Proposed Study:
Comparative Carbon Footprint of Underground Civil Engineering Facilities for Future Colliders

Benno List, DESY and CERN
Liam Bromiley, CERN
John Osborne, CERN
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Several options for future Higgs factories are presently discussed, among them the International Linear Collider (ILC), the Compact Linear Collider (CLIC), and the Future Circular Collider (FCC-ee). The concepts each have differing requirements for underground facilities, ranging from 11km of straight tunnel for phase 1 CLIC to close to 100km of circular tunnel for FCC-ee.

The proposed Life Cycle Assessment (LCA) will evaluate the environmental impact of the construction of underground facilities (tunnels, caverns, and access shafts), considering the present state of design and the specifics of the proposed locations (Kitakami region for the ILC, CLIC, and FCC-ee).

Three different tunnel cross sections are presented below. To be assessed per kilometre length (i.e. kg CO2-eq/km), or as deemed most appropriate by the consultant.

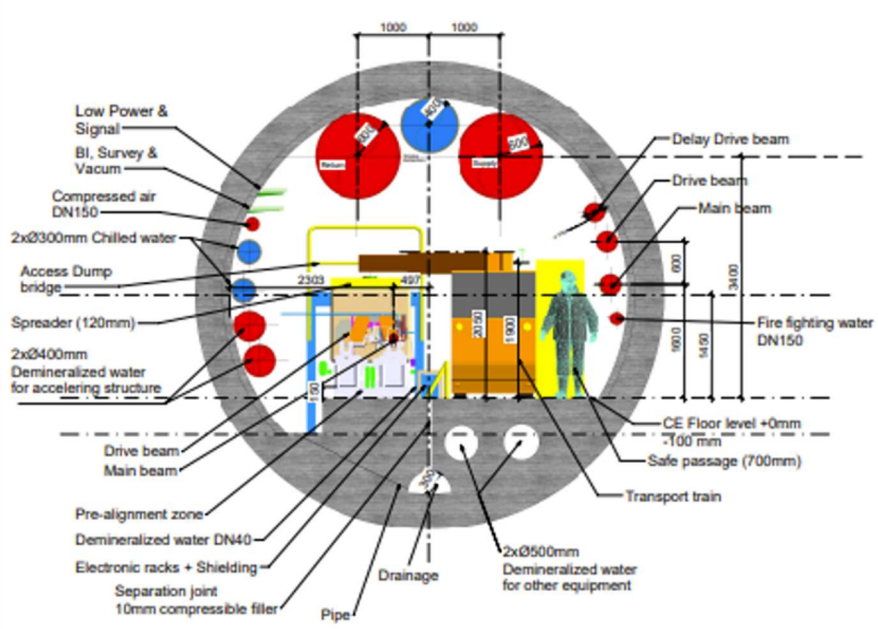

Figure 1 - CLIC 5.6 m internal diameter drive beam tunnel.

Figure 1 shows the cross section proposed for the CLIC drive beam option. This is a 5.6 m internal diameter tunnel constructed of 500 mm thick concrete segments.

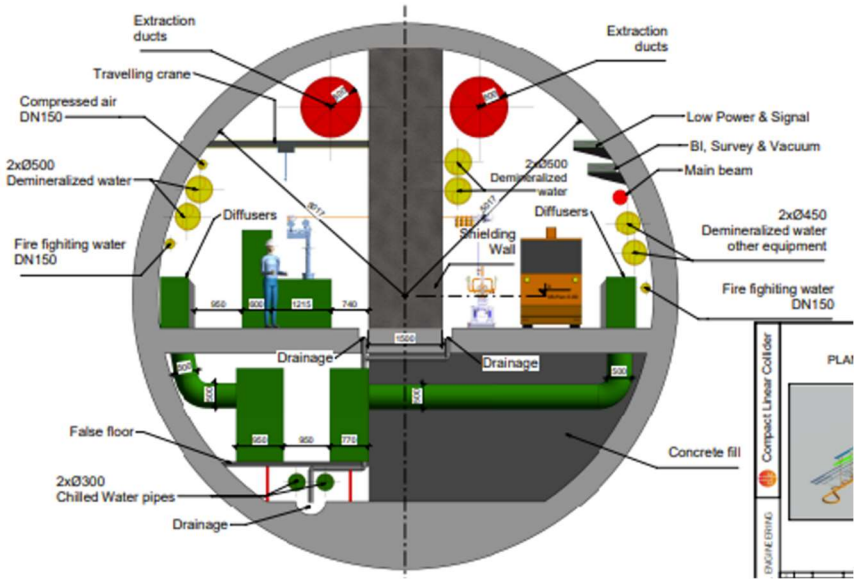

Figure 2 - CLIC Klystron Option, 10 m internal diameter.

Figure 2 shows the cross section proposed for the CLIC Klystron option. This is a 10 m internal diameter tunnel constructed of 500 mm thick concrete segments and includes a non-structural 1.5 m thick concrete shielding wall.

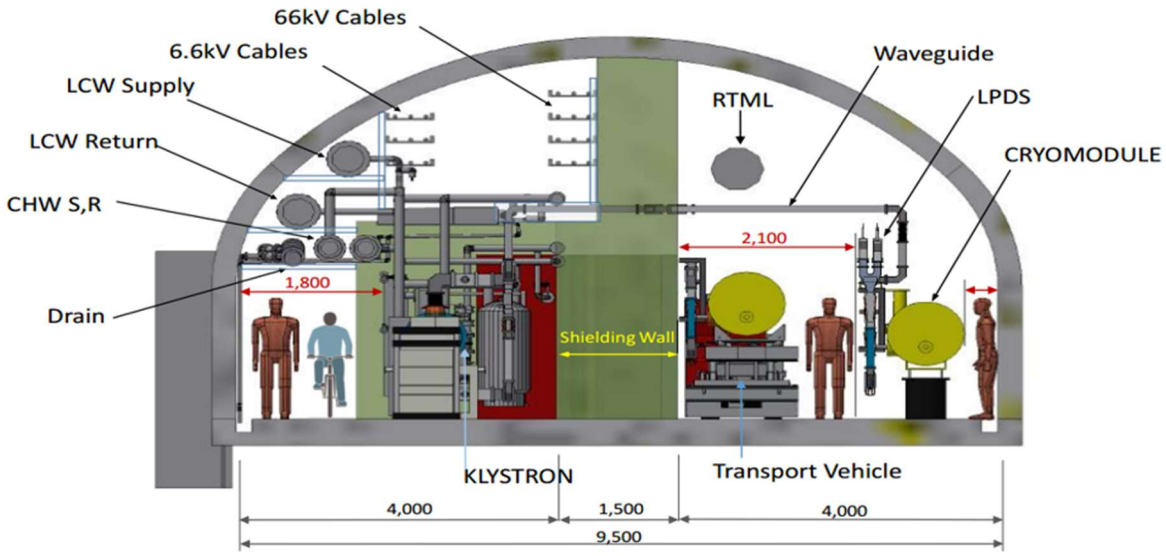

Figure 3 - ILC Japan tunnel cross section.

Figure 3 shows the cross section proposed for the ILC in Japan. This is an arched tunnel of 9.5 m span, within granite geology. It is envisaged that studies in this case would be coordinated with consultants in Japan (i.e. Arup Tokyo office).

The LCA should cover the construction period up to the point where the technical equipment (water and electrical supplies, heating and ventilation, lighting etc.) can be installed.

Impact categories to be considered are primarily:

- Greenhouse gas emissions, quantified by the 100-year global warming potential (GWP_{100}), measured in kg CO2-eq

Other impact categories that could be studied, insofar as quantifiable and relevant:

- Ecotoxicity (terrestrial and aquatic), quantified by Ecotoxicity Potential (ETP), measured kg 1,4
- Acidification, quantified by Acidification Potential (AP), measured in kg SO2-eq
- Eutrophication, quantified by Eutrophication Potential (EP), measured in kg PO4-eq (phosphate equivalent)
- Ozone depletion, quantified by Ozone Depletion Potential (ODP), measured in kg CFC11-eq
- Summer smog, quantified by Photochemical Ozone Creation Potential (POCP), measured in kg C2H4-eq (ethene equivalent)
- Particulate Matter emissions below 2.5µm ($PM_{2.5}$)

These impact categories are likely to arise mainly from the production of concrete used in the construction of underground structures. Additional impacts arising from excavation, disposal, transport, energy use, fuel consumption, and any other significant ancillary activities will also need to be assessed.

As a starting point, the methodology of Rodríguz and Pérez[1] may be applied and extended to the use of Tunnel Boring Machines (TBM). Specific assumptions will need to be checked and possibly adapted to the situation and construction codes in the Geneva or Japan regions.

To formulate the estimate, the current civil engineering proposals shall be provided by the respective design teams, with a list of tunnel segments (portions of tunnels with roughly uniform cross section and geological conditions) giving length, cross section dimensions, planned lining, excavation method, access routes etc., and appropriate figures for underground caverns and access shafts.

Deliverables

The results of the LCA shall be delivered in a technical report, including all relevant assumptions, calculations, results, and appendices. An interim note/report will be required by the end of 2022 to evaluate progress.

[1] R. Rodriguez and F. Pérez: *Carbon footprint evaluation in tunneling construction using conventional methods*, Tunn. Undergr. Space Tech. **108** (2021) 103704. doi:10.1016/j.tust.2020.103704

Programme

- 4 to 5 online progress meetings with CERN during the study period.
- Face to face meeting to present study findings during Linear Collider workshop at SLAC, San Francisco.
- Interim technical note/report by March 2023 to evaluate progress.
- Final technical report by end of May 2023.