Update on the LIGHT prototype development
Radiation therapy with charged hadrons

Radiation beam in matter
LIGHT = Linac for Image Guided Hadron Therapy

- Proton Source
- Radio Frequency Quadrupole (RFQ)
- Side Coupled Drift Tube Linac (SCDTL)
- Coupled Cavity Linac (CCL)
- Modulator-klystron systems

25 m
Features:

- **Active energy modulation.**
  - No absorber and degrader.
- **Pulsed beam at 200Hz.**
  - Fast intensity and energy modulation.
  - Image guided hadron therapy.

 Beam is suitable for 3D spot scanning.

- **Pencil beam scanning or ‘spot’ scanning:**

![Diagram showing proton beam and tumor](image-url)
LIGHT DESIGN
## LIGHT Main Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>~25</td>
<td>m</td>
</tr>
<tr>
<td>Max. Energy</td>
<td>230</td>
<td>MeV</td>
</tr>
<tr>
<td>Output Peak Current (at the end)</td>
<td>0.3 - 90</td>
<td>μA</td>
</tr>
<tr>
<td>Pulse Length</td>
<td>5</td>
<td>μs</td>
</tr>
<tr>
<td>RF Frequency</td>
<td>2997.92</td>
<td>MHz</td>
</tr>
<tr>
<td>Max. Repetition Rate</td>
<td>200</td>
<td>Hz</td>
</tr>
<tr>
<td>Peak RF Power</td>
<td>~60</td>
<td>MW</td>
</tr>
<tr>
<td>Quantity</td>
<td>Value</td>
<td>Unit</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>Output Energy</td>
<td>40 ± 0.4</td>
<td>keV</td>
</tr>
<tr>
<td>Output pulsed Current</td>
<td>Range: [1-300] ± 2%</td>
<td>µA</td>
</tr>
<tr>
<td>Current ripple during flattop</td>
<td>± 1</td>
<td>%</td>
</tr>
<tr>
<td>Pulse to pulse current reproducibility</td>
<td>± 2-3</td>
<td>%</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>Range: [5-200]</td>
<td>Hz</td>
</tr>
<tr>
<td>Beam pulse width</td>
<td>Range: [0.5-5]</td>
<td>µs</td>
</tr>
</tbody>
</table>
The Radio Frequency Quadrupole (RFQ)

- High frequency RFQ designed by CERN
  - 4 vanes type
  - 750 MHz
  - 4 modules - 2 m
  - 5 MeV energy gain

<table>
<thead>
<tr>
<th>Section</th>
<th>RFQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF frequency [GHz]</td>
<td>0.749</td>
</tr>
<tr>
<td>Energy [MeV]</td>
<td>0.04-5</td>
</tr>
<tr>
<td>Length [m]</td>
<td>2</td>
</tr>
</tbody>
</table>
The Side Coupled Drift Tube Linac (SCDTL)

- Designed in collaboration with ENEA (Frascati, I)
- Manufactured at TSC

<table>
<thead>
<tr>
<th>Section</th>
<th>SCDTL</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF frequency [GHz]</td>
<td>2.998</td>
</tr>
<tr>
<td>Energy [MeV]</td>
<td>5-37.5</td>
</tr>
<tr>
<td>Length [m]</td>
<td>6.2</td>
</tr>
</tbody>
</table>
The Coupled Cavity Linac (CCL)

- Designed by ADAM
- Manufactured by VDL
- 4 modules already conditioned

<table>
<thead>
<tr>
<th>Section</th>
<th>CCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF frequency [GHz]</td>
<td>2.998</td>
</tr>
<tr>
<td>Energy [MeV]</td>
<td>37.5-230</td>
</tr>
<tr>
<td>Length [m]</td>
<td>15.5</td>
</tr>
</tbody>
</table>
SCDTL and CCL E-field measurements

- SCDTL

- CCL
Fields in the CCL accelerating cells

Mode 1
- Cathode Name: Cross Section A
- Cathode Normal: 1, 8, 9
- Cathode Positions: 0
- Component: Anode
- Orientation: Outside
- 2D Maximum [kV]: 252, 11.6 kV
- Frequency: 1.00 MHz
- Phase: 0

Mode 2
- Cathode Name: Cross Section A
- Cathode Normal: 1, 8, 9
- Cathode Positions: 0
- Component: Anode
- Orientation: Outside
- 2D Maximum [kV]: 133.4 kV
- Frequency: 3.000 MHz
- Phase: 90
Power from klystron: 7.5 MW

P_loss wg network: ~ 15%

Power available per unit: ~ 6.4 MW

Max power used: ~5 MW

Power safety/operational margin: ~ 28%

RF network includes Isolator for protection of the klystron from reflected power.
Part of RF network under SF6!

LIGHT: 70-230 MeV

<table>
<thead>
<tr>
<th>Parameter</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Peak power [Mw]</td>
<td>48</td>
</tr>
<tr>
<td>Total length [m]</td>
<td>12.3</td>
</tr>
<tr>
<td>Active length [m]</td>
<td>9.5</td>
</tr>
<tr>
<td>Fill factor</td>
<td>0.77</td>
</tr>
<tr>
<td>Number of kl.</td>
<td>8</td>
</tr>
</tbody>
</table>
LIGHT PROTOTYPE TEST RESULTS
LIGHT (Linac for Image Guided Hadron Therapy) @point 2
### LIGHT (Linac for Image Guided Hadron Therapy) @point 2

#### SCDTL Module

<table>
<thead>
<tr>
<th></th>
<th>Mod1</th>
<th>Mod2</th>
<th>Mod3</th>
<th>Mod4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Tanks</td>
<td>11</td>
<td>13</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Bore hole [mm]</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Length [m]</td>
<td>1.12</td>
<td>1.70</td>
<td>1.52</td>
<td>1.60</td>
</tr>
<tr>
<td>Power [MW]</td>
<td>0.83</td>
<td>2.59</td>
<td>2.46</td>
<td>2.48</td>
</tr>
<tr>
<td>Energy [MeV]</td>
<td>7.5</td>
<td>16</td>
<td>26.5</td>
<td>37.5</td>
</tr>
</tbody>
</table>

#### CCL Module

<table>
<thead>
<tr>
<th></th>
<th>Mod1</th>
<th>Mod2</th>
<th>Mod3</th>
<th>Mod4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Tanks</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Bore hole [mm]</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Length [m]</td>
<td>0.80</td>
<td>0.83</td>
<td>0.76</td>
<td>0.81</td>
</tr>
<tr>
<td>Power [MW]</td>
<td>2.21</td>
<td>2.21</td>
<td>2.31</td>
<td>2.33</td>
</tr>
<tr>
<td>Energy [MeV]</td>
<td>44.9</td>
<td>52.9</td>
<td>61.3</td>
<td>70.2</td>
</tr>
</tbody>
</table>
Proton source test results

Emittance measurements and rms emittances (white) with the representation of the RFQ acceptance ellipse (red).

Proton Source

LEBT

a) horizontal

b) vertical
Results from RFQ commissioning

Proton Source

LEBT   RFQ   MEBT   Diagnostic Bench

V. Dimov et al., TUPAF002-IPAC18
Results from RFQ commissioning

Proton Source

LEBT   RFQ   MEBT   Diagnostic Bench

V. Dimov et al., TUPAF002-IPAC18
Results from RFQ commissioning

Proton Source

LEBT  RFQ  MEBT  Diagnostic Bench

V. Dimov et al., TUPAF002-IPAC18
Commissioning: Jan-Apr 2018

Source

Credit: M. Volpi
Commissioning: Jan-Apr 2018

Example of RF pulse envelopes measured from RF pickups installed on RFQ (yellow) and SCDTL (red).

A. Degiovanni et al., MOPML014-IPAC18
Commissioning: Jan-Apr 2018

Source

A. Degiovanni et al., MOPML014-IPAC18

40 µA

[Graphs showing signal distribution with measurements 3.5 mm and 4.8 mm]
Commissioning: Jan-Apr 2018

Measured emittance at 7.5 MeV in horizontal and vertical plane after SCDTL module 1.

A. Degiovanni et al., MOPML014-IPAC18
Commissioning: May-June 2018
Commissioning: May-June 2018

LEBT  RFQ  MEBT  SCDTL1  SCDTL2  Test Bench
Experience with conditioning and operation
Some RF gymnastics – reducing the filling time
CONCLUSION
First prototype of LIGHT is under construction and test with beam at CERN P2.

Beam commissioning has advanced during this year, with energies now up to 16 MeV.

Beam characterization is performed in stages, with measurements of beam current, beam profiles, energy, energy spread and transverse emittance.

The ongoing activity is crucial for gaining experience in machine operation and beam tuning.
感谢您的关注！

THANK YOU FOR YOUR ATTENTION
Energy and Intensity modulations

Pulsed source

Active energy modulation

Active intensity modulation

Klystron RF pulse

RF power into the tanks

Proton pulses from source

Variation 70 < E < 230 MeV

Rep rate 200 HZ

~ 5 ms

5.0 μs

$E_{\text{inj}}$
▪ Presence of electric field free spaces (for PMQ and flanges!) reduces real estate gradient!

▪ Typical filling factor is ~ 70-75%
Gradient vs Power

\[ ZT^2 = \frac{(E_0 T)^2}{P \cdot L} \]

\[ W = q \sqrt{E_0 T \cdot P \cdot L \cos(\phi + \phi_s)} \]

\[ L = n \cdot l_c \]

\[ W \sim \sqrt{(ZT^2) \cdot P \cdot n l_c} \]

Shorter linac = higher power!
A modular approach towards industrialization

Unit Systems

1) Accelerating System
2) Control System
3) Cooling System
4) Focusing System
5) RF Network System
6) RF Power System
7) Support System
8) Vacuum System
Accelerator shielding

Example of shielding impact on the foot-print (only accelerator is considered, since treatment room will be all the same independent of accelerator)
Typical beam spot at the output of the linac

- $X(mm)$ vs $X'(mrad)$
- $Y(mm)$ vs $Y'(mrad)$
- $Z(mm)$ vs $dp/p(\%)$
- $X(mm)$ vs $Y(mm)$

Values:
- $<1mm$
- $Z_{max} = 0.989 mm$
- $dp/p_{max} = 0.081 \%$
- $X_{max} = 0.832 mm$
- $Y_{max} = 2.190 mm$