Alessandra Valloni

PRELIMINARY DESIGN OF THE CERN ERL TEST FACILITY
EIC14 Workshop on Accelerator Science and Technology for Electron-Ion Collider

17–21 March 2014,
Thomas Jefferson National Accelerator Facility
Goals of a CERN ERL Test Facility

- Test facility for SCRF cavities and modules
- Test facility for multi-pass multiple cavity ERL
- Injector studies: DC gun or SRF gun
- Study reliability issues, operational issues!
- Vacuum studies related to FCC
- Test facility for controlled SC magnet quench tests
- Possible use for detector development, experiments and injector
  suggests ~1 GeV as final stage energy
- Could it be foreseen as the injector to LHeC ERL and to FCC?
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<table>
<thead>
<tr>
<th>TARGET PARAMETER*</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection Energy [MeV]</td>
<td>5</td>
</tr>
<tr>
<td>Final Beam Energy [MeV]</td>
<td>900</td>
</tr>
<tr>
<td>Normalized emittance $\gamma\varepsilon_{x,y} [\mu m]$</td>
<td>50</td>
</tr>
<tr>
<td>Beam Current [mA]</td>
<td>10</td>
</tr>
<tr>
<td>Bunch Spacing [ns]</td>
<td>25 (50)</td>
</tr>
<tr>
<td>Passes</td>
<td>3</td>
</tr>
</tbody>
</table>

*in few stages
Outline

1. STAGES OF BUILDING DESIGN
   - LAYOUTS
   - BASELINE PARAMETERS

2. ARC OPTICS ARCHITECTURE

3. TEST FACILITY FOR SC MAGNET TESTS
Planning for each stage

STEP 1
SC RF cavities, modules and e⁻ source tests
- Injection at 5 MeV
- 1 turn
- 75 MeV/linac
- Final energy 150 MeV

<table>
<thead>
<tr>
<th>ARC</th>
<th>ENERGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARC 1</td>
<td>80 MeV</td>
</tr>
<tr>
<td>ARC 2</td>
<td>155 MeV</td>
</tr>
</tbody>
</table>

*4 SRF 5-cell cavities at 802 MHz
Planning for each stage

STEP 2
Test the machine in Energy Recovery Mode
- Injection at 5 MeV
- 3 turns
- 75 MeV/linac
- Final energy 450 MeV

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<td>ARC 2</td>
<td>155 MeV</td>
</tr>
<tr>
<td>ARC 3</td>
<td>230 MeV</td>
</tr>
<tr>
<td>ARC 4</td>
<td>305 MeV</td>
</tr>
<tr>
<td>ARC 5</td>
<td>380 MeV</td>
</tr>
<tr>
<td>ARC 6</td>
<td>455 MeV</td>
</tr>
</tbody>
</table>

Recirculation realized with vertically stacked recirculation passes
Planning for each stage

STEP 3
Additional SC RF modules test
Full energy test in Energy Recovery Mode
- Injection at 5 MeV
- 3 turns
- 150 MeV/linac
- Final energy 900 MeV

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<td>300 MeV</td>
</tr>
<tr>
<td>ARC 3</td>
<td>450 MeV</td>
</tr>
<tr>
<td>ARC 4</td>
<td>600 MeV</td>
</tr>
<tr>
<td>ARC 5</td>
<td>750 MeV</td>
</tr>
<tr>
<td>ARC 6</td>
<td>900 MeV</td>
</tr>
</tbody>
</table>
Outline

1. STAGES OF BUILDING DESIGN
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2. ARC OPTICS ARCHITECTURE FOR STEP 3

3. TEST FACILITY FOR SC MAGNET TESTS
Layout

5 MeV Extraction

6 4 2

1 3 5

5 MeV Injector

ARC 1 – 155 MeV
ARC 3 – 455 MeV
ARC 5 – 755 MeV
Linac 1 Multi-Pass Optics

A. Valloni, A. Bogacz
Linac 2 Multi-Pass Optics

β_y, β_x, Disp_x

905 MeV  755 MeV  605 MeV  455 MeV  305 MeV  155 MeV  5 MeV
Arc 1 optics

155 MeV

Arc dipoles:
Ldip = 71.8 cm
B = 5.67 kGauss
ρ = 91.45 cm
Arc 3 optics

455 MeV

\[ \beta_x, \beta_y, \text{Disp}_x, \text{Disp}_y \]

Arc dipoles:
\[ L_{\text{dip}} = 90.58 \text{ cm}, \quad B = 6.58 \text{ kGauss}, \quad \rho = 230.66 \text{ cm} \]

9.8° bends
(1 rec. + 3 sec.)

2-step vert. Spreader

8×22.5° sector bends

2-step vert. Combiner

A. Valloni, A. Bogacz
Arc 5 optics

755 MeV

Arc dipoles:
Ldip = 90.58 cm
B = 10.92 kGauss
ρ = 230.66 cm

Vertical chicane
8×22.5° sector bends
Vertical chicane

A. Valloni, A. Bogacz
Arc 1,3,5 layout

- Synchronous acceleration
- Isochronous arcs
- Achromatic arc
- FMC optics

Total Arc length for Arc 1,2,3:
- 34.5112 m
- 94 x λrf

For 6 arcs:
- 84 DIPOLES
- 114 QUADRUPOLES
Footprint

**ARCS**

Total length for Arc 1, 2, 3
34.5112 m
94 x λrf
(last cavity linac 1 to first cavity linac 2)

Total length for Arc 2, 4
34.2704 m
101 x λrf
(last cavity linac 1 to first cavity linac 2)

Total length for Arc 6
34.4574 m
101.5 x λrf
(last cavity linac 1 to first cavity linac 2)

**LINAC**

Total length ~ 13 m

**CHICANE INJ/EXTR**

Length ~ 1.75 m

**TOTAL DIMENSIONS**

42 m x 13.7 m
Arc optics OPTION 2

SAME OPTICS LAYOUT FOR ALL THE ARCS 900/750/600/450/300/150 MeV

Arc dipoles:
- 8×22.5° bends
- Ldip = 100.6 cm
- $\rho = 256.3$ cm

3 DIOPOLES ON TOP OF EACH OTHER

* Attilio Milanese

<table>
<thead>
<tr>
<th>B FIELD</th>
<th>1GeV</th>
<th>750MeV</th>
<th>600MeV</th>
<th>450MeV</th>
<th>300MeV</th>
<th>150MeV</th>
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<tbody>
<tr>
<td>1.30 T</td>
<td>0.97 T</td>
<td>0.78 T</td>
<td>0.58 T</td>
<td>0.39 T</td>
<td>0.19 T</td>
<td></td>
</tr>
</tbody>
</table>

Arc quadrupoles
- Lquads = 30 cm

<table>
<thead>
<tr>
<th>Kq[m$^{-2}$]</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1.01</td>
<td>2.91</td>
<td>2.09</td>
<td>1.19</td>
<td></td>
</tr>
</tbody>
</table>
Incoherent Synchrotron radiation in return arcs

<table>
<thead>
<tr>
<th>ARC</th>
<th>E [MeV]</th>
<th>ρ [cm]</th>
<th>ΔE [keV]</th>
<th>σE/E [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150</td>
<td>91.459</td>
<td>0.0280</td>
<td>1.17e-5</td>
</tr>
<tr>
<td>2</td>
<td>300</td>
<td>91.459</td>
<td>0.4191</td>
<td>6.42e-5</td>
</tr>
<tr>
<td>3</td>
<td>450</td>
<td>230.66</td>
<td>0.8230</td>
<td>8.13e-5</td>
</tr>
<tr>
<td>4</td>
<td>600</td>
<td>230.66</td>
<td>2.5726</td>
<td>1.53e-4</td>
</tr>
<tr>
<td>5</td>
<td>750</td>
<td>230.66</td>
<td>6.2394</td>
<td>2.73e-4</td>
</tr>
<tr>
<td>6</td>
<td>900</td>
<td>230.66</td>
<td>12.881</td>
<td>4.47e-4</td>
</tr>
<tr>
<td>7</td>
<td>750</td>
<td>230.66</td>
<td>6.2394</td>
<td>5.89e-6</td>
</tr>
<tr>
<td>8</td>
<td>600</td>
<td>230.66</td>
<td>2.5726</td>
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<td>0.0280</td>
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- **Beam Energy loss**
  \[
  \Delta E = \int P_\gamma dt = P_\gamma \frac{\pi \rho}{\beta c} \quad \Delta E(GeV) = C_\gamma \frac{E^4}{\rho} \frac{1}{2}
  \]

- **Beam Energy Spread**
  \[
  \frac{\sigma_E}{E} = \sqrt{1.4397 \times 10^{-27} \frac{\pi \gamma^5}{\rho^2}}
  \]
Next steps

- Complete Step 2 and Step 1 configuration and optics layout
Linac 1 - Step 2
Linac 2 - Step 2

\(\beta_y, \beta_x, \text{Disp}_x\)

\[
\begin{align*}
455 & \text{ MeV} \\
380 & \text{ MeV} \\
305 & \text{ MeV} \\
230 & \text{ MeV} \\
155 & \text{ MeV} \\
80 & \text{ MeV} \\
5 & \text{ MeV}
\end{align*}
\]
Step 2 optics

- **80 MeV**
- **230 MeV**
- **380 MeV**

Dimensions:
- 13.43 m
- 13.66 m
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Controlled quench tests of SC magnets

WE ARE INVESTIGATING THE POSSIBILITY OF USING THE TEST FACILITY FOR SC MAGNET TESTS

Requirements in terms of:

- Beam energy, intensity and pulse length (energy deposition)
- Space for the magnets installation (possible tests of cable samples and full cryo magnets)
- Cryo requirements
- Vacuum requirements
- Powering needs
Controlled quench tests of SC magnets

Study beam induced quenches (quench thresholds, quenchino thresholds) at different time scales for:

- SC cables and cable stacks in an adjustable external magnetic field
- Short sample magnets
- Full length LHC type SC magnets

Quench limits of LHC dipole as expected from QP3 simulations for different pulse durations

Courtesy A. Verweij
Beam parameters to generate a given amount of energy deposition

**CALCULATIONS AND FLUKA SIMULATIONS**

**Beam parameters**

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<tr>
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<td>1000</td>
<td>2.55E-08</td>
<td>0.036</td>
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Results are given for half of bulky target because of symmetry

Binning: 1 mm³ bins

Copper target
(no magnetic field)

Cylinder of copper
Radius = 50cm
Length = 100cm

Energy deposition, GeV/cm³/e⁻
Beam parameters to generate a given amount of energy deposition

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Results are given for half of bulky target because of symmetry

Binning: 1 mm^3 bins

Energy deposition, GeV/cm^3/e^-

- Peak at z = 0.6 cm, r=0
  - Peak value = 0.2199 GeV/cm^3

- Peak at z = 2.1 cm, r=0
  - Peak value = 1.0785 GeV/cm^3

150 MeV

1 GeV

V. Chetvertkova, D. Wollmann

CERN
Beam parameters to generate a given amount of energy deposition

![Graph showing energy deposition and depth of max dE/dx against energy.](image)

- **Max energy deposition**
- **Depth of max dE/dx**

**Graphs showing**
- Depth of maximum dE/dx vs. energy (MeV)
- Maximum energy deposition vs. energy (MeV)
Beam parameters to generate a given amount of energy deposition

Number of particles

Beam parameters to generate a given amount of energy deposition

MB quench limit @ 3.5 TeV

1 GeV = $1.602 \times 10^{-7}$ mJ

MB quench limit 450 GeV is 140 mJ/cm$^3$ in 10ms:
~$2.2 \times 10^9$ e$^-$ @ 1 GeV necessary

MB quench limit 7 TeV is 16 mJ/cm$^3$ in 10ms:
~$2.6 \times 10^8$ e$^-$ @ 1 GeV necessary

Quench threshold

Maximum value for the energy deposition
Summary

- The concept of the ERLTF is designed to allow for a staged construction with verifiable and useful stages for an ultimate beam energy in the order of 1 GeV.

- Design complementary to & synergetic with other proposals

- A Design Study of the ERL-TF has started (a sketch of the optics configuration is provided and other options are under investigation) in collaboration with other institutes (as JLAB)

- First analysis of having controlled quench tests of next generation superconducting magnets has been carried out. Beam parameters seem to match the requirements….further investigation is required!

- Completion of Conceptual design study of an ERL-TF at CERN by the end of 2015

Thank you for your attention

Many thanks to A. Bogacz, V. Chetvertkova, D. Wollmann, and the LHeC Study Group Collaboration