Mechanical Integration of a Digital Tracking Calorimeter for the Purposes of Particle Computed Tomography

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Outlines:

- Introduction
- DTC Mechanical Package challenges (Design Parameters)
- Stave assembly considerations
- Creating sensitive area for particle trajectory (One Slab)
- Full calorimeter structure
- Simulation results
- Tracker plates (Front Layer) structure
- Future Studies
Introduction:

• Particle therapy:
  ✓ Novel method in cancer treatment; irradiation of cancerous tissue with protons and carbon ions

• Why Proton CT
  ✓ Accuracy (Bragg peak)
  ✓ Reducing uncertainties in Bragg peak location (from 1cm to < 1mm)
  ✓ Direct measurement of stopping power instead of deriving it from a normal X-ray CT
  ✓ Reduced dose to healthy tissue
  ✓ Find proton energy after patient

Samsung Medical Center
(http://www.samsunghospital.com)

(PHYS231, Roehrich D, 2017)
Introduction:

• Proton imaging

✓ Tracking proton beams: tracking individual protons through the detector
  - Estimating path of individual protons

✓ Proton CT 3D image reconstruction by:
  - Finding proton vectors before / after patient
  - Finding proton energy before / after patient
  - Energy loss calculation
  - Repeating for different projections (phantom or device)
DTC Mechanical Package

• Digital Tracking Calorimeter (Design parameters)
  ✓ Number of absorber layers and thickness
  ✓ Material uniformity along proton trajectory
  ✓ Mechanical stability
  ✓ Fabrication & manufacturing aspect
  ✓ Chip & readout electronics (mounting, sensitive area)
  ✓ Bonding method
  ✓ Heat transfer & Cooling
  ✓ Mechanical deformation & errors

(Pettersen H.E.S., 2017)
Digital Tracking Calorimeter (DTC)

- Number of absorber layers for stopping 230MeV protons

- Absorber thickness

- Material:
  - ✓ Mechanical properties such as density, hardness, thermal capacity
  - ✓ Homogeneity
  - ✓ Ionization energy
  - ✓ Mechanical integrity, economy and clinical considerations

- Material uniformity along proton trajectory
  - ✓ Electrical connectors, wirings
  - ✓ Coolant channel
  - ✓ Support structure

<table>
<thead>
<tr>
<th>Absorber thickness</th>
<th>Number of layers</th>
</tr>
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<tbody>
<tr>
<td>2 mm</td>
<td>~63</td>
</tr>
<tr>
<td>3 mm</td>
<td>~45</td>
</tr>
<tr>
<td>4 mm</td>
<td>~35</td>
</tr>
<tr>
<td>5 mm</td>
<td>~29</td>
</tr>
<tr>
<td>6 mm</td>
<td>~25</td>
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</tbody>
</table>
Digital Tracking Calorimeter (DTC)

• Mechanical Stability
  ✓ Solid & stiff structure
  ✓ Assembly and maintenance reliability
  ✓ No vibration
  ✓ Production feasibility

• Clinical considerations
  ✓ Working temperature range
  ✓ No poisonous materials
  ✓ Coolant leakage
  ✓ Short circuit
Digital Tracking Calorimeter (DTC)

- Stave assembly of Chip & read-out electronics
  - Chip size = 1.5cm x 3cm
  - Required sensitive area = 18cm x 27cm
  - Space for data readout strip
  - Cooling methods & coolant channel
  - Uniformity

Figures from LTU: “9 Alpide string” & Nikhef “Mock up of Focal slab”
Digital Tracking Calorimeter (DTC)

- Bonding method
  - Mechanical Connection
  - Dielectric connection
  - Ultrasound welding
  - Glue protection

Figure from: LTU: “Applied glue in mock up of detector layer for Focal m Tower”
Digital Tracking Calorimeter (DTC)

- Sensitive area (placement of chips)
  - 12 Rows, each with 9 chips side-by-side

Two Scenarios:

1) [Diagram]

2) [Diagram]
Digital Tracking Calorimeter (DTC)

- Sensitive area (placement of chips):
  - Temperature distribution (FEM study)
  - Using both sides of absorber
Digital Tracking Calorimeter (DTC)
Digital Tracking Calorimeter (DTC)

- proton CT calorimeter configuration
Digital Tracking Calorimeter (DTC)

- proton CT calorimeter configuration
Digital Tracking Calorimeter (DTC)

- proton CT calorimeter configuration
Digital Tracking Calorimeter (DTC)

- Simulation result for 5 stack layers pack
  - Free convection
  - 50 mW/Cm2 heat generation

Temperature distribution (°C)
Max ~ 26.7°C

- Laminar water cooling (T=5°C, V=1m/s)
- Ambient Temperature 22

Heat Flux (W/m²)
Max ~ 14828 W/m²
Digital Tracking Calorimeter (DTC)

- Simulation result for 5 stack layers pack
  - free convection
  - 50 mW/Cm2 heat generation

Laminar water cooling (T=5°C, V=1m/s)
- Ambient Temperature 22

Total Deformation (m)
Max ~ 1.8e-6 m

Equivalent Stress (Pa)
Max ~ 2.4e7
Digital Tracking Calorimeter (DTC)

- Tracker Plates (Front layers)
  - Minimize multiple scattering
  - Mechanical stiffness, stability, integrity

Assembly & fabrication challenge

Cooling challenge

Al Thickness = 200 μm
Electronics = 253 μm
Total ~ = 0.5 mm
Digital Tracking Calorimeter (DTC)

Future Studies:

- Integrity & Reliability of front tracker layers:
  - Mechanical stability
  - Cooling
  - Protection

- Detector Coolant study:
  - intensive heat transfer methods (Fluid Mechanics -CFD-)
  - Humidity & ventilation solution
  - Stave in plate heat transfer (Bonding, Thermal contact resistance )

- Data readout development

- Sensitivity study of electronic layer arrangement

- Deformation analysis (Operational & accidental) and effect imaging accuracy
Thank You