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OncoRay
National Center for Radiation Research in Oncology Dresden

TECHNISCHE UNIVERSITÄT DRESDEN

Universitätsklinikum Carl Gustav Carus
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The next frontier in image guided proton therapy:

Developments towards in-beam Magnetic Resonance Imaging

Georgian-German Science Bridge | August 20th, 2025

Sergej Schneider - OncoRay – National Center for Radiation Research in Oncology

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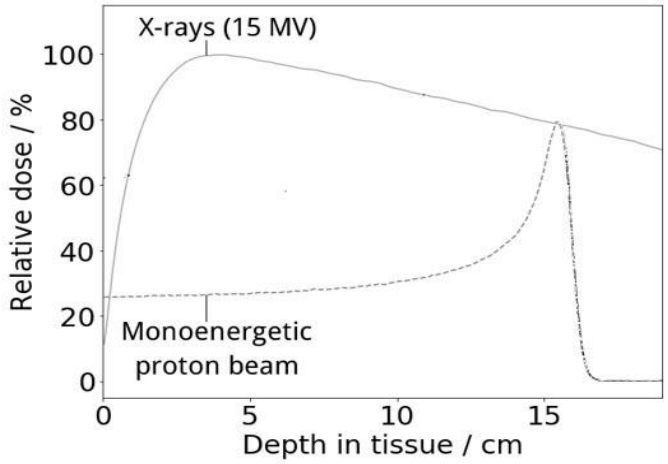
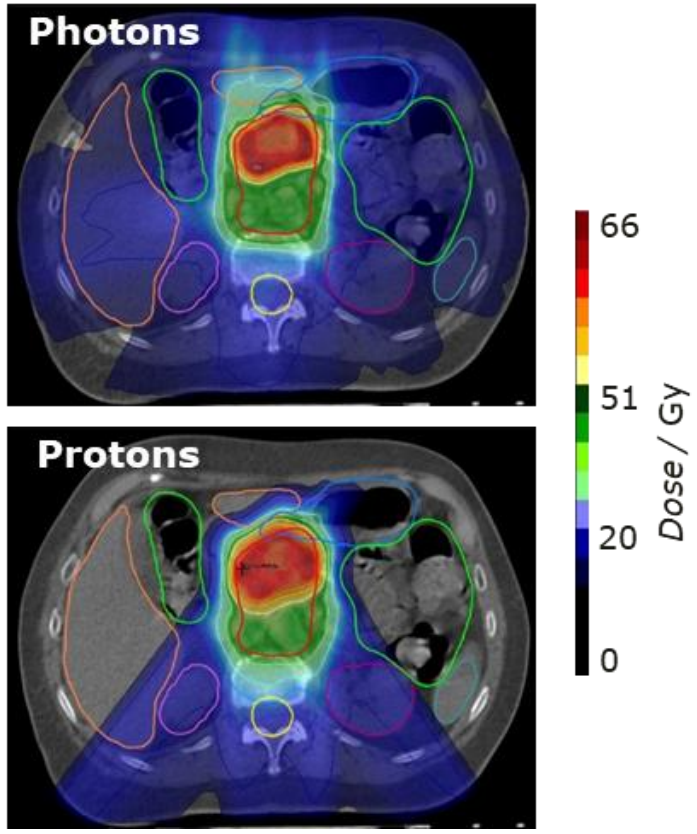
Dosimetric benefit of proton therapy

High dose conformality

- Proton therapy (PT) delivers highly conformal dose distributions with steep dose fall off after dose maximum (Bragg Peak)
  - \+ Reduces integral dose and enables improved healthy tissue sparing
  - \- Highly sensitive to setup inaccuracies and anatomy changes (organ motion and deformation)



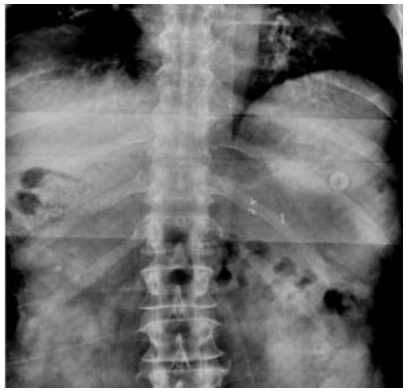


Courtesy: S. Stefanowicz (OncoRay)

Dosimetric benefit of proton therapy not fully exploited

Problems: (1) we do not know exactly what we shoot at and (2) what we hit!

- We cannot accurately **localize the target** during dose delivery
- We cannot assess the **beam range** and **control** the beam in real time
- We currently **lack the imaging tools** to overcome these critical limitations



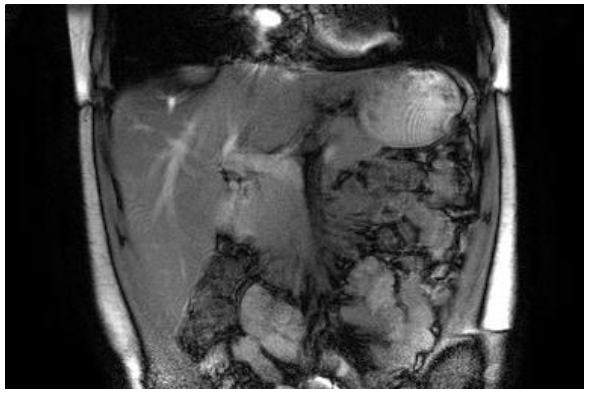
Proposed solution: full integration of proton therapy and MRI

- Bring together **exquisite soft-tissue imaging** of MRI and **superior dose conformity** of PT

Full integration of MRI and proton therapy

MRI provides:

- ✓ Excellent soft-tissue contrast → accurate organ **delineation**
- ✓ Real-time imaging capabilities → captures **organ motion**
- ✓ No ionizing imaging dose → **continuous** imaging
- ✓ Functional imaging → **response** assessment



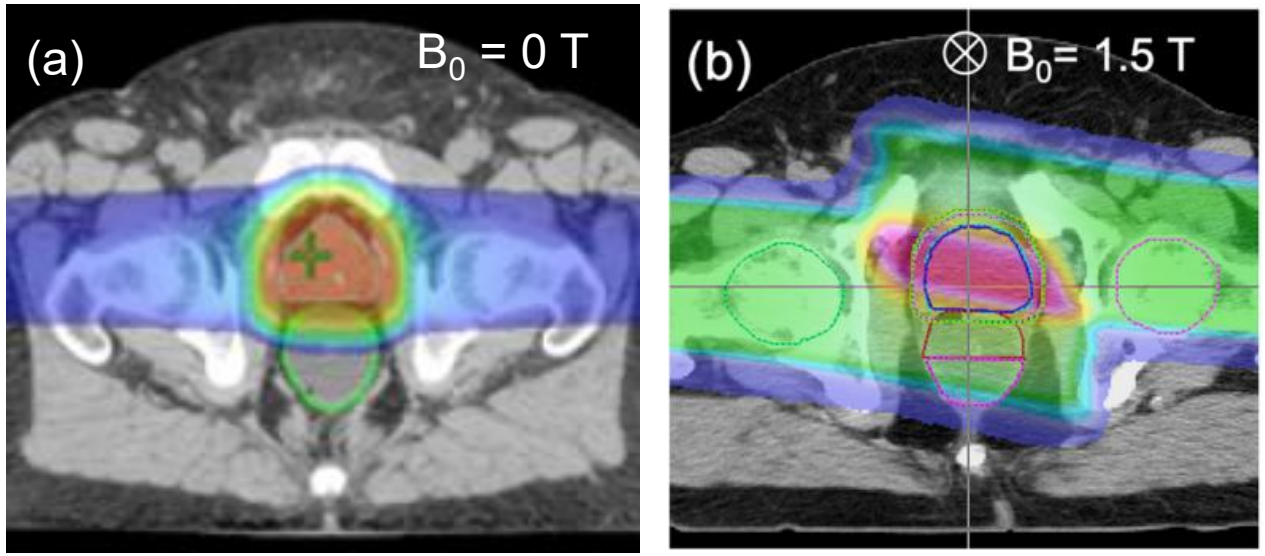
MR-integrated Proton Therapy (MRiPT): in-beam MRI-guided proton therapy

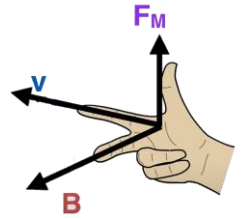
- **Synchronisation** of tumor position and dose delivery increases the **targeting precision**

Challenges in the integration of MRI and proton therapy

Proton dose delivery affected by magnetic field of MRI scanner:

- Lorentz force induced deflection of proton beam significantly disturbs dose delivery



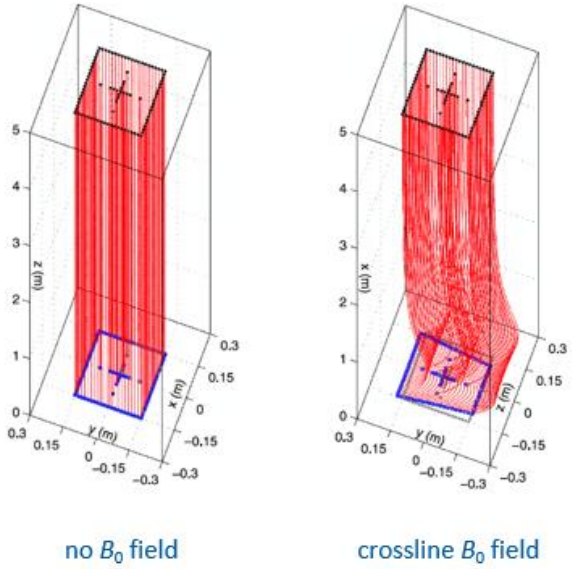


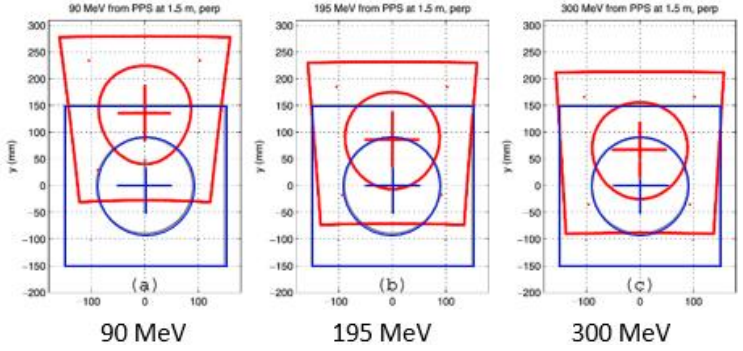
Hoffmann *et al.* Rad. Oncol. 2020

Challenges in the integration of MRI and proton therapy

Dosimetric impact on beam trajectory and dose distribution

- Effect of **magnetic field orientation** and **fringe fields**: MC simulations in Geant4
  - **crossline** B_0 field ⊥ beam : energy-dependent proton beam **deflection** and radiation field shape **deformation**
  - **inline** B_0 field || beam : energy-dependent proton beam **rotation** around central beam axis





Oborn *et al.* Med Phys 2015

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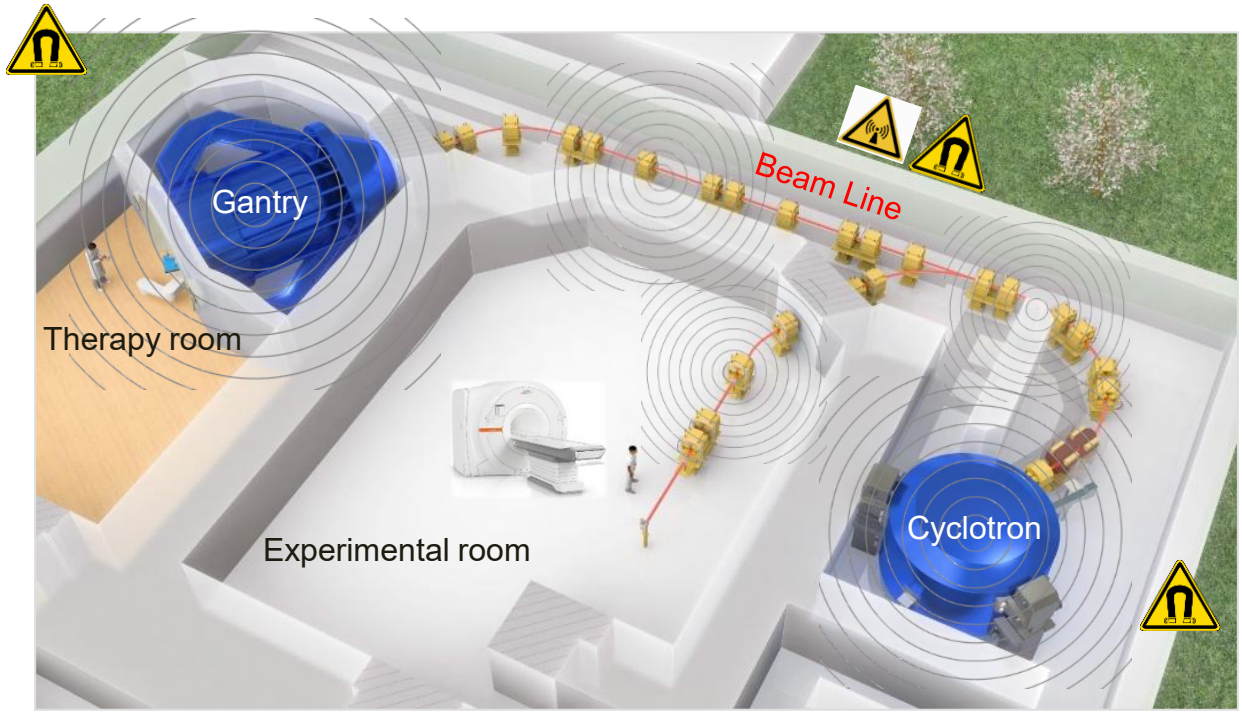
Challenges in the integration of MRI and proton therapy

Electromagnetic environment in proton therapy facility unfavorable for MRI



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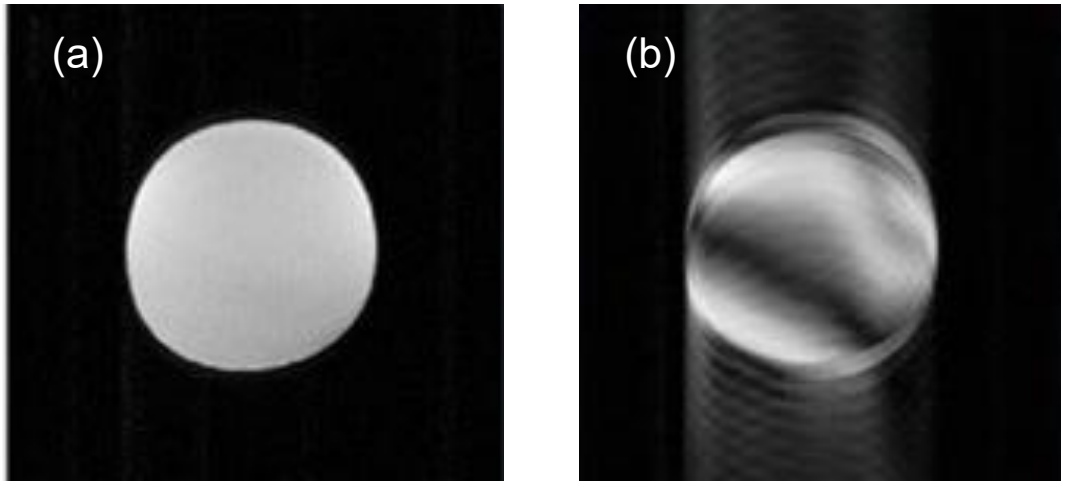
Challenges in the integration of MRI and proton therapy

Electromagnetic environment in proton therapy facility unfavorable for MRI

- Proton therapy facility can distort imaging capability of MRI scanner



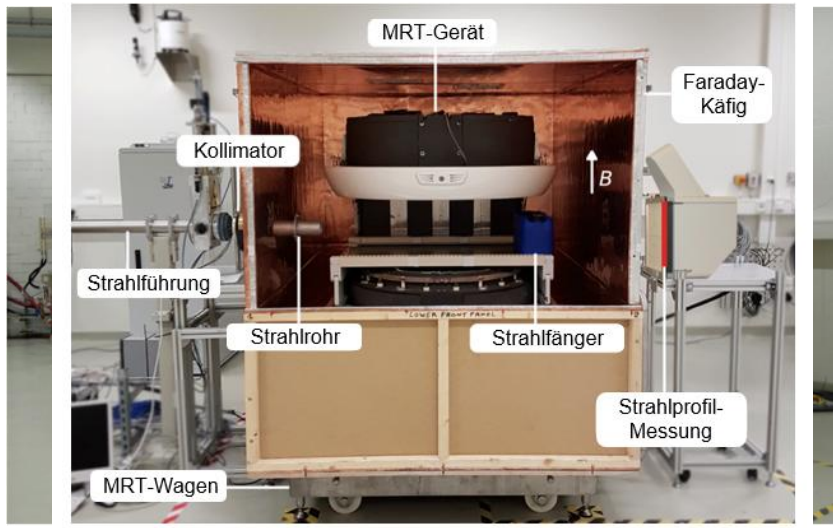
(a) Undistorted and (b) distorted MRI image of homogeneous phantom

Hardware Developments towards MRiPT

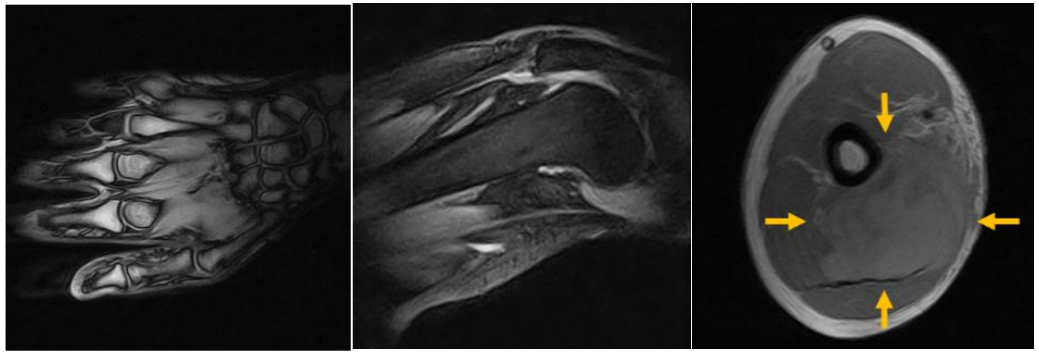
1st prototype in Dresden: proof-of-concept during static proton beam delivery

- **0.22 T** open in-beam MRI at horizontal **static** **research beam line**
  - ✓ MR image **quality sufficient** for tumor delineation
  - ✓ MR image **quality preservation** during simultaneous proton beam irradiation

Schellhammer *et al*. *Phys Med Biol* 2018; 63(23)



In-beam MRI scanner at horizontal fixed beam line



Anatomical images of healthy volunteer and patient with soft tissue sarcoma

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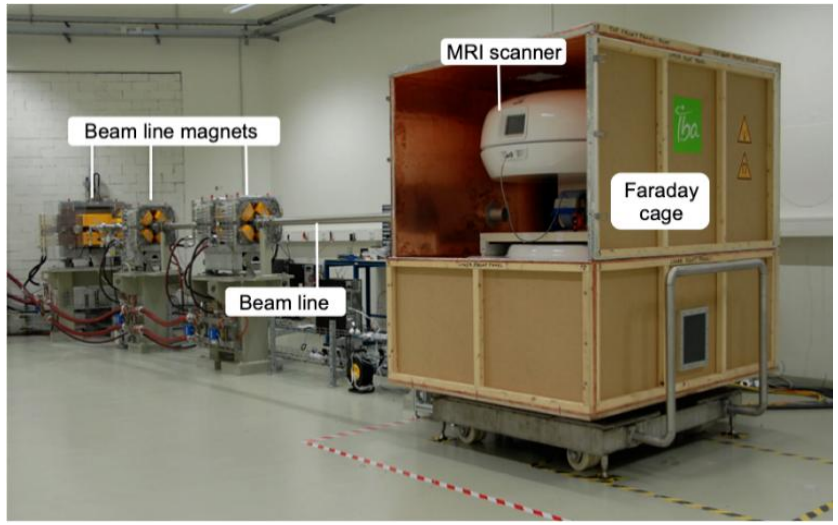

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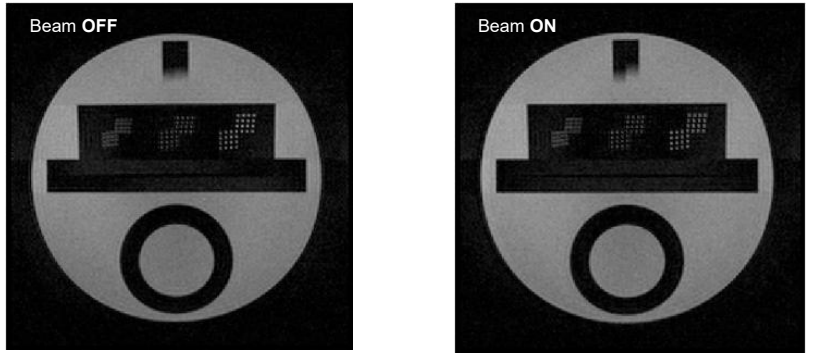


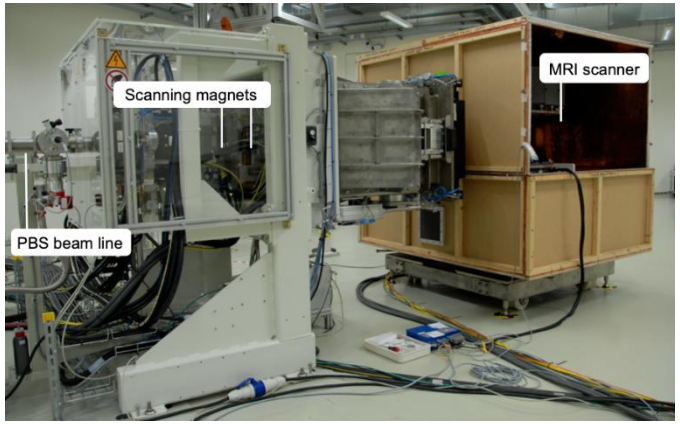
MR image quality of centrally irradiated phantom (ø 10 cm) does not degrade when beam (ø 2 cm) is ON

Hardware Developments towards MRiPT

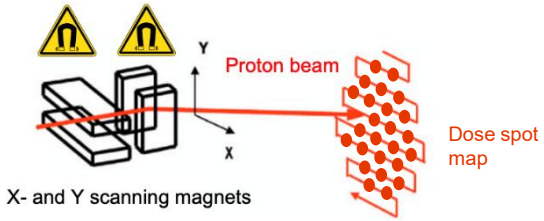
1st prototype in Dresden: proof-of-concept during static proton beam delivery

- **0.22 T** open in-beam MRI at horizontal **PBS research beam line**
  - Severe MR image **ghosting artefacts** occur during PBS delivery of equidistant proton dose spot

Gantz et al. Phys Med Biol 2020; 65(21)



In-beam MRI scanner at proton PBS beam line in Dresden

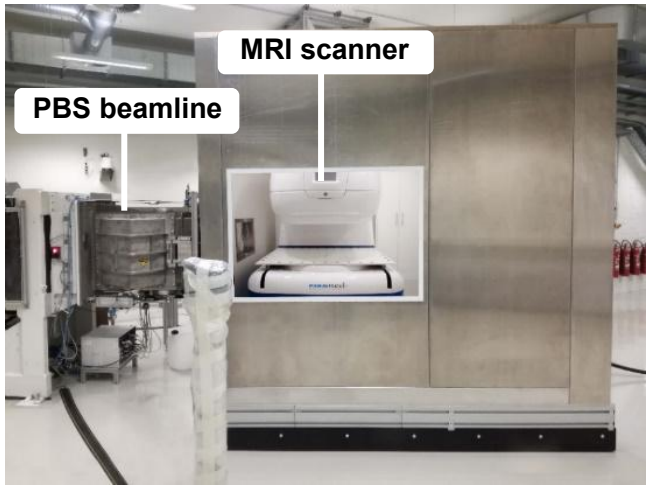


Transversal MR images of homogeneous cylindrical phantom

Hardware Developments towards MRiPT

2nd prototype in Dresden: towards first-in-human MRiPT application

- **0.32 T** open in-beam MRI at horizontal PBS research beam line
  - ✓ Installation and commissioning of **MR scanner** and **Faraday cabin** on mobile **air-cushion platform** completed
  - ✓ Developed dedicated positioning system and MRI receiver coil
  - ▫ Validation of **workflow** for **first patient treatment** with static target volume is ongoing



In-beam MR scanner at proton PBS beam line

In-cage view of MR scanner

RF cabin with in-beam MR scanner on air-cushion transporter

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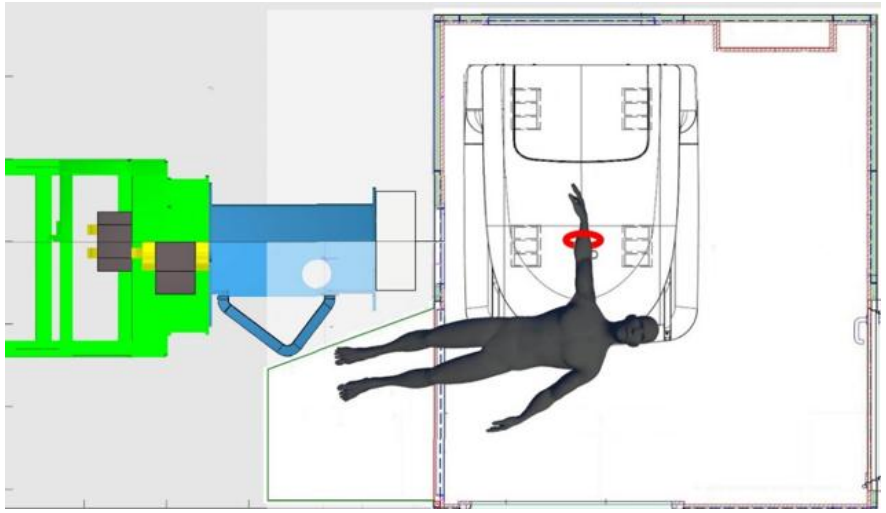
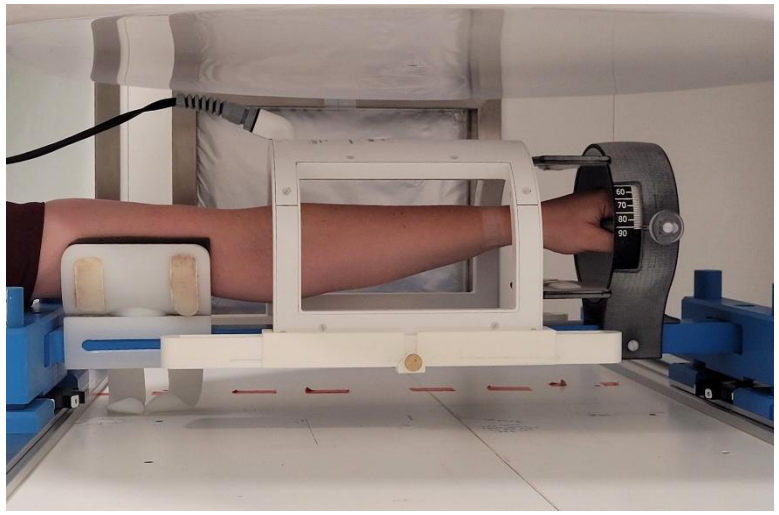


Schematic of patient positioning for soft tissue sarcoma



Arm in dedicated receiver oil and positioning system

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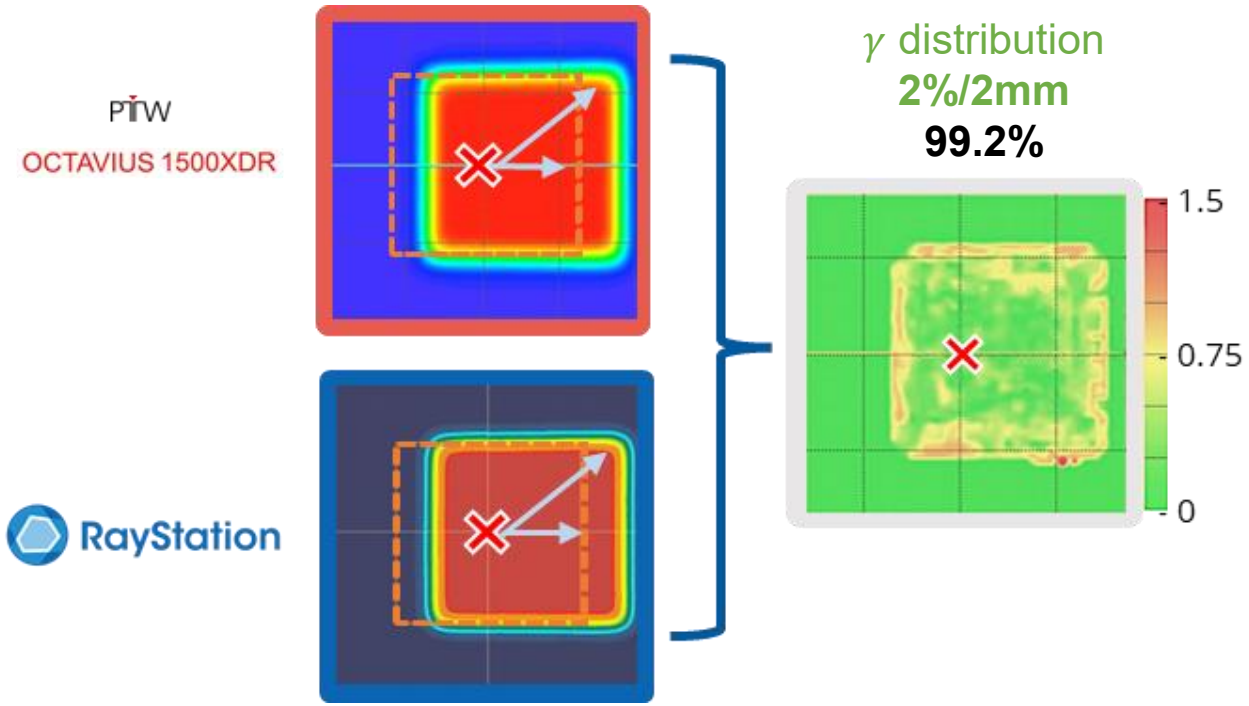
Treatment planning for MRiPT

2nd prototype in Dresden: Treatment planning in magnetic fields using RayStation

- Dosimetric validation shows satisfactory compensation of magnetic field deflection in simulation and measurement



Courtesy: M. Cobanaj (OncoRay)

Treatment planning for MRiPT

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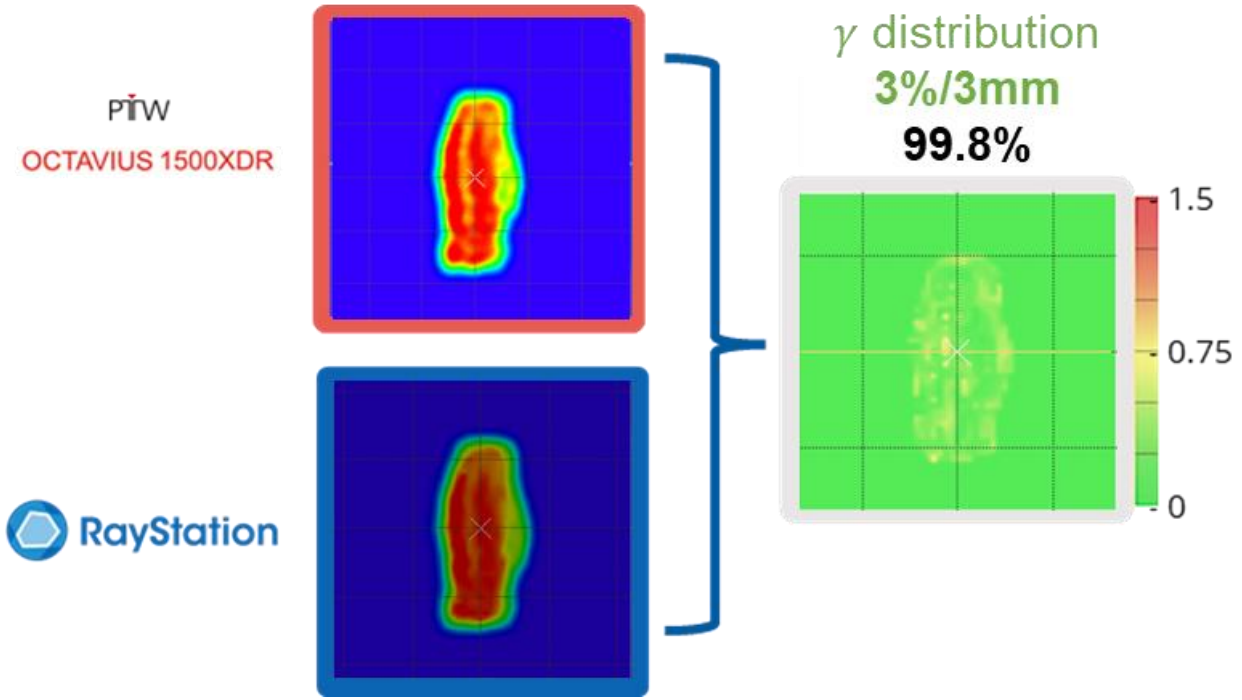
RaySearch Laboratories



Courtesy: M. Cobanaj (OncoRay)

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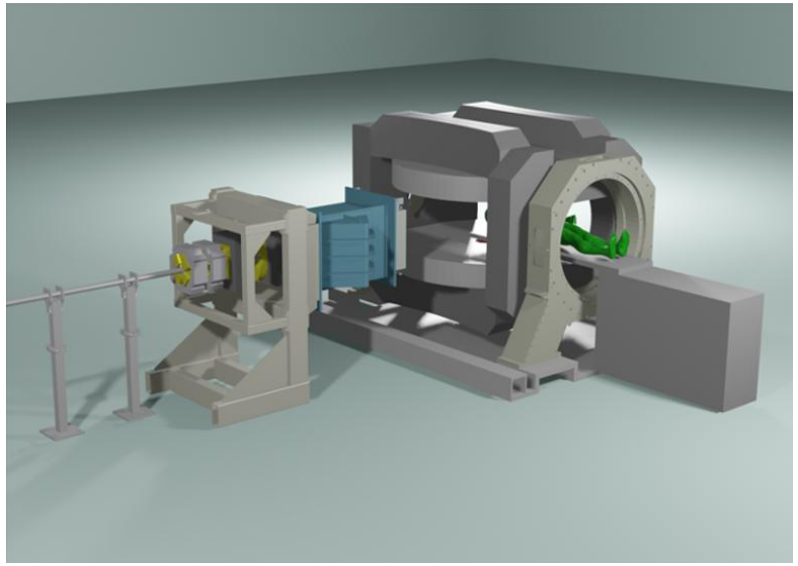
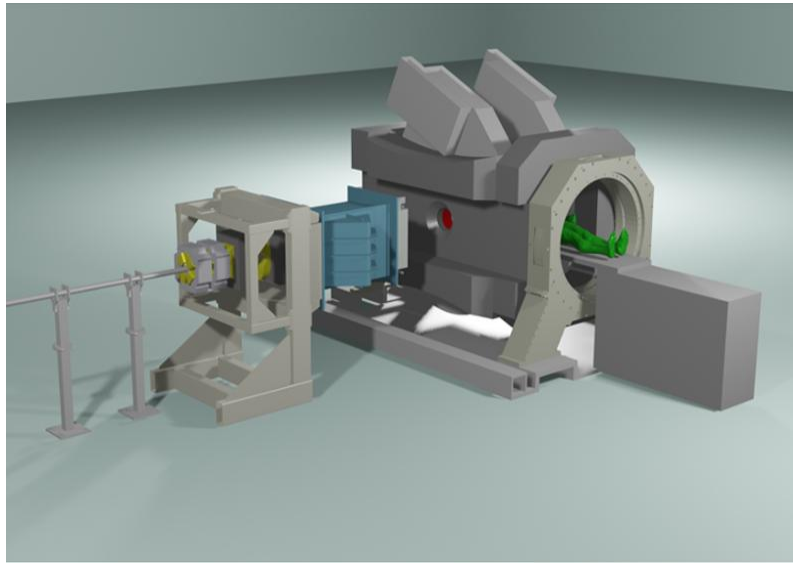
Hardware Developments towards MRiPT

3rd prototype in Dresden: whole-body, real-time MRI and beam gating

- 0.5 T whole-body bi-directional in-beam MRI at horizontal proton PBS research beam line
  - ✓ 2021: Development with industrial partners based on “Aurora-RT” LINAC-MR from Alberta group
  - ✓ 2023: Delivery and installation of MRI system at OncoRay completed



Horizontal magnets: beam perpendicular to B_0 field



Vertical magnets: beam parallel to B_0 field

Hardware Developments towards MRiPT

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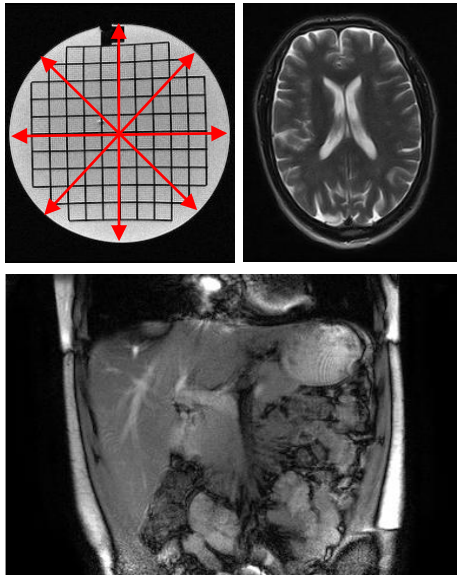
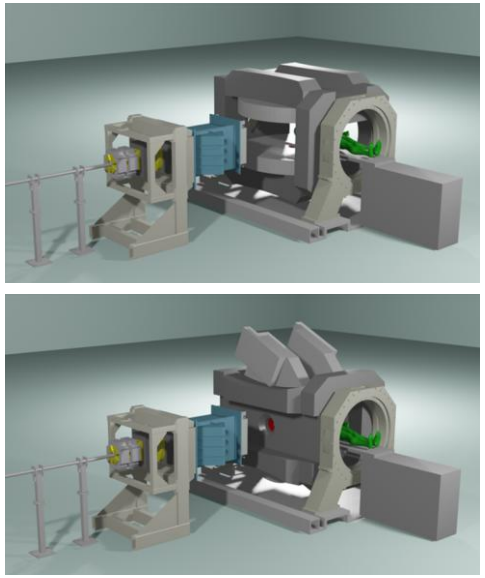
Hardware Developments towards MRiPT

Research Questions

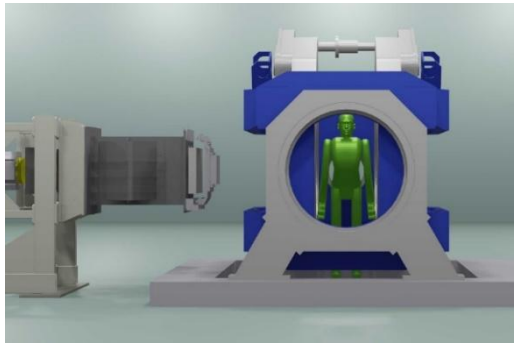
Image quality sufficient for **target tracking?**



Impact of magnetic **field direction**?



Upright MRiPT feasible and beneficial?



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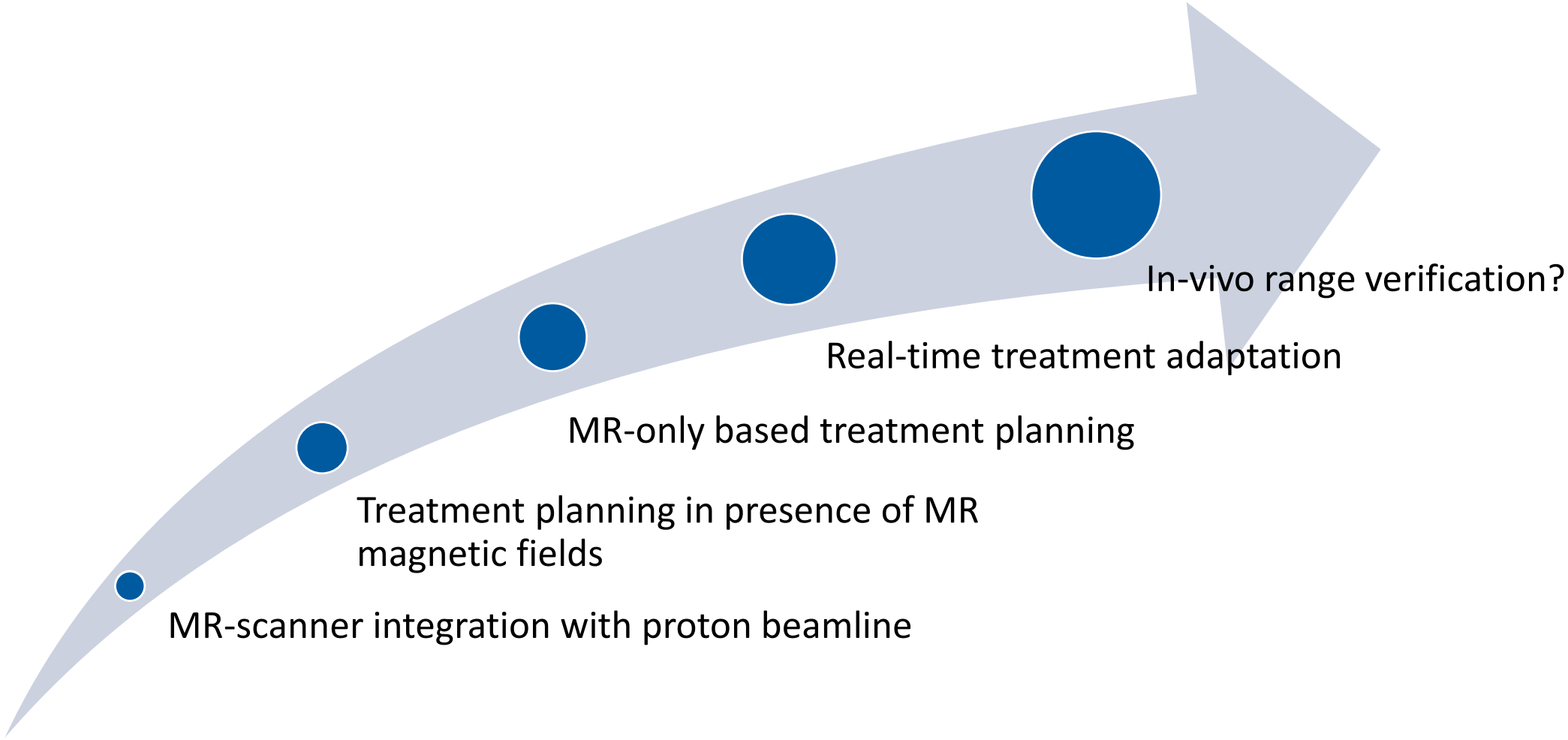
Roadmap to in-beam MRI guided proton therapy



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