Issues and Challenges for Imaging in Proton Radiotherapy

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Need for Imaging in Proton Radiotherapy

- Correction patient model
  - Set-up positioning
  - Anatomy model in treatment planning system
- Correct dosimetry
  - Dose distribution
  - Beam energy and profile
  - Range measurement

How to Image

- Projection radiography
  - kV X-ray of treatment portal
  - Proton beam
- Tomograph
  - X-ray kVCT
  - pCT
- Beam monitoring
  - Beam penumbra imaging
  - Range in phantom
- Interaction of patient with beam
  - In-vivo dosimetry approach

Challenges of kV Imaging and Stopping Power

- Relationship between x-ray and proton attenuation?
  - H or μ/ρ (120 keV) $\Rightarrow$ S/ρ (150 MeV)?
  - Spectral effects?
  - Look-up table
  - Stoichiometric approach – effects of H content
  - Dual energy CT
- Protons
  - Still need to extrapolate
  - S/ρ (high MeV) $\Rightarrow$ S/ρ (150 MeV)

Proton Radiography

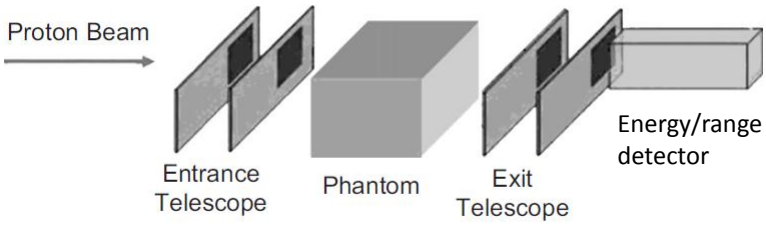
- Image high energy protons passing through patient
  - Integral of stopping power
  - Halo effect – scattered radiation
- Need to correct for scattering artefacts for high spatial resolution

Proton CT

- Needs data to satisfy CT requirements
  - Multiple angles encompass object extent
  - Broad beam and gantry?
- Proton interactions v. photon interactions
  - Photons travel in straight lines and either pass through or are absorbed
  - Protons scatter and almost always pass through but with distorted path

Proton CT

- Protons scatter and almost always pass through but with distorted path
  - Need to track path and measure energy
  - Range telescope concept



Proton CT

- Entrance and exit telescope measure path and position of each proton
- Energy/range detector measures energy
- Combine for CT reconstruction

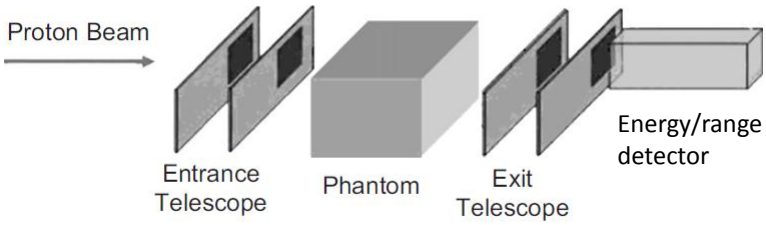
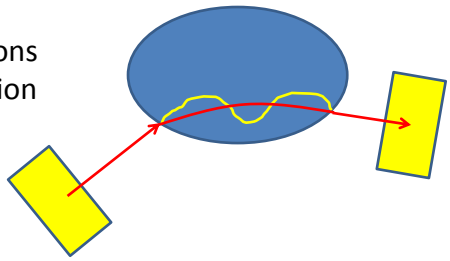


Image Reconstruction

- Protons do not travel in straight lines
  - Estimate path of protons for image reconstruction
  - Cubic spline
  - Most likely path
  - Others?

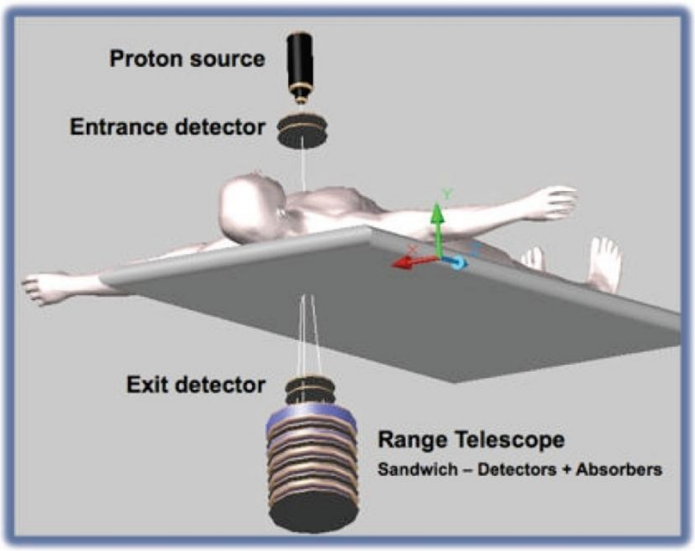


Proton CT Approaches

- Paul Scherrer Institut
  - Tracking: fibre hodoscope, Range: plastic scintillator
- Loma Linda
  - Tracking: silicon strips, Range: CsI calorimeter
- AQUA/ENVISION
  - Tracking: gas electron multipliers, Range: plastic scintillator
- PRIMA
  - Tracking: silicon strips, Range: YAG:Ce calorimeter

PRaVDA – Proton Radiotherapy Verification and Dosimetry Applications

– Integrated computed tomography and dosimetry instrument for proton therapy



Beam Monitoring

- Liverpool/Clatterbridge Solution
  - Array of strip detectors to measure beam halo

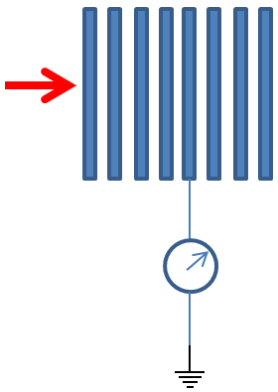
Range Uncertainties

- Proton radiotherapy accuracy relies on accurate knowledge of proton range
  - Statistics of range: Mean and spread
  - Variation with characteristics
- Measure with purpose built phantom

- Knopf and Lomax, PMB, **58**, R131, 2013

Multi-Layer Faraday Cup

- Measure beam range
- Faraday cup
  - Standard method of measuring charged particle beams
    - measure current in metal collector
  - Multi-Layer, stack of plates
    - Measure current at set of depths – energy information



Model of anatomy on Day of Treatment

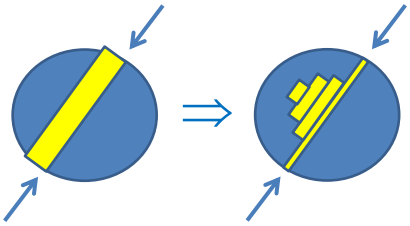
- Imaging on treatment set
  - Image guided radiotherapy
  - Adaptive radiotherapy
- Similar imaging challenge to x-ray radiotherapy
  - Many of the x-ray methods have been studied
- Proton imaging

Imaging Beam Interactions

- In-beam PET
  - EU Envision project
  - PET camera in treatment room
  - Detects positron decays from (p,x) reactions – fragmentation, evaporation

In-Beam PET

- First demonstrations of in-beam PET becoming available
- New imaging methods?
  - Time of Flight



Conclusions

- Imaging challenges in proton radiotherapy
  - Anatomy at treatment
  - Rad/tissue interaction
  - Beam characteristics
- Methods
  - Radiography
  - CT
  - Beam imaging
  - Dose deposition

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