OncoRay – National Center for
Radiation Research in Oncology, Dresden

Translational Medical Physics Research at OncoRay

Christian Richter
Head of Medical Radiation Physics

Dresden, August 20 2025

OncoRay National Center for Radiation Research in Oncology Dresden
Technische Universität Dresden
HZDR Helmholtz Zentrum Dresden Rossendorf
Universitätsklinikum Carl Gustav Carus
Georgian-German ScienceBRIDGE
CONNECTING PEOPLE AND KNOWLEDGE

2024 in Kutaisi: 20 years of GGSB

Overview

1. OncoRay
2. Dresden proton therapy facility
3. Medical physics research

OncoRay – was ist das?

- **Founded in 2005**
- **3 host institutions**

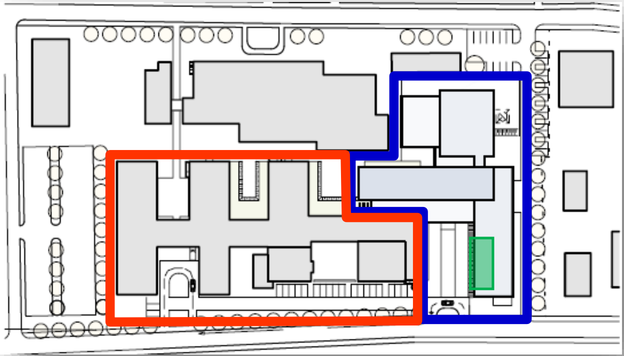
Universitätsklinikum Carl Gustav Carus | TECHNISCHE UNIVERSITÄT DRESDEN | HZDR

Goals

- Improvement of cancer treatment by means of biologically individualized, technically optimized radiotherapy.
- Cancer resrearch in radiation oncology, imaging, technology development
- Youth development for cancer research und cancer care

Infrastructure: Full integration of research, education & clinics

- Clinical infrastructure (LINACs, PET-CT, PET-MR, MR-Linac, PT)
- Research infrastructure (Proton experimental room, in vivo & in vitro labs, small animal imaging)
- Lecture rooms for Master program Medical Radiation Sciences



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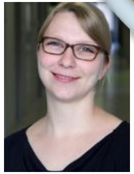
OncoRay: Research Focus

Improve the treatment of cancer by means of biologically individualised, technically optimised radiotherapy.



Translational Research

- Biomarkers for Individualized Radiotherapy
- Tumor patho-physiology
- Molecular & Cellular Radiobiology
- Laser Radiooncology
- Modeling and Biostatistics in RO
- Translational Radiooncology & Clinical Radiotherapy
- High precision proton therapy
- Preclinical Imaging for Radiooncology
- Prompt-Gamma based treatment verification
- Clinical Study Center
- Image-Guided High-Precision Radiotherapy
- Experimental MR-integrated proton therapy

OncoRay ZIK
National Center for Radiation Research in Oncology Dresden

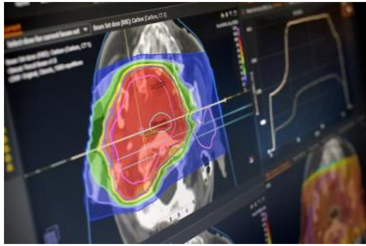







Master program: Medical Radiation Sciences

- Education of **Medical physics experts (MPE) for**:
  Radiotherapy, Radiology and Nuclear Medicine



- **One program, two certificates:**
  - Master of Science
  - MPE certification (German radiation protection law)
- **Practical focus:** 3.5 days/ week in the clinics, 1.5 days lectures & seminars
- **Small, but excellent:** 12 students per year, 1:1 supervision in the clinics
- **Modern job profile:** High-tech, Interdisciplinary, responsibility
- **Different perspective for jobs:** Clinic, Research or Industry



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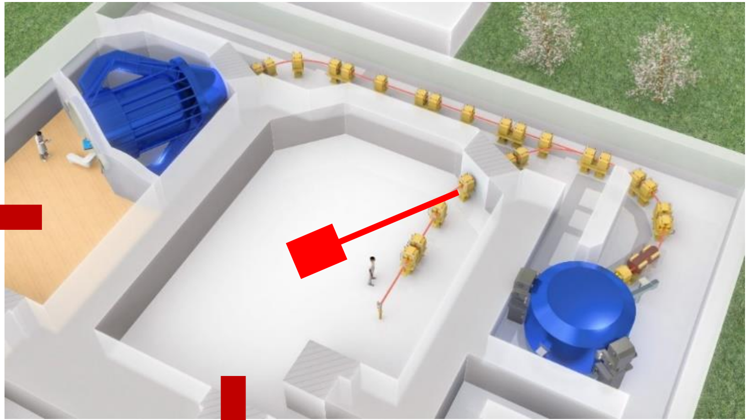
Our alumnis: Important for clinic & research

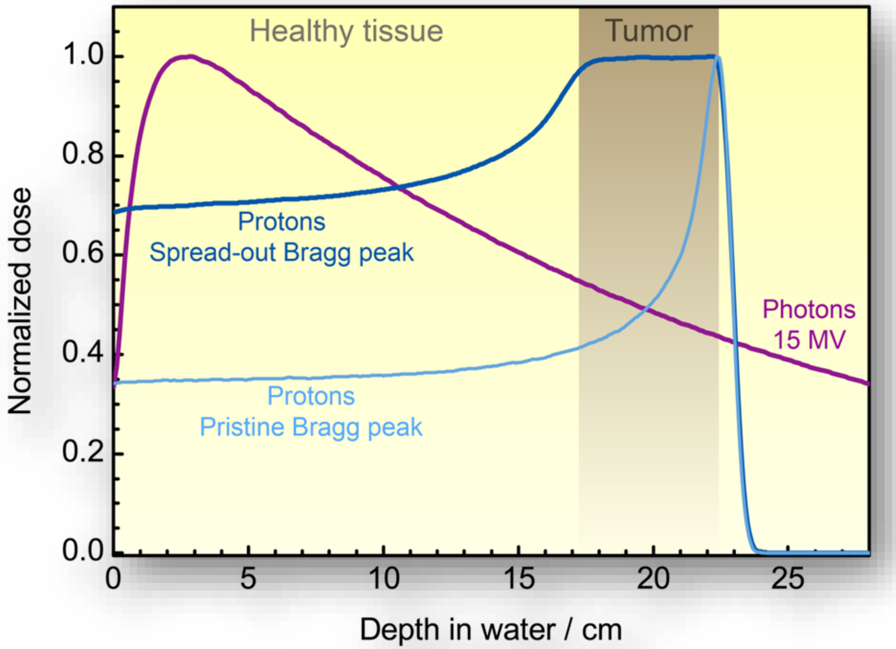
Dresden proton therapy facility (UPTD)



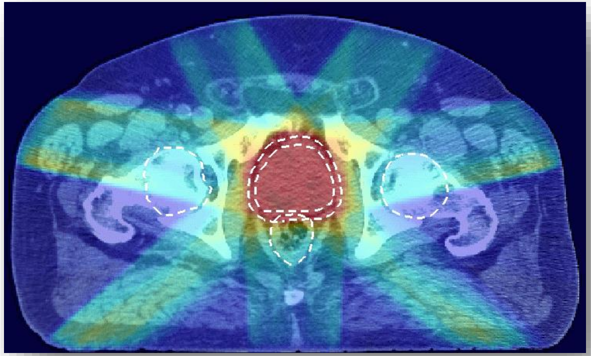
- 1 Clinical room with in-room DECT
- 1 Experimental room (250 m^2)
  with PBS nozzle and fixed beam line
- Clinical since **2014**, >2100 patients treated
- Efficient use of clinical room: 260 pts / year

Clinical routine + Translational research

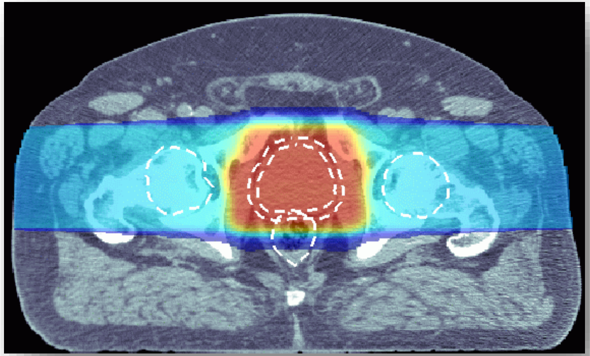
The rationale for proton therapy



Photons



Protons

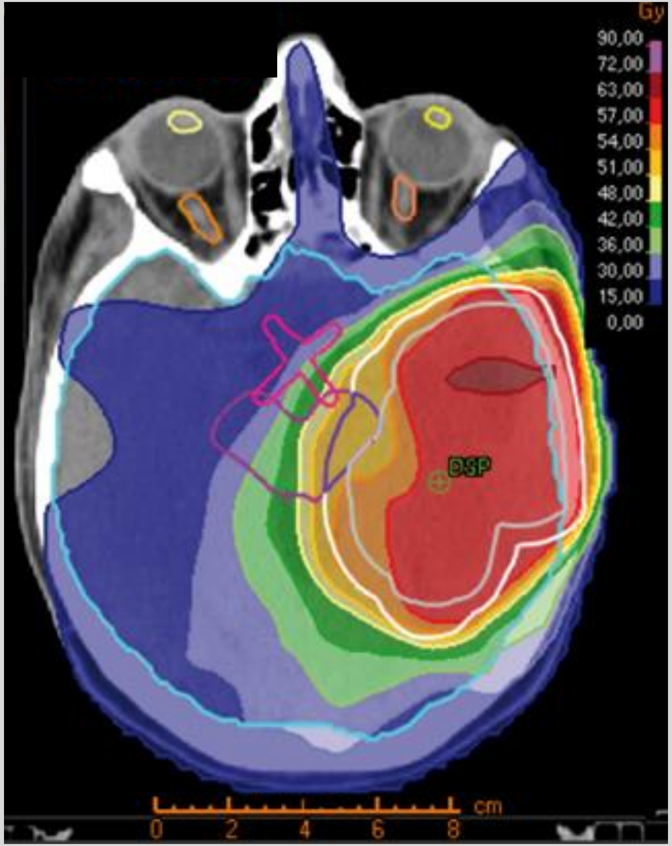


Protons:

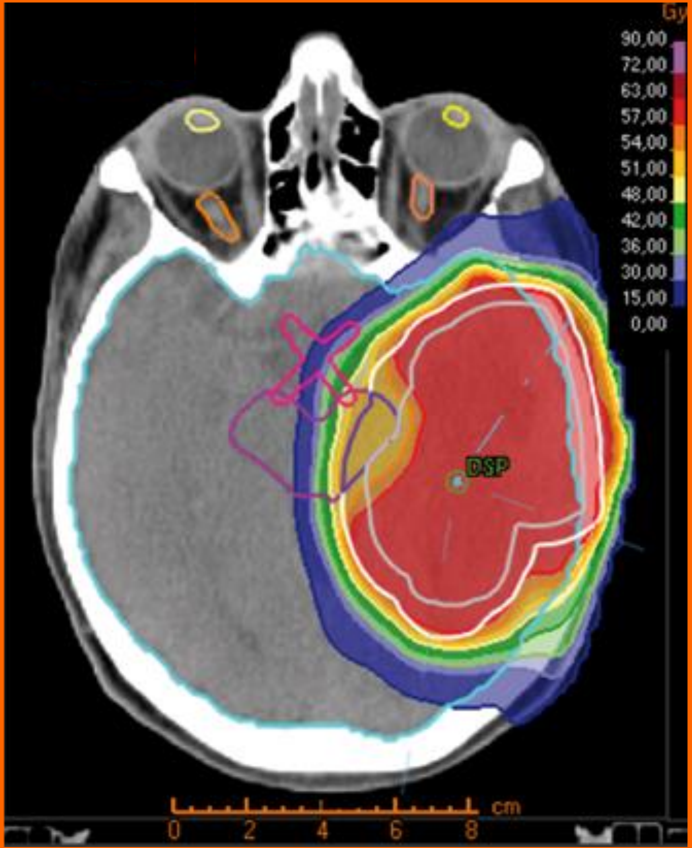
- Stop in the patient → **Less dose in normal tissue (-50%)**
- Dose maximum in tumor → **Less beam directions required**

The rationale for proton therapy

Photons



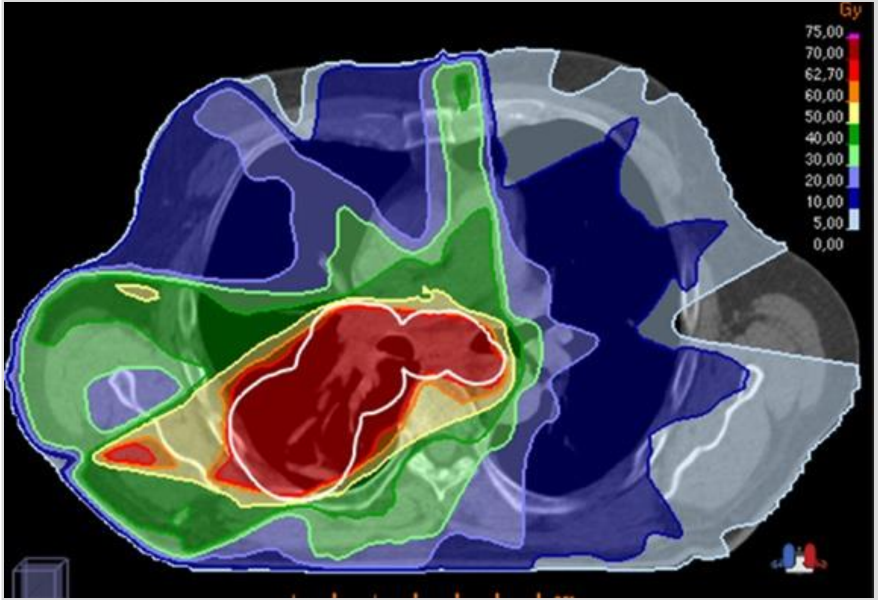
Protons



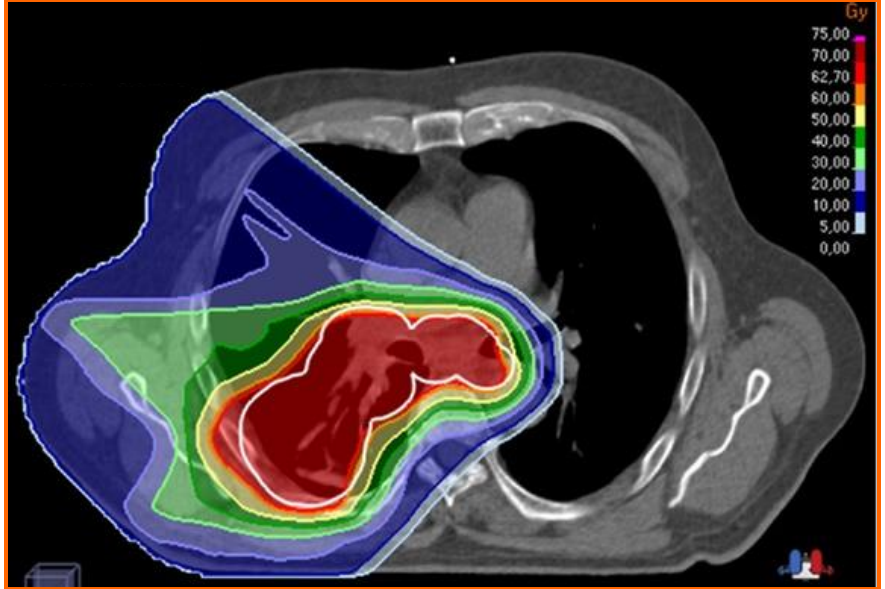
Baumann et al. Nature Review Cancer 2016

The rationale for proton therapy

Photons



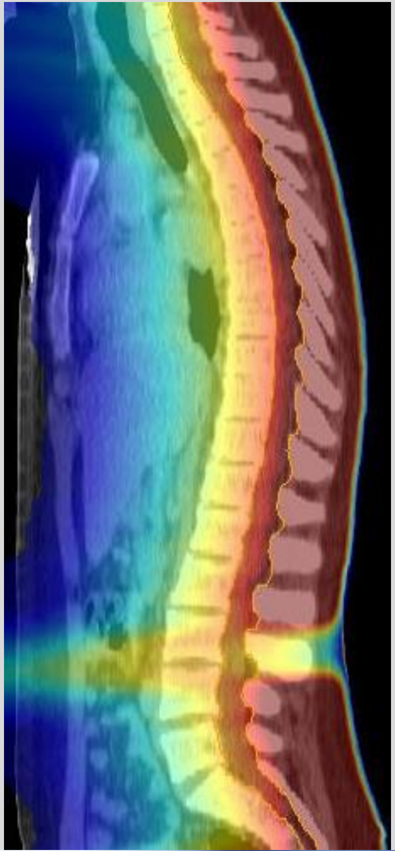
Protons

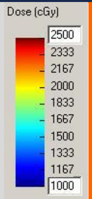


Wink et al. Frontiers Oncol 2015

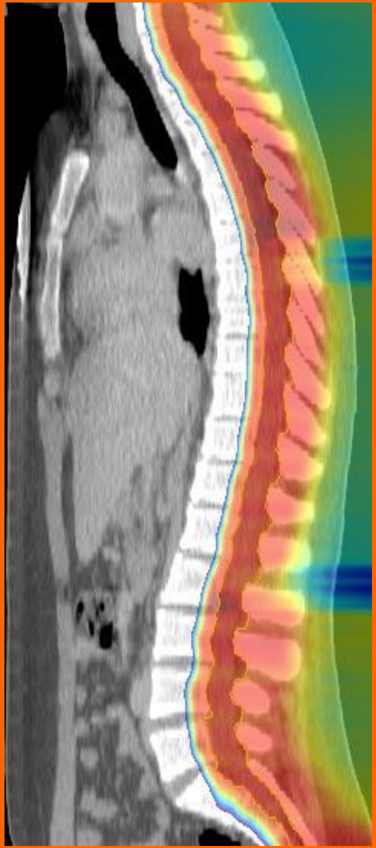
The rationale for proton therapy

Photons





Protons



Dresden proton therapy facility

Isochronous Cyclotron:

- Mass: 210 t
- Ø: 4,34 m
- Proton energy: 230 MeV
- Beam current: < 500 nA
- Beam power: < 100 W
- Connection power of whole system: 1,5 MW

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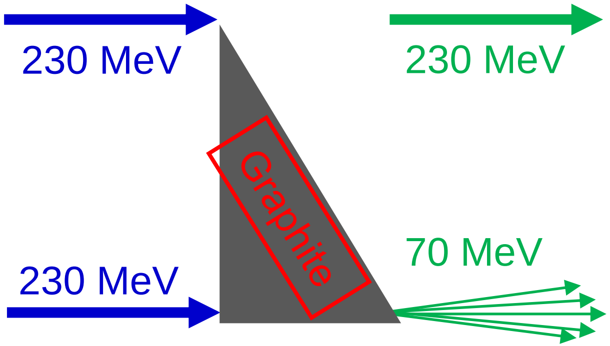
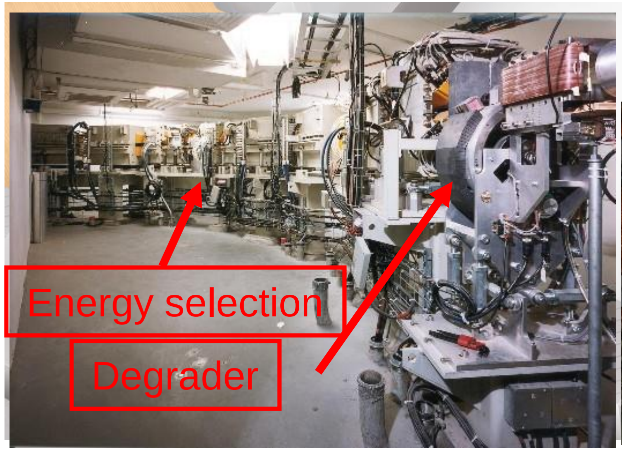
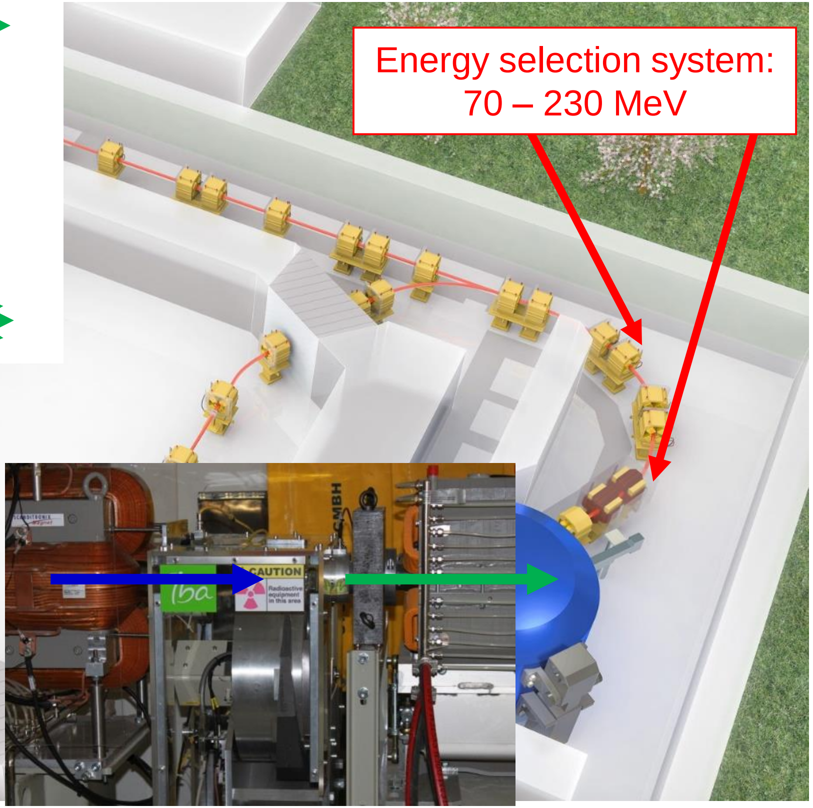
Dresden proton therapy facility







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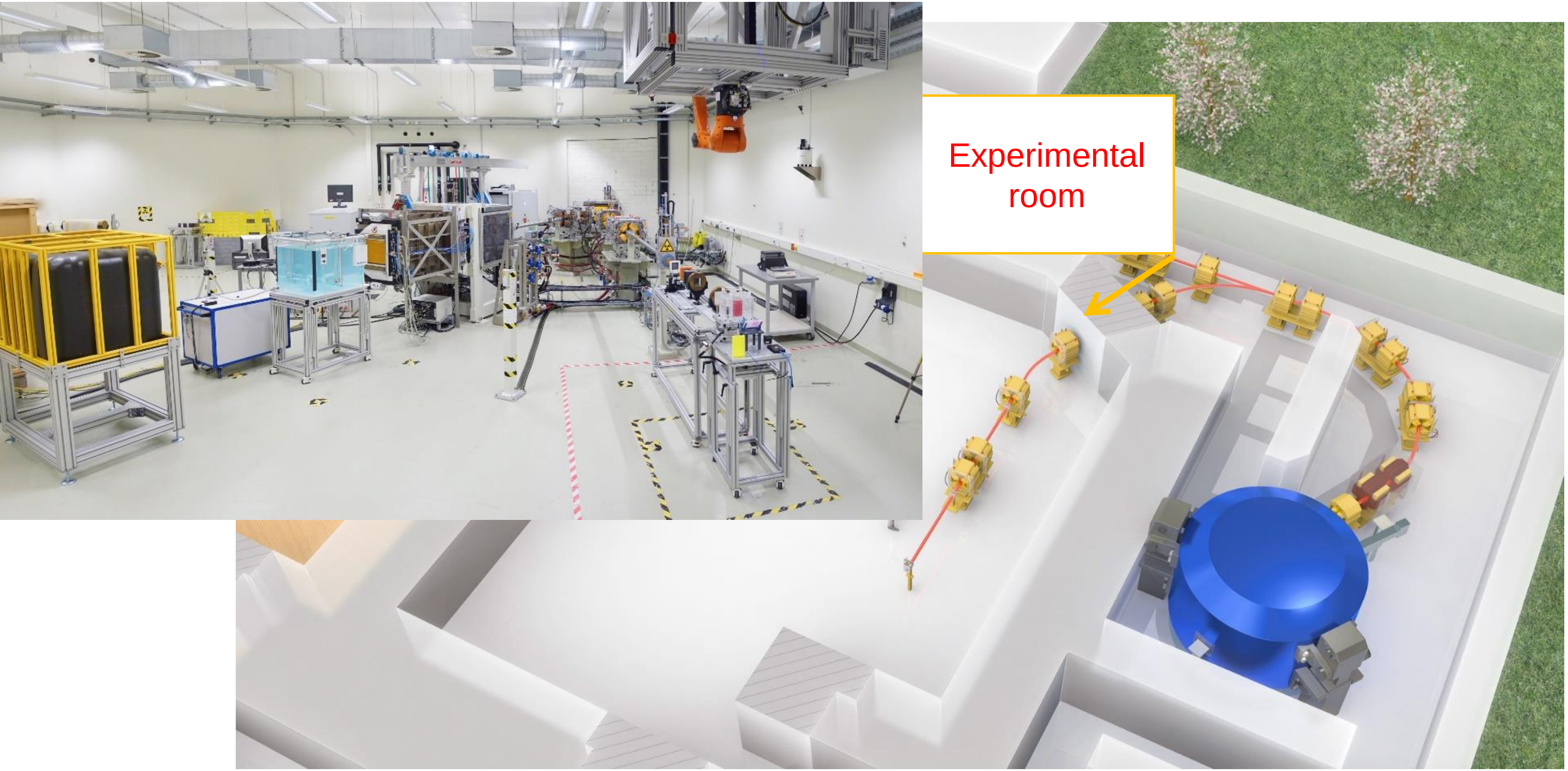
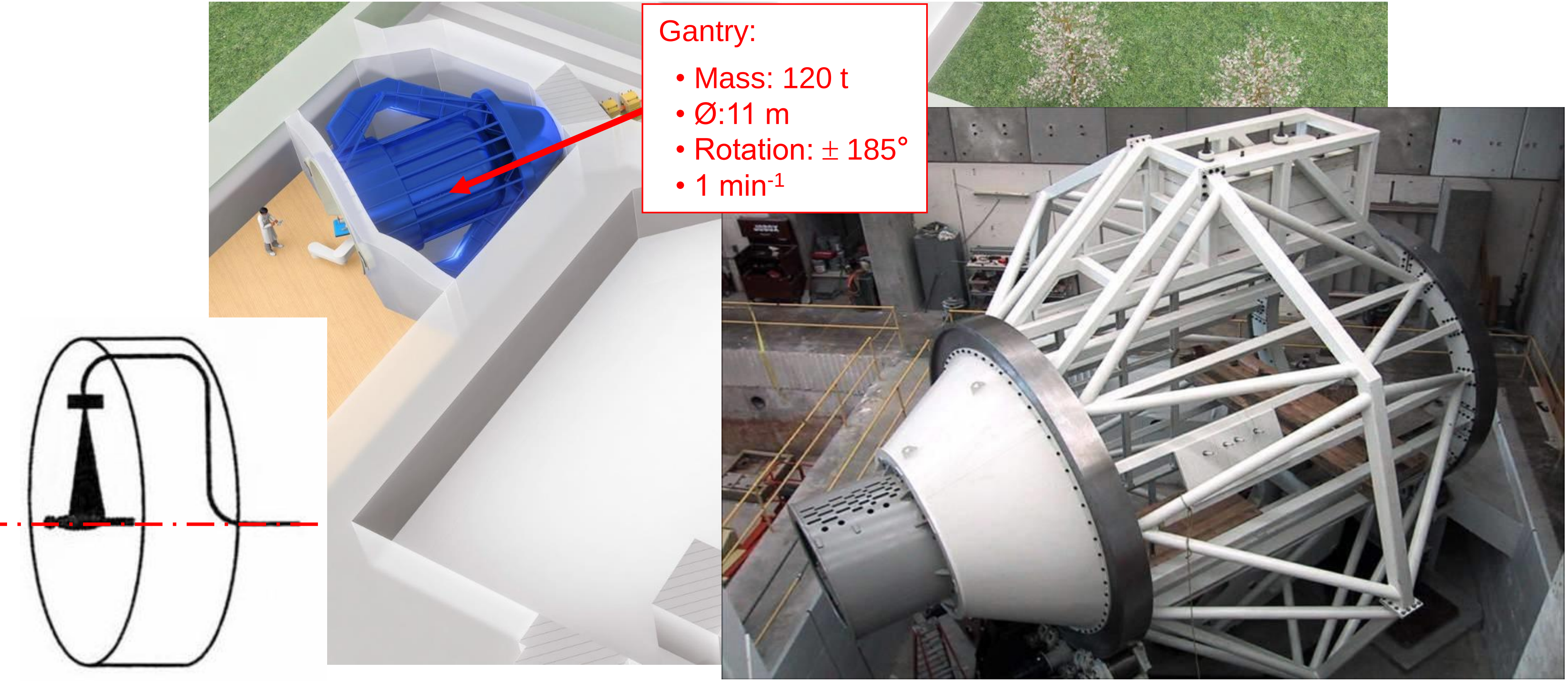
Dresden proton therapy facility

Dresden proton therapy facility



Dresden proton therapy facility

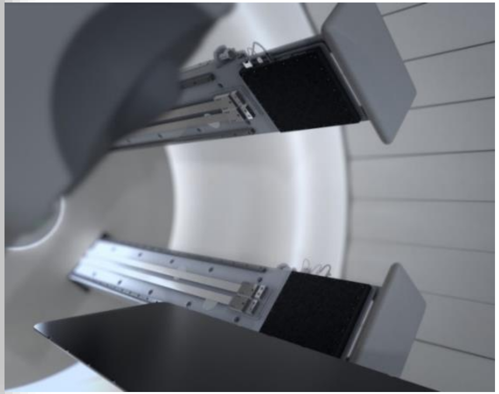


Gantry:

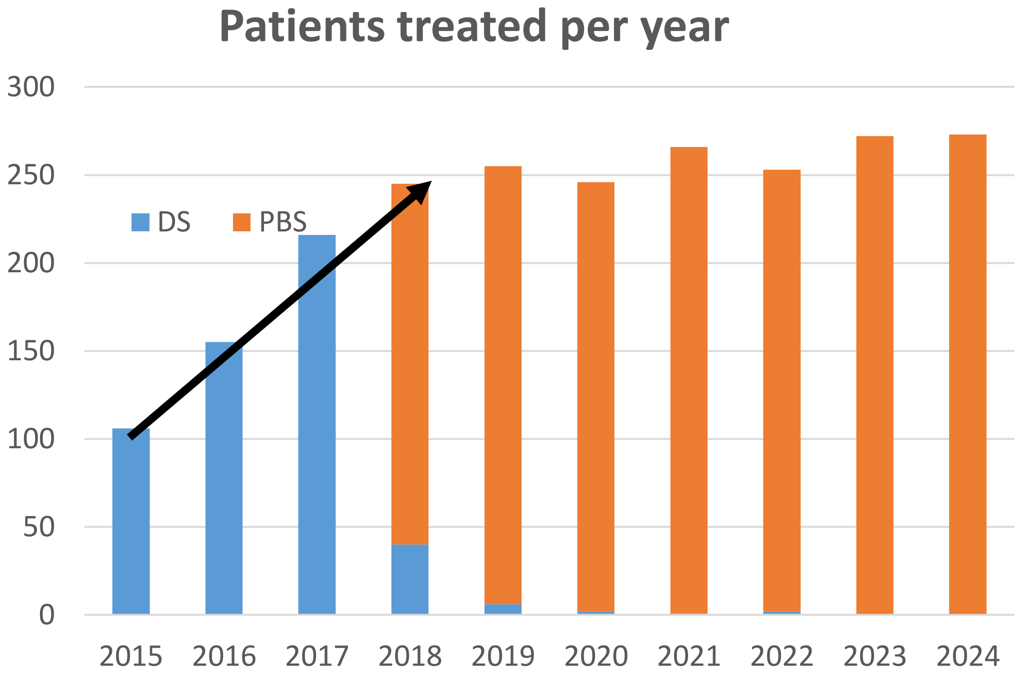
- Mass: 120 t
- Ø:11 m
- Rotation: ± 185°
- 1 min^{-1}

U. Linz (Ed.): Ion Beams in Tumor Therapy; Chapman & Hall,1995

Dresden proton therapy facility



Patients treated



- **95% of patients treated in clinical trials or registries**
- Ramp up over 4 years
- >13 h clinical treatment
- **Case mix:**
  - Brain
  - CSI
  - H&N
  - Lymphoma
  - Lung
  - Esophagus
  - Pediatric
  - Prostate
- Most PT centers worldwide treat <150 patients per room

Cyclotron issue 2025: July 23-27

24.07.

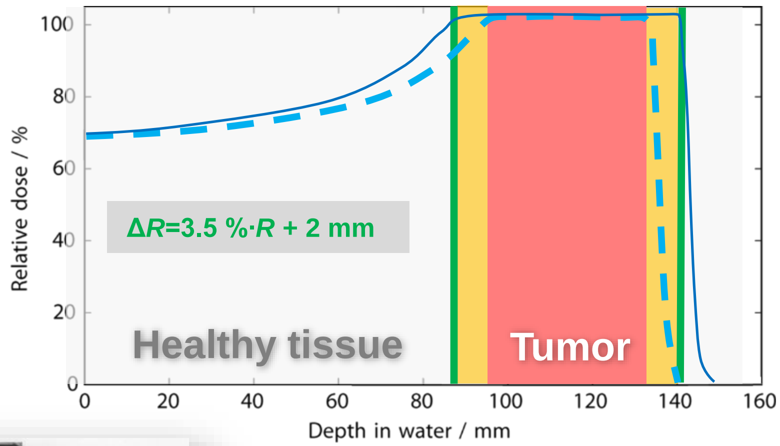
25.07.

30.07.

**All patients switched to photon therapy–
Triage in 3 groups: 0,1,2 days of treatment interruption**

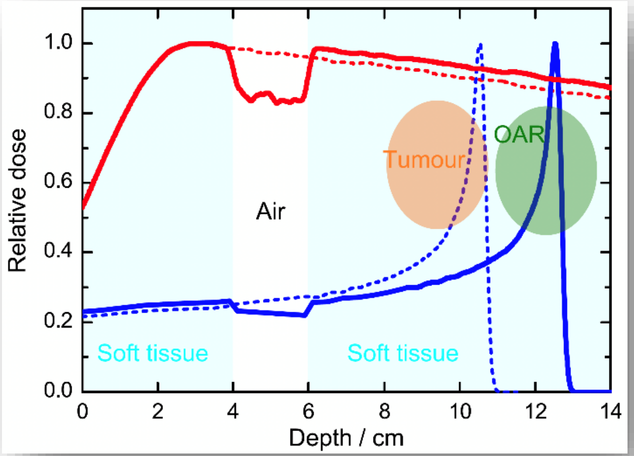
The other side of the coin: Challenges

1. CT-based range prediction



Range margins practically unchanged over the last 3 decades

2. Anatomical changes and motion



Anatomical changes can have severe influence on dose deposition in the patient

We do not use the full potential of the technology

OncoRay: Medical Physics Research

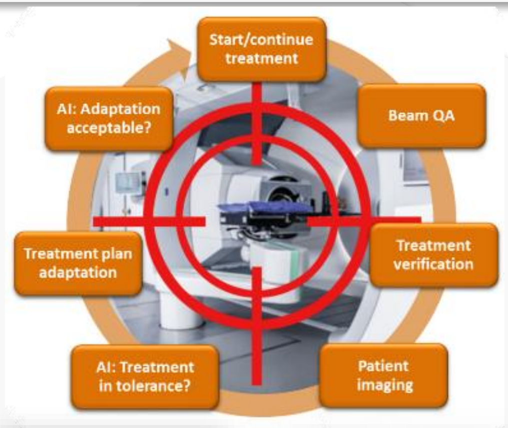
Next generation online-adaptive particle therapy:
online imaging & verification, online adaptation, minimal safety margin

Improve accuracy & adaptation capability towards physical limit


High Precision Proton Therapy
C. Richter, K. Stützer

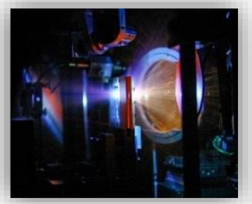
Experimental Biophysics in PT
Jörg Pawelke

Modeling & Biostatistics in Radiation Oncology
Steffen Löck
cross-sectional

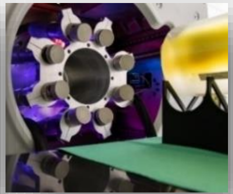


Prompt-Gamma based Treatment Verification
Toni Kögler

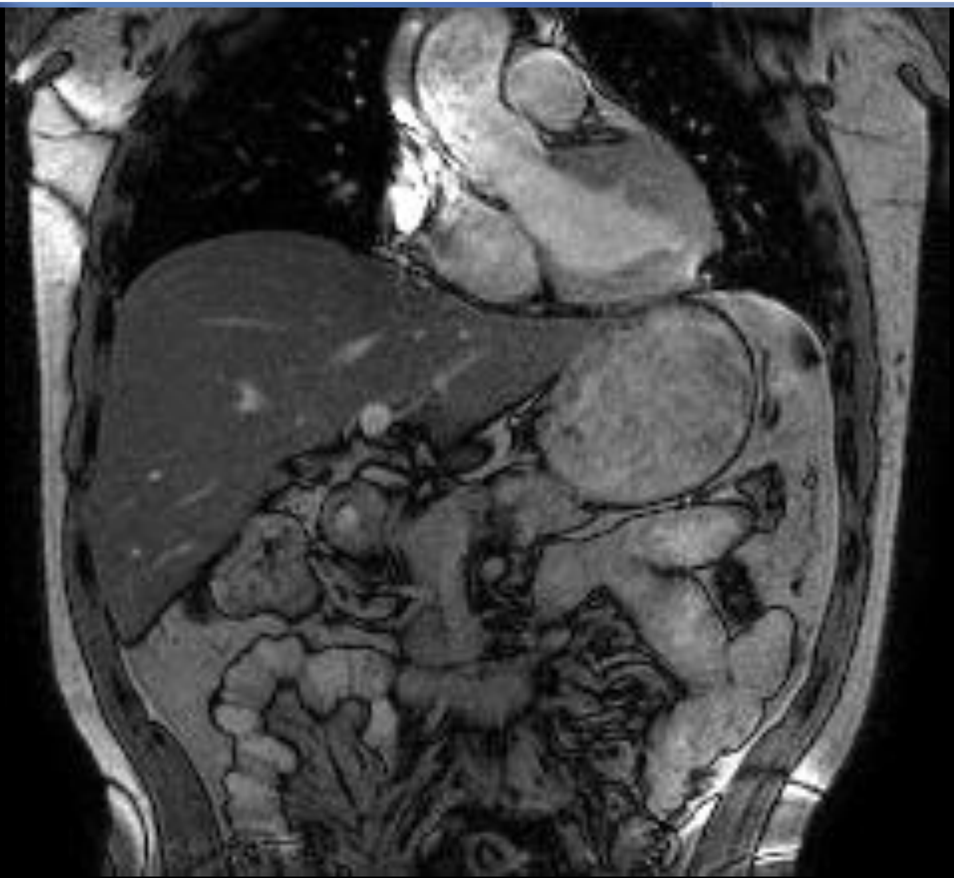
Experimental MR-integrated PT
Aswin Hoffmann








Why we need adaptive proton therapy?



@ Dr. Sergej Schneider, OncoRay

„Photon world" already solved the issue

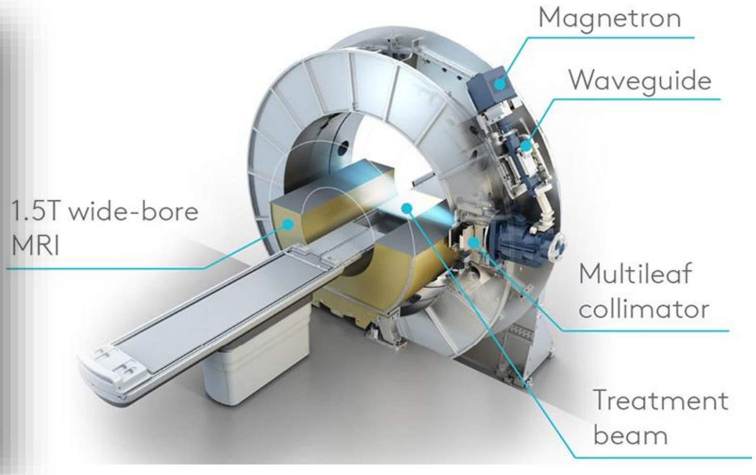
MR-Linac for photon therapy

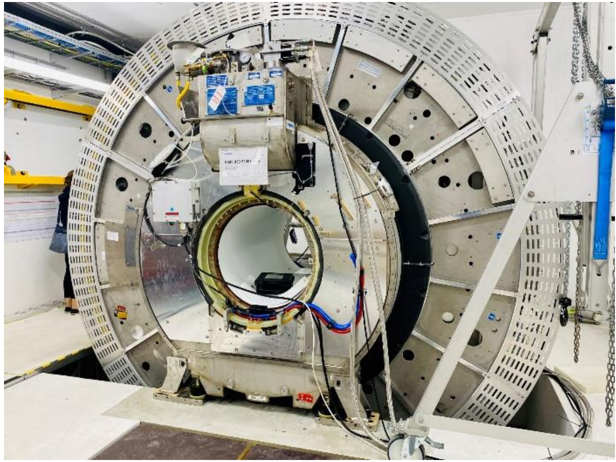
- Compact linear accelerator + 1.5 T MRI
- MR imaging in treatment position
- Approved for clinical use since 2018

☑ Daily adaption before irradiation

☑ Beam on/off depending on motion (manually)

☒ Realtime adaptation (Beam) - Work in progress





Motivation: Why OAPT is needed?

	Photon therapy	Proton therapy
Physical dose deposition	inferior	superior
Adaption speed	Online daily (MR-Linac)	Offline adaptation (2-4 days)
Status treatment of moving /changing anatomy	superior	inferior
Relevance / Need for online adaption	limited	**much higher**

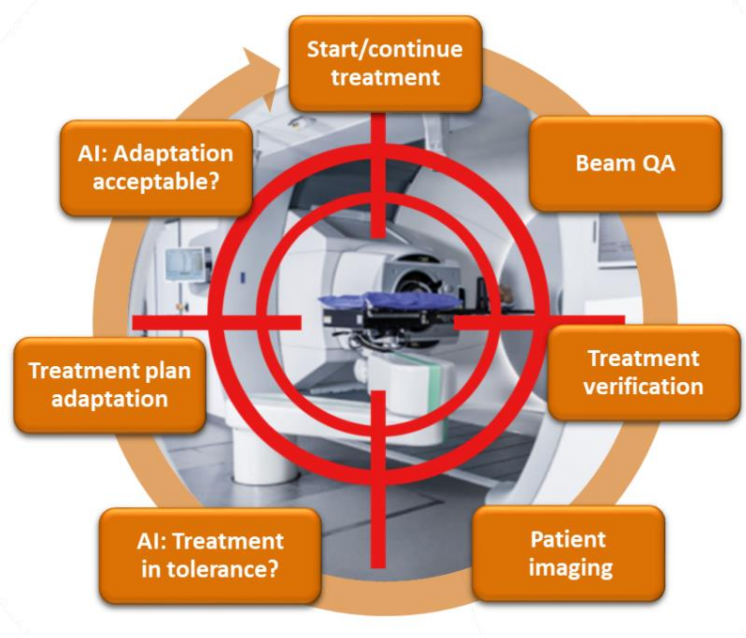
Benefit of superior dose distribution + **Benefit of online adaption capability** = **Best possible radiation therapy: Maximized clinical benefit**

Online adaptive proton therpay

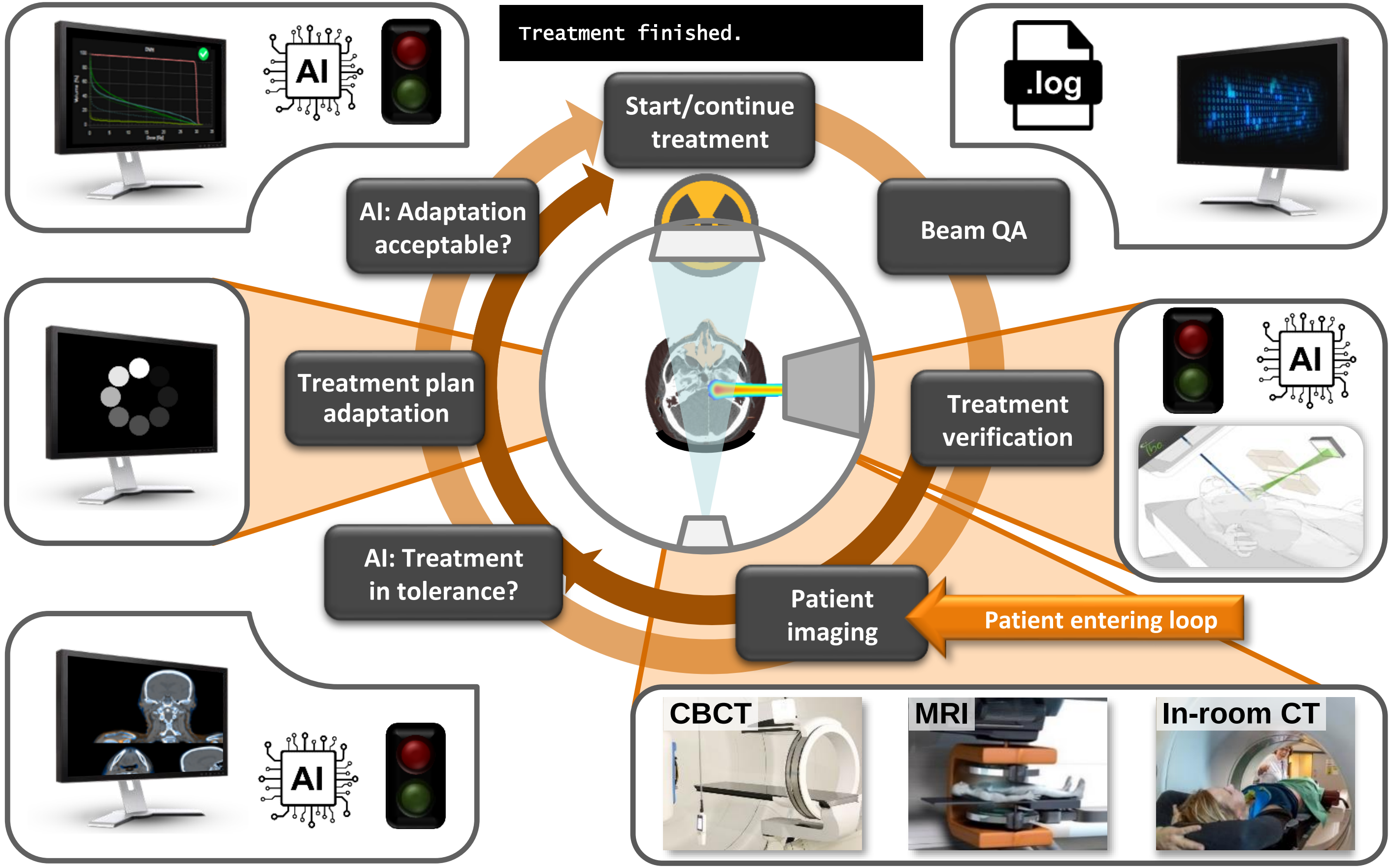
- **Why:** To react on anatomical changes during the course of treatment.
  To shrink uncertainty margins.

- **How:** Detect → React → Check
  Closed feedback loop between imaging, adaption and verification

- **Crucial:** Safety net! Do we actually do what we think we are doing?



Worflow onine apdaptive proton therapy



Animation: J. Berthold & Julian Pietsch

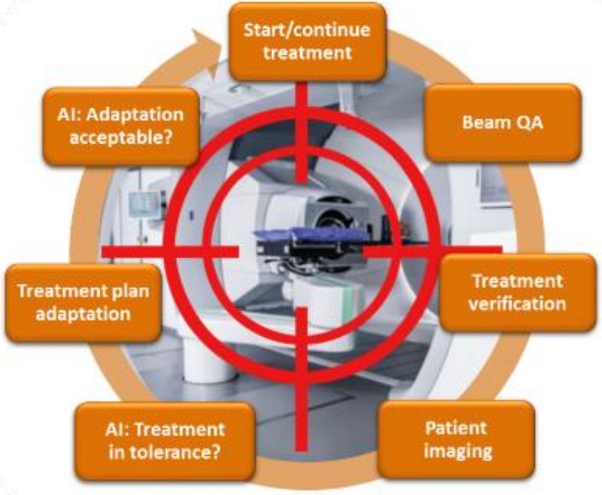
Stepwise increase of adaption speed

Adapation speed	Adaptation need identified	Adaptation while	Application for
One day	After fraction treatment	Patient is home	**Next fraction**

Offline

Two flavors of realization

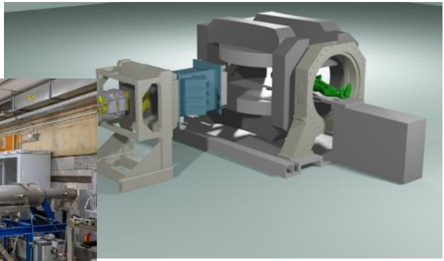
Gantry based



- Imaging: **CBCT** (or in-room CT)
- Full clinical flexibility
- Patient laying
- Non-coplanar fields possible

At horizontal beamline

@ARTEMIS, Heidelberg



@MRiPT, Dresden

- Imaging: **MRI**
- One beam direction
- Patient either laying or even sitting (to restore flexibility)
- Some restrictions concerning coplanar fields

Realization: ProtOnART Konsorium

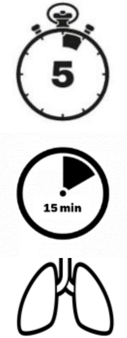
- **Unique clinical-industrial-academic consortium**
- **Founded 2021** on OncoRay initiative
- **Gantry-based realtime adaptive proton therapy:** Realized in IBA/RaySearch facility → Integrated solution with efficient workflow
- As-fast-as-possible adaptation speed, via a pragmatic step-wise approach

Consortium Scope:

Long-term: **Near-real time-adaptive** proton therapy, adaptation within/between fields

Mid-term: Efficient **daily-adaptive** proton therapy, adaptation before start of delivery

Short-term: **Daily-adaptive** proton therapy, for **specific entities: Esophagus & Lung**

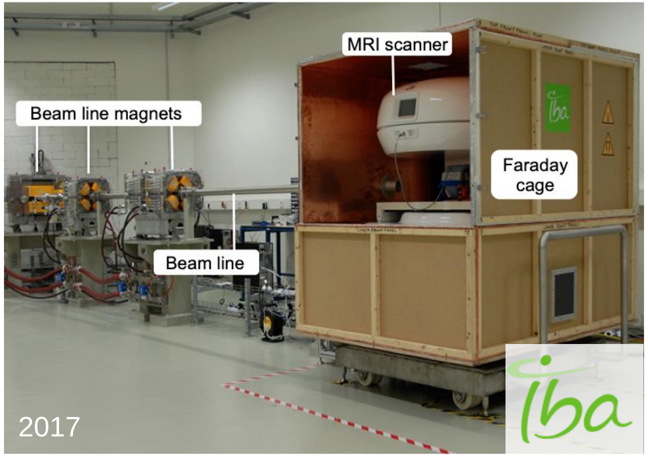


~40 people working in 9 groups

MR integrated proton therapy

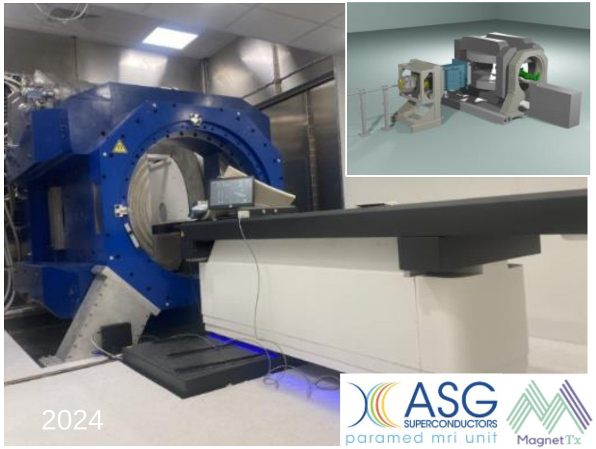
From the world's first research prototype… to the world's first clinical prototype in-beam MRI

1. Prototype: Proof-of-concept



2. Prototype: Towards first-in-human

3. Prototype: Towards realtime imaging



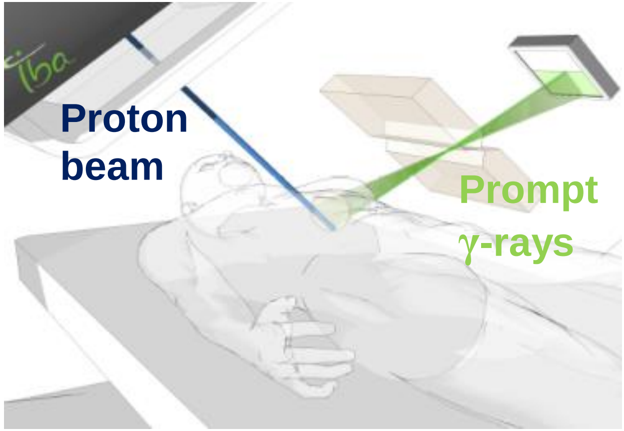
- **First MRiPT system**
- 0.2 T at static beam

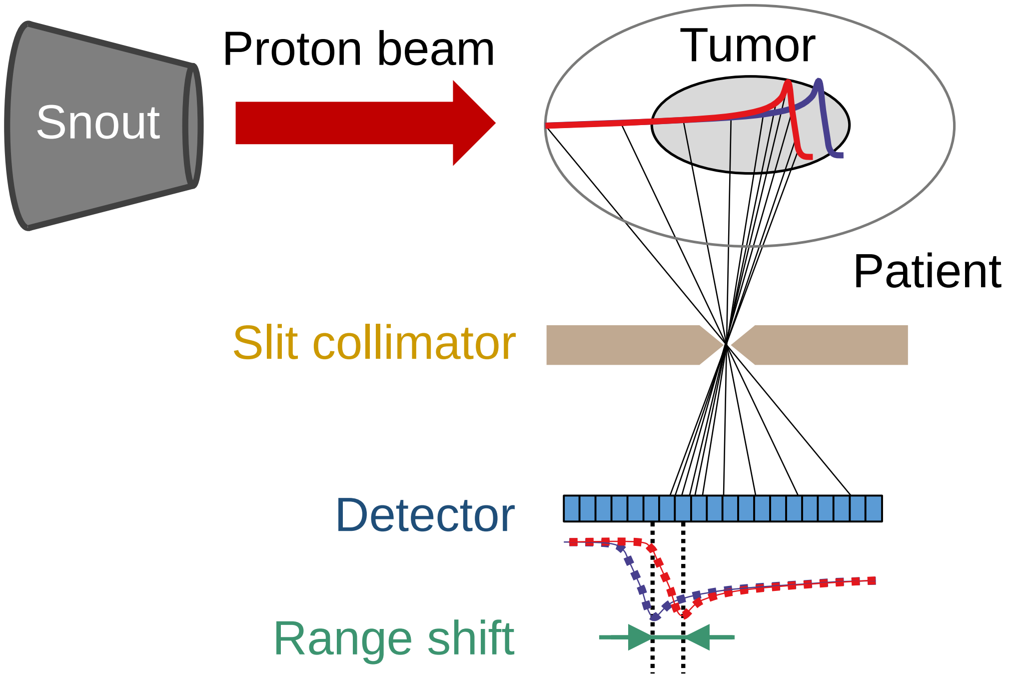
- **MRI with patient couch**
- 0.33 T at PBS beamline

- **Whole-body MRI**
- 0.5 T on gantry

Prompt gamma based treatment verification

Goal: Online treatment verification system to detect deviations from planned delivery

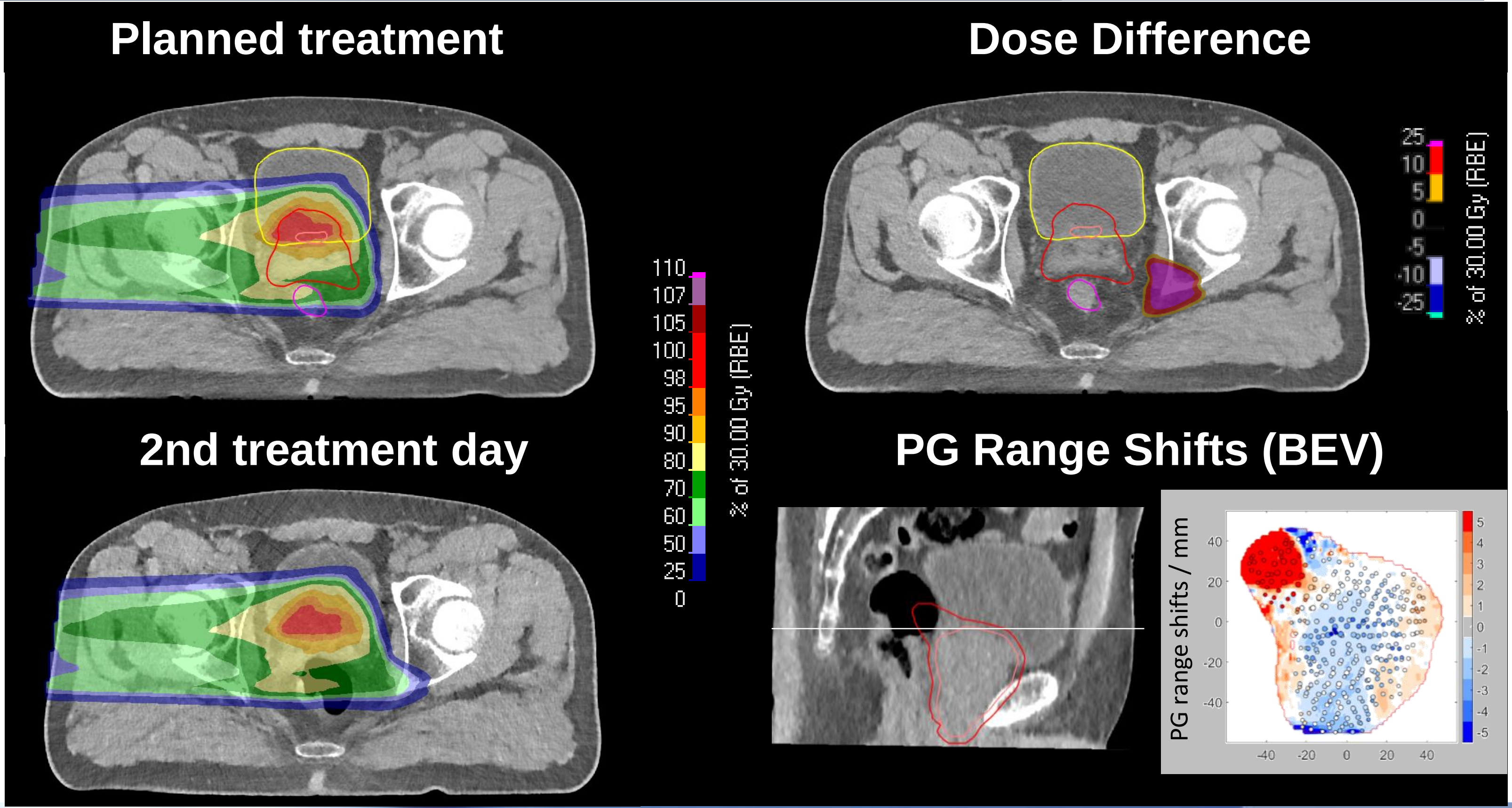




Benefits of PGI

- ✓ No additional dose
- ✓ No treatment prolongation
- ✓ Safety net functionality

PGI: Example of anatomical change

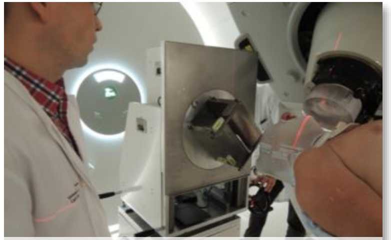


Prompt gamma based treatment verification

1st idea:
Y. Jongen
2003

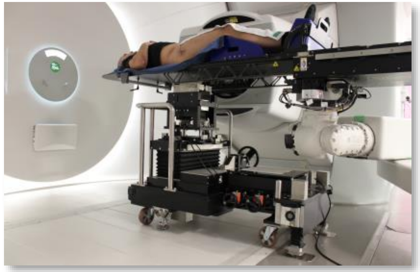
2014
1st generation prototype @ OncoRay

2015
First in-human application

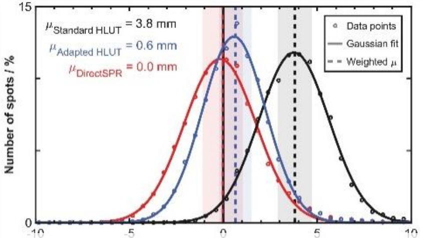


Richter et al. Radiother Oncol 2016

2018
2nd generation positioning system



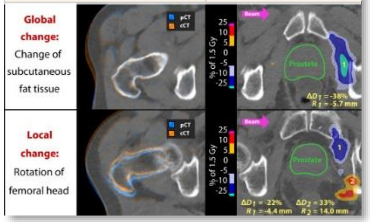
2020
In-human validation of DECT-based range prediction



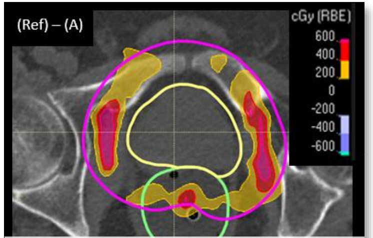
Berthold et al. IJROBP 2021

2022
Detectability of anatomical changes

Pietsch et al. Med Phys 2022;
Berthold et al. IJROBP 2023



2023
Margin reduction potential quantified

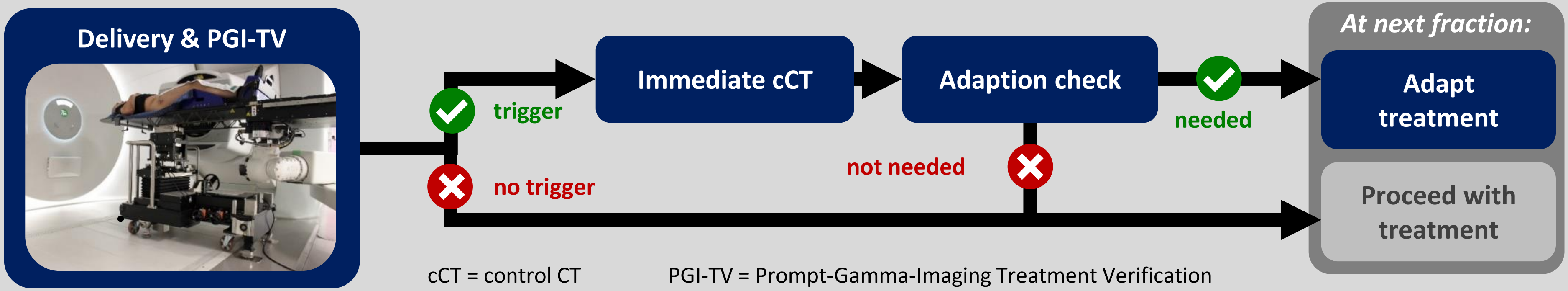


Bertschi et al. phiRO 2023

2025
1st interventional study: Trigger of adaption

NCT

Outlook: Towards first interventional use

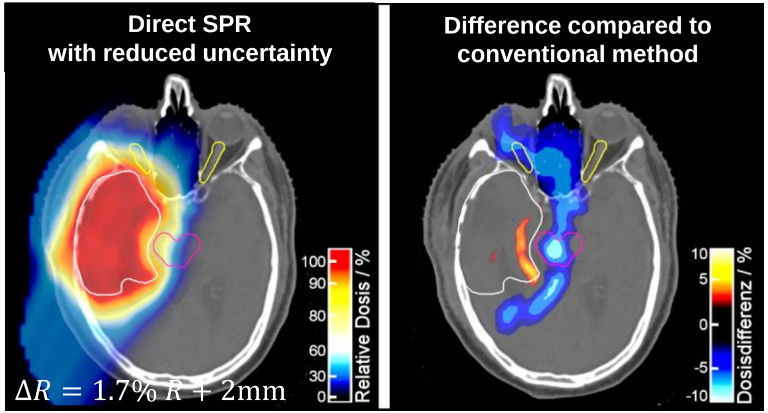


- **PT treatment:** Prostate, 3 Gy/fx to 60 Gy, 2 fields
- **Main endpoint:** False positive rate to trigger control CT <20%
- **Patient benefit: Reduced uncertainty margin**
- Medical Device Regulation demanding!

Most accurate PT planning w. CT innovations

- Translational research on application of spectral CT imaging in RO since 9 years, cooperation with SIEMENS Healthineers
- More accurate range prediction in patients allows for more targeted irradiation

2019: Worldwide first application of Dual-Energy CT for PT treatment planning with substantial margin reduction (-35%)



→ Wolrdwide most accurate treatment planning

→ Application only in non-moving body regions

2025: Worldwide first Single-Source Photon-Counting CT in radiation therapy installiert

Expected benefits:

- Less imaging dose at same image quality
- Benefits for PT also for moving tumors
- Eventually further margin reduction

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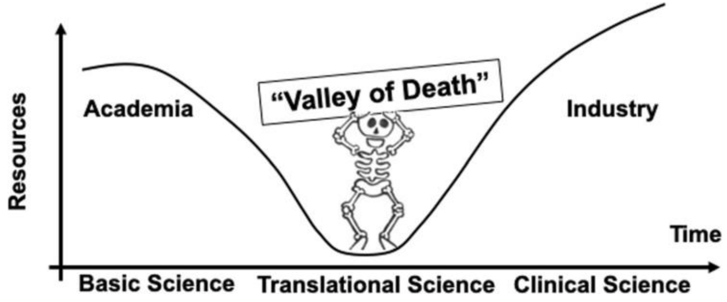
Wohlfahrt et al. RedJ 2017, Wohlfahrt et al. RedJ 2018, Wohlfahrt et al. REDJ 2019, Wohlfahrt & Richter BJR 2020, Peters et al. GreenJ 2021, Berthold et al. RedJ 2021, Richter & Wohlfahrt Springer 2022, Peters, Wohlfahrt, Richter, IOP 2024

Key factors for sucessful clinical translation

- **Choice a stepwise approach – Accept to not be perfect in the first place – Don’t wait until technology is perfect**

- **Have a long breath – “Valley of death” (includes funding!)**



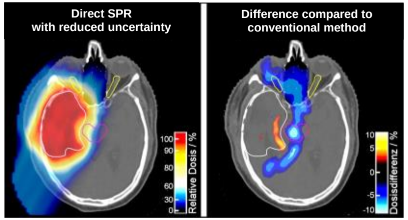
Seyhan. Transl Med Commun 2019

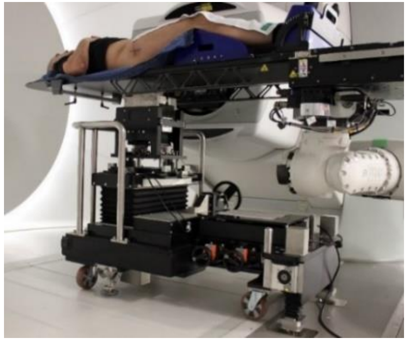
- **Foster a team effort:**
  - Collaboration with industry
  - Interdisciplinary (do not stay in the niche of domain ”experts”)
- **Active support from clinical leaders!**

Summary

- **Translational research in proton therapy**
  → Bring innovations in clinical application:
  - Direct DECT-based treatment planning
  - Prompt-Gamma treatment verification
  - On the way: MR integrated proton therapy
- In most cases, initial idea was not from us – but we brought it to the patients
- **Focus: Realization of near-realtime online adaptive PT**

→ Gantry-based OAPT with prompt gamma treatment verification
→ Gantry-less OAPT with realtime MR imaging





Thank you!

Agenda

time	content	who
10:00 - 11:00	**Overview: Translational Medical Physics Research at OncoRay**	Christian Richter
11:00 - 12:30	**Talks on specific research projects** (each talk 15 min + 7 min discussion) ○ The next frontier in image guided proton therapy – Developments towards in-beam Magnetic Resonance Imaging ○ Prompt gamma-based treatment verification ○ Preclinical in-vivo radiobiology experiments towards proton FLASH therapy ○ Exploring the relative biological effectiveness of proton therapy in brain tumor patients	 Sergej Schneider Aaron Kieslich Manuel Bernabei Aaron Kieslich
12:30 - 13:45	**Lunch in Mensa of Medical Faculty**	
14:00 - 14:45	**Tour through the facility in two parallel groups**	Johannes Triller / Felix Horst