The normal conducting linac

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Accelerator Division

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Outline

1. Introduction

2. Ion source and Low Energy Beam Transfer (LEBT) line
   - Ion source
   - LEBT

3. Radio-Frequency Quadrupole (RFQ)

4. Medium Energy Beam Transfer (MEBT)

5. Drift Tube Linac (DTL)
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5 Drift Tube Linac (DTL)
Introduction

Ion source and Low Energy Beam Transfer (LEBT) line
Radio-Frequency Quadrupole (RFQ)
Medium Energy Beam Transfer (MEBT)
Drift Tube Linac (DTL)

Figure: The ESS linac layout.

Table: Top level parameters.

<table>
<thead>
<tr>
<th>Ion type</th>
<th>$H^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak current</td>
<td>50 mA</td>
</tr>
<tr>
<td>Pulse length</td>
<td>2.86 ms</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>14 Hz</td>
</tr>
</tbody>
</table>

Figure: Warm linac cost distribution.
Introduction

Ion source and Low Energy Beam Transfer (LEBT) line
Radio-Frequency Quadrupole (RFQ)
Medium Energy Beam Transfer (MEBT)
Drift Tube Linac (DTL)

<table>
<thead>
<tr>
<th>Goals (challenges) of the NC linac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation of a high quality beam with well defined temporal pulse, a short emittance and minimal halo:</td>
</tr>
<tr>
<td>- Minimization of the losses throughout the high energy part</td>
</tr>
<tr>
<td>- Maximizing the overall reliability of ESS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design philosophy</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Rely on the expertise and knowledge of our partner institutions</td>
</tr>
<tr>
<td>- Conventional designs</td>
</tr>
<tr>
<td>- Take into consideration the lessons learned from current and past machines/devices</td>
</tr>
</tbody>
</table>

The following table shows the work distribution:

<table>
<thead>
<tr>
<th>Management</th>
<th>Head</th>
<th>Institutes</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion Source and LEBT</td>
<td>S. Gammino</td>
<td>INFN-LNS</td>
<td>Catania</td>
</tr>
<tr>
<td>RFQ</td>
<td>L. Celona</td>
<td>INFN-LNS</td>
<td>Catania</td>
</tr>
<tr>
<td>MEBT</td>
<td>B. Pottin</td>
<td>CEA-Irfu</td>
<td>Saclay</td>
</tr>
<tr>
<td>DTL</td>
<td>I. Bustinduy</td>
<td>ESS-Bilbao</td>
<td>Bilbao</td>
</tr>
<tr>
<td></td>
<td>A. Pisent</td>
<td>INFN-LNL</td>
<td>Legnaro</td>
</tr>
</tbody>
</table>

Table: Work distribution.
Introduction

Ion source and Low Energy Beam Transfer (LEBT) line

- Ion source
- LEBT

Radio-Frequency Quadrupole (RFQ)

Medium Energy Beam Transfer (MEBT)

Drift Tube Linac (DTL)
**Ion Source**

<table>
<thead>
<tr>
<th>Type</th>
<th>MDIS(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>2.45 GHz</td>
</tr>
<tr>
<td>Power</td>
<td>1 – 1.5 kW</td>
</tr>
<tr>
<td>Background pressure</td>
<td>1 · 10(^{-5}) mbar</td>
</tr>
<tr>
<td>Magnetic system</td>
<td>3 solenoids</td>
</tr>
<tr>
<td>Extraction system</td>
<td>4 electrodes</td>
</tr>
<tr>
<td>Extraction Voltage</td>
<td>75 keV</td>
</tr>
<tr>
<td>Extracted current</td>
<td>50 – 90 mA</td>
</tr>
</tbody>
</table>

**Table:** Ion source main parameters.

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1 Microwave Discharge Ion Source: plasma direct absorption of EM waves through the ECR mechanism

**Figure:** The ESS ion source drawing.

**Similarities:** TRIPS and VIS sources (Catania), SILHI source (Saclay)
Introduction

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General layout and roles

Roles

1. Transport and match the beam from the ion source into the RFQ
2. Chop the unwanted parts of the beam pulse due to rise/fall time of the ion source

Figure: Ion source and LEBT set-up.
Transport of the unchopped beam

Design choices

- Dual solenoid LEBT similar to IFMIF and LINAC 4
- Solenoids are IFMIF-type
- 2 repeller electrodes to enhance the electron population and enable high Space Charge Compensation (SCC):
  - In the ion source extraction system
  - In the RFQ collimator cone

Figure: Beam transport in the LEBT (98% SCC).
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Introduction
Ion source
LEBT

Chopping

Characteristics of the LEBT chopper
- Electrostatic
- Placed in between the 2 solenoids
- Electronics similar to Spiral 2 (tested): switching speed 15 ns

Beam behavior during transient SCC process
- Beam fall time: 20 ns
- Beam rise time: 300 ns (we need a little bit more to restore the beam matched parameters into the RFQ)

Figure: LEBT chopper

Figure: RFQ collimator.

Figure: LEBT chopper

Figure: RFQ collimator.
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Evolution of the performance requirements:

**Before 2012**
- Initial operation at peak current of 50 mA but upgradeable to 75 mA
- Beam loss above 2 MeV is limited to 1 W/m
- Both transverse and longitudinal emittances are minimized to reduce the potential for subsequent halo development
- There should be no longitudinal tails as they are known to translate into transverse halo

⇒ 5 meters RFQ

**2012**
- Peak operational beam current will not exceed 50 mA
- No limit to allowable beam loss below 3 MeV
- Halo development and beam loss in the high energy linac section traceable to the RFQ are minimized
- No longitudinal tails as they are known to translate into transverse halo
- Phase advances are matched to adjacent sections

⇒ 4 meters RFQ
**Introduction**

**Ion source and Low Energy Beam Transfer (LEBT) line**

**Radio-Frequency Quadrupole (RFQ)**

**Medium Energy Beam Transfer (MEBT)**

**Drift Tube Linac (DTL)**

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**Benefits of a shorter RFQ**

- Reduced potential fabrication and operational risks
  - Less tuners and vacuum and RF seals
  - Less vacuum pumps
- Lower cost:
  - Construction: machining and brazing
  - Operation: less dissipation in copper

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**Present and future work**

- Recent design change
- Beam dynamics study (pole tip design) just completed
- The following deals with the 5 meters RFQ
- Work on progress to update the RFQ engineering design
- Construction phase planning unaffected
- Methodology already established
Introduction

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Main parameters of the 4-vanes RFQ for ESS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter-vane voltage</td>
<td>kV</td>
<td>80 to 120</td>
</tr>
<tr>
<td>Synchronous phase, $\phi_S$</td>
<td>deg</td>
<td>-90 to -31</td>
</tr>
<tr>
<td>Minimal aperture, $a$</td>
<td>mm</td>
<td>3 to 3.9</td>
</tr>
<tr>
<td>Modulation factor, $m$</td>
<td></td>
<td>1 to 2.06</td>
</tr>
<tr>
<td>Vane radius of curvature, $\rho$</td>
<td>mm</td>
<td>3 (constant)</td>
</tr>
<tr>
<td>Vane length, $L$</td>
<td>m</td>
<td>4.93</td>
</tr>
<tr>
<td>Kilpatrick limit, $k_p$</td>
<td></td>
<td>1.8</td>
</tr>
<tr>
<td>RF power budget</td>
<td>kW</td>
<td>1 638</td>
</tr>
<tr>
<td>Frequency</td>
<td>Mhz</td>
<td>352.21</td>
</tr>
</tbody>
</table>

Table: RFQ main parameters.

Figure: Geometric parameters of the RFQ.

Roles of the RFQ

- Acceleration from 75 keV to 3 MeV
- Focalization in the 3 planes
- Shape the continuous beam in a train of bunches suitable for RF acceleration
2D cross section design

In order to produce the voltage profile $V(z)$ the position of the electrode lateral surface (points J5 and J6) varies: $x_{J6} \in [63, 73]$ mm, $y_{J6} = x_{J6}$.
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Stability analysis

Goals
1. Tune the accelerating mode boundary conditions to a null quadrupole voltage slope at both ends
2. Tune dipolar voltage log-slope parameter to some value in the stability region

How?
1. Quadrupolar rods
2. Proper choice of the vane undercuts

Figure: 3D views of the RFQ extremities.
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How?
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2. Proper choice of the vane undercuts

Remarks
- Unsegmented RFQ: no coupling plates
- No dipole rods required

Table: Stability study results.

<table>
<thead>
<tr>
<th>Vane undercut [mm]</th>
<th>input</th>
<th>output</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>28.2</td>
<td>31.5</td>
</tr>
</tbody>
</table>

Aurélien Ponton
NC Linac
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Tuning

Figure: Distributions of tuner and field-sampling locations.

- Slug tuners dedicated to compensate the voltage errors resulting from **construction tolerances only**
- S=15 equispaced tuners per quadrant
- 80 mm diameter and position range in $[-30, +30]$ mm
- Bead pull measurement in the magnetically dominant region
- T=2S sampling points
- $V/H_z$ perturbation is smaller than 1% at the field sampling points
RF power coupling

Figure: 3D view of the tuning loop.

Half circular loops

- TRASCO and SPIRAL 2
- Can be rotated
- Coupled power varies from 469 kW to 234 kW (45 degrees rotation)
- Preferably located at mid point between two adjacent tuners
- Voltage perturbation smaller than $1.8 \cdot 10^{-3}$
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Main parameters and roles

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<tr>
<th>Parameters</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>MeV</td>
<td>3</td>
</tr>
<tr>
<td>Number of quadrupoles</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Min. quadrupole gradient</td>
<td>T/m</td>
<td>9</td>
</tr>
<tr>
<td>Max. quadrupole gradient</td>
<td>T/m</td>
<td>30</td>
</tr>
<tr>
<td>Number of bunchers</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Frequency</td>
<td>Mhz</td>
<td>352.21</td>
</tr>
<tr>
<td>Peak power per cavity</td>
<td>kW</td>
<td>14</td>
</tr>
<tr>
<td>Effective voltage, $E_0TL$</td>
<td>kV</td>
<td>150</td>
</tr>
<tr>
<td>Length</td>
<td>m</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Table: MEBT main parameters.

Goals
- Match the beam from the RFQ into the DTL: quads and bunchers
- Give the beam its temporal structure: electrostatic chopper with 10 ns rise time
- Address a collimation strategy
- Fully characterize the beam with a given set of diagnostics
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General layout

Figure: ESS MEBT general layout and RMS beam size (blue: x and red: y)
Scrapers

Figure: Beam parameters evolution with and without scrapers (blue: x, red: y, green: z).

- 3 locations determined by beam dynamics study
- 4 stepping motors per location
- IFMIF-like design

Collimation strategy is mandatory to limit halo development and hazardous losses at high energy
Bunching cavities

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>MHz</td>
<td>352.21</td>
</tr>
<tr>
<td>$Q_0$</td>
<td></td>
<td>23477</td>
</tr>
<tr>
<td>$T$</td>
<td></td>
<td>0.593</td>
</tr>
<tr>
<td>$V_0 T$</td>
<td>kV</td>
<td>140</td>
</tr>
<tr>
<td>$P$</td>
<td>kW</td>
<td>14.02</td>
</tr>
<tr>
<td>$r$</td>
<td>MΩ</td>
<td>1.4</td>
</tr>
<tr>
<td>$ZT^2$</td>
<td>MΩ/m</td>
<td>11.1</td>
</tr>
<tr>
<td>$E_{surf}$</td>
<td>MV/m</td>
<td>27.2</td>
</tr>
<tr>
<td>$k_p$</td>
<td></td>
<td>1.47</td>
</tr>
</tbody>
</table>

Table: Bunching cavity main parameters.

Figure: Bunching cavity and coupler.
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### Main parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>MHz</td>
<td>352.21</td>
</tr>
<tr>
<td>Energy</td>
<td>MeV</td>
<td>3 to 78</td>
</tr>
<tr>
<td>Lattice type</td>
<td></td>
<td>FODO</td>
</tr>
<tr>
<td>Number of tanks</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>RF power per tank</td>
<td>MW</td>
<td>2.15</td>
</tr>
<tr>
<td>$k_p$</td>
<td></td>
<td>1.4</td>
</tr>
<tr>
<td>Trans. focusing</td>
<td>perm. magnets</td>
<td>30 to 70</td>
</tr>
<tr>
<td>Quad. gradient</td>
<td>T/m</td>
<td>30 to 70</td>
</tr>
<tr>
<td>Long. focusing scheme</td>
<td>ramped field</td>
<td>2.8 to 3.2</td>
</tr>
<tr>
<td>$E_0$</td>
<td>MV/m</td>
<td>2.8 to 3.2</td>
</tr>
<tr>
<td>$k_p$</td>
<td></td>
<td>1.47</td>
</tr>
</tbody>
</table>

Table: DTL main parameters.

### design choices
- Mechanical design based on LINAC 4
- FODO: half of the DTs for allocation of steerers and diagnostics
- Surface electric field limited to avoid sparking
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Layout

Figure: DTL overview and summary of tank properties.
RF design

- Ramped $E_0$: variation of the face angle
- Validated by 3D analysis
- Mechanical feasability checked/
  Consistent tank design
- Post couplers needed for field stability
- Frequency errors: slug tuners, 45
  degrees from stem, 90 mm diameter,
  uniformly spaced every 30 cm

Figure: DT design.

Figure: 3D model.
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Thanks for your attention