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Imaging for Proton Treatment Setup and Verification

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Acknowledgements

- T.J. Whitaker; Mayo Clinic
- Hiroki Shirato, Kikuo Umegaki; Hokkaido University
- Mark Pankuch; ProCure
- Alessandra Bolsi, Tony Lomax; PSI
- Sung Park; McLaren
- Jonathon Farr; St. Jude
- Lei Dong; Scripps

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Proton vs Photon IGRT

- In the past 15 years IGRT for x-ray therapy has evolved and matured
    - EPID
    - kV Radiographic systems
    - CBCT
    - MR Linacs
- Proton therapy IGRT has lagged behind
    - Market size
    - Different needs, priorities in proton therapy

Photon IGRT Systems

- What is the purpose of the system?
  - Pre-treatment setup imaging
  - Intra-fractional monitoring
  - Feed adaptive planning protocols
- Targeting strategy
  - Bony anatomy
  - Fiducials
  - Soft tissue visualization

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Proton IGRT Considerations

- Delivery system constraints
  - Gantry geometry
  - Treatment modality
- Efficiency
  - Proton treatment rooms are expensive
  - Precise setup critical – protons more sensitive to changes in volume, pose
- Targeting goals
  - Anatomy targeting for protons different than for photons

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Photons: Radiographic Localization

- Suitable for when bony anatomy is a good surrogate for target tissue, or when fiducials are placed
- Gantry mounted
  - MV EPID
  - kV Systems
- Fixed position imagers
  - BrainLab ExacTrac
  - Hokkaido fluroscopic system

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Gantry Mounted Imagers

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Photon Gantry Mounted Imagers

- Use of treatment beam for imaging
  - Imaging during treatment
  - BEV imaging – Important 'Sanity Check' on patient setup, other IGRT procedures
- Rotating gantry facilitates CBCT

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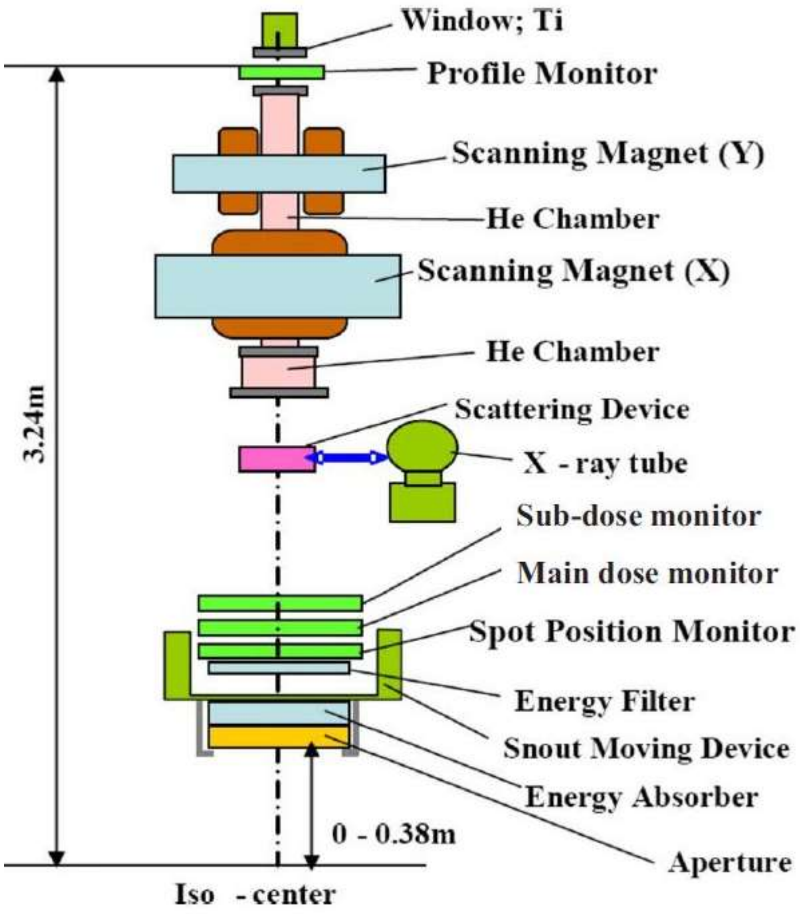
BEV Imaging in Protons

- Small spot size important for scanning proton facilities
- X-ray tube in a scanning nozzle introduces atmospheric drift length; larger spot size
- Can't image during proton treatment



Gillin et al., Med Phys 37 (2010) p. 154

Gated Spot Scanning Proton Beam Therapy System with Real-time Tumor-tracking (RT) Technology

Real-time Tumor-tracking Radiation Therapy

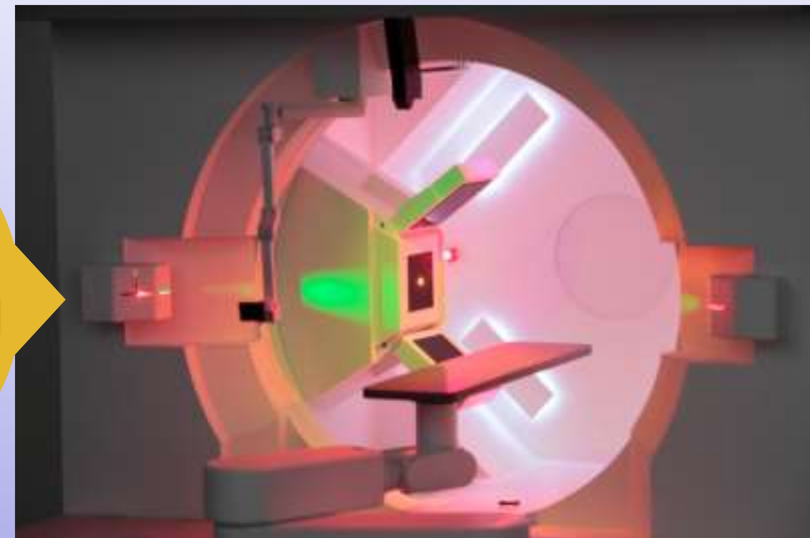
Developed by Hokkaido University

Integration

Spot scanning Proton Beam Therapy

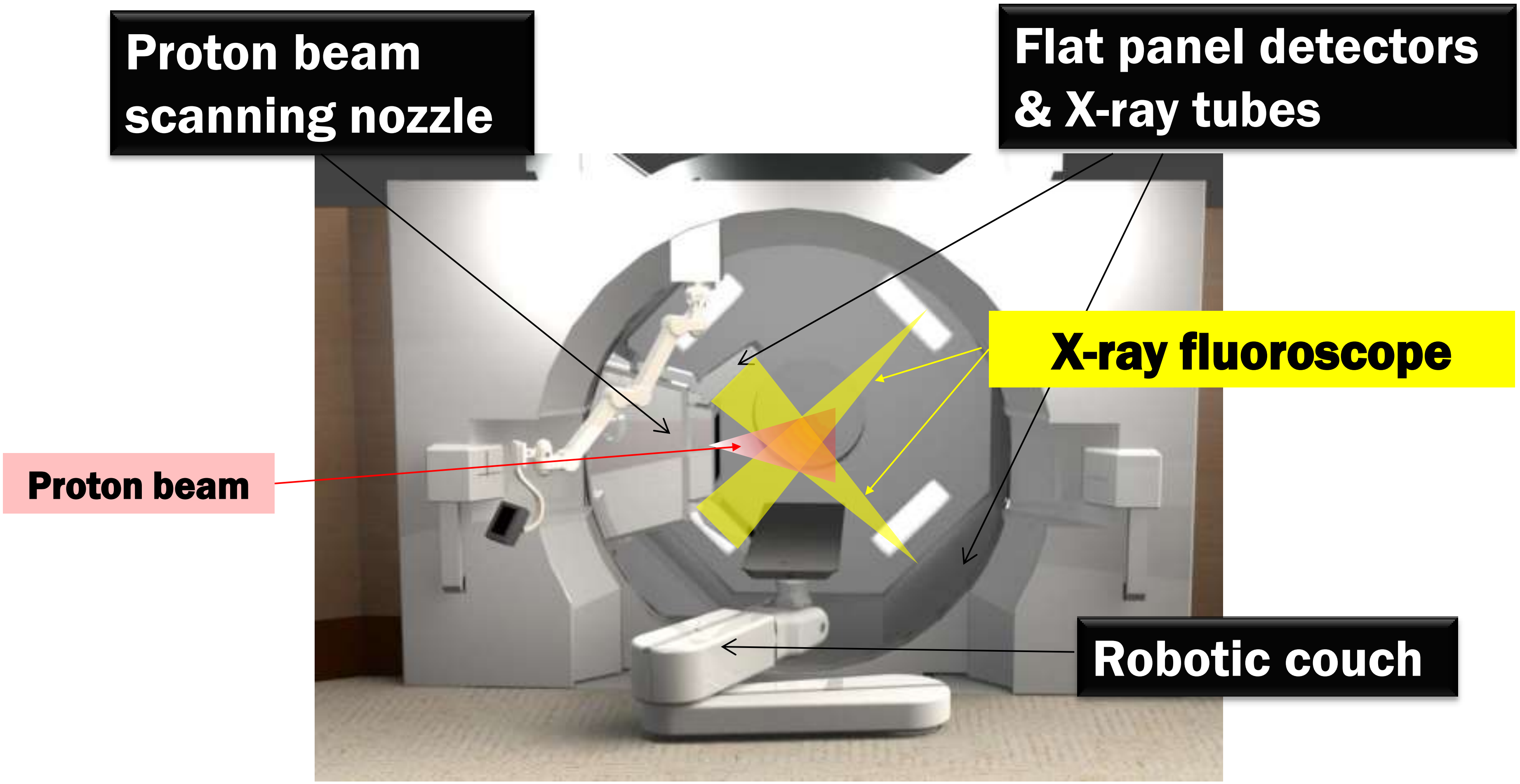
Developed by Hitachi, Ltd.

HITACHI
Inspire the Next



New PBT System

Cone-beam Computed Tomography, Real-time tumor-monitoring, and gated proton spot-scanning beam therapy.

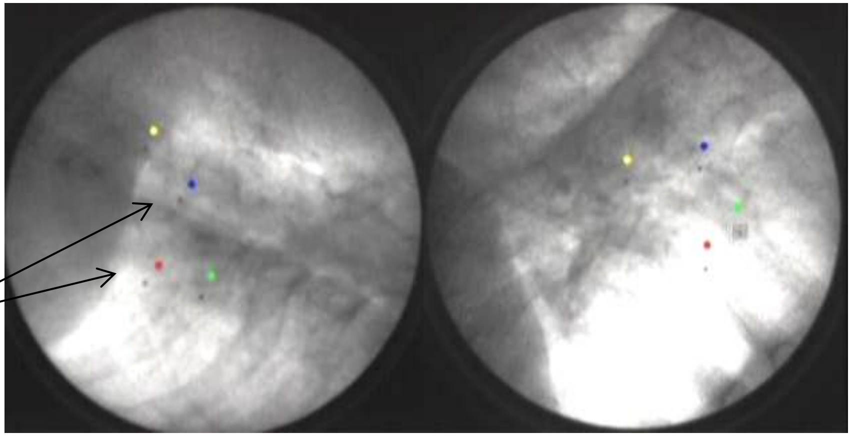


Hokkaido University ; Supported by a grant from the Japan Society for the Promotion of Science (JSPS) through the “Funding for World-Leading Innovative R&D on Science and Technology”(FIRST program).

High precision positioning system (2D, 3D, and 4D)

- ✓ 2D, 3D positioning based on bony anatomy and soft tissue matching (radiography, CBCT)
- ✓ 4D positioning (real-time tumor-monitoring system)
- ✓ Verification
  - ･fiducial migration (radiography, CBCT)
  - ･inter-fractional variation of proton range (CBCT)

Gold marker



3 + 1 dimensional positioning
(real-time tumor-monitoring system, Hokkaido University)

Limited Gantry Proton Systems

- Proton gantries are large and expensive
- Limited number of beam angles gives adequate plan quality for a number of treatment sites
- Lose the gantry support structure for imaging equipment

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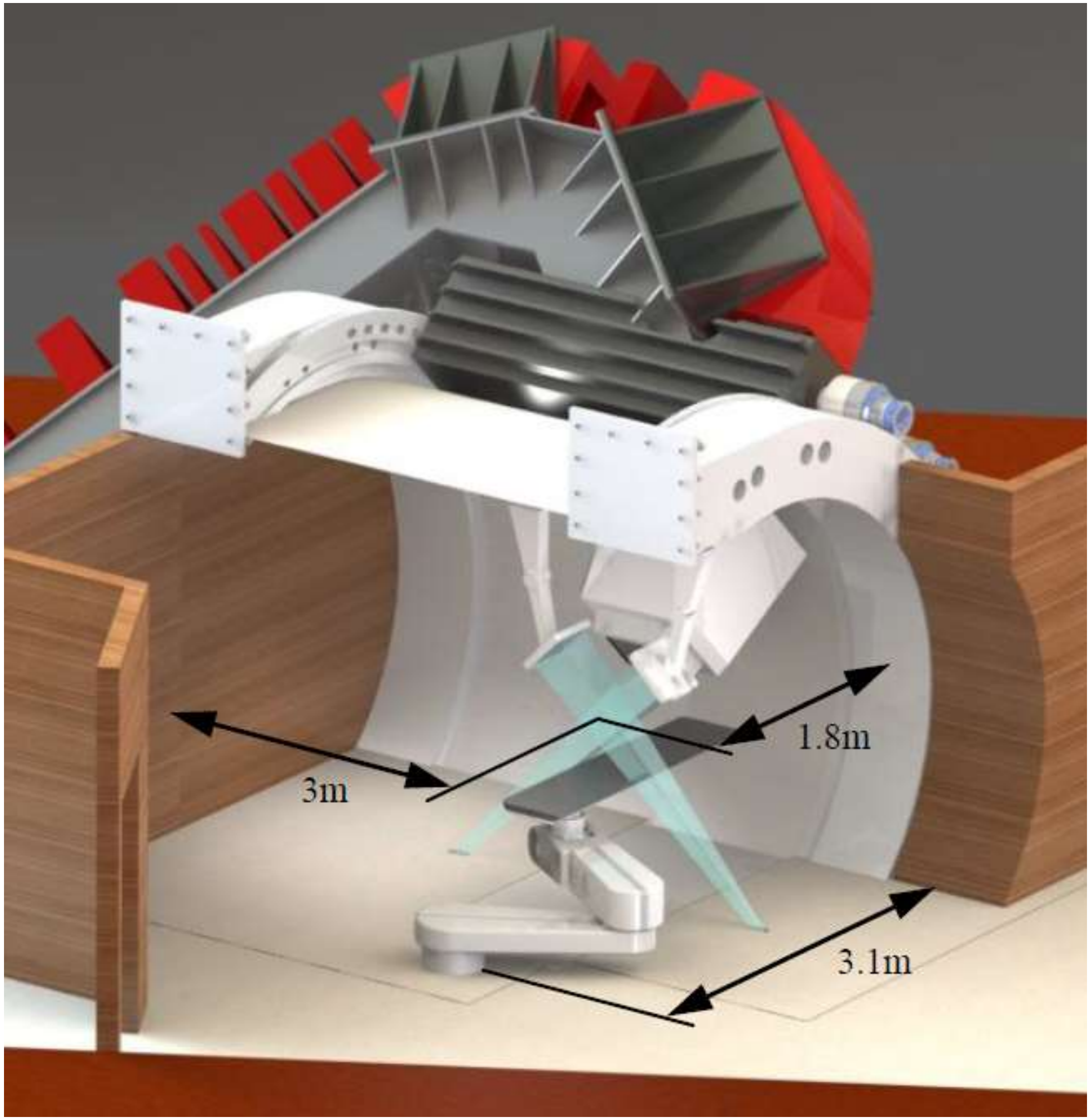
ProCure Fixed Beam Imaging

Image from ProCure Website

Mayo Clinic Half Gantry



- Fast Intra-Tx imaging at any gantry/couch position
- Fluoroscopy capable
- Large FOV
- No moving parts – stable imaging isocenter
- 6 DOF matching software

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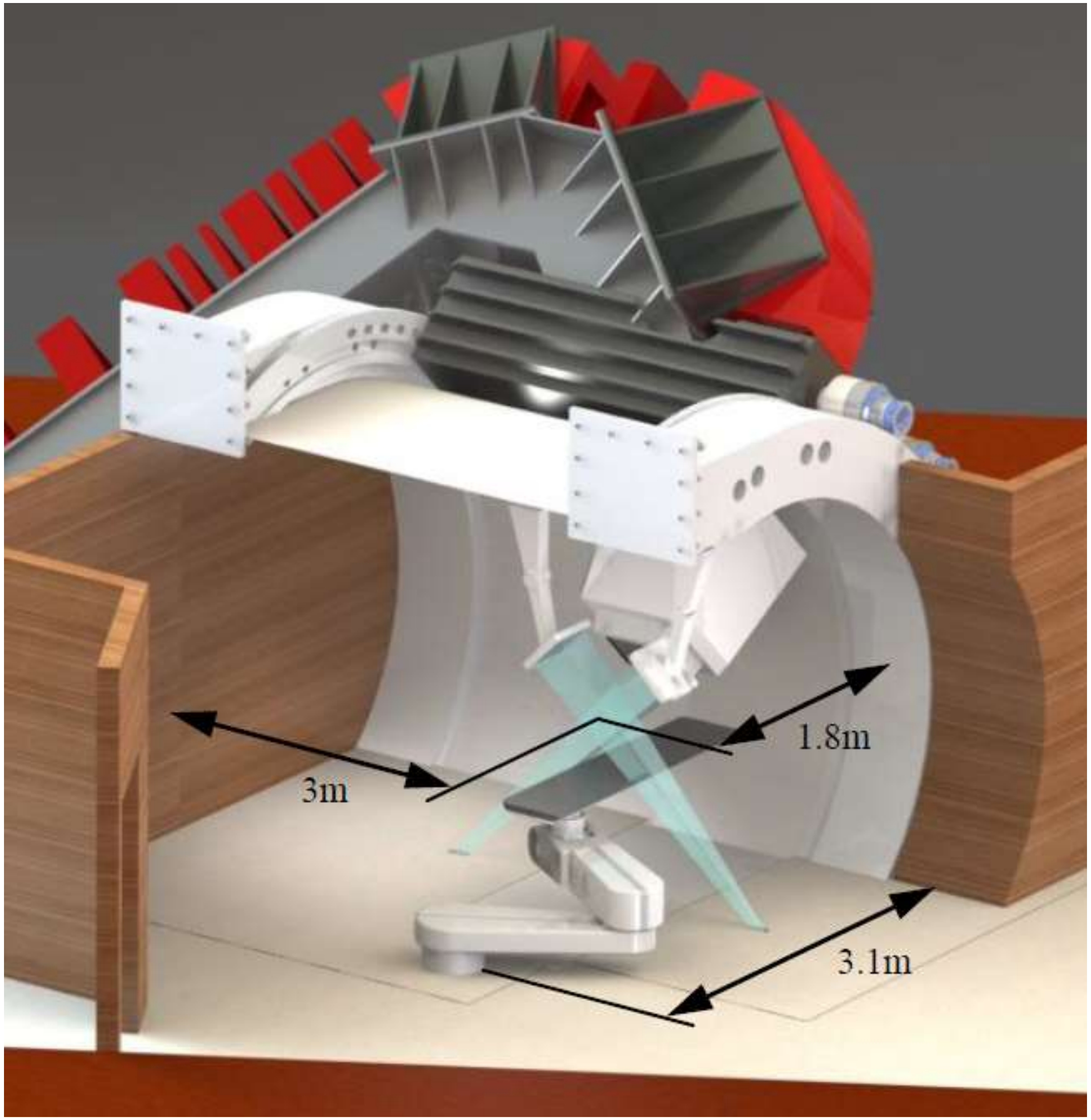
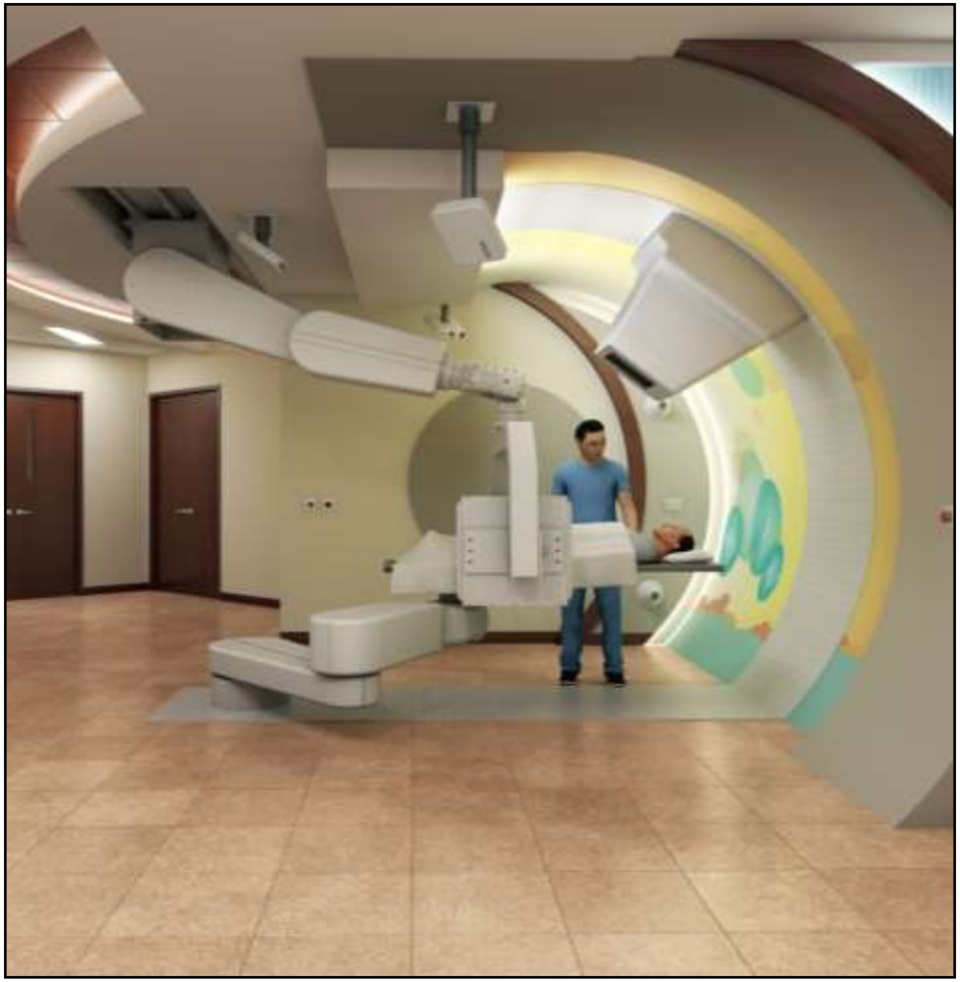
Mayo Clinic Half Gantry



- Limited to two imaging angles
- FOV is 30 cm x 30 cm at isocenter – may not see center of tumor volume for non-isocentric plans

ProTom Robotic C-Arm



- Rotates to acquire radiographic projections for setup on 2D images
- Robotic arm allows for mobile imaging isocenter
- CBCT capable

Courtesy of Sung Park

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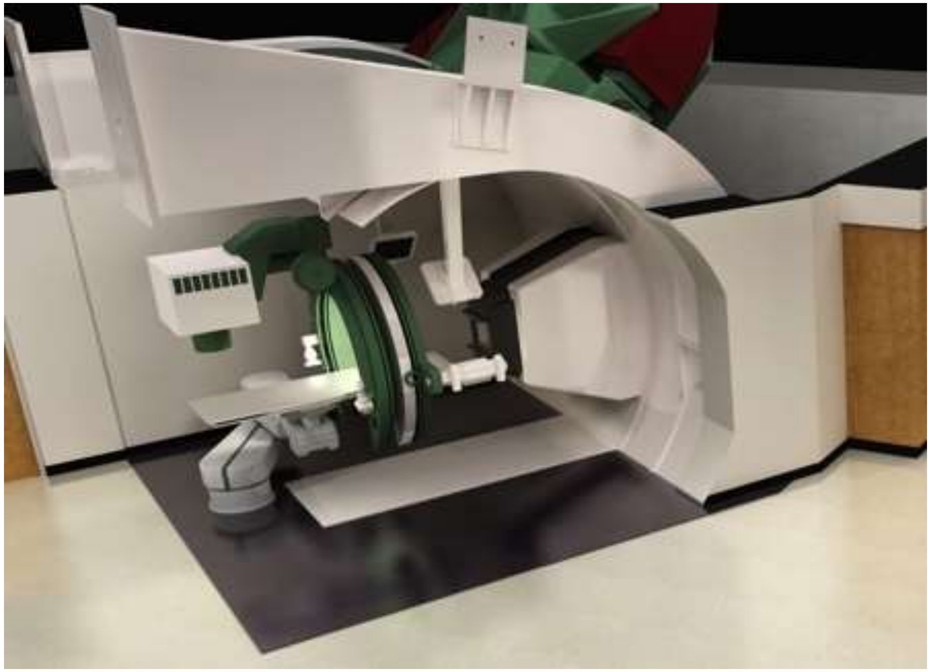
ProTom Robotic C-Arm

- Imager Retracts to avoid interference with therapy nozzle, rotating couch

Courtesy of Sung Park

St. Jude Hitachi Robotic C-Arm



- Retractable C-Arm for radiographic/CBCT localization
- St. Jude IGRT protocols rely heavily on CBCT
- Emphasis on imaging dose reduction

Courtesy of Jonathon Farr

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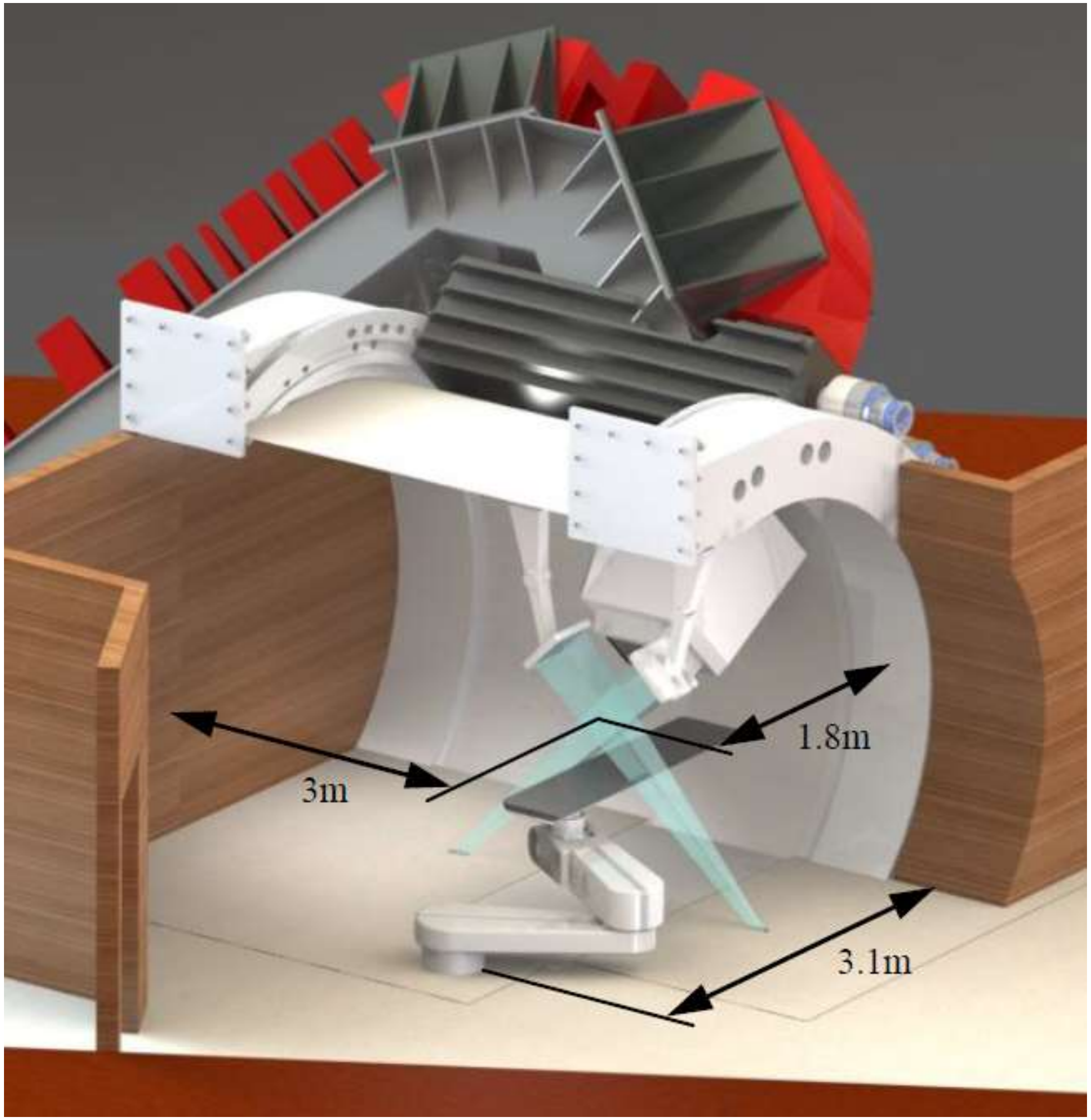
Mayo Clinic Half Gantry



- Limited to two imaging angles
- FOV is 30 cm x 30 cm at isocenter – may not see center of tumor volume for non-isocentric plans
- Not CBCT capable

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Utility of CBCT for Protons

- Bony anatomy is often a poor surrogate for target/critical anatomy
- Fiducials or CT localization required in cases where we expect movement of soft tissues relative to radiographically evident bony anatomy
- Photons: Place target tissue at isocenter, don't worry about 'upstream' bony anatomy
- Protons: ??

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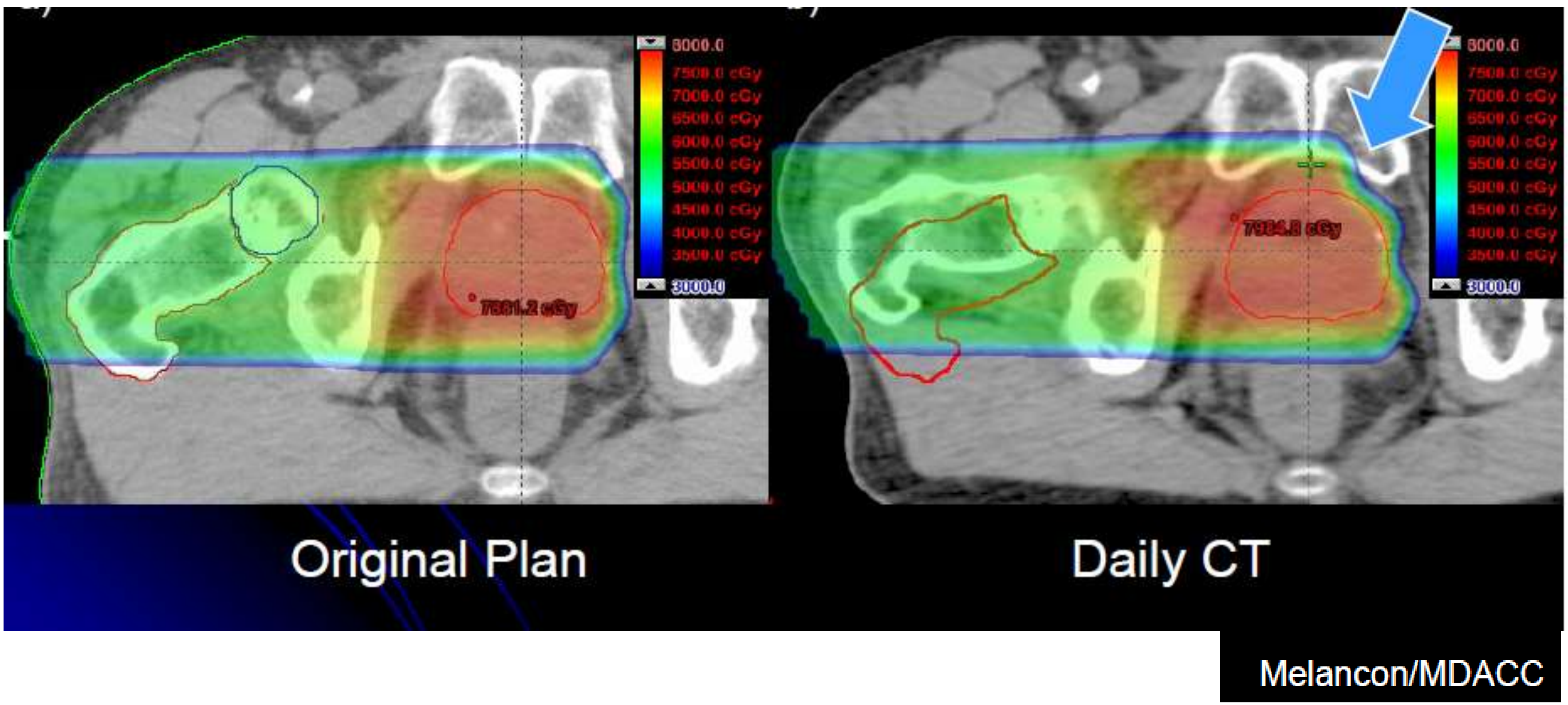
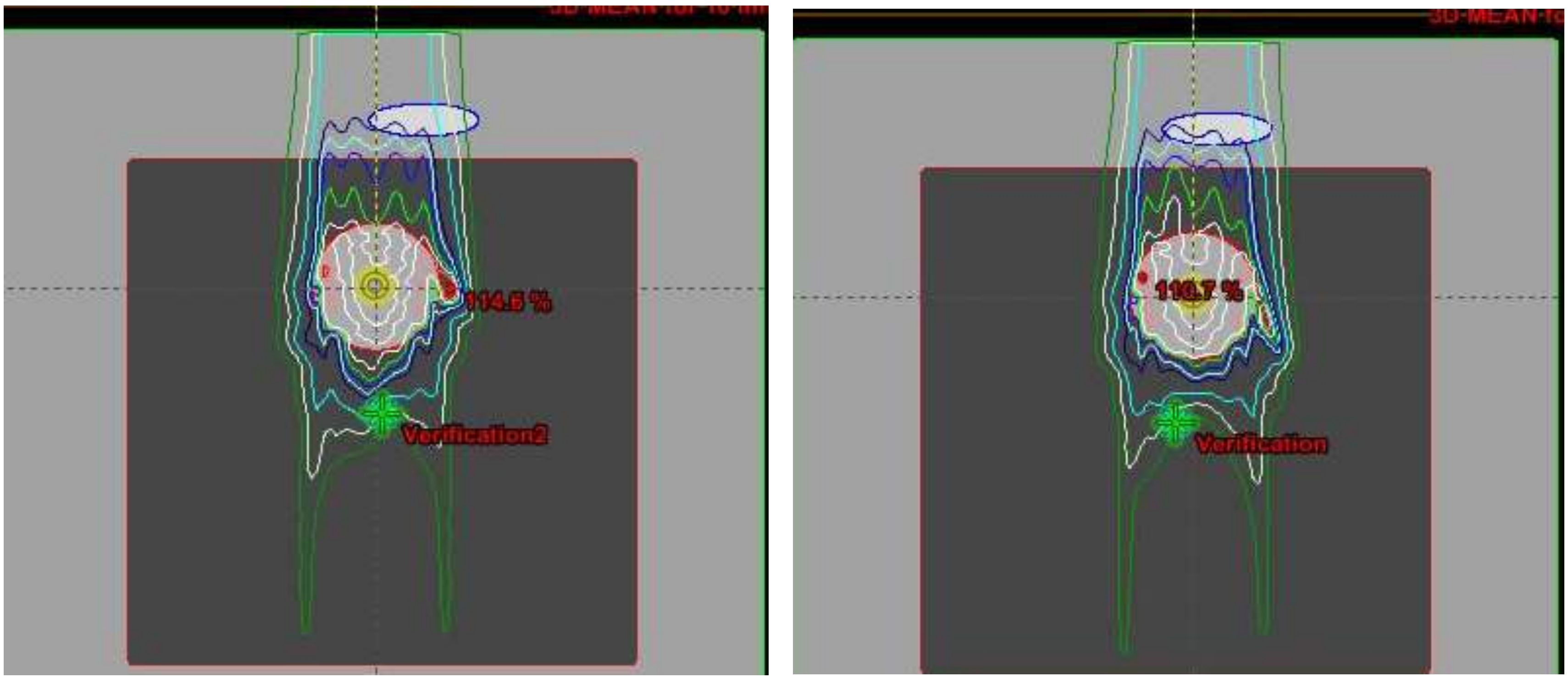
CT Localization for Protons: Pelvis

- Change in position of bony anatomy alters dose distribution
- CT localization may be of limited use



CT Localization for Protons: Lung

- Change in position of rib causes minimal disturbance of dose distribution



- CT localization of lung tumors desirable for proton therapy

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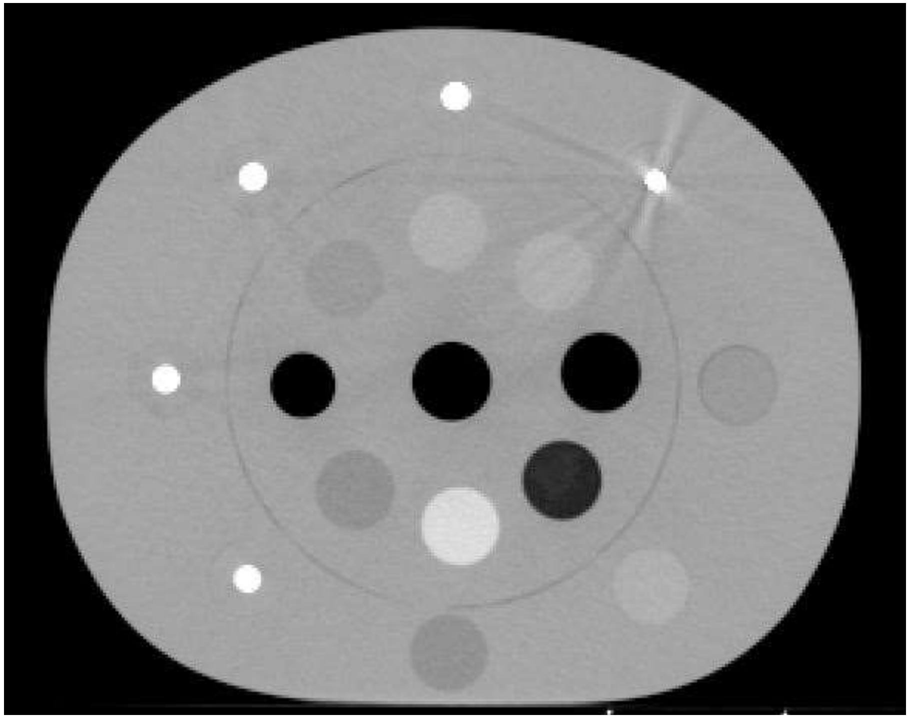
CBCT for Lung?

- Mayo proton facilities will be scanning beam only
- Treatments of mobile tumors will probably require gating/breath hold
- Free-Breathing CBCT imaging a poor reference for gated/breath held treatment
- Gated/breath held CBCT not impossible, but not easy

CBCT for Adaptive Protocols

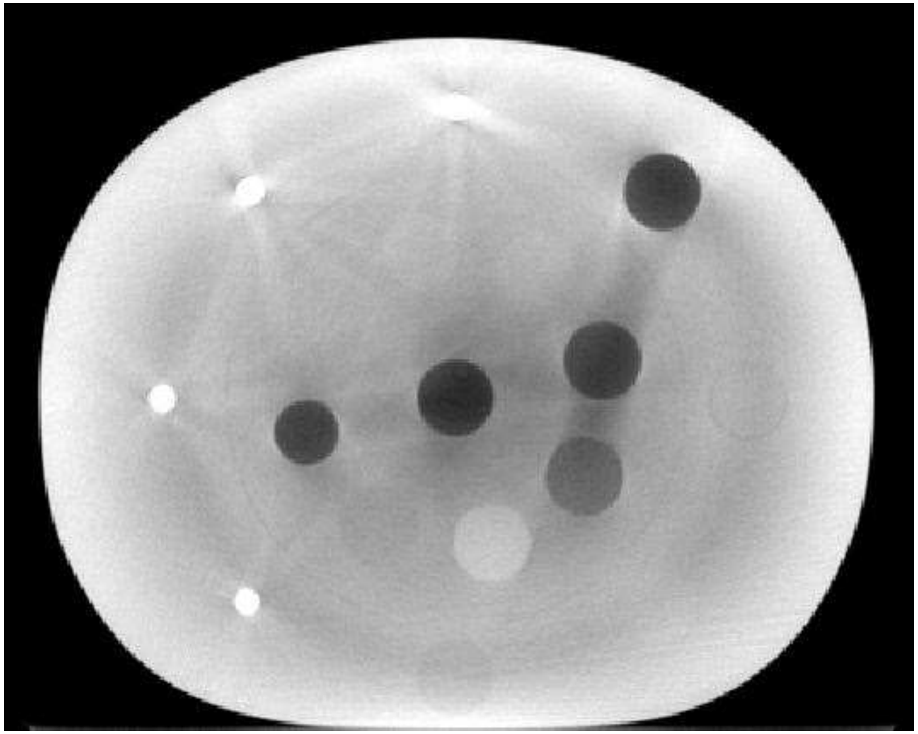
- Proton dose calculation is extremely sensitive to CT number accuracy
- CT number accuracy / consistency not generally a priority in CBCT
- Increased scatter relative to helical CT degrades imaging performance

Helical/CBCT Phantom Images



Helical CT

CBCT



Images Courtesy of T.J. Whitaker

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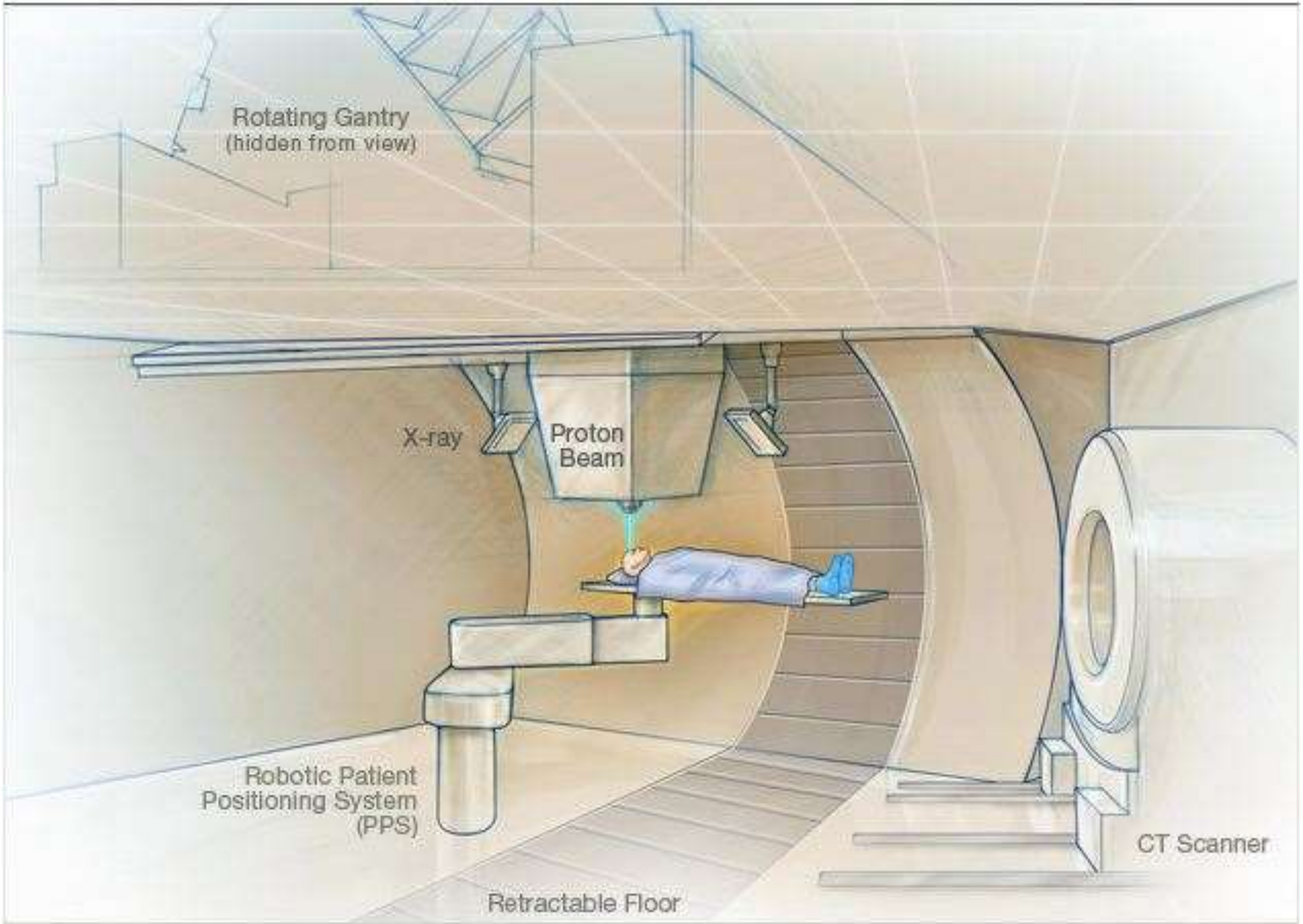
CT on Rails



CT on Rails

- Robot moves patient to imaging isocenter
- CT translates over patient for imaging
- Robot moves patient back to treatment isocenter while CT registration is performed
- Helical CT image quality
  - Images for adaptive imaging
- Fast image acquisition
- 4D imaging capability

Imaging Outside Treatment Room

- To increase throughput some imaging and treatment preparation has been moved outside the treatment room
- Patients should not be in the treatment room unless they're being aligned for treatment or being treated
- Various approaches
  - Immobilization/treatment preparation
  - Treatment localization
  - Imaging for adaptive planning protocols

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Treatment Preparation

- Some treatment sites require difficult/time consuming preparation and immobilization
  - CSI
  - Brain cases – fluid in surgical sites
  - Head and Neck – changes in mask fit
- Immobilize and image patient outside treatment room to verify that patient pose is correct

Treatment Preparation Outside Tx Room

- 2 rooms with robotic positioners, lasers, and fixed orthogonal imagers
- Patient is immobilized and imaged
- Images are compared to DRRs to assess patient pose, not position
- Patient immobilization can be adjusted and re-imaged with little time pressure
- When pose is correct, transported to Tx room

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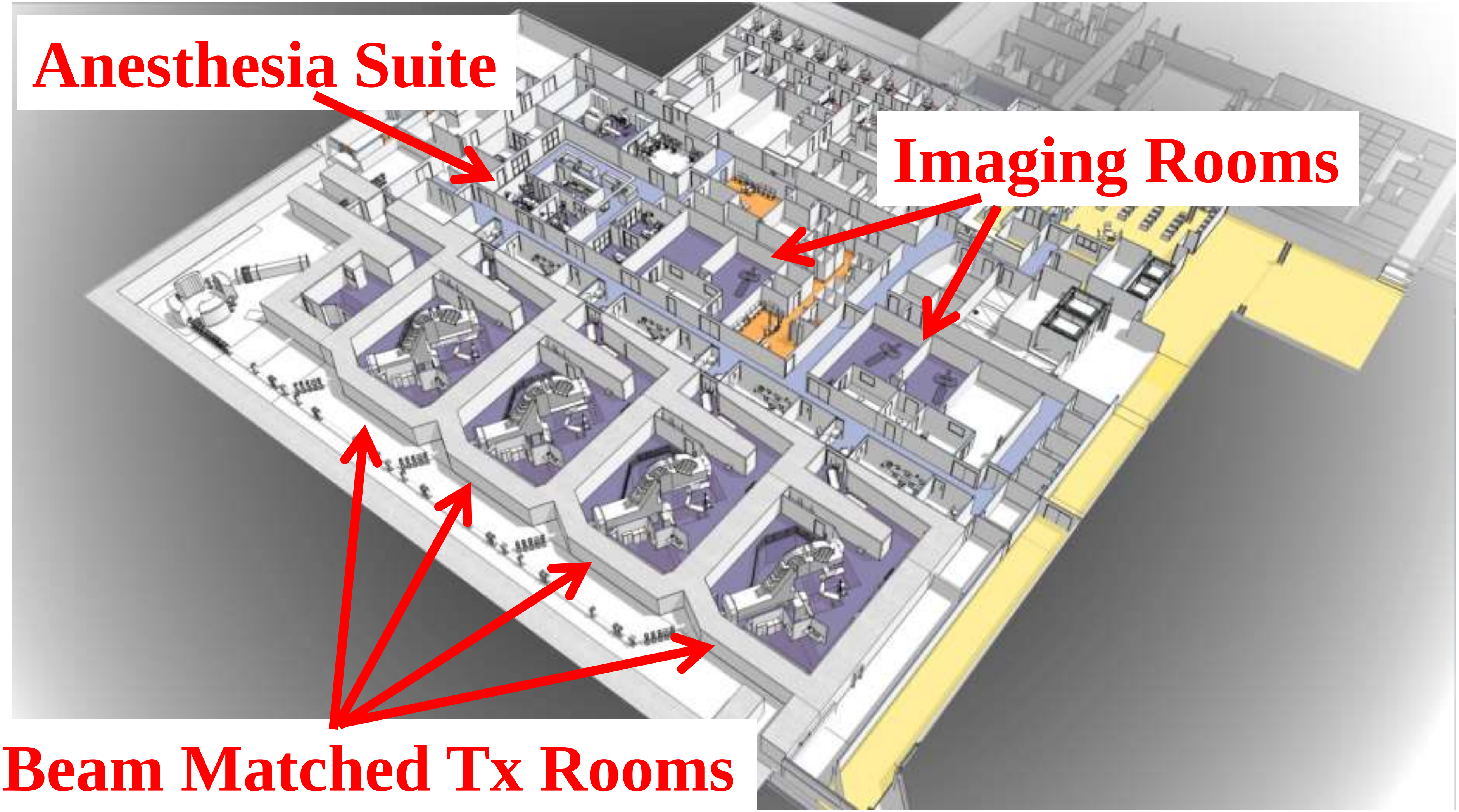
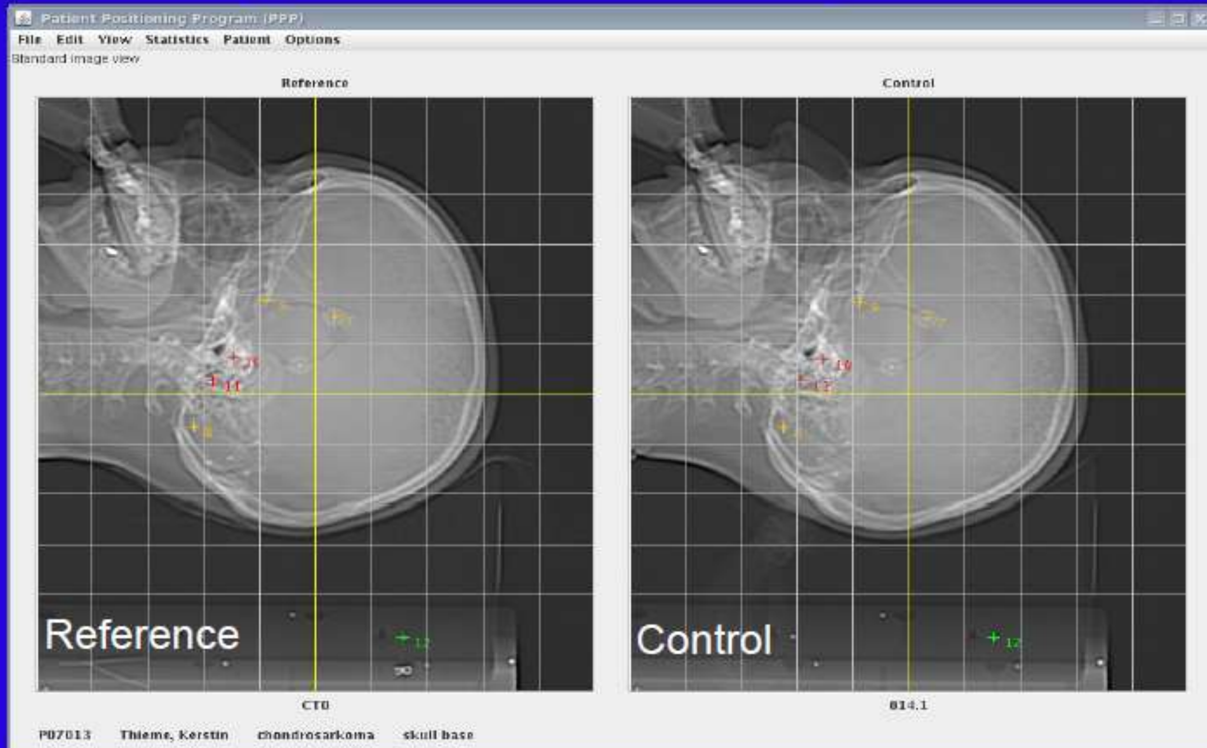
Treatment Preparation Outside Tx Room



Treatment Localization Outside Room

- In some centers treatment localization is performed outside treatment room
  - Less work in treatment room
  - Access to various imaging modalities
- Imaging isocenter in one room tied to treatment isocenter in another
  - Careful, multiroom QA protocols
  - Precise patient transport systems

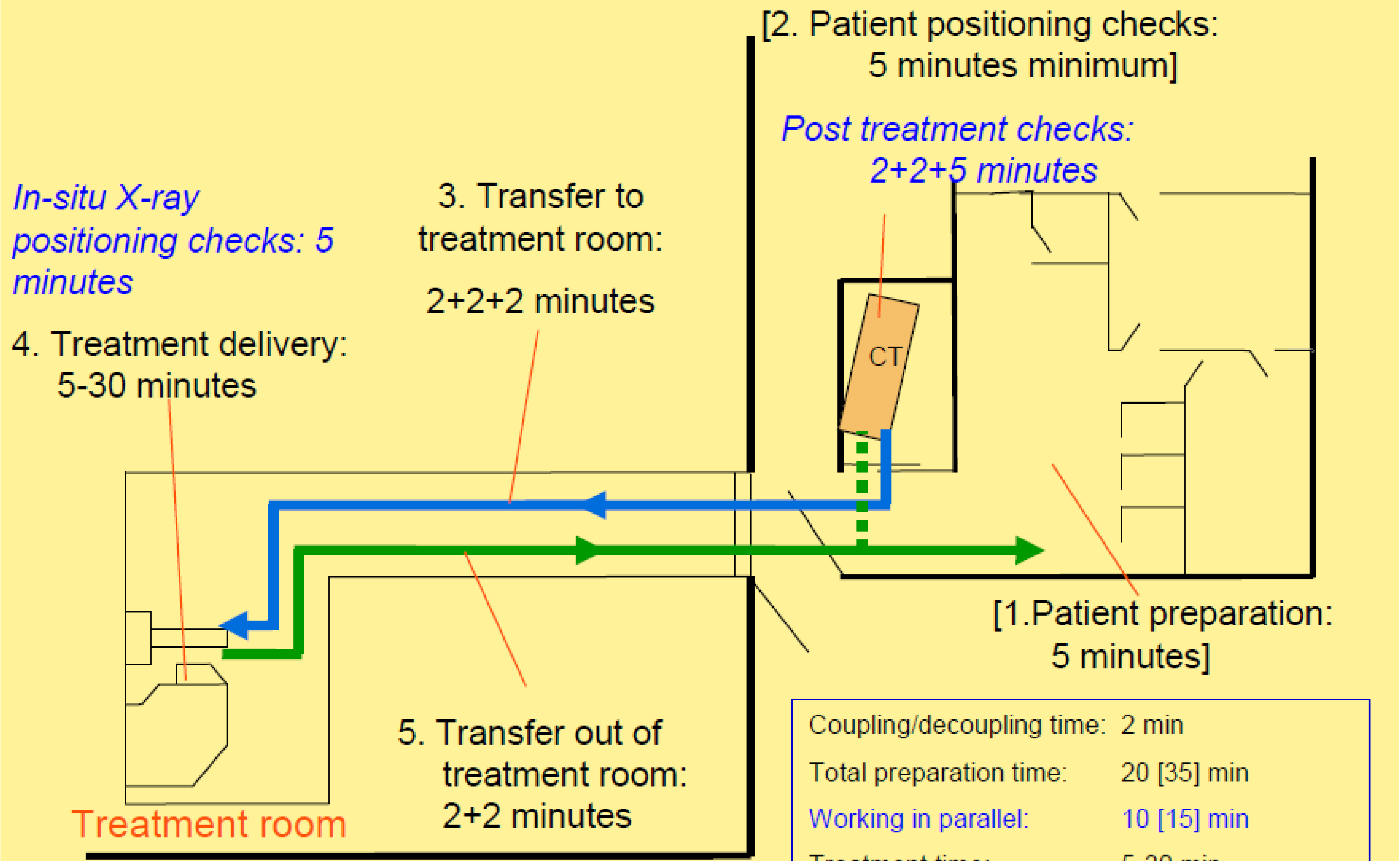
Daily Treatment Setup at PSI



Alessandra Bolsi, Tony Lomax

Centre for Proton Radiotherapy, Paul Scherrer Institute, Switzerland

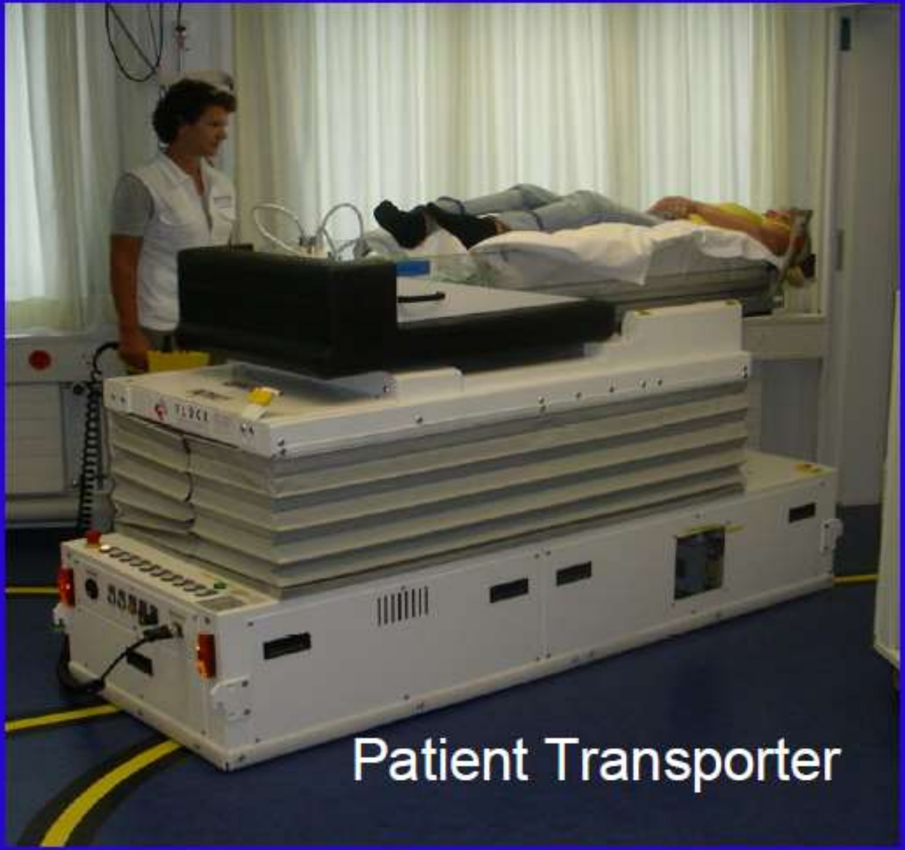
Remote patient positioning at PSI



Coupling/decoupling time:	2 min
Total preparation time:	20 [35] min
Working in parallel:	10 [15] min
Treatment time:	5-30 min

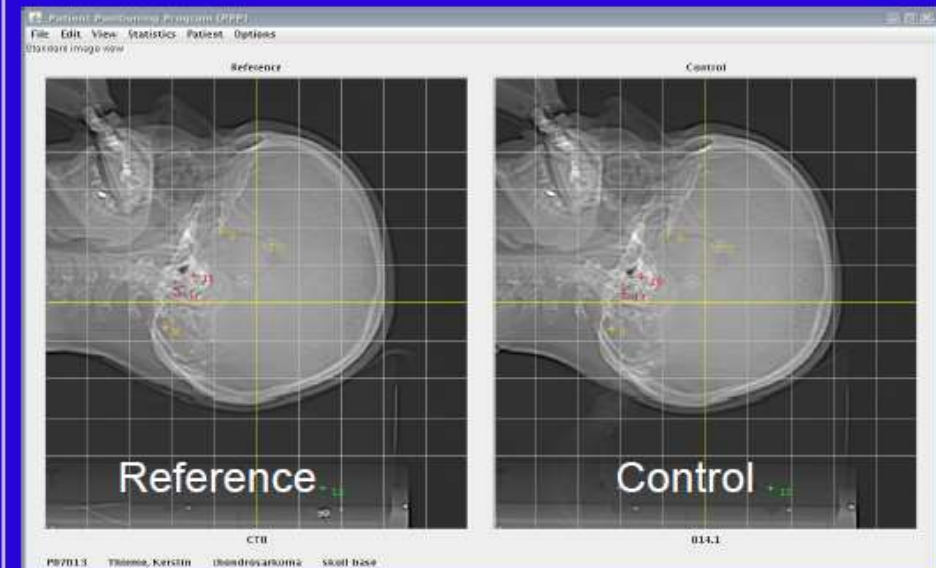
PAUL SCHERRER INSTITUT

EIPATRANS Patient Transporter



- Twin system for parallel operation
- Operatable by one person
- Guided by optical tracks
- Connecting various predefined locations:
  - → Preparation room
  - → Anesthesia room
  - → CT room
  - → Gantry room
- Table coupling at CT and Gantry
- Reliable operation
  - → Increased comfort for patient
  - → Decreased physical work for staff

Patient positioning: Remote Positioning at CT



Daily pre-treatment positioning at CT

- Horizontal and vertical scouts
- Compared against reference scouts (from treatment planning CT series).
- No axial CT scan acquired
- Online matching of anatomical landmarks

  → Semi-automatically and/or manually

  → Offsets for table coordinates at Gantry (translations only)

  → Linked to Gantry Control System (via PatBase "R&V" interface)
- Software developed in-house ("ppp")

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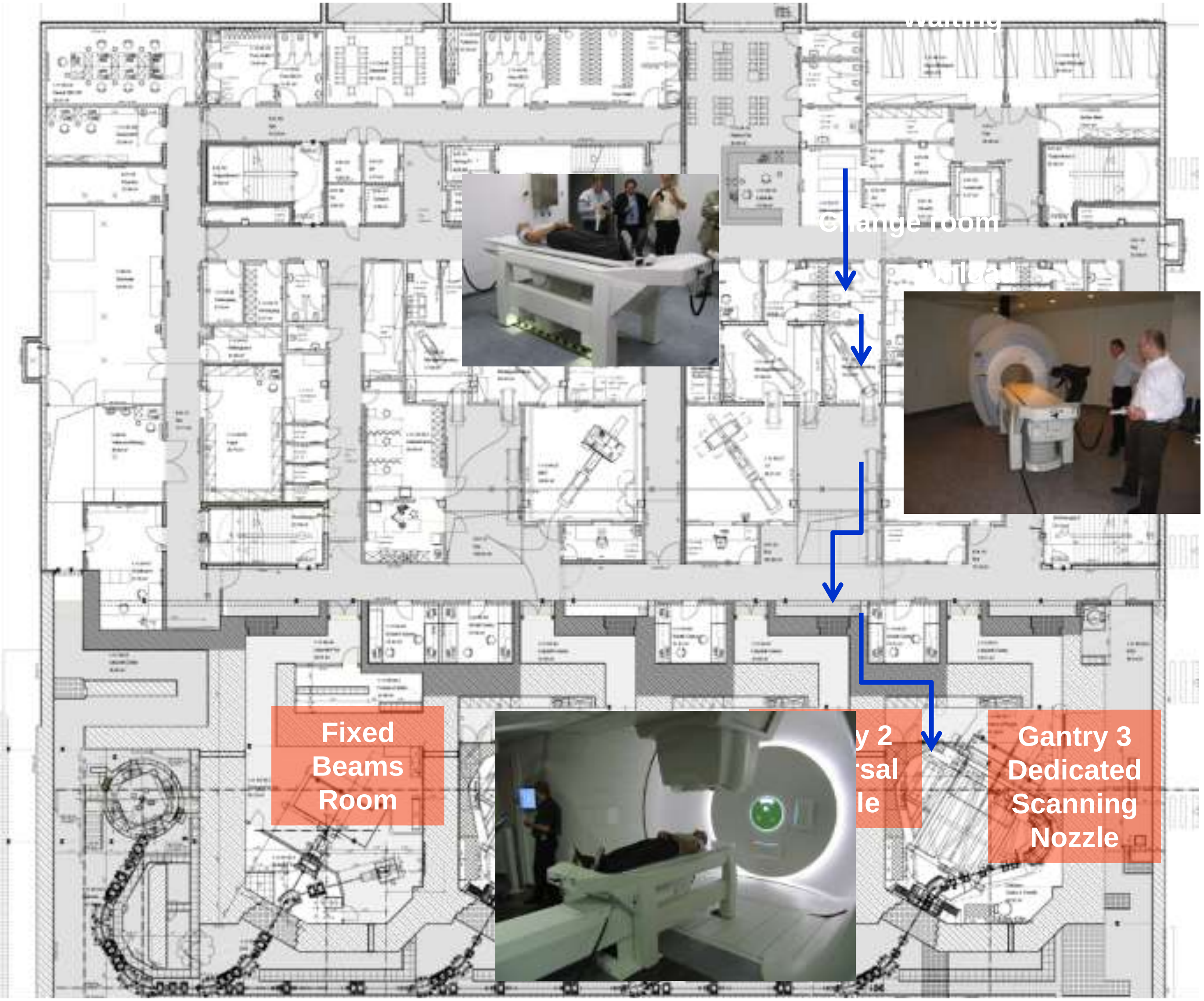
Multi Modality Remote Localization



WPE Essen

Courtesy of
Jonathon Farr

Multi Modality Remote Localization

PTC Prague

Courtesy of Jonathon Farr

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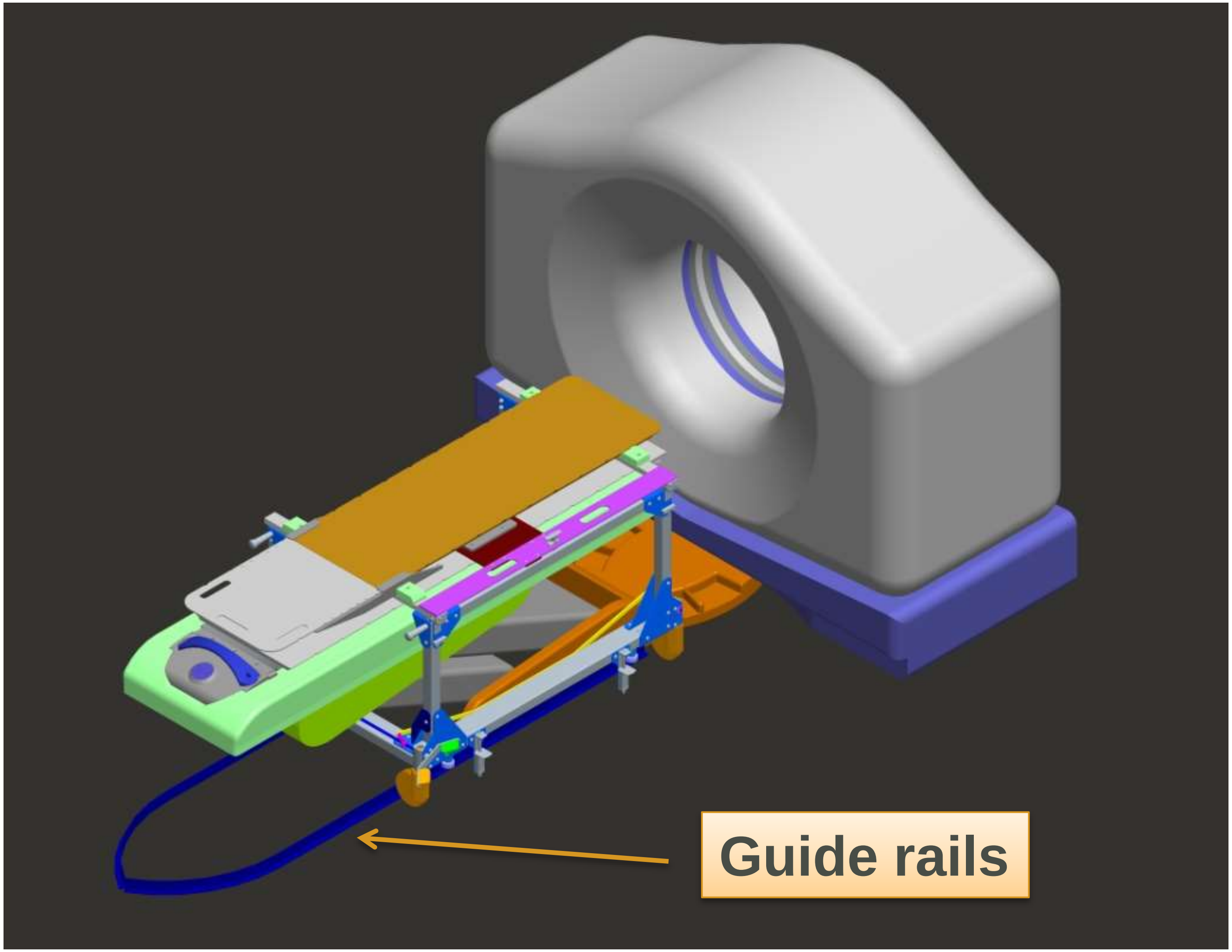
Multi Modality Remote Localization

PTC Prague

Courtesy of Jonathon Farr

CT Gurney

Load Position

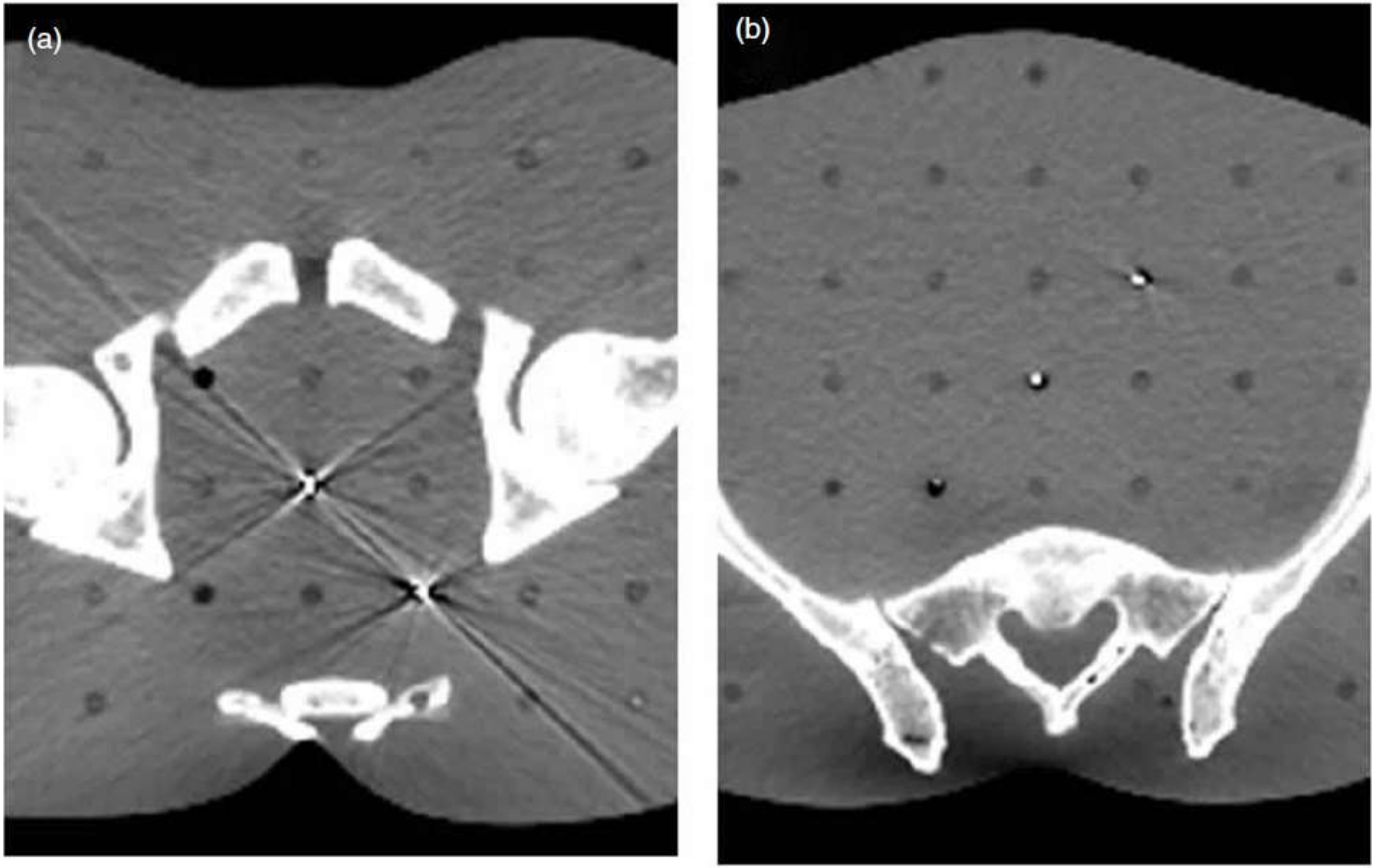


Handoff in the treatment room

Use of Fiducials

- Fiducial markers used to great effect in photon therapy in place of volumetric imaging
- Proton specific concerns with use of fiducials
    - CT artifact
    - Dose shadowing

CT Artifact from Fiducials



Huang et al., PMB 56 (2011) 5287

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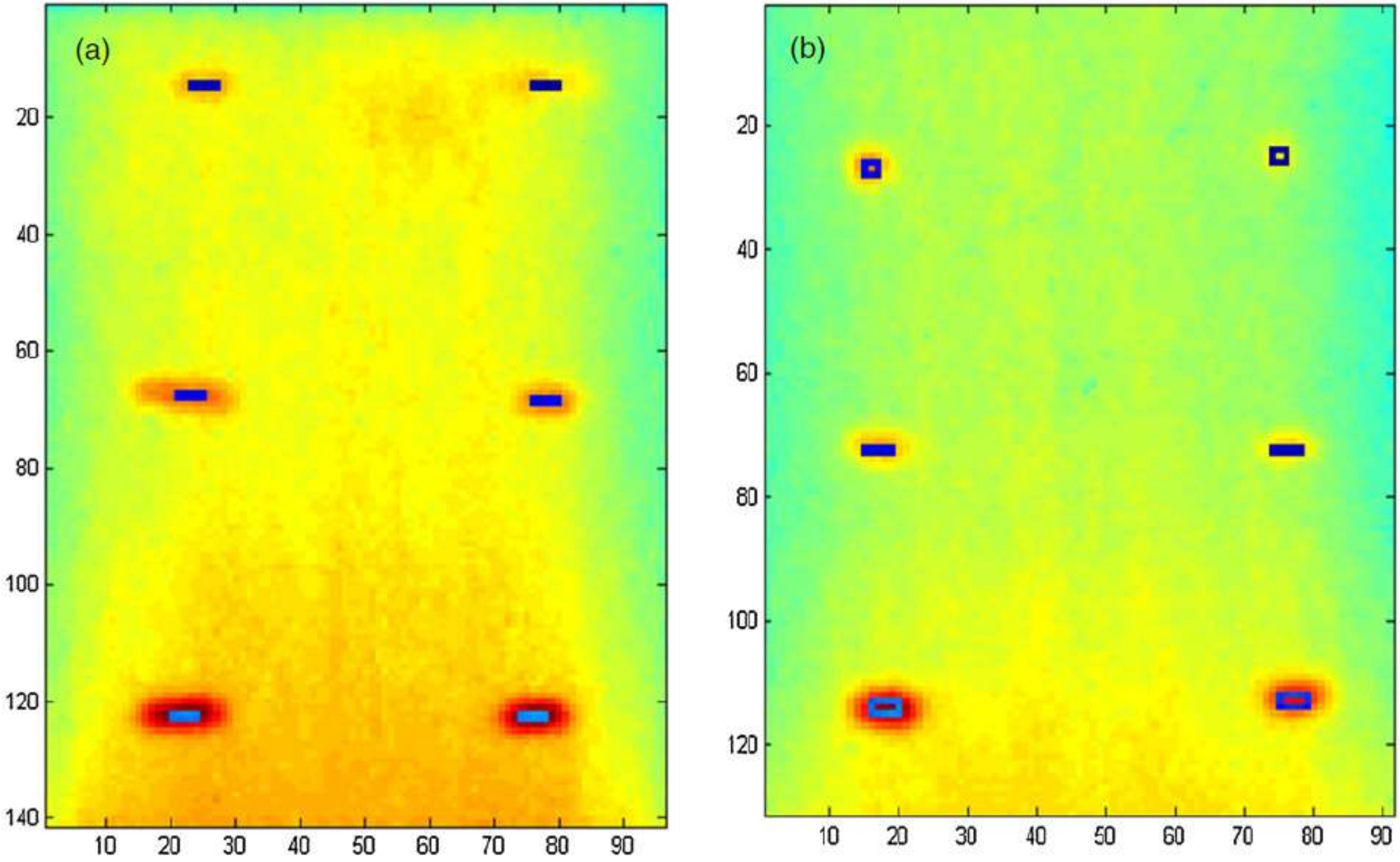
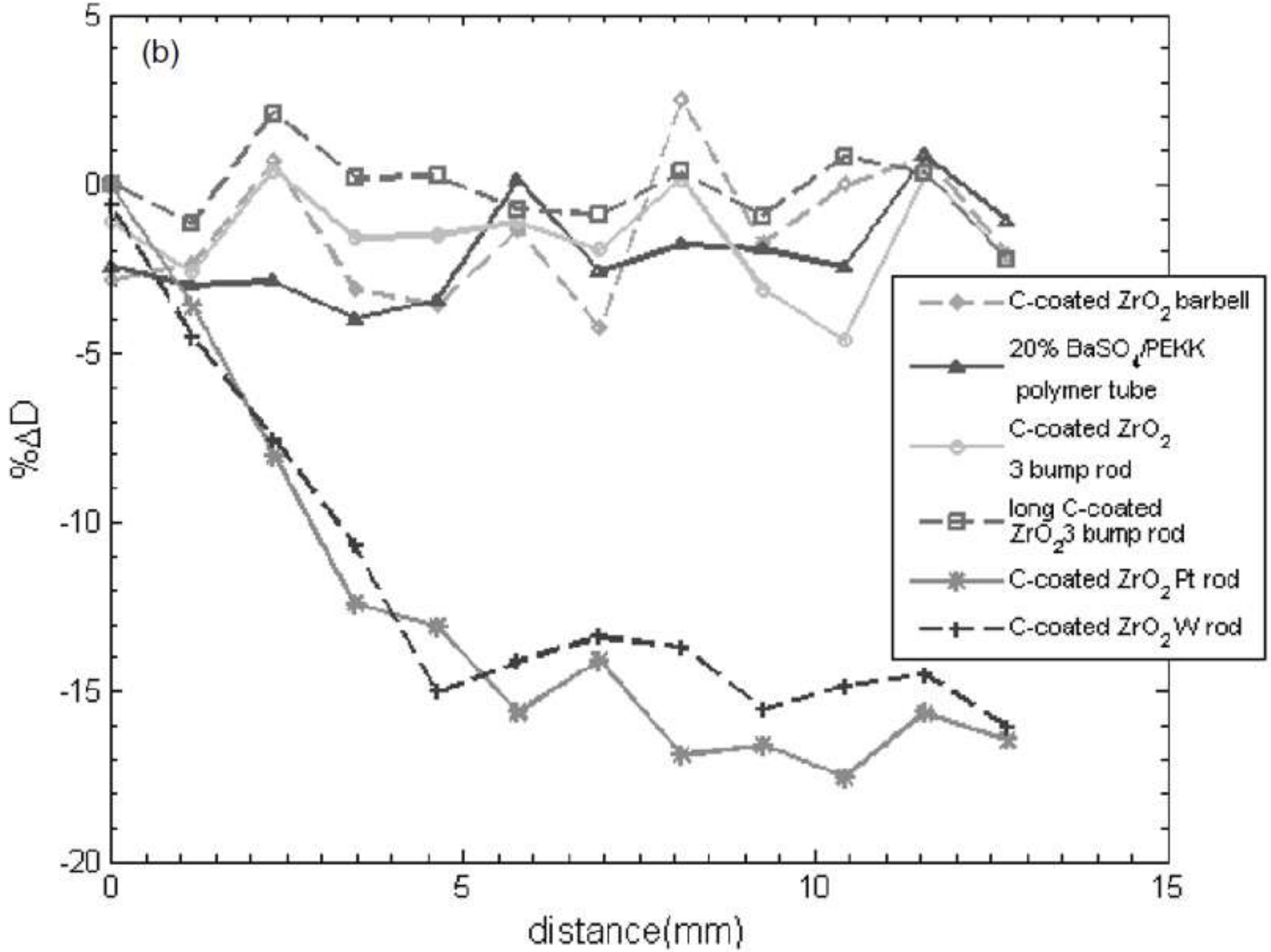
Dose Perturbations from Fiducials



Huang et al., PMB 56 (2011) 5287

Dose Perturbations from Fiducials

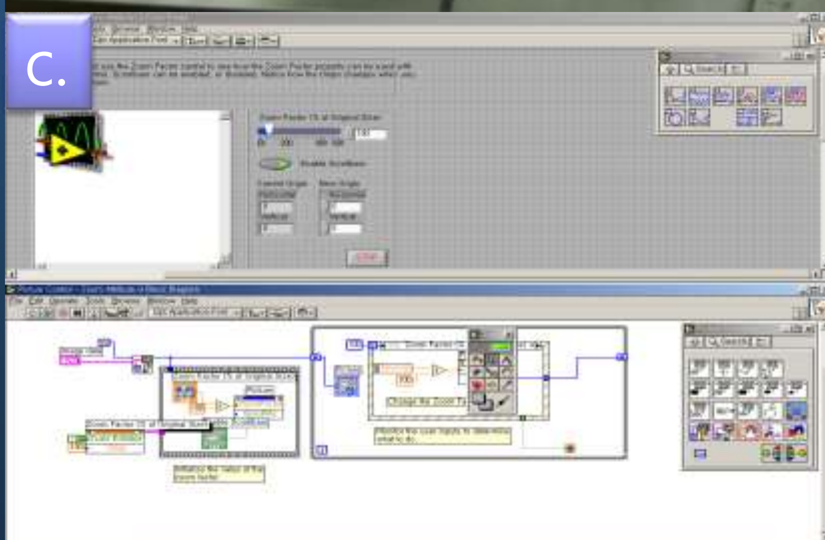


Huang et al., PMB 56 (2011) 5287

Proton Specific Imaging

- Proton beams used to treat uveal melanoma
- Radiographic localization can be used to position skull and orbit
- Treatment planning optimizes gaze angle of eye
- Must be replicated and maintained at treatment

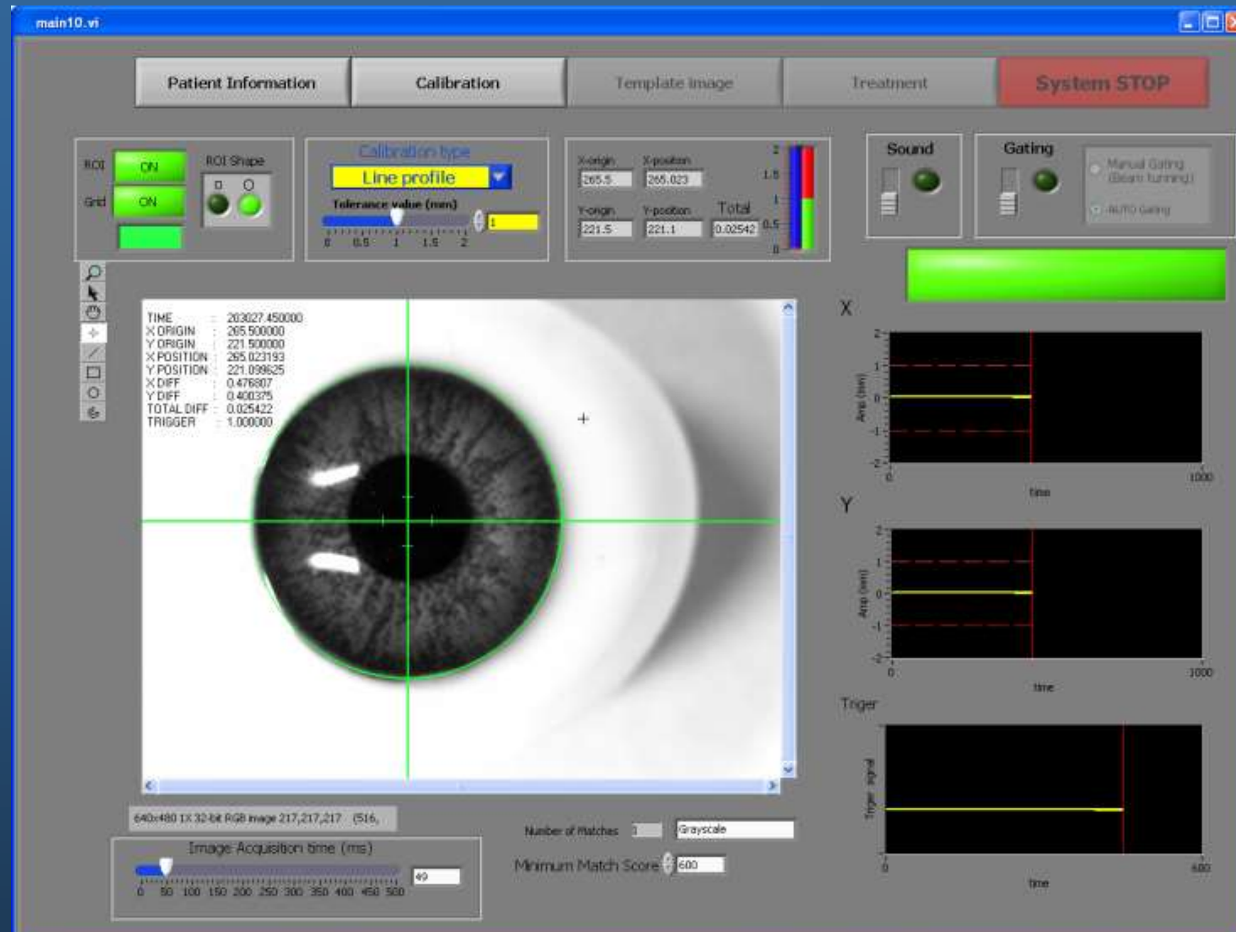
System components



a. NI PXI system for image acquisition from CCD camera and monitoring eye movement
b. CCD camera on eye snout for proton therapy unit
c. Labview program for eye tracking system

Eye tracking system for gated ocular proton therapy

Moving eye phantom



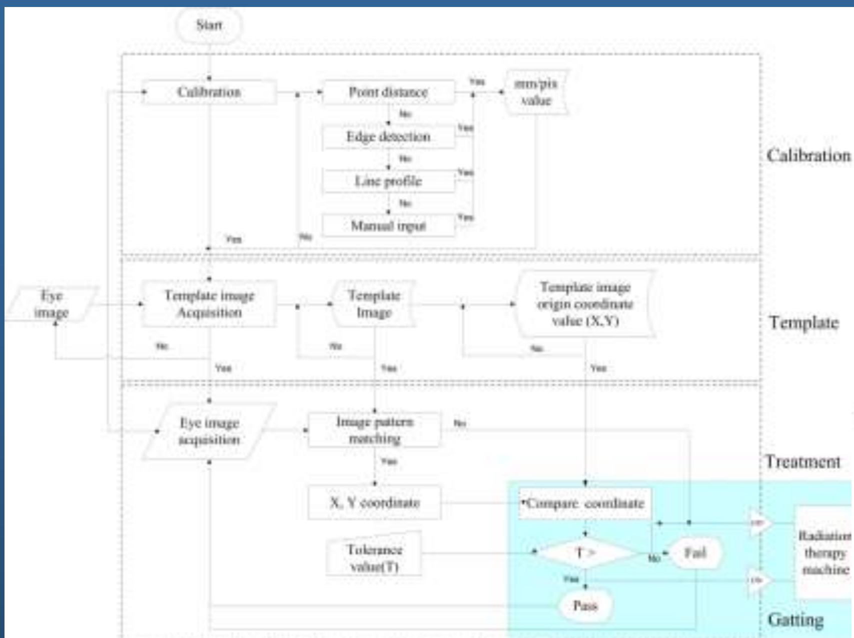
- Eye tracking system for Gated Proton therapy
  - Exact simulation with in-house moving eye phantom using infrared CCD camera
  - Quantitative analysis of eye movement is performed using LabView H/W, S/W.
  - Promoting collaboration with IBA

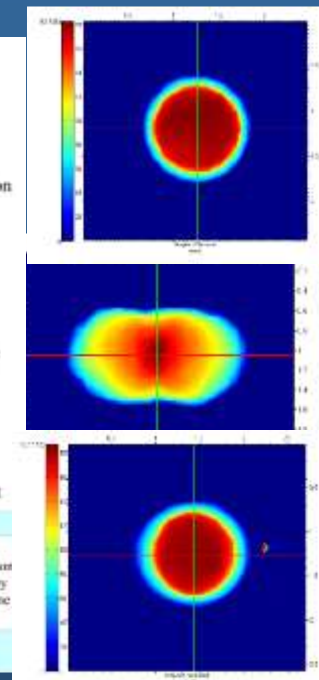
양성자치료센터 PROTON THERAPY CENTER

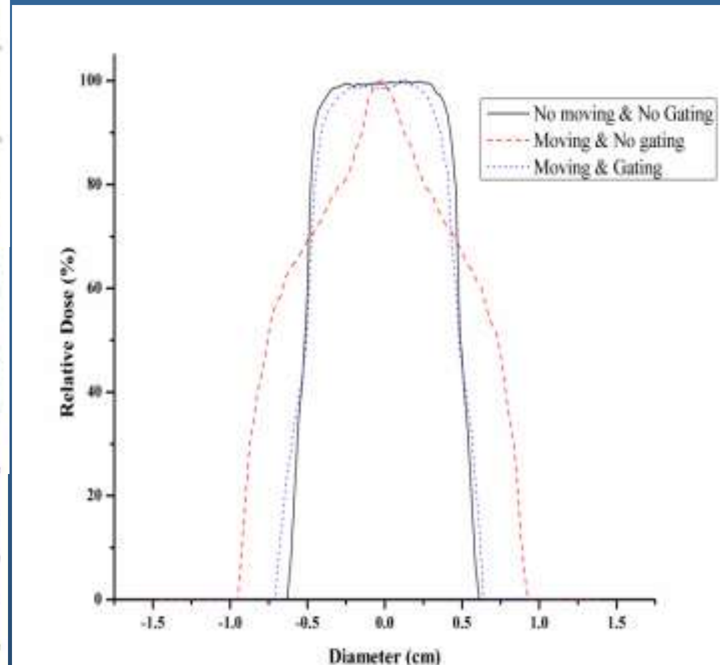
Shin DH, Park SY, et al., Med. Phys., Vol. 39(7), pp. 4265-73, 2012

국립암센터 NATIONAL CANCER CENTER

Eye tracking and gating system for proton therapy of uveal melanomas







-Developed an eye tracking and gating system using an image pattern matching algorithm for uveal melanoma proton therapy.

Korea Patent No. 10-2008-0034405, 2008

US, Europe, Japan Patents, 2009

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Summary

- Imaging for proton therapy setup verification is catching up to photon modalities
- Sometimes different priorities and constraints
- It's an exciting time to be involved in the development of a proton therapy facility