Linac3: LEBT, RFQ and MEBT Measurements, Travel Simulations and Beam Tomographic Reconstruction for Pb\textsuperscript{29+} beam

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The Linac3

• Electron Cyclotron Resonance source (Pb$^{29+}$ at 2.5keV/u)
• Low Energy Beam Transport
• Radio Frequency Quadrupole (101MHz, 250 keV/u)

• Medium Energy Beam Transport
• Interdigital H structures (101, 202 MHz, 4.2MeV/u)
• Filter Line (Pb$^{29+}$ to Pb$^{54+}$)

Figure 1. Linac3 drawing
Outline

1. We will reconstruct the transverse beam distribution at LEBT triplet entrance using a back track Tomographic Reconstruction (TR) method and compare the transverse beam profiles measured and simulated in TRAVEL at LEBT SEM Grid location.

2. We will study by means of simulations in TRAVEL the change in beam transmission through the beam line due to the change in the amplitude of the solenoid ITL.SOL02 field map and compare with measurements.

3. We will study by means of simulations in TRAVEL the change in beam transmission and energy through the beam line due to the change in the amplitude of the RFQ field map and compare with measurements.

4. We will compare the transverse beam profiles between a beam from LEBT and a beam from MEBT TR at RFQ output also we will compare the beam profiles simulated with measured profiles at MEBT SEM Grid.

5. Conclusion and acknowledgments.
1. LEBT Tomographic Reconstruction

- In order to perform the TR study we need to know the quadrupoles (Qs) conversion factor (from current to magnetic field).
- The LEBT triplet Qs were characterized in 1993 and we just have the conversion factor for a specified current.

Figure 2. LEBT and devices used in TR (red square).
1. LEBT Tomographic Reconstruction

- Using several measurements with different quadrupoles setting we reconstructed the transverse beam profile at Q3 input location.
- To obtain this result we did variations in Q5 current.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emit n xxp (mm mrad)</td>
<td>0.12</td>
</tr>
<tr>
<td>Beta xxp (mm/mrad)</td>
<td>0.14</td>
</tr>
<tr>
<td>Alpha xxp</td>
<td>-3.89</td>
</tr>
<tr>
<td>Emit n yyp (mm mrad)</td>
<td>0.09</td>
</tr>
<tr>
<td>Beta yyp (mm/mrad)</td>
<td>0.98</td>
</tr>
<tr>
<td>Alpha yyp</td>
<td>-2.90</td>
</tr>
</tbody>
</table>

Figure 3. Transverse emittance reconstructed at LEBT Q3 input.
1. LEBT Tomographic Reconstruction

- At this point the only way to know if the reconstructed beam is like the beam from the source is comparing their profiles.
- We tracked the reconstructed beam through the triplet to the LEBT SEM grid with the Qs at operational setting.

![Graphs showing comparison between measured and simulated transverse beam profiles with Qs at operational setting at LEBT SEM Grid.](image)

**Figure 4.** Comparison between measured and simulated transverse beam profiles with Qs at operational setting at LEBT SEM Grid.
2. Beam Line for ITL.SOL02 amplitude field map variations

- Q3, Q4 and Q5 are fixed at operational current.

Figure 5. Beam Line used for ITL.SOL02 amplitude field study

We need to track the beam to the MEBT because it is the next place to take measurements after the BCT05.
2. Solenoid field map – Simulation Vs measurements

- The transmission was measured and calculated as ratio of the current between FC3 and BCT05.
- Using the historical calibration factor, 29.75G/A, the simulation and measurements do not agree very well.
- If we assume that the solenoid operational current equal to 139A correspond to the Simulated Amplitude Scaling Factor with highest transmission we can calculate a new conversion factor, 31.98G/A, that makes the simulations agree with the measurements.
- There is ~7.5% of difference between the conversion factors.
- For the subsequent studies we will assume a calibration factor for the ITL.SOL02 equal to 31.98/A.

Figure 5. Comparison between measured and simulated transmission using two different calibration factors (CF). The historical calibration factor is 29.75G/A.
3. RFQ amplitude variations – Transmission

- The RFQ measured amplitude is normalized to the operational one equal to 3100mV.

- Q3, Q4 and Q5 are fixed at operational current.
- The RFQ field map was created in Parmteq by V. Bencini
- The matching occurs when the simulated amplitude scaling factor equal to 1.0 corresponds to the operational voltage.

Figure 7. Match between simulated and measured transmission due to RFQ amplitude variations.
3. RFQ amplitude variations – **Energy**

- It is not possible to take beam energy measurements at FC3, we need to transport the beam to the ITFS Line.

$$B\rho = \frac{\gamma m_0 v}{q}$$

**Figure 8.**

- Pb$^{29+}$ beam from Tomographic Reconstruction
- ITL.BCT05 Quadrupoles Triplet
- ITL.SOL02 Solenoid
- RFQ From 2.5 keV/u to 250keV/u
- MEBT Q1 Q2
- MEBT SEM Grid and FC3
- Steerer
- Dipole
- ITFS SEM Grid

**Equation:**

$$B\rho = \frac{\gamma m_0 v}{q}$$
3. RFQ amplitude variations – Energy

- In simulations we take the energy at FC3 positions, it is not in the same place where it is measured but we will still try to match simulations and measurements.

- We are assuming that 1.0 in simulations correspond to 1.0 in measurements

- For both cases, the average energy is 250±1 keV/u.

- The difference between simulations and measurements is lower than 1 keV/u for the RFQ range of amplitudes studied.

**Figure 9.** Energy match between measurements and simulations
4. MEBT Tomographic Reconstruction

- We will reconstruct the transverse beam profile using TR method at RFQ output and we will compare with the beam from LEBT TR.
- For MEBT TR we will use beam profiles measured at ITM SEM Grid
- In order to see only Qs effects the Steerers are in OFF.

**Figure 10.** Beam Line used for MEBT TR.
4. MEBT Tomographic Reconstruction

- The MEBT Qs calibration factor (CF) were measured by R. Scrivens in 1994 before installation, Table 1.

<table>
<thead>
<tr>
<th>Current (A)</th>
<th>Calibration Factor (kG/Am)</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>3.0</td>
</tr>
<tr>
<td>68</td>
<td>2.93</td>
</tr>
<tr>
<td>135</td>
<td>2.48</td>
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</tbody>
</table>

- For TR we used CF shown in Table 1 for different current ranges but reduced in 15%, Table 2.

<table>
<thead>
<tr>
<th>Current ranges (A)</th>
<th>Calibration Factor (kG/Am)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 55</td>
<td>2.55</td>
</tr>
<tr>
<td>56 to 100</td>
<td>2.49</td>
</tr>
<tr>
<td>101 and more</td>
<td>2.10</td>
</tr>
</tbody>
</table>

We suspect that because the quadrupoles are very close their fields overlap, so we decided to reconstruct each plane separately with one of the quadrupoles turned off.

- For Vertical profile TR study Q1 is fixed at 0A, and Q2 scanned between 10 and 130A
- For Horizontal profile TR study Q2 is fixed at 0A, and Q1 scanned between 20 and 130A
4. MEBT TR Vs Beam From LEBT at reconstruction point

- For simulation From LEBT the ITL.SOL02 is fixed for maximum transmission and the RFQ Amplitude scaling factor is 1.0.

![Figure 11](image)

**Figure 11.** Transverse emittance comparison between MEBT TR (blue) and Beam From LEBT (red) at reconstruction point (RFQ output).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>From LEBT</th>
<th>MEBT TR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emit n xxp (mm mrad)</td>
<td>0.13</td>
<td>0.12</td>
</tr>
<tr>
<td>Beta xxp (mm/mrad)</td>
<td>0.21</td>
<td>0.18</td>
</tr>
<tr>
<td>Alpha xxp</td>
<td>-1.6</td>
<td>-1.17</td>
</tr>
<tr>
<td>Emit n yyp (mm mrad)</td>
<td>0.13</td>
<td>0.16</td>
</tr>
<tr>
<td>Beta yyp (mm/mrad)</td>
<td>0.15</td>
<td>0.11</td>
</tr>
<tr>
<td>Alpha yyp</td>
<td>1.48</td>
<td>0.08</td>
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</table>
4. Profiles at MEBT SEM Grid

- We compared the transverse profiles between a beam From LEBT and MEBT TR with measured profiles at MEBT SEM Grid for Qs at operational currents.

**Figure 12.** Beam profiles comparison with Qs at operational values. A) Horizontal plane and, B) vertical plane. For vertical plane, the beam from MEBT TR agrees better with the measurements.
4. Profiles at MEBT SEM Grid

**Figure 13.** Transverse emittances comparison with Qs at operational values between MEBT TR(blue) and beam From LEBT (red) at MEBT SEM Grid.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>From LEBT</th>
<th>MEBT TR</th>
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<tbody>
<tr>
<td>Emit n xxp (mm mrad)</td>
<td>0.13</td>
<td>0.12</td>
</tr>
<tr>
<td>Beta xxp (mm/mrad)</td>
<td>0.26</td>
<td>0.32</td>
</tr>
<tr>
<td>Alpha xxp</td>
<td>-0.42</td>
<td>-0.67</td>
</tr>
<tr>
<td>Emit n yyp (mm mrad)</td>
<td>0.13</td>
<td>0.15</td>
</tr>
<tr>
<td>Beta yyp (mm/mrad)</td>
<td>5.7</td>
<td>3.53</td>
</tr>
<tr>
<td>Alpha yyp</td>
<td>8.63</td>
<td>6.22</td>
</tr>
</tbody>
</table>
Conclusion and acknowledgments

• As the transverse profiles of the beam From LEBT and MEBT TR are quite similar to those measured in the MEBT SEM grid it suggests to us that the Qs, solenoid and RFQ are being correctly modelled in Travel Software.

• We will now focus on adding the rest of the MEBT Line and the IH Structure to the Travel simulation.

• Thanks to Jean-Baptiste Lallement for checking the TR code and suggesting a reduction in the MEBT Qs calibration factors.

• Thanks to Beam Dynamics Group for all their support