Diagnostic Proton Computed Tomography Using Laser-Driven Ion Acceleration

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Outline

- Need for low-dose diagnostic computed tomography (CT)
- Proton CT (pCT)
  - Potential advantages of diagnostic pCT
  - Principles of pCT
  - Current research at Loma Linda University Medical Center (LLUMC)
- Project approach and system requirements
- Challenges and possible solutions

Need for Low-Dose Diagnostic CT

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- Over 62 million X-ray CT scans each year in U.S.
- High contrast and high spatial resolution of CT make it a crucial diagnostic tool
- X-ray CT dose 2 orders of magnitude higher than radiographs
  - Responsible for half of radiation from medical imaging in the U.S.
  - Radiation risk from CT in children is a special concern

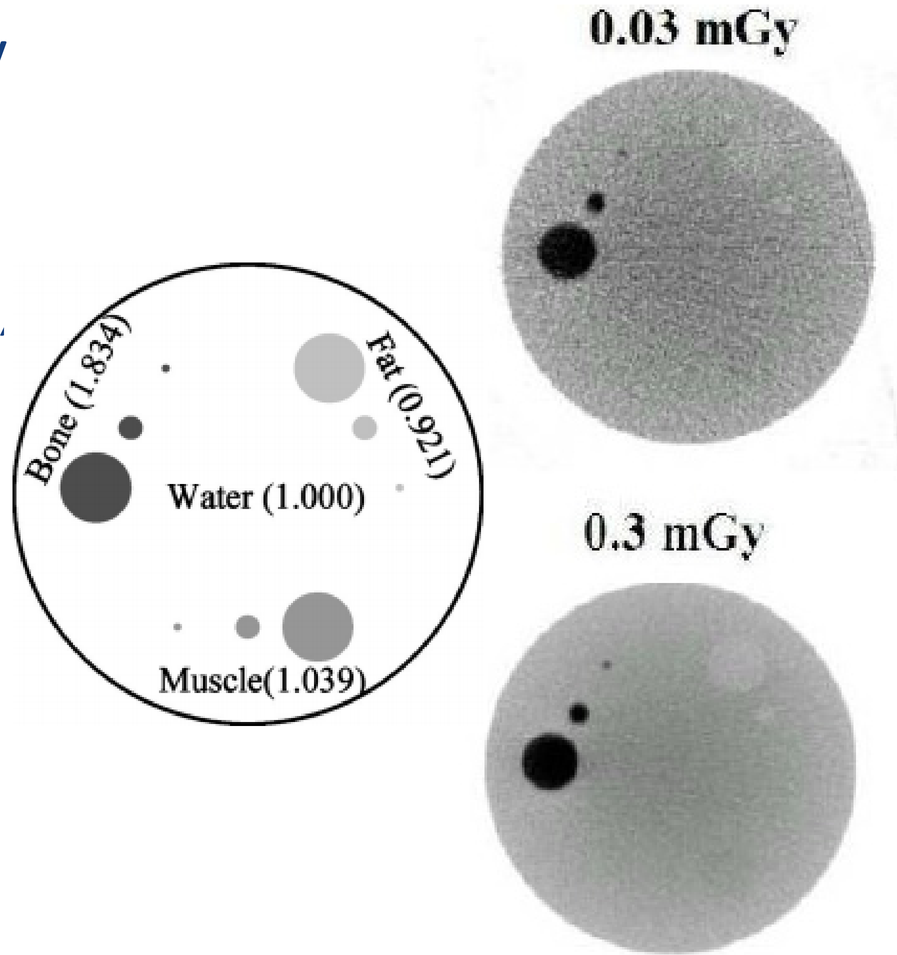
Typical organ radiation doses from various radiologic studies

Study Type	Relevant Organ	Relevant Organ Dose (mGy or mSv)
Dental radiography	Brain	0.005
Posterior–anterior chest radiography	Lung	0.01
Lateral chest radiography	Lung	0.15
Screening mammography	Breast	3
Adult abdominal CT	Stomach	10
Barium enema	Colon	15
Neonatal abdominal CT	Stomach	20

[D.J. Brenner et al, 2007]

Potential solution: Proton CT

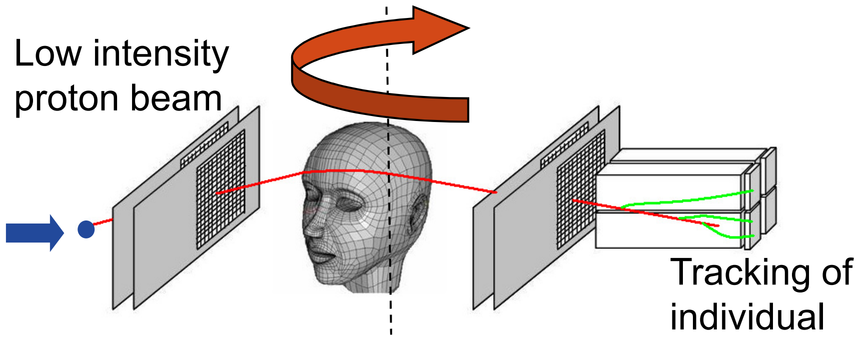
- Estimated dose 0.03 – 0.3 mGy
  - ~100 times smaller than X-ray CT dose
  - Not evaluated from absorption, like X-ray CT
- Quantitative imaging – faithful reproduction of small differences in electron density
- Many common applications:
  - Lung cancer screening
  - Bone density measurements
  - Kidney or urinary stone detection



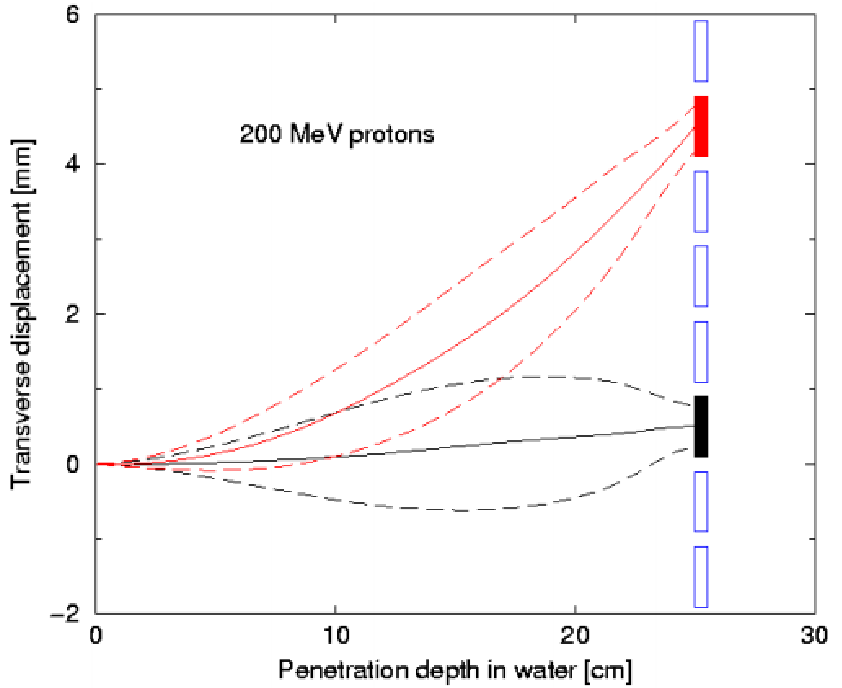
Reconstructed images based on GEANT4-simulated 200 MeV pCT data of the illustrated phantom.

[R. Schulte, Med. Phys. 2005]

Principles of pCT



[Courtesy of Reinhard Schulte, LLUMC]

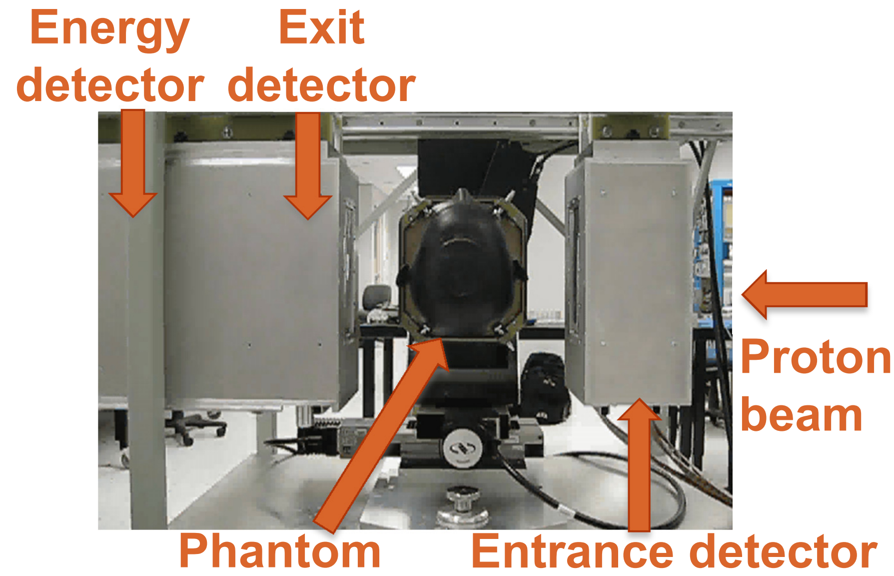


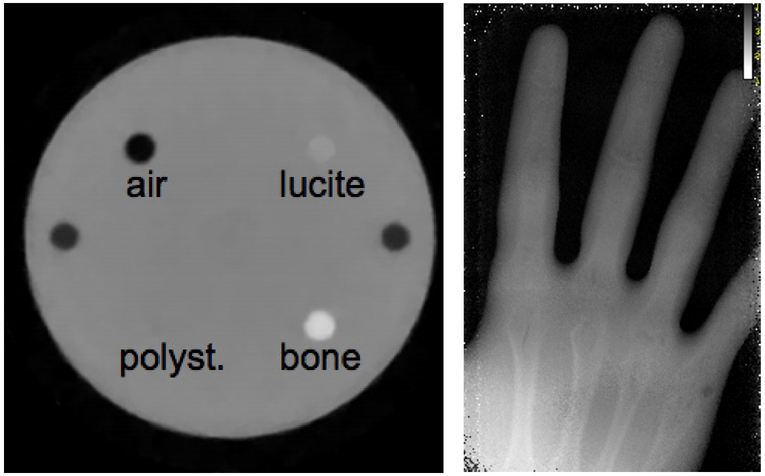
Monte Carlo simulation of most likely paths for 200 MeV protons.

- Proton energy needed depends on object size
  - 250 MeV protons: 37.7 cm range in water
- Position-sensitive detectors track entry and exit of individual protons
- Energy detector/range counter measures energy loss of individual protons
- Iterative reconstruction algorithms use most likely path concept

Proton CT at LLUMC – Phase I

- pCT for improved treatment planning in proton therapy
- Proton relative stopping power reconstructed directly
- 2008 – 2010: Phase I scanner as proof of principle
  - Silicon strip detectors and data readout from Fermi Space Telescope
  - Multi-segmented crystal calorimeter
  - FPGA-based DAQ and GPU-based reconstruction



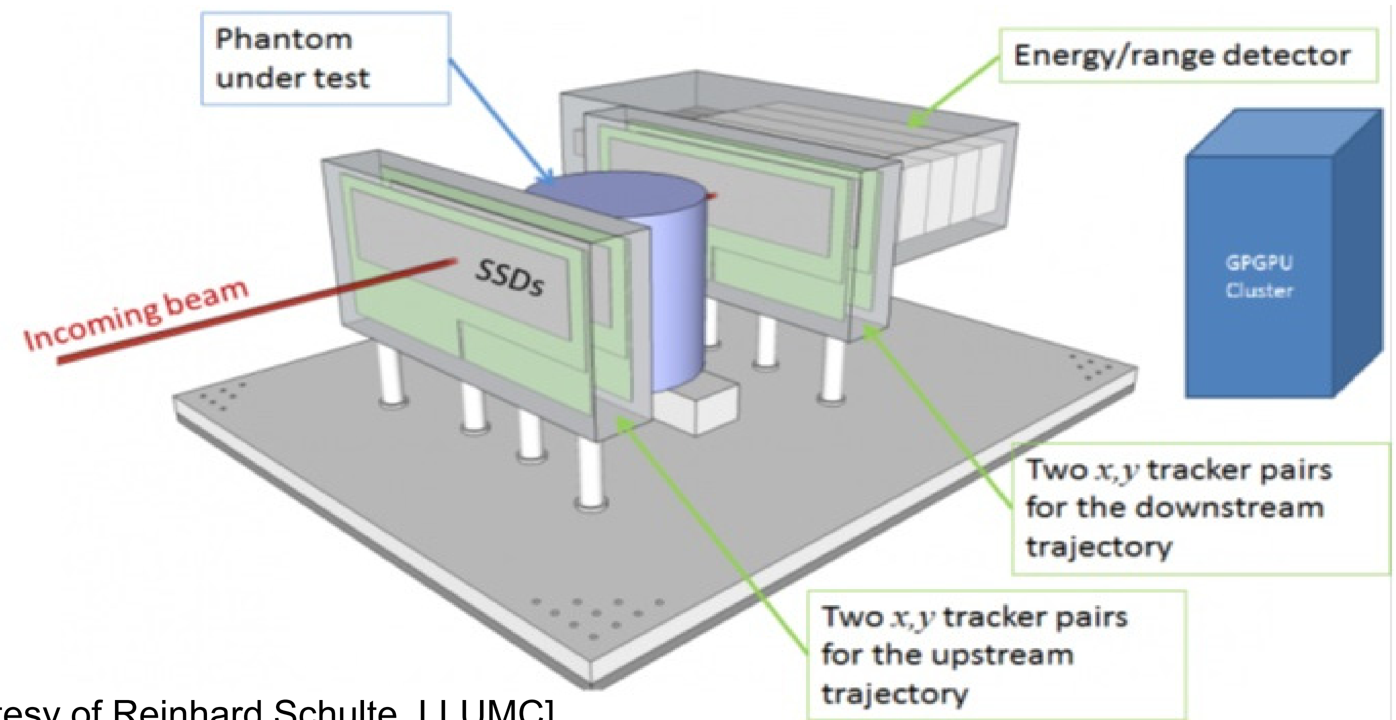


Proton radiographs of head (left) and hand phantoms (right).

[Courtesy of Reinhard Schulte, LLUMC]

Proton CT at LLUMC – Phase II

- 2011 – 2015: Phase II scanner
  - Twice the detector area
  - "Slim-edge" silicon detectors
  - Simple 5-stage scintillator-based energy detector
  - ASIC for data acquisition times <5 minutes
  - GPU cluster for reconstruction times <10 minutes

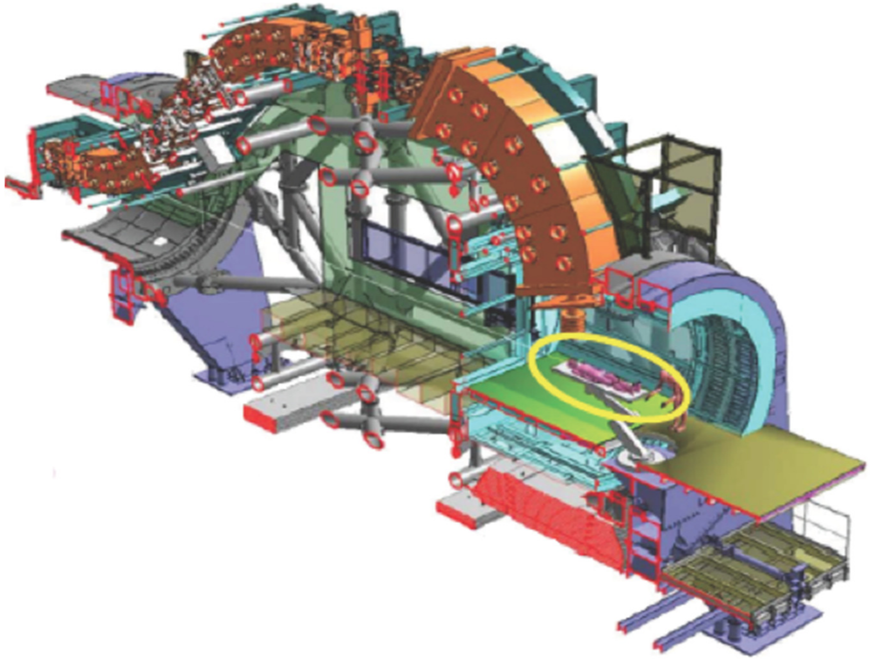


[Courtesy of Reinhard Schulte, LLUMC]

Diagnostic pCT System

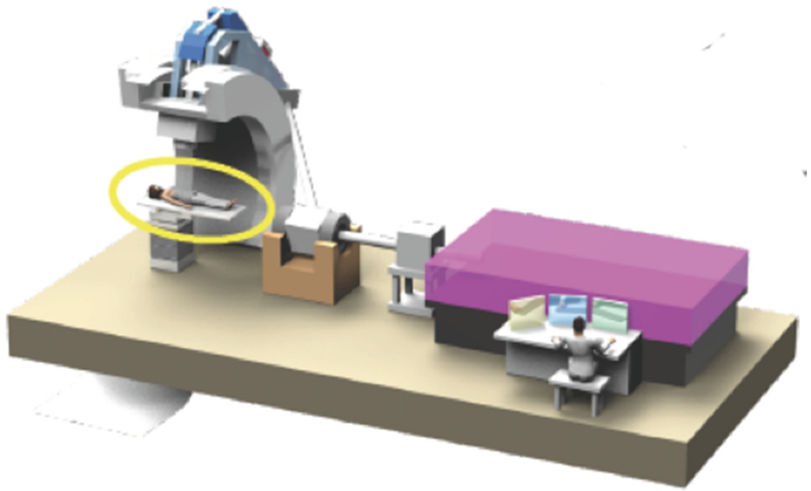
LLUMC pCT scanner

- For treatment planning
- Uses therapeutic synchrotron
- 3-story, 90 ton gantry

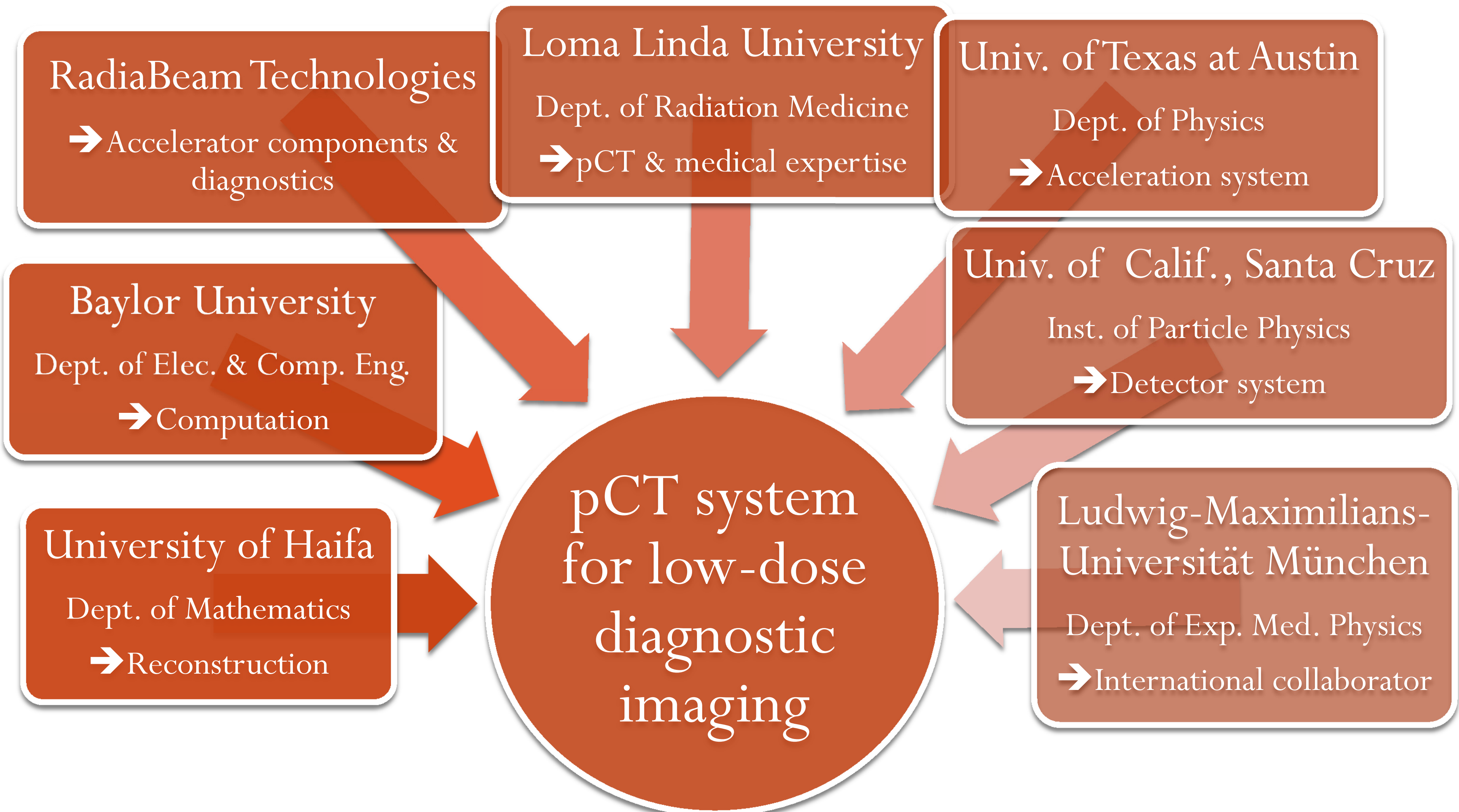


Proposed pCT scanner

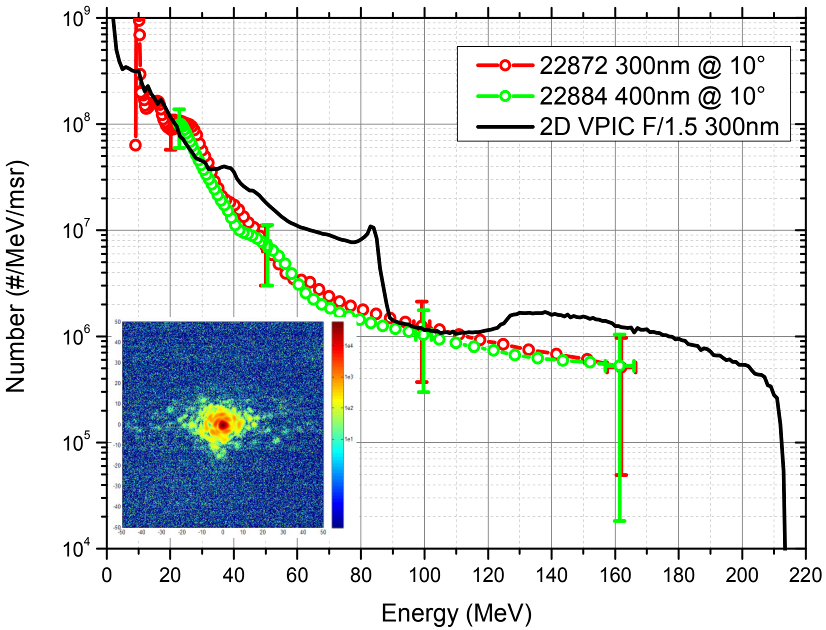
- For diagnostic use
- Uses laser-driven accelerator
- Compact, single-room



Diagnostic pCT Collaboration



Design Approach

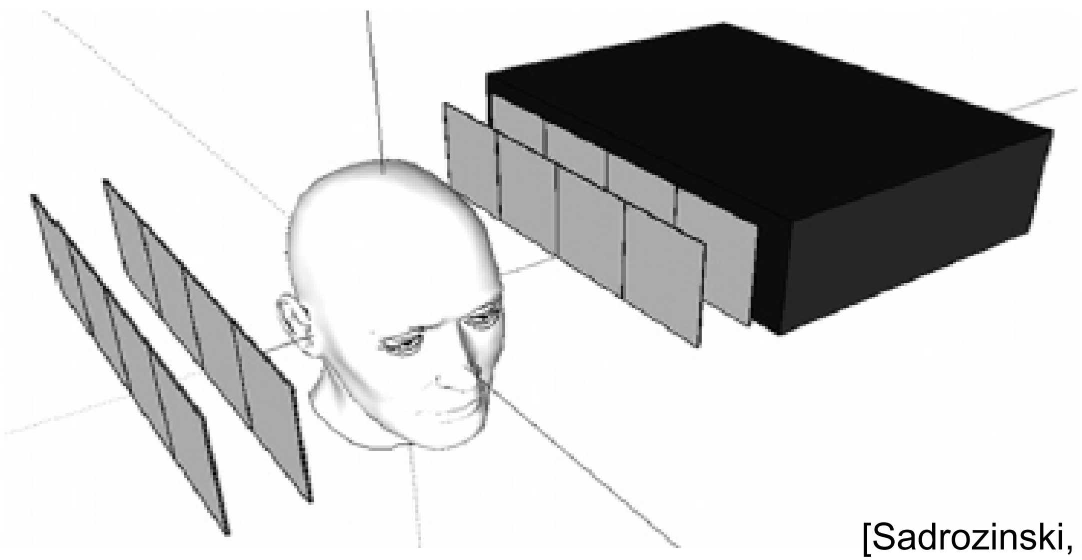


Proton spectra from interaction of LANL Trident laser with 80J, 600fs, r<2μm with 300nm and 400nm CH_2 targets. Inset shows focal spot with F/1.5 off-axis parabola.

- Need a compact, less expensive proton accelerator
- Must provide sufficiently high-energy and low-intensity
- Test the feasibility of using laser-driven ion acceleration (LDIA)
- Collaborating with Dr. Manuel Hegelich at UT Austin
- Demonstrated record-breaking laser-driven proton energies >160 MeV at LANL
- Now using Texas Petawatt Laser

System Requirements

Specifications	
Energy	330 MeV (60 cm range in water)
Intensity	10^6 protons/sec
Detection rate	>1 MHz
Size	Single room
Scan time	~5 minutes
Cost	Comparable to X-ray CT



[Sadrozinski, NIMA 2012]

Potential Challenges

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- Cost
  - Laser costs steadily decreasing as the technology advances
- Low intensity and high repetition rate required
  - Experiment with new acceleration techniques
  - Could instead improve spatial and time resolution of detectors
- Faster data acquisition and reconstruction
  - Develop ASIC for high-resolution tracking and energy detectors, use parallel reconstruction algorithms and GPGPU cluster for parallel processing

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