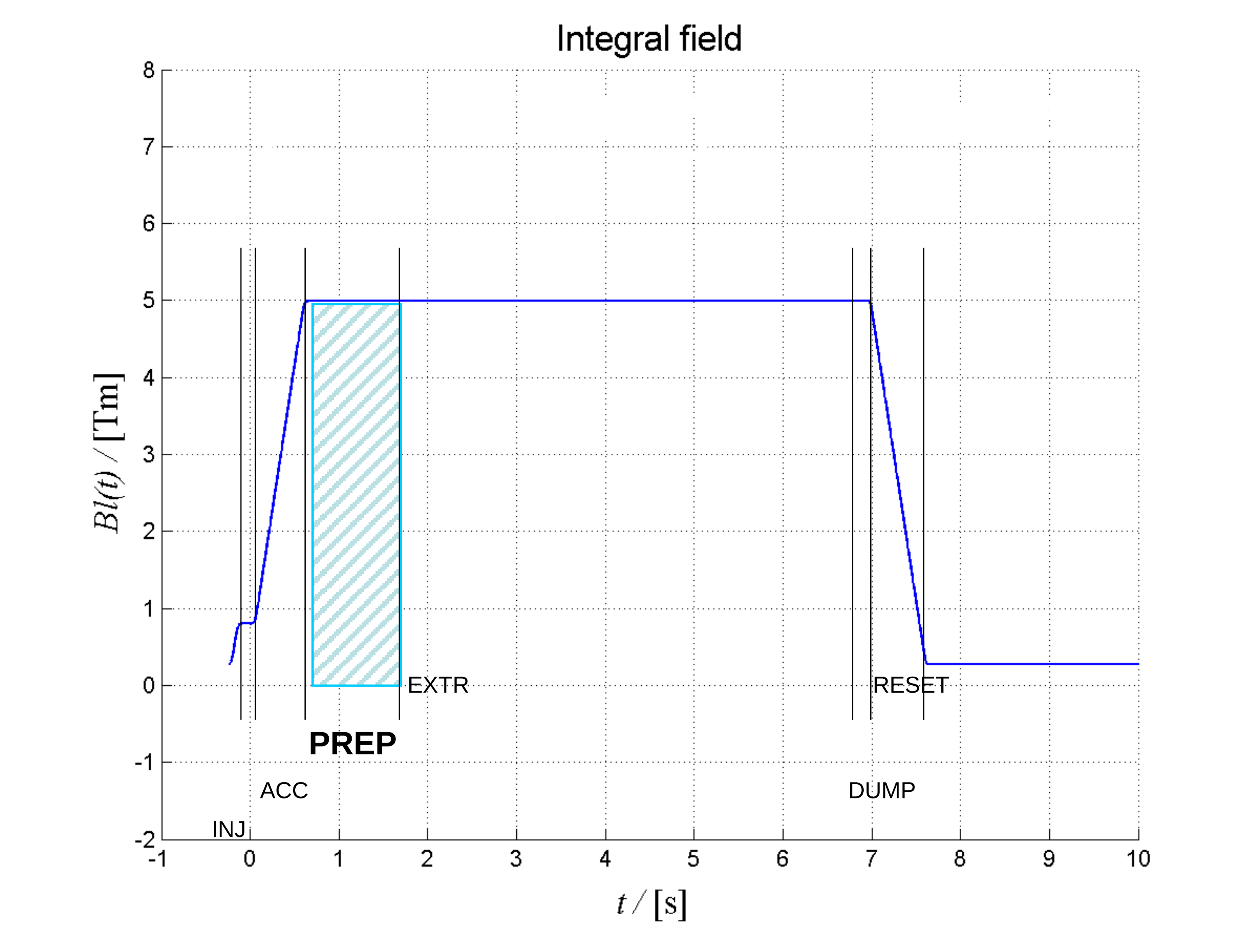

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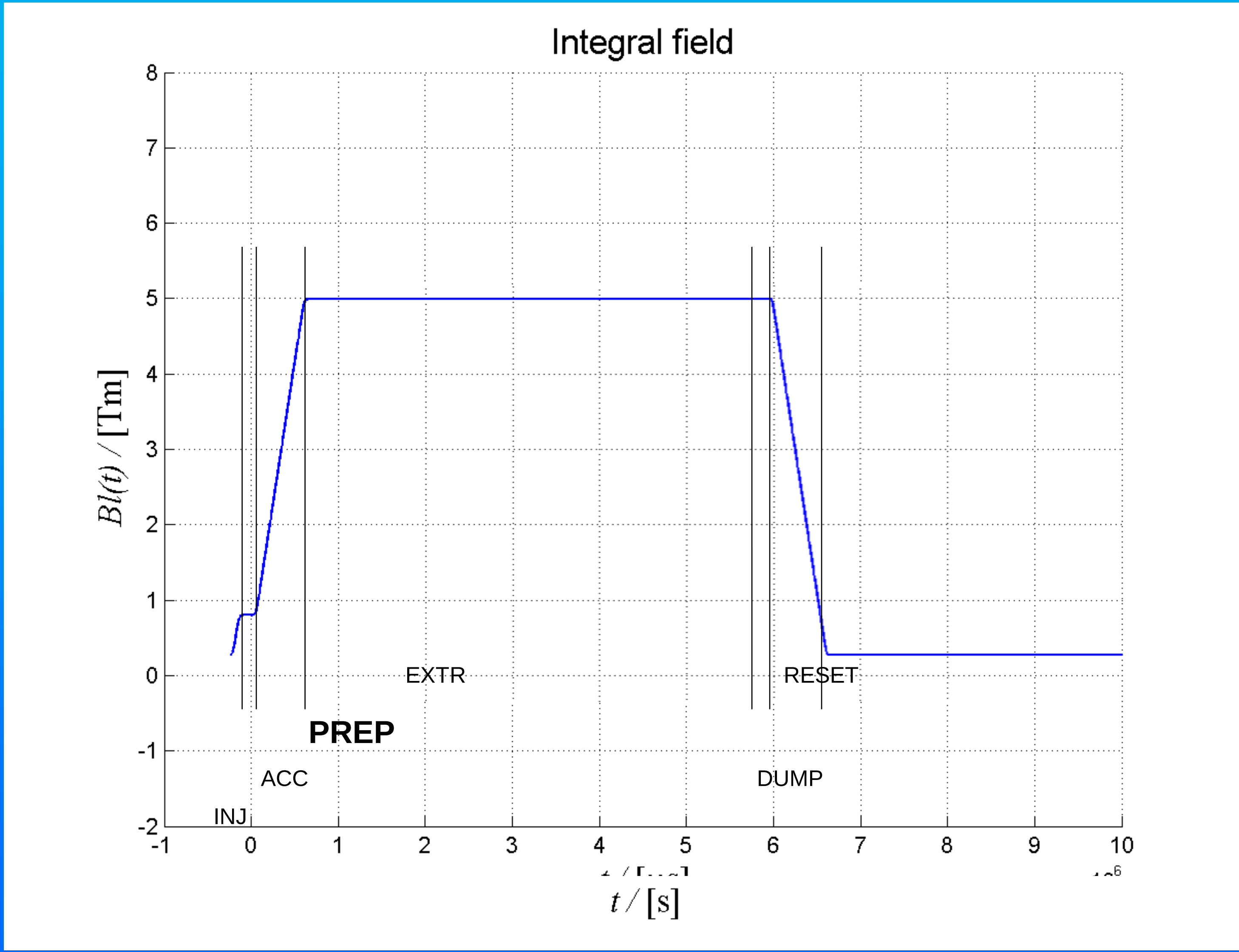

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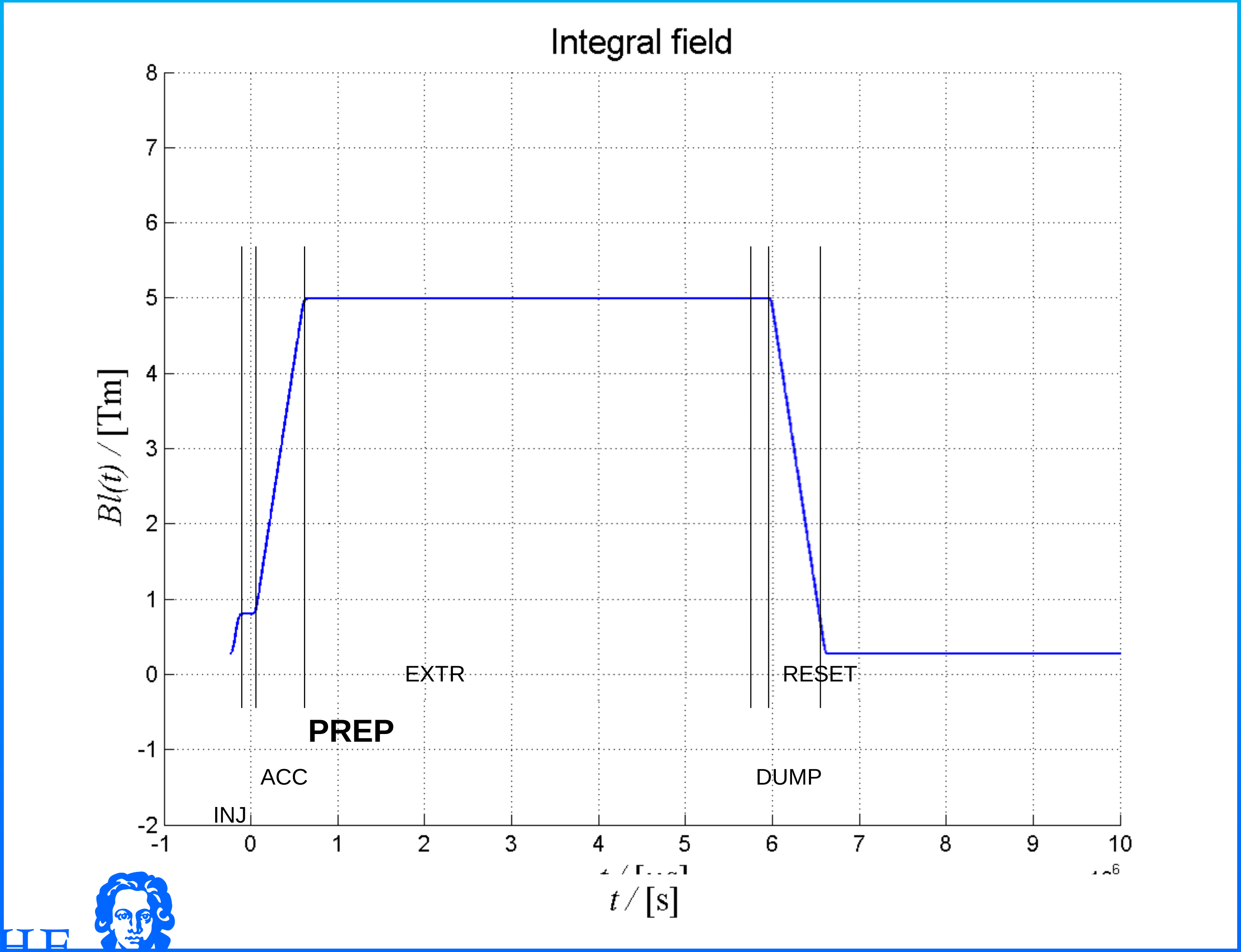

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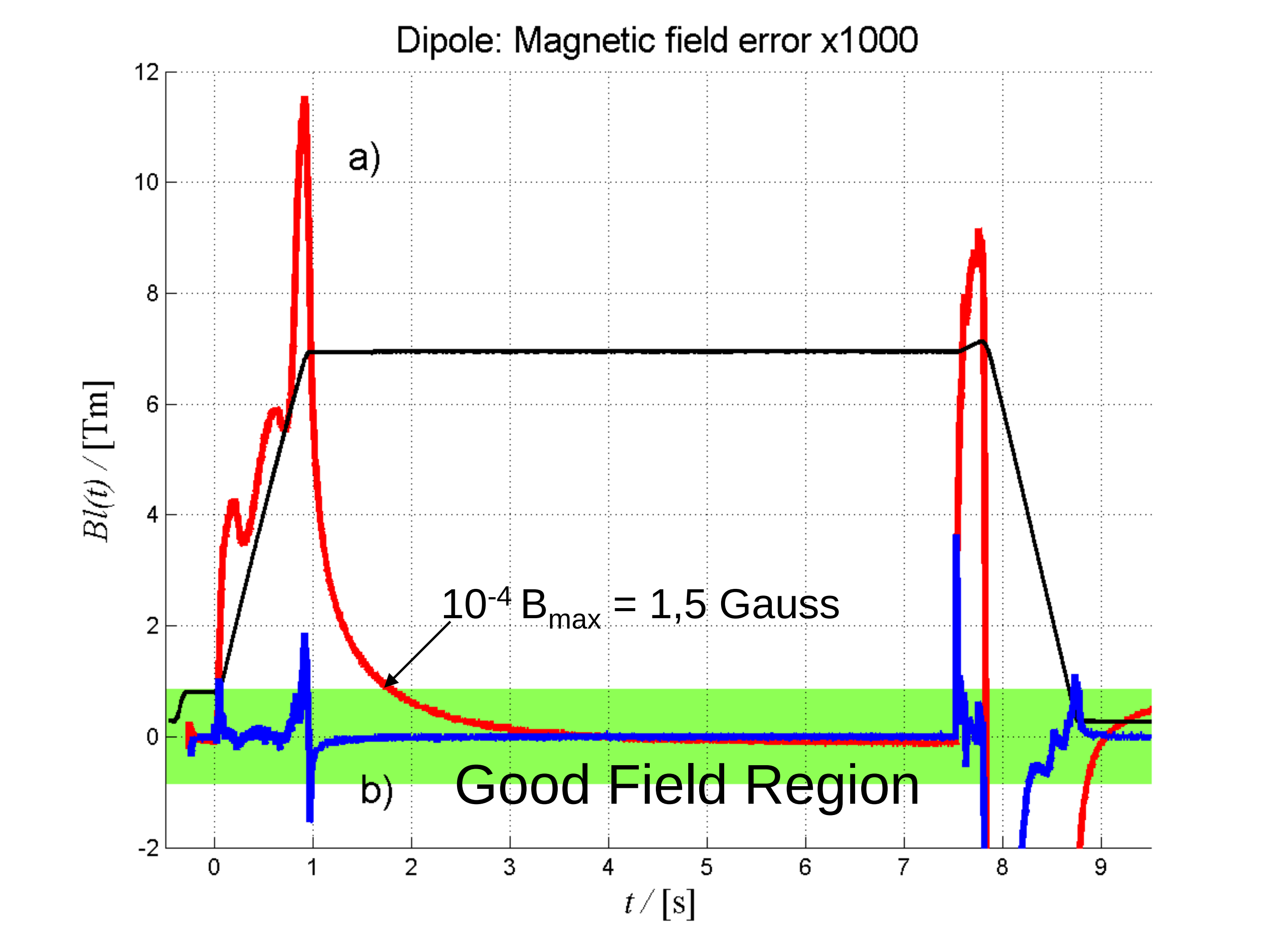
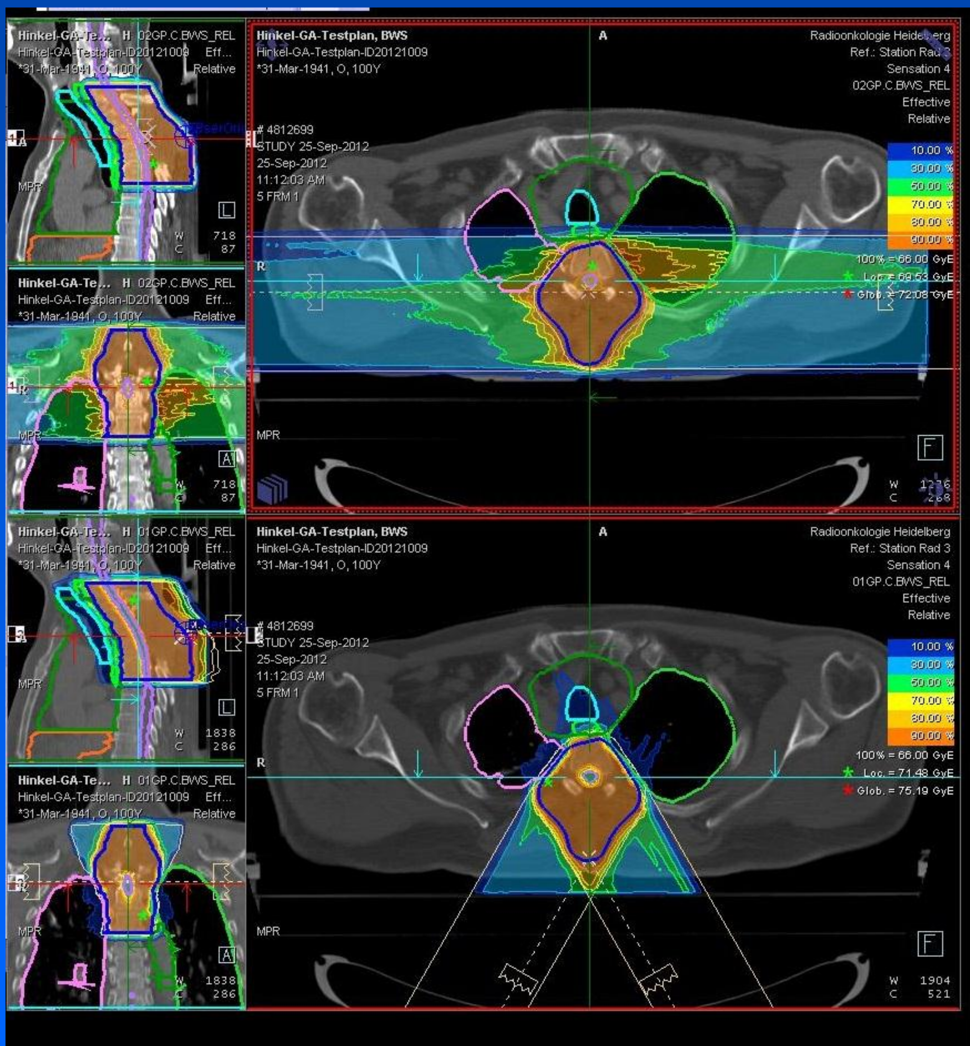


Gantries / Challenges

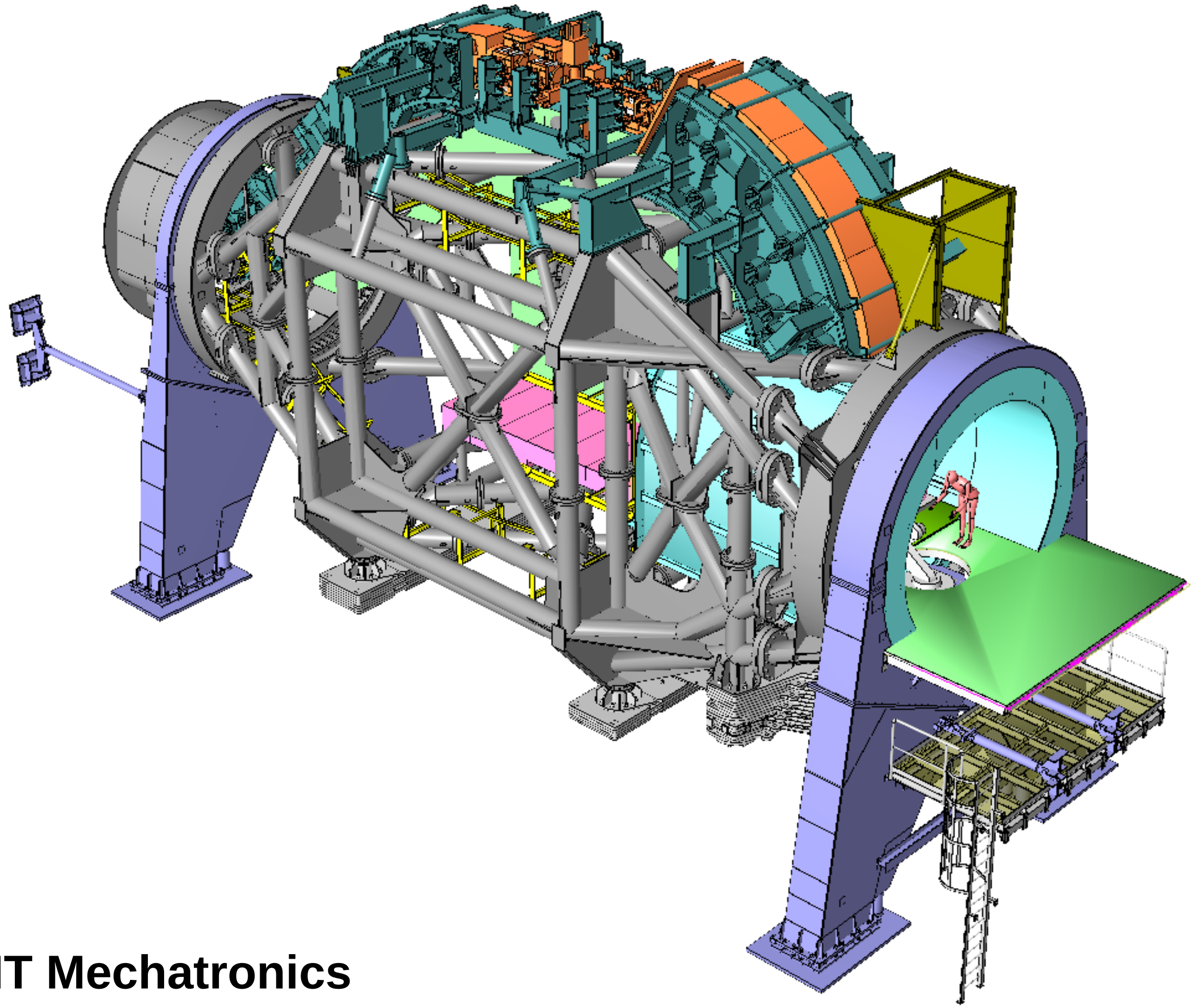


Fixbeam horizontal

with Gantry: relevant sparing of Normal tissue

Design for HIT

- isocentric barrel-type
- world-wide first
  ion gantry
- 2D beam scanning upstream to final bending, almost parallel due to edge focussing
- ± 180^o rotation
  3^o / second
- 13m diameter
  25m length
  600 to rotating
  (145 to magnets)



MT Mechatronics

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Patient Environment / Nozzle

Patient Gantry Room November 2007

Tilt floor, pending on Gantry position

Nozzle

Bumber mats

Patienttable, Roboter

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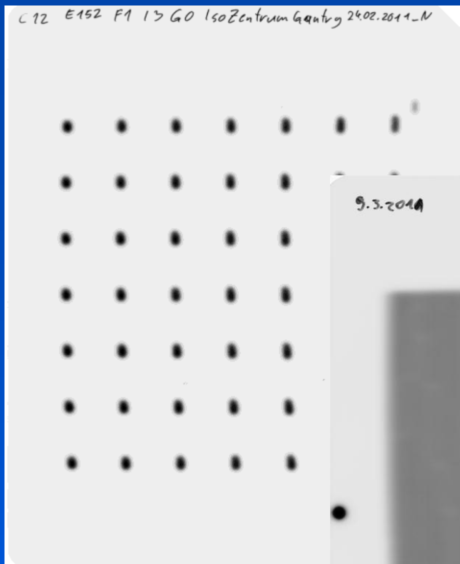
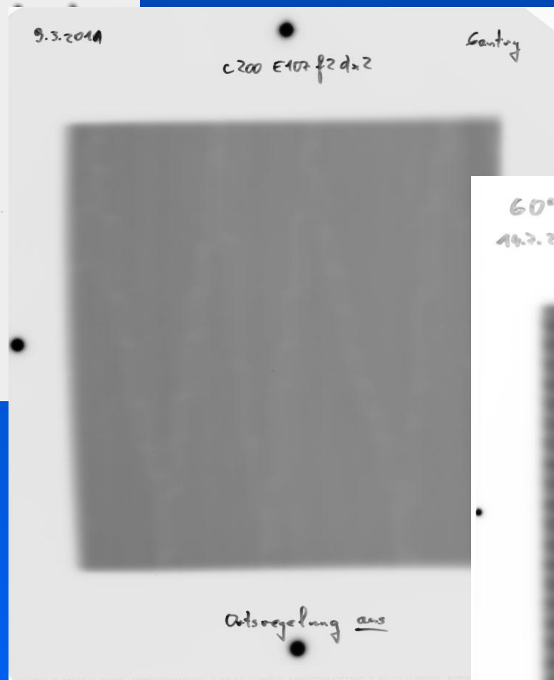
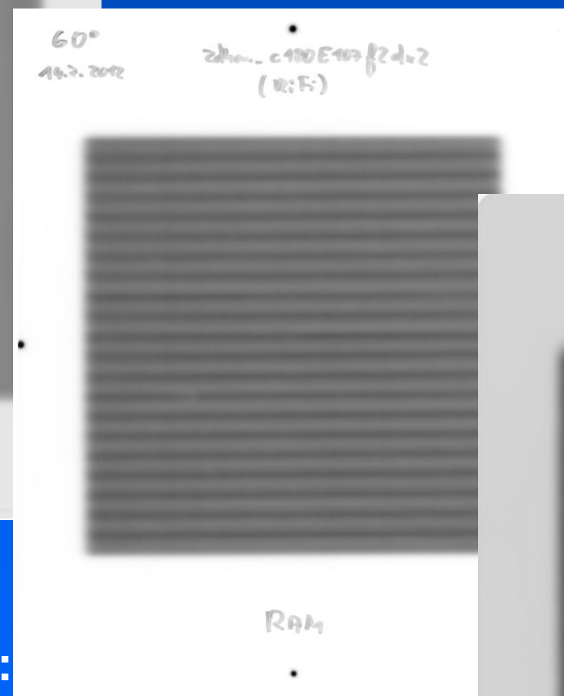
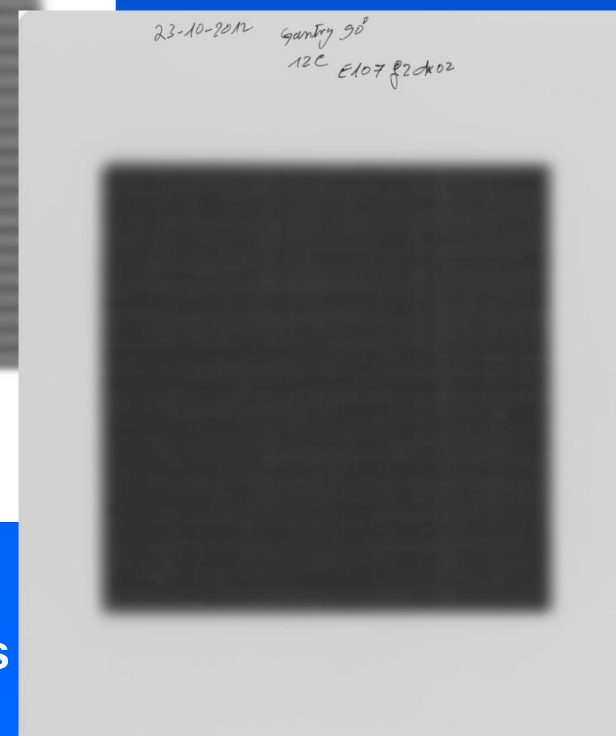
Some challenges …









February 2011 until October 2012:

(i) Beam spot varies with position

(ii) beam position varies

(iii) beam spot too small at the patient monitors

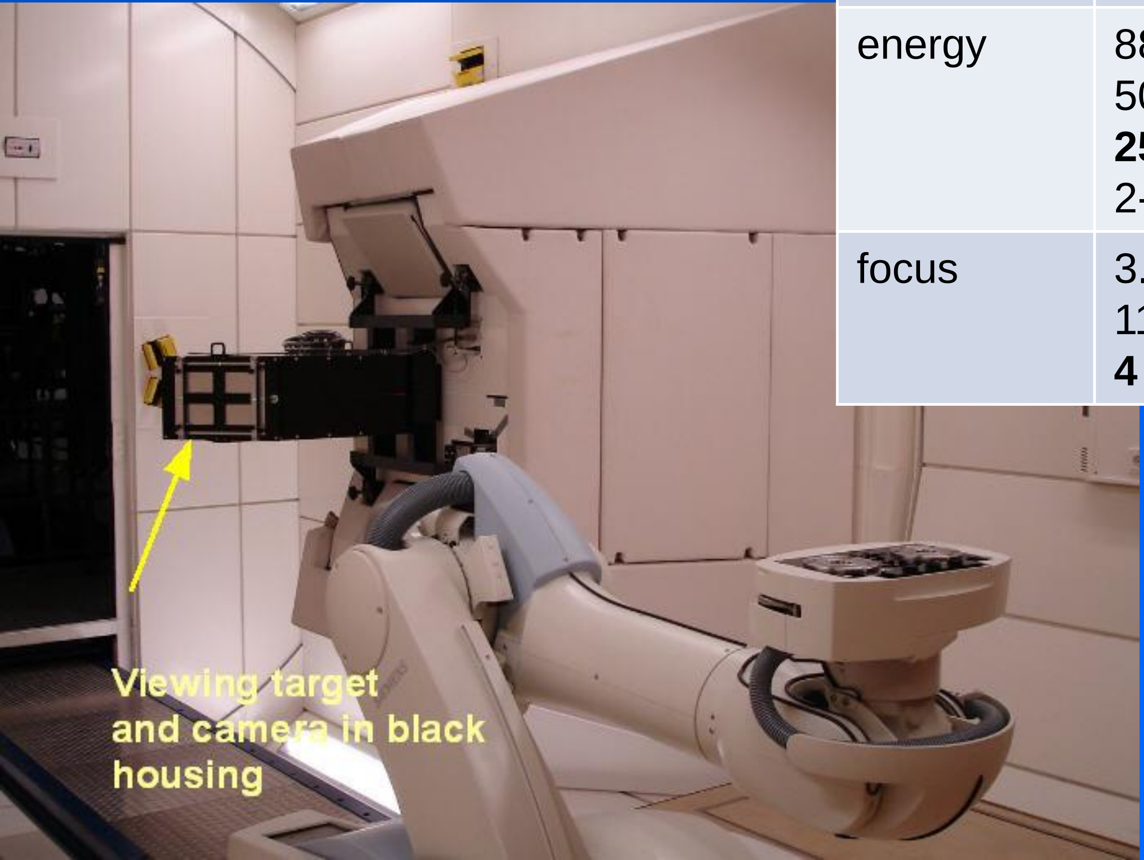
(iv) therapy quality level (~3%) achieved

Countless nights…

... lots of optics

See poster: M. Galonska, HIT

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**



2 x 10 x 255 x 4 = 20400
combinations per vault!!!
Gantry-angles at 0.1°-steps

=> 73.440.000

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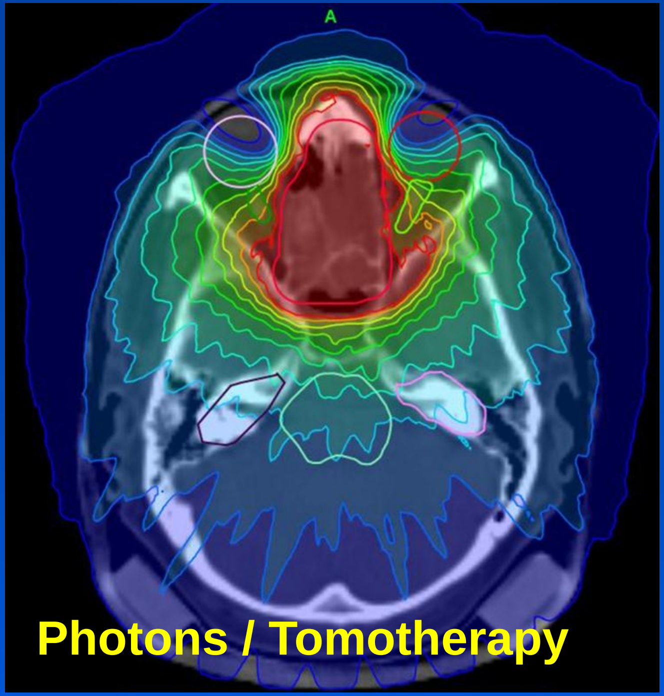
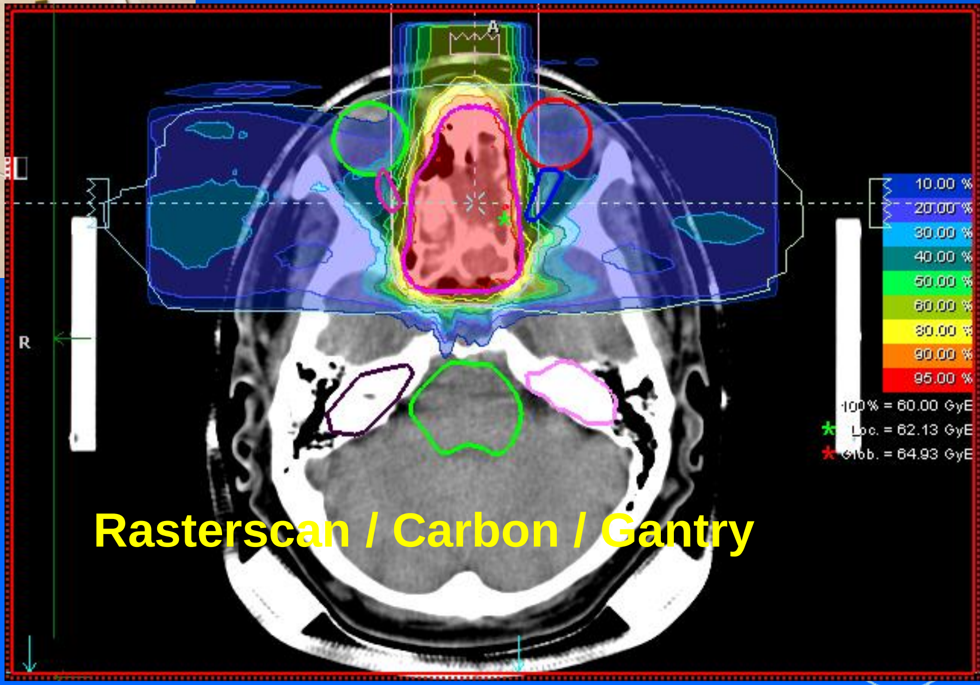
1st treatment at the HIT‘s wolrd-wide only scanning ion gantry



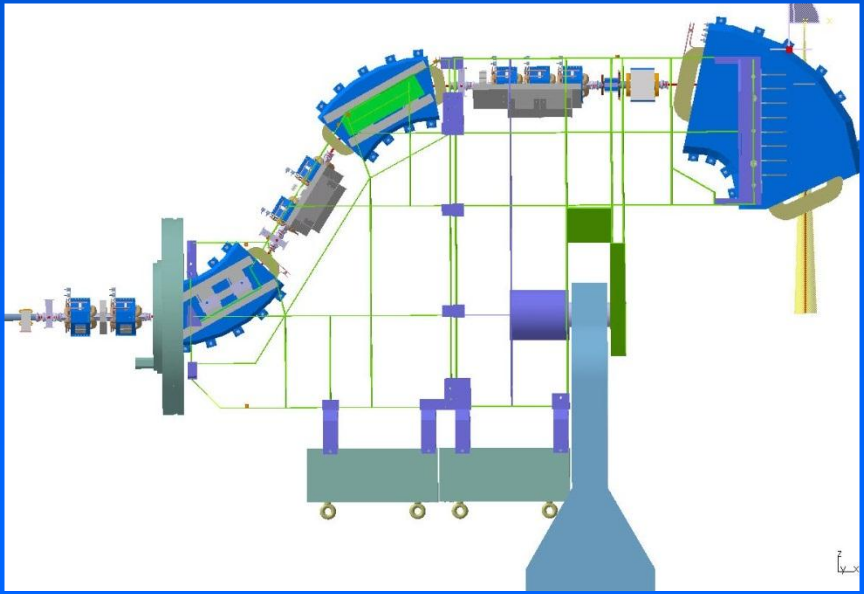


October 19th, 2012
oligo-astrocytoma

The new PSI Gantry 2

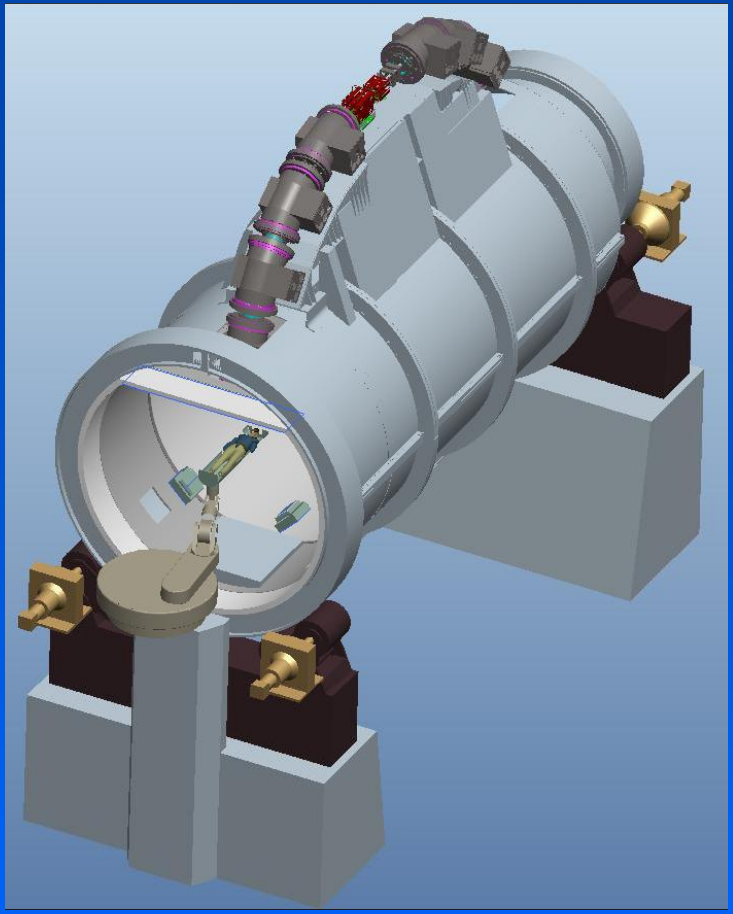
- A <u>tool for developing</u> advanced beam scanning techniques
  - Iso-centric layout
  - Double magnetic scanning (double-parallel)
  - Dynamic beam energy variations with the beam line

- New characteristic
  - The new PSI gantry rotates only on <u>one side</u> by -30° to 185°
  - Flexibility of beam delivery achieved by rotating the patient table in the horizontal plane

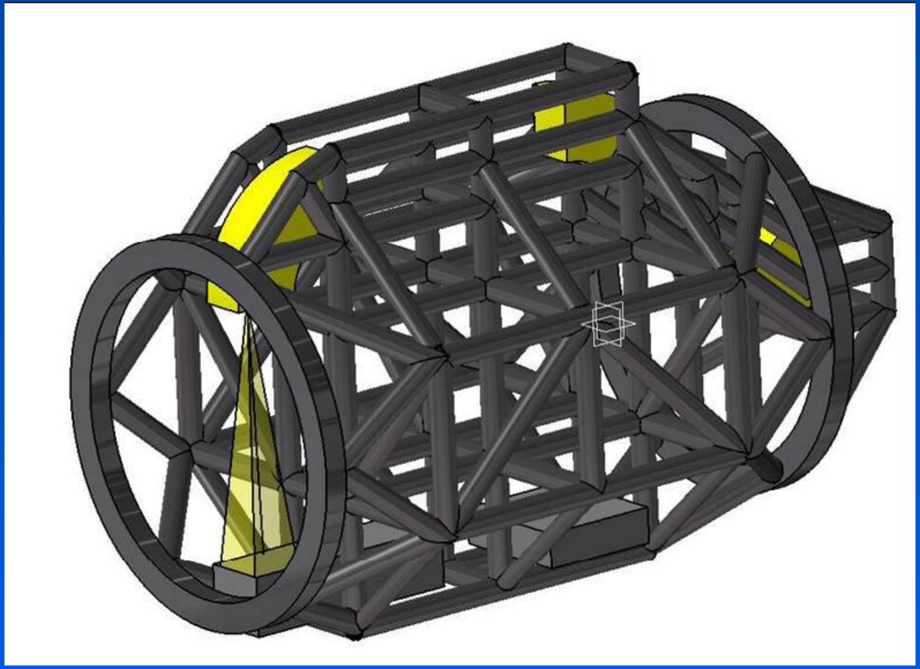


Courtesy E. Pedroni, D. Meer, S. Zenklusen

Design of Superconducting Gantries



NIRS / HIMAC (J): 200 to, Radius: 5.5 m, L: 13m, 3 T



CEA (F) and IBA (B)): 210 to, Radius: 4m, Length: 13m, B_{max}(90°-Dipole): 5.39 T (NbTi)

Use of cryocoolers foreseen → Long recovery time in case of quenches!

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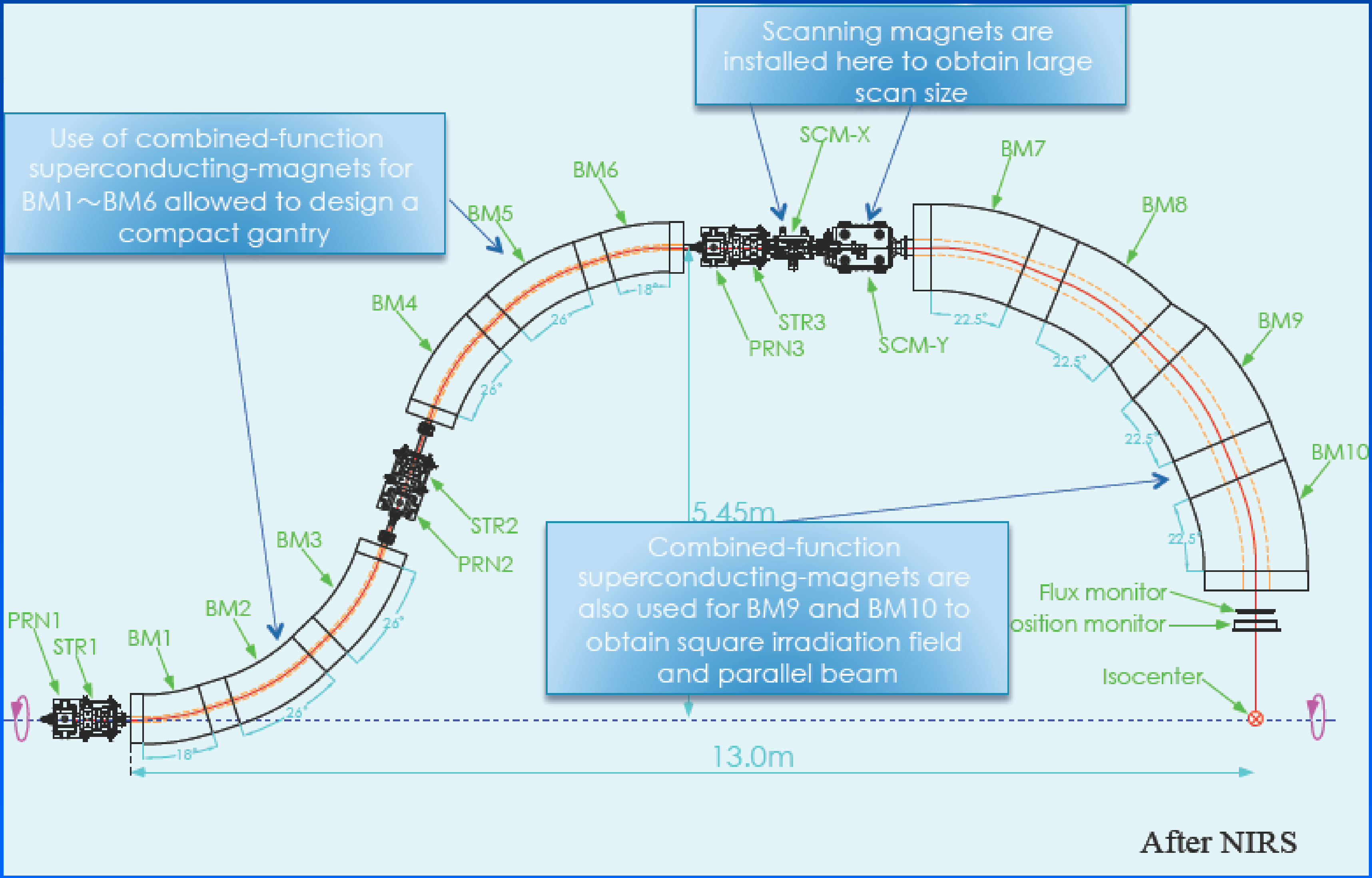
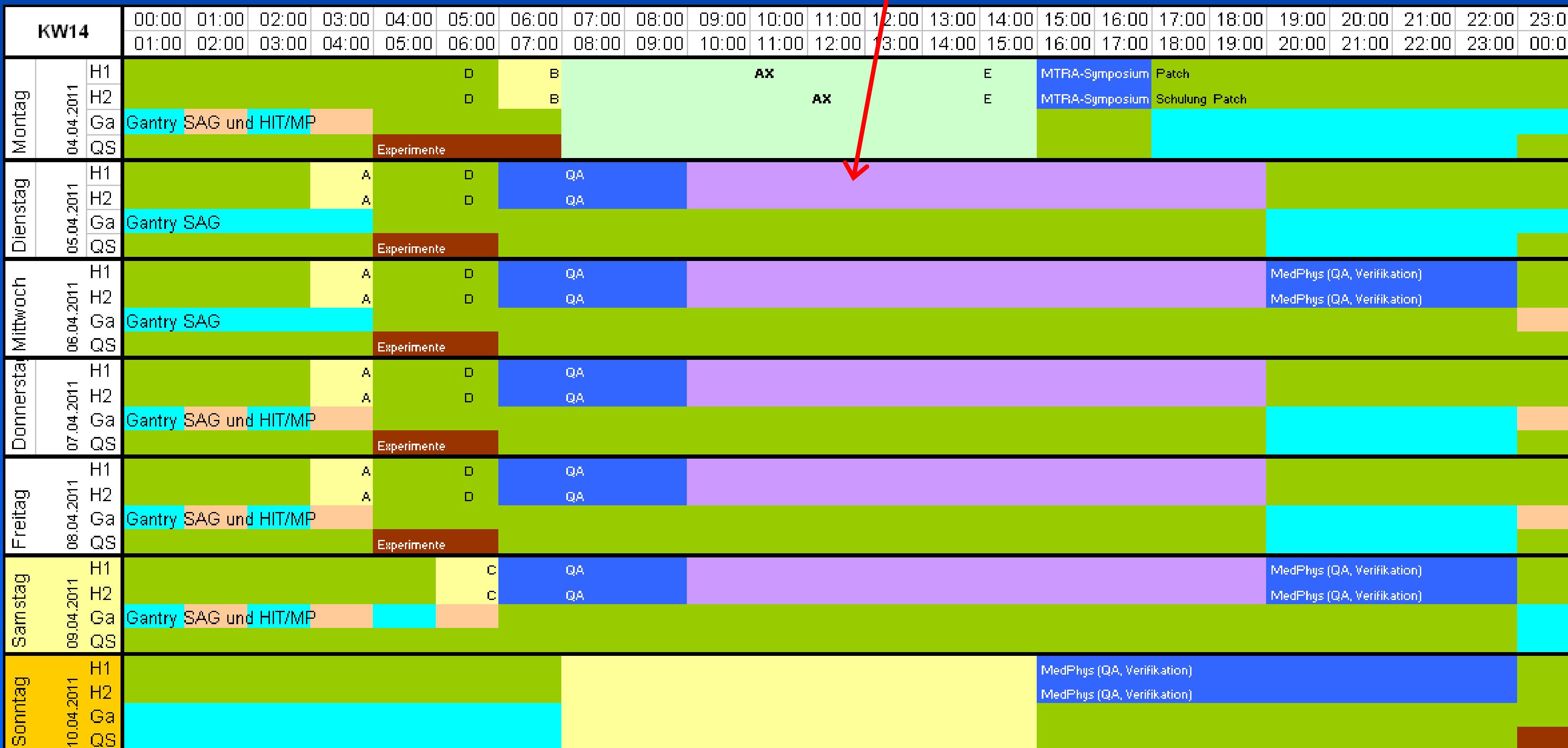
NIRS Version of a s.c. Gantry



Weekly Beam Time Schedule

Patient treatment 5-6 days a week



- **06:00 – 08:00:** Daily QA
- **08:00 – 19:00:** Patient treatment
- **19:00 – 06:00:** Treatment plan verification, Gantry dev., experiments, accelerator QA

Clinical Trials @ HIT

1 **Not yet recruiting** [Treatment of Malignant Sinonasal Tumours With Intensity-modulated Radiotherapy (IMRT) and Carbon Ion Boost (C12)]
Conditions: Sinonasal Malignancies:; Adenocarcinoma and Squamous Cell Carcinoma of the Paranasal Sinuses
Intervention: Radiation: carbon ion boost

2 **Recruiting** [TPF Followed by Cetuximab and IMRT Plus Carbon Ion Boost for Locally Advanced Head and Neck Tumors]
Condition: Locally Advanced Squamous Cell Carcinoma of the Head and Neck (SCCHN): Oro-, Hypopharyngeal and Laryngeal Cancer
Intervention: Radiation: carbon ion boost

3 **Recruiting** [Trial of Proton Versus Carbon Ion Radiation Therapy in Patients With Low and Inter-mediate Grade Chondrosarcoma of the Skull Base]
Condition: Chondrosarcoma
Interventions: Radiation: carbon ion therapy; Radiation: proton therapy

4 **Recruiting** [Trial of Proton Versus Carbon Ion Radiation Therapy in Patients With Chordoma of the Skull Base]
Conditions: Chordoma; Tumor; Treatment
Interventions: Radiation: Carbon ion; Radiation: Protons

5 **Recruiting** [CO(Mbined Therapy of Malignant) S(Alivary Gland tu)M(Ours With)I(MRT and) c(Arbon Ions): COSMIC]
Conditions: Malignancy; Salivary Glands; Tumor
Intervention: Radiation: carbon ion boost

6 **Not yet recruiting** [Carbon Ion Radiotherapy for Atypical Meningiomas]
Condition: Meningioma
Intervention: Radiation: Carbon Ion Radiotherapy

7 **Not yet recruiting** [Carbon Ion Radiotherapy for Recurrent Gliomas]
Condition: Glioma
Interventions: Radiation: Carbon Ion Radiotherapy; Radiation: Fractionated Stereotactic Radiotherapy (FSRT)

8 **Recruiting** [Carbon Ion Radiotherapy for Primary Glioblastoma]
Condition: Primary Glioblastoma
Interventions: Radiation: Carbon Ion Radiotherapy; Radiation: Proton Radiotherapy

9 **Not yet recruiting** [Adenoid Cystic Carcinoma, Erbitux, and Particle Therapy]
Condition: Adenoid Cystic Carcinoma
Intervention: Drug: cetuximab weekly

10 **Not yet recruiting** [Carbon Ion Radiotherapy for Hepatocellular Carcinoma]
Condition: Hepatocellular Carcinoma
Intervention: Radiation: Carbon Ion Radiotherapy

ClinicalTrials.gov
A service of the U.S. National Institutes of Health

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

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