Infrastructure challenges for the CLIC Main Linac tunnel and impact on costing

Matthew Stuart – John Osborne SMB-SE-FAS

Introduction - Content

- Who is involved and what are the objectives of the Civil Engineering, Infrastructure and Siting CEIS Working Group?
- Recap the baseline design produced in the CDR.
- Updates since the CDR?
  - Civil Engineering – New layouts and Tunnel Optimisation Tool
  - Cooling and Ventilation
  - Electrical (CLIC Power Supply).
  - Transport
  - Survey
  - Cost
- Further Study – A summary of requirements for the different disciplines.

Representatives of the Civil Engineering, Infrastructure & Siting (CEIS) Working Group Disciplines:

Discipline	Representative
Civil Engineering & Chair	J.Osborne & M.Stuart
CLIC Link Persons	S.Stapnes/D.Schulte/C.Rossi/R.Corsini /W.Wuensch/A.Latina
Cooling and Ventilation (CV)	M.Nonis
Electricity (EL)	D.Aguglia/D.Bozini
Survey (SU)	H.Mainaud Durand
Transport & Handling (HE)	I.Ruehl/M.Czech
Interaction Region	K.Elsener
Logistics/Lab readiness	M.Tiirakari
CE Layouts & Cross-sections	SMB/CE Design Office
Health Safety & Environment (HSE)	S.Baird/S.Marsh
Schedule	K.Foraz/M.Bernardini
ILC Link Persons	J.Osborne/A.Yamamoto

General Objective: *Develop the existing layouts for the project from a civil engineering and technical infrastructure point of view, and work with the various actors towards a realistic design and project planning as needed for the 'CLIC Implementation Plan', due late 2018.*

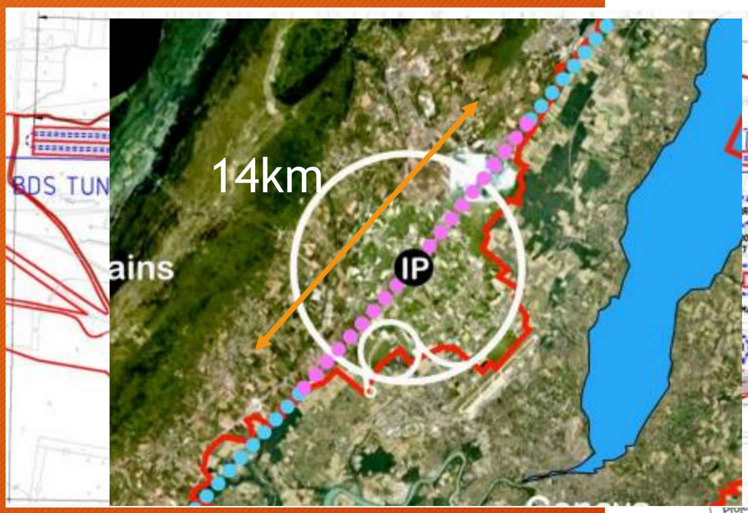
What are the Objectives?

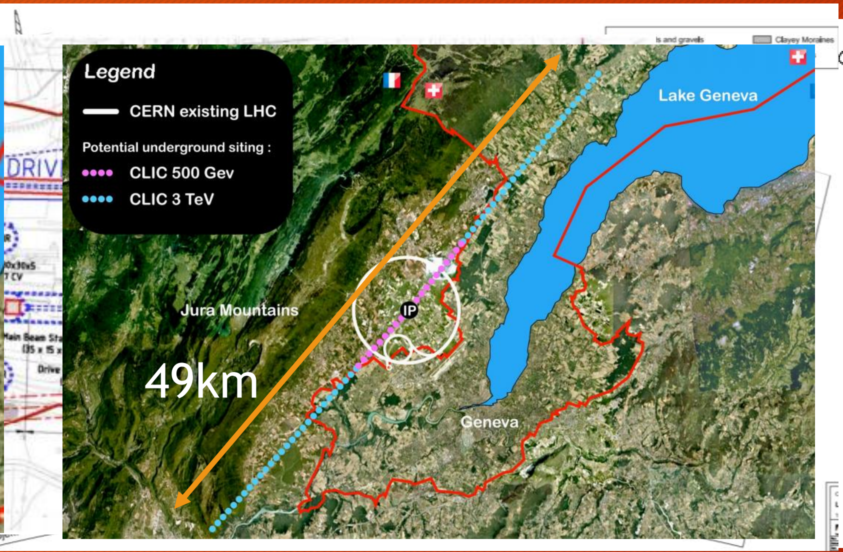
Specific responsibilities:

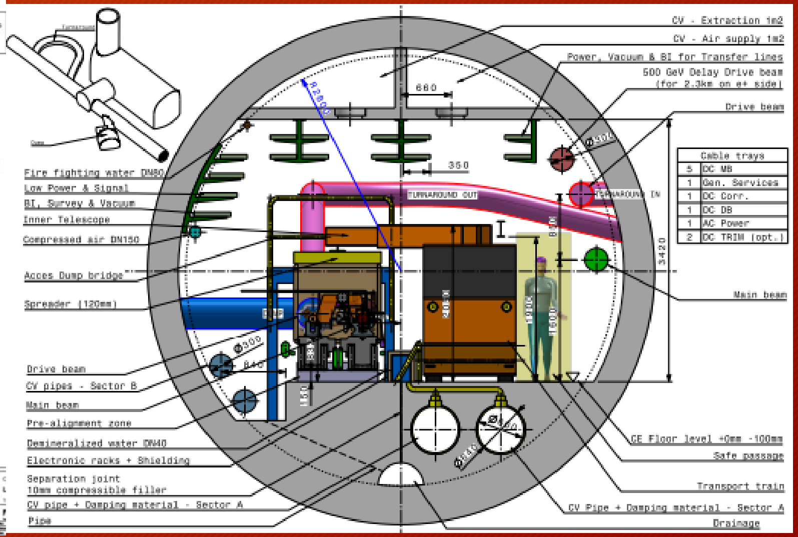
- Develop new and/or update civil engineering layouts for 380 GeV, 1.5 TeV and 3 TeV machine.
- Develop new civil engineering layout for 380 GeV machine using Klystron technology.
- Update the tunnel design and layout to accommodate the machine (e.g. ventilation, electrical equipment, survey, controls, safety and handling equipment).
- Develop a layout for the interaction region.
- Study environmental aspects of the project and siting preparation. Work together with ILC on areas of synergy.
- Produce schedule and cost estimates.
- Consider and update transport, installation and CERN logistics issues for the project.
- Technical infrastructure and installation scheduling.

Brief History – CDR Design

- **Conceptual Design Report: Published in 2012.**
  - 5.6m diameter 2 stage linear collider, an initial 500 GeV with the possibility to upgrade to 3 TeV.
  - 500 GeV energy stage consisted of a site length of 14km
  - 3 TeV energy stage consisted of a site length of 49km
  - 2 Independent Detector Caverns.
  - Central injection complex located on CERN land.
  - 30m wide and 2.5km Long drive beam building.
  - Depth ranging from approximately 100 – 150m below the surface along the majority of the tunnel length.

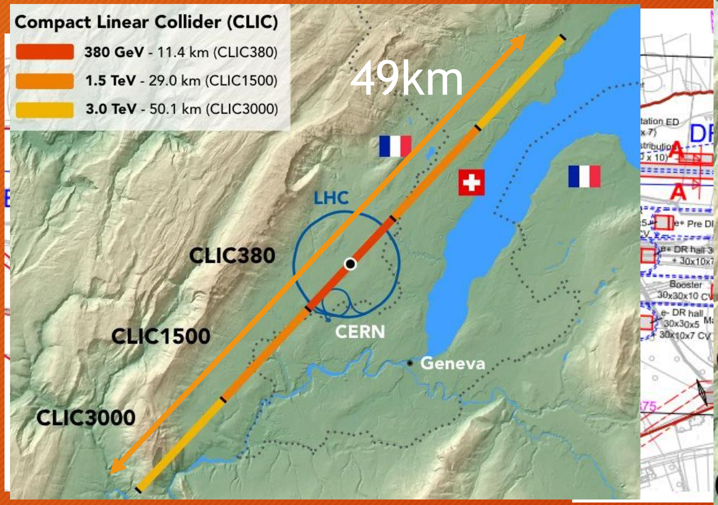


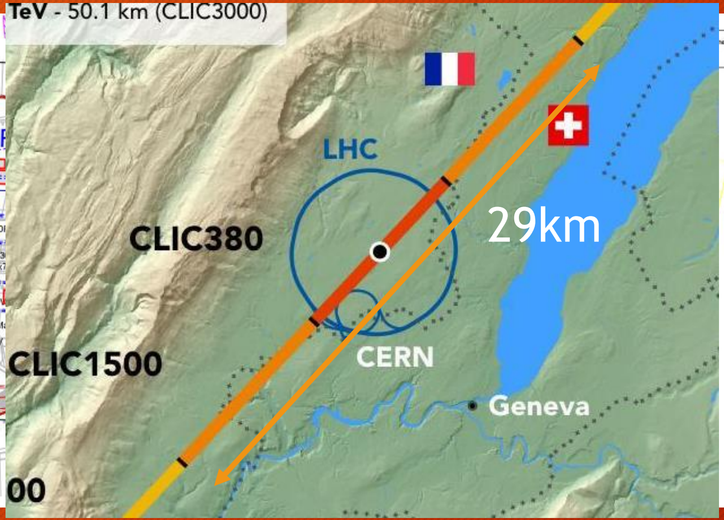


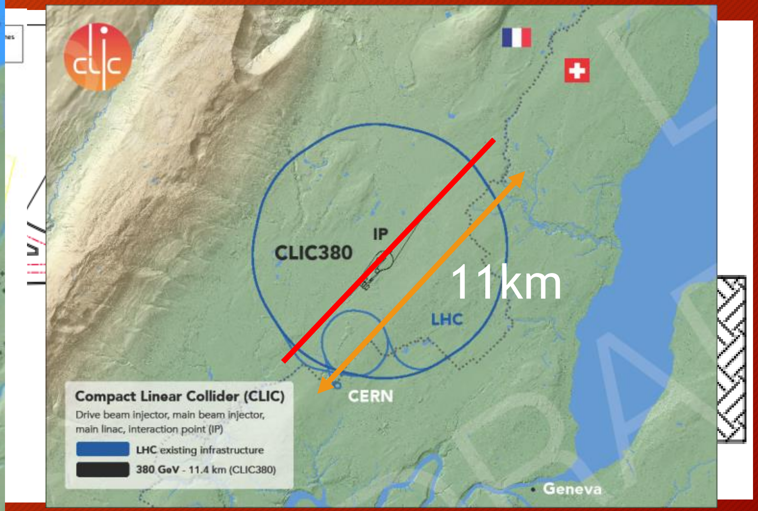


Changes Since the CDR

- **Civil Engineering, Infrastructure and Siting Working Group (CEIS): Kick off meeting March 2017**
  - 3 stage linear collider, an initial 380 GeV with the possibility to upgrade to 1.5 TeV and 3 TeV.
  - 380 GeV energy stage consists of a site length of 11km
  - 1.5 TeV energy stage consists of a site length of 29km
  - 3 TeV energy stage consisted of a site length of 49km
  - Only one detector cavern and a service cavern introduced.
  - 30m wide and 2.5km Long drive beam building with the possibility to reduce the size for lower energy stages.
  - Depth and position of the machine to be optimised using CLIC Tunnel Optimisation Tool.

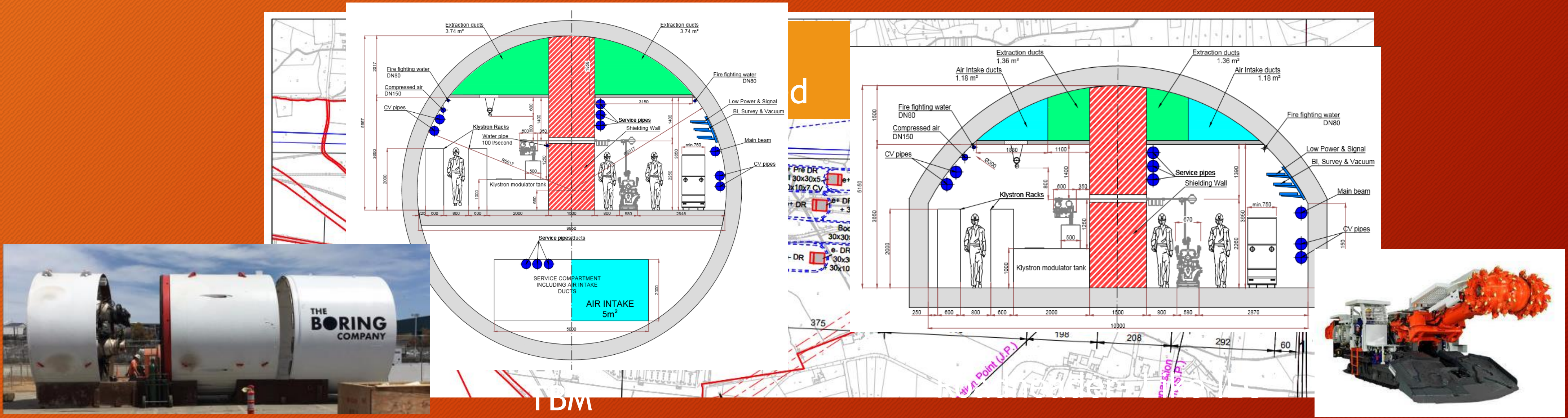






Changes Since the CDR – NEW Design

- **Civil Engineering, Infrastructure and Siting Working Group (CEIS): Kick off meeting March 2017**
  - ➢ New Klystron Design introduced for the 380 GeV energy stage
  - ➢ No longer requires the Drive Beam complex.
  - ➢ Larger tunnel to house the Klystron modules and the beam modules – shielding wall required. Roadheader and TBM tunnelling method considered.



Civil Engineering – Tunnel Optimisation Tool

1. Geology along alignment:
    - Maximum proportion of tunnel in molasse.
    - Avoid limestone formations wherever possible due to associate risk of water ingress and karsts.
    - Avoid water bearing moraines wherever possible due to risk of water ingress and potential contamination of water sources.
    - Minimise overburden.

2. Shaft length:
    - Minimise total shaft length.
    - Avoid very deep individual shafts – utilise inclined access tunnels where required.

3. Geology of shafts and caverns
    - The greater the depth of the moraine before reaching the molasse layer, the more costly/ time consuming the construction.
    - Cavern construction requires good ground conditions.

4. Environmental Constraints
    - Avoid protected water sources and protected habitats.

5. Shaft Surface Locations
    - Initial assessment to avoid clashes with buildings, natural features or protected zones.
    - Followed by a more refined assessment of feasibility including potential access to the site.

Civil Engineering – Tunnel Optimisation Tool

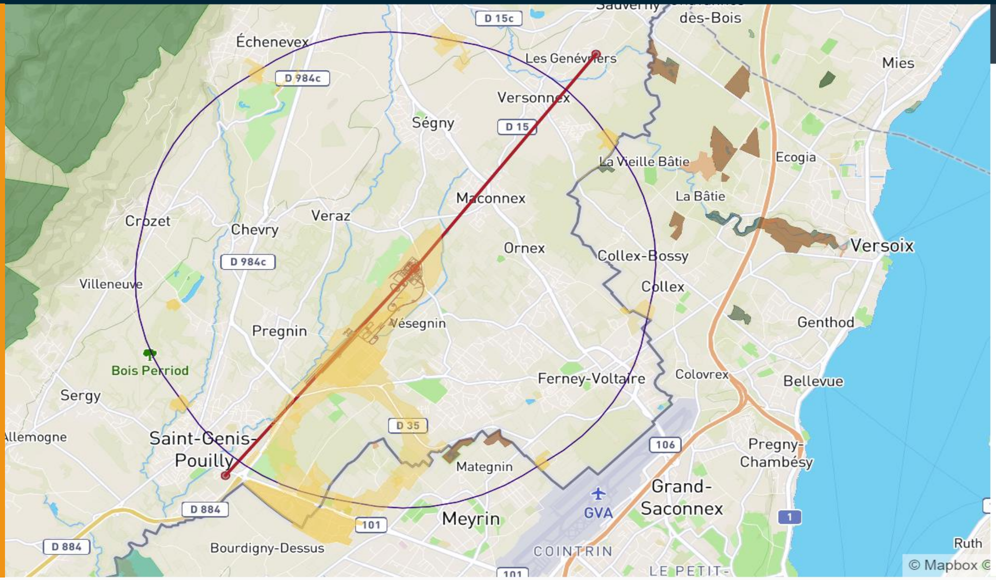
CERN ARUP

Scenarios My Profile Log out

3
IP
2

CLIC Advantages

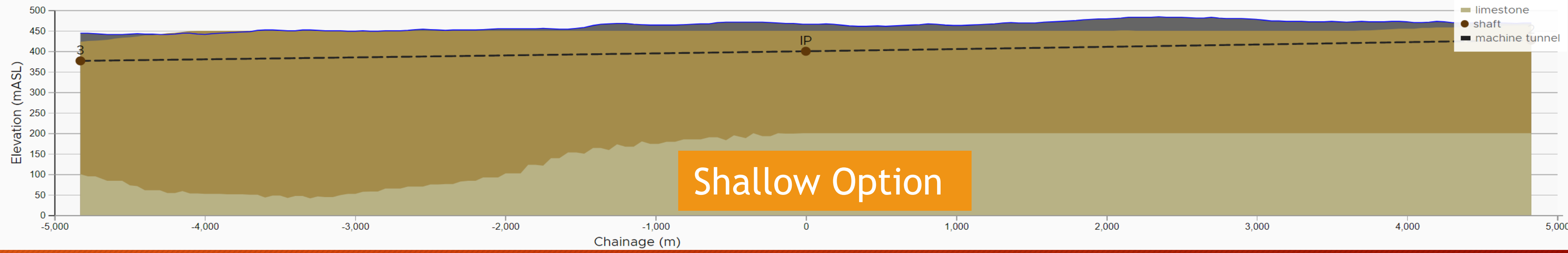
- Allows quick movement of the entire machine.
- Easier to find optimised locations.
- User can run through many positions quickly and efficiently.
- Simpler to find and compare new positions.



Map Layers

- Streets
- Satellite
- Light
- Focus scenario
- comparison-15
- Nature area
- LHC
- CERN land
- Nature reserve
- Protected habitat
- Wetlands
- Study area
- Geothermal boreholes

380 SHALLOW

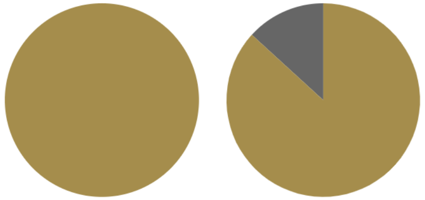


Shallow Option

Civil Engineering – Tunnel Optimisation Tool

Focus: 380 Baseline

Tunnel	IP
Energy stage: 380 GeV	x: 2494510.09
Gradient: 0.3˚	y: 1125552.01
Created by: matthew.stuart	Elevation: 350mASL
Last edit date: 20/10/2017	



Total tunnel geology   Total shaft geology

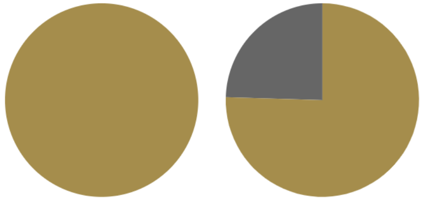
moraine · molasse · limestone

Shaft geology & length (m)

3: 117.44	
IP: 116.00	
2: 91.90	

380 shallow

Tunnel	IP
Energy stage: 380 GeV	x: 2494510.09
Gradient: 0.3˚	y: 1125552.01
Created by: matthew.stuart	Elevation: 400mASL
Last edit date: 20/10/2017	



Total tunnel geology   Total shaft geology

moraine · molasse · limestone

Shaft geology & length (m)

3: 67.44	
IP: 66.00	
2: 41.90	

380 GeV "CDR" Design

- Total Shaft Length: 325m
- Main Tunnel entirely in Molasse

380 GeV Shallow Option

- Total Shaft Length: 175m
- Main Tunnel still remains in the molasse

Focus: 380 Baseline

Natural feature overview (machine)

Under water body (%)	0.00
Nature area (%)	0.00
Protected habitat (%)	0.00
Wetlands (%)	0.00

Distance between shafts (m)

3-IP	4,826.84
IP-2	4,826.59

380 shallow

Natural feature overview (machine)

Under water body (%)	0.00
Nature area (%)	0.00
Protected habitat (%)	0.00
Wetlands (%)	0.00

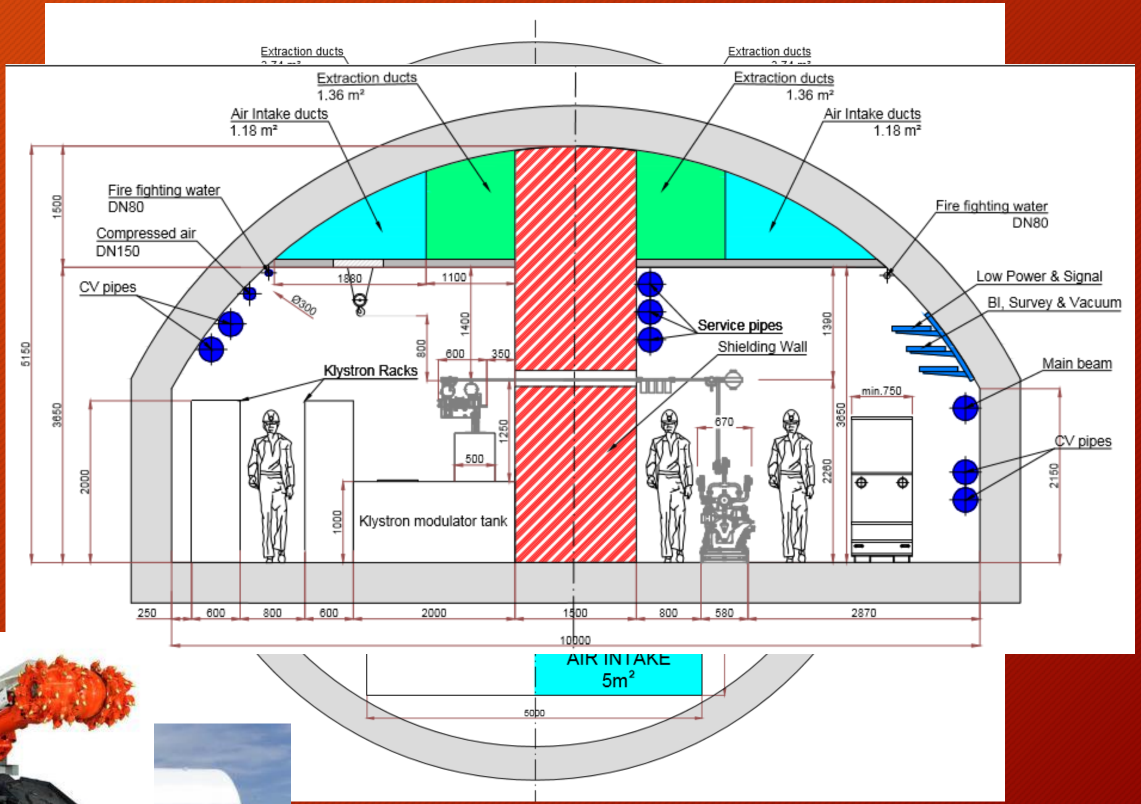
Distance between shafts (m)

3-IP	4,826.84
IP-2	4,826.59

What has been done – Civil Engineering

Two options for the Klystron Tunnel have been looked at:

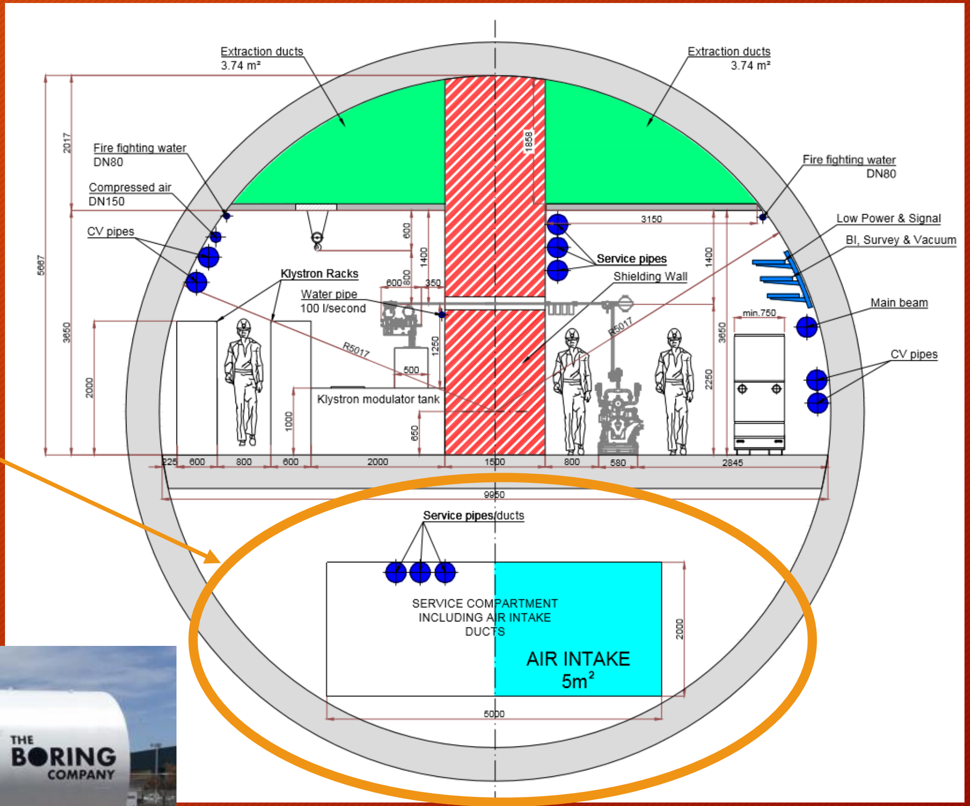
1. <u>10m wide Roadheader mined tunnel – Like ILC.</u>
   - Shape can be determined by tunnel requirements.
   - No wasted space below the tunnel floor.
   - Can mine through varying rock types using one machine.
2. <u>10m internal Diameter TBM Bored tunnel.</u>
   - Considerably quicker rate of excavation through “good rock”.
   - Cheaper per m of tunnel construction for this length of tunnel.
   - Under floor space can be utilised for services to avoid wasted space.



What has been done – Civil Engineering

<u>10m Internal Diameter TBM tunnelling method is proposed for the Klystron 380 GeV design:</u>

- The cost for an 11km tunnel for the TBM is an estimated 10% cheaper than a mined tunnel.
- The underfloor space can be utilised and therefore reduce the amount of wasted space.
- The excavation rate per m of tunnel is considerably quicker for a TBM and therefore construction time is reduced.
- The geology for the 380 GeV is expected to be majority molasse and suited for a TBM.

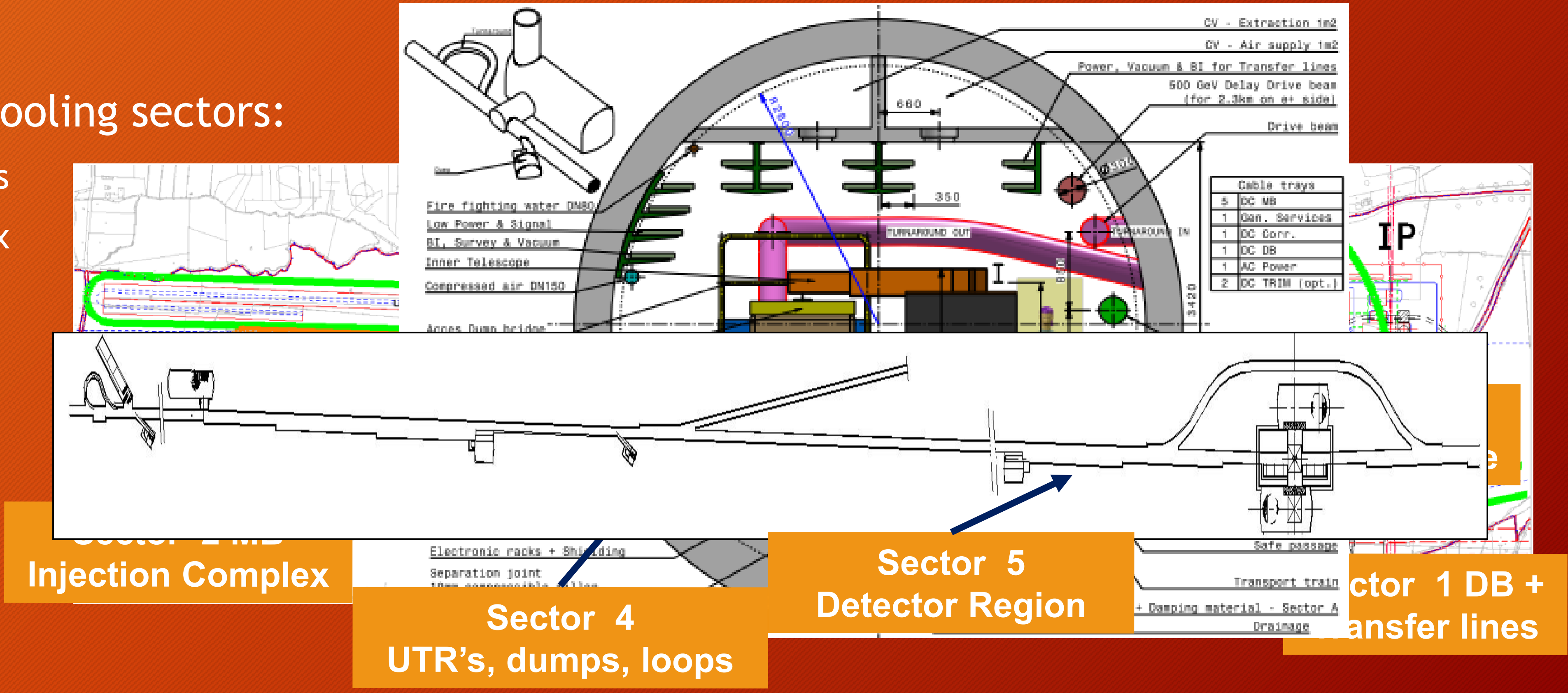


Cooling - CDR

The cooling and ventilation is a critical aspect of the tunnel integration design as it has a large effect on the required dimensions of the tunnel cross-section.

Facilities divided into 5 cooling sectors:

- Drive beam and transfer lines
- Main beam Injection Complex
- Main Tunnel A
- Main Tunnel B
- IR and BDS



Cooling and Ventilation - CDR

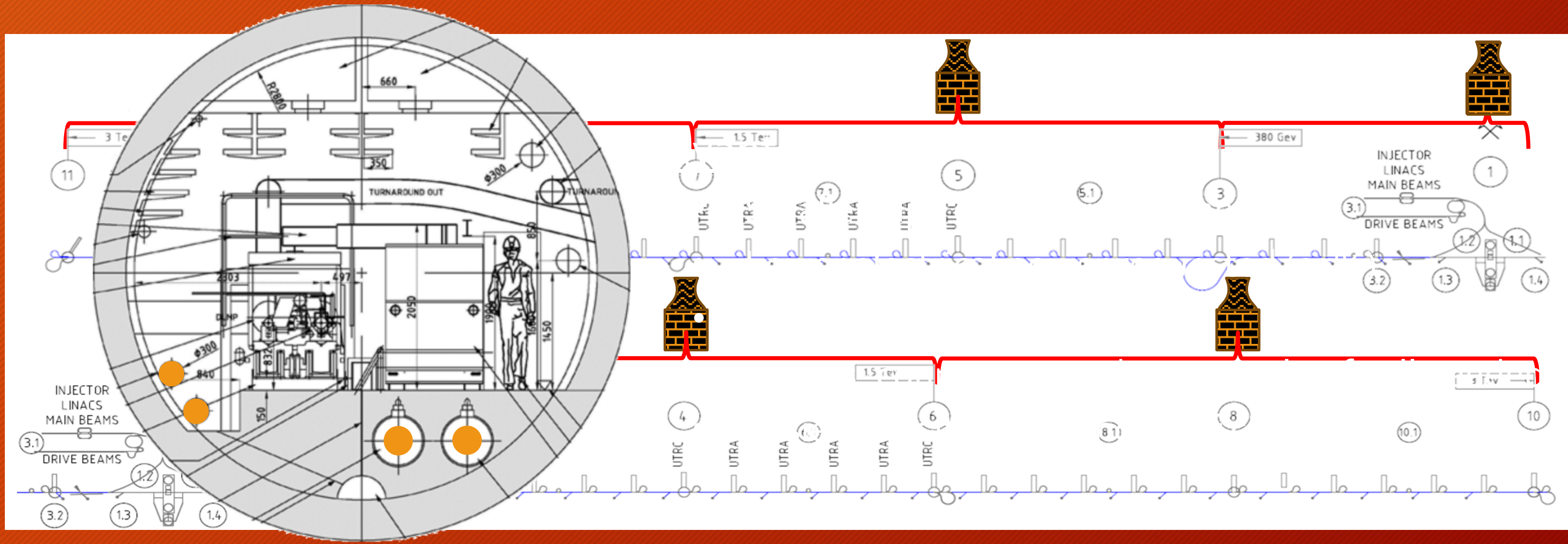
The cooling and ventilation is a critical aspect of the tunnel integration design as it has a large effect on the required dimensions of the tunnel cross-section.

The CDR Design used a central cooling tower however, due to a change in policy this is no longer a requirement for CLIC.

Centralising cooling towers results in larger pipes and booster pump requirements.

Proposed Solution:

- New cooling towers located at points 4, 5, 8 and 9.



Cooling and Ventilation - CDR

The cooling and ventilation is a critical aspect of the tunnel integration design as it has a large effect on the required dimensions of the tunnel cross-section.

CDR tunnel ventilation not adapted for the increased heat load to air in the main tunnel.

Some possible solutions are shown below:

Ventilation:

- Insulate/Encapsulate CLIC Modules – Install heat exchangers or fans inside the "box".
- Increase allowable temperature in the tunnel.
- Install AHU machines to tackle heat load locally

Power dissipation to air 3 TeV (CDR)		Power dissipation to air 3 TeV (New)	
Components	Power [kW]	Components	Power [kW]
RF str.	0.00	RF str.	8,751.38
Girder pre-alignment	122.77	Girder pre-alignment	40.93
MB quadrupole pre-alignment	0.00	MB quadrupole pre-alignment	0.00
WFM	125.31	WFM	125.31
Vacuum system	408.00	Vacuum system	1,088.85
Beam instrumentation	228.16	Beam instrumentation	295.57
DB Q cables	408.00	DB Q cables	408.00
MB Q cables	132.00	MB Q cables	132.00
Stabilisation	184.22	Stabilisation	185.04
Others	500.00	Others	0.00
DB quadrupoles [W]	0.00	DB quadrupoles [W]	177.33
MB quadrupole [W]	0.00	MB quadrupole [W]	265.31
Total per linac [W]:	2,108,462.40	Total per linac [W]:	11,469,709.00
Total per linac [W/m]:	100.40	Total per linac [W/m]:	546.18

What has been done – Electrical (CLIC Powering)

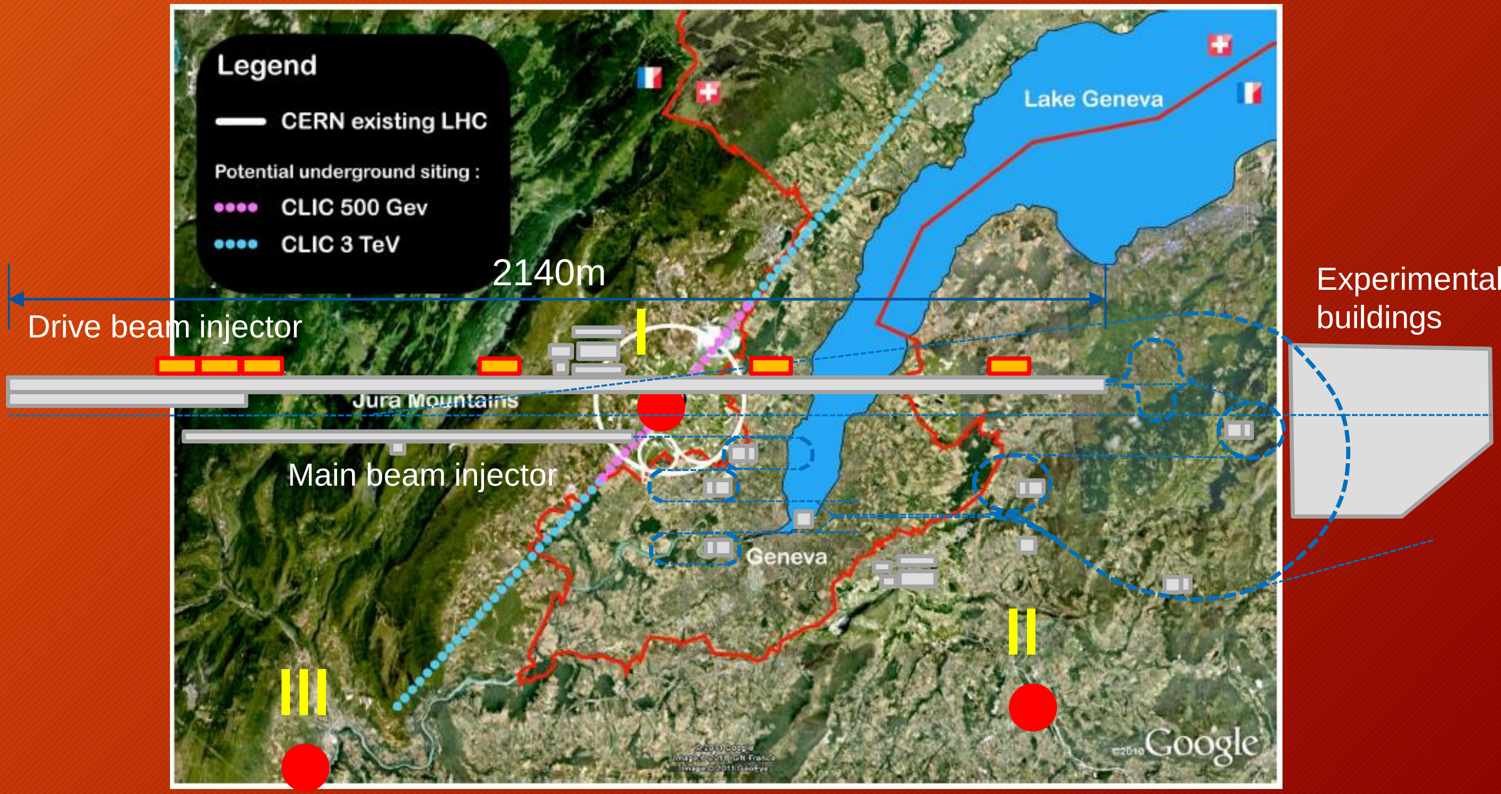
CLIC Powering

Grid Design Solution: Since 2012 TE/EPC has focussed on RF powering and has made steps toward the powering grid design, this includes the proposed solution as seen here:

- 6 sectors for RF power distribution (3 TeV)
- Each sector needs a substation/location.
- One substation needs an indoor space of (**very** roughly): ~ 1500 m2 x 10m height

EN/EL - Availability of Power:

- Power available at European level have been identified at the three locations shown.



Transport – Inventory Input

List of Equipment for the CDR Design was provided in 2010:

- Existing data from 2010 **Must be updated and verified**
- New components to be added where required.

The new klystron design requires similar information to that of the CDR:

- New input table created for the Klystron Design.
- Will allow a transport design and study to be undertaken for the Klystron design.

Input for Transportation Study of CLIC : TBM Klystron General Equipment Table

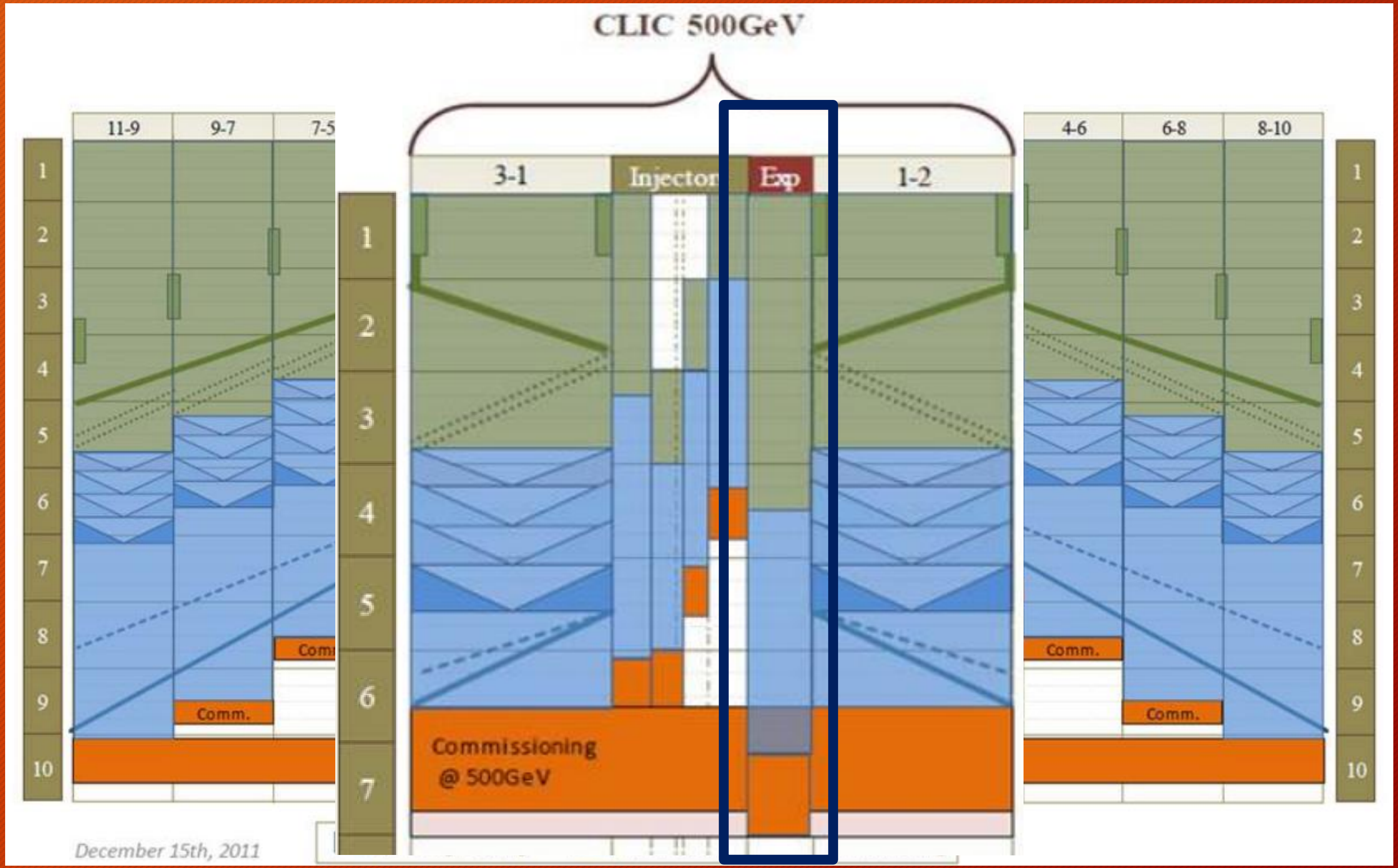
2017

part of the tunnel	equipment	total	Weight /unit (kg)	Weight /total (kg)	Overall dimension (mm)	Support points	Lift points	MAX acceler.	Time available

CDR 3 TeV and 500 GeV Schedule

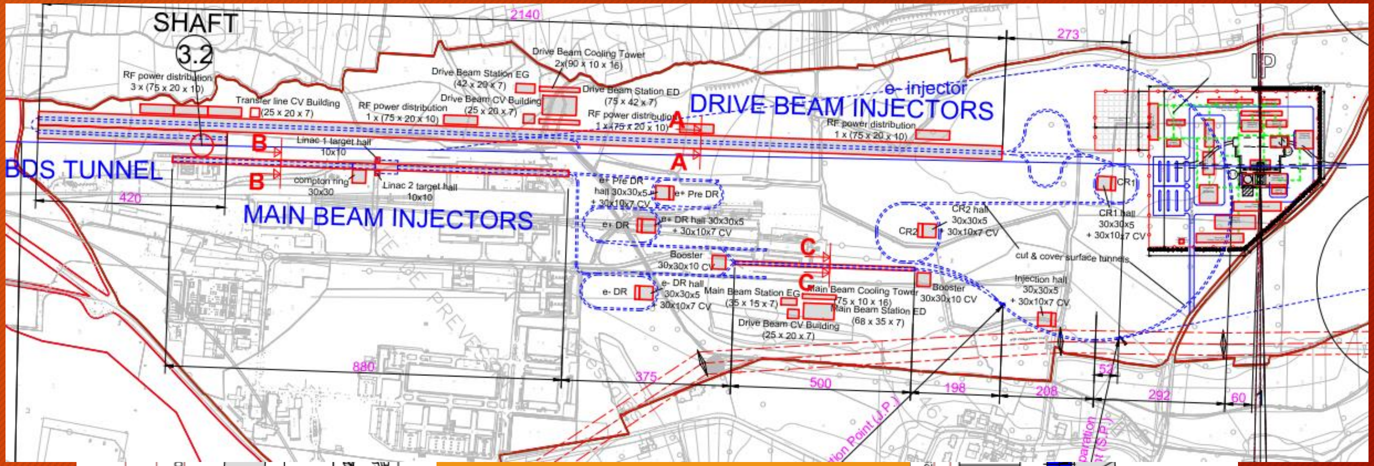
CDR Schedule key points:

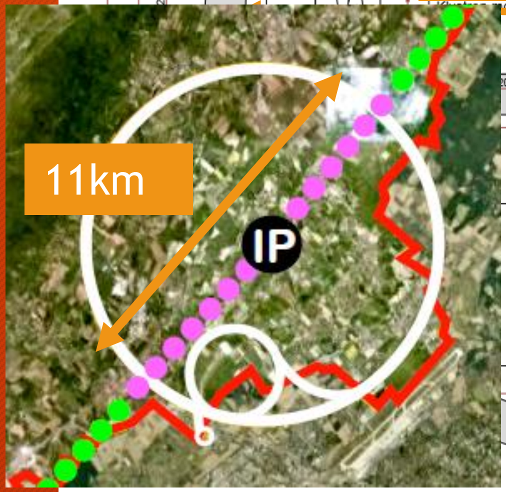
- Schedule produced for 500 GeV and 3 TeV
- Almost 10 years to operation of 3 TeV
- 7 years from construction to beginning operation for 500 GeV.
- Critical path for 500 GeV is the experimental region.

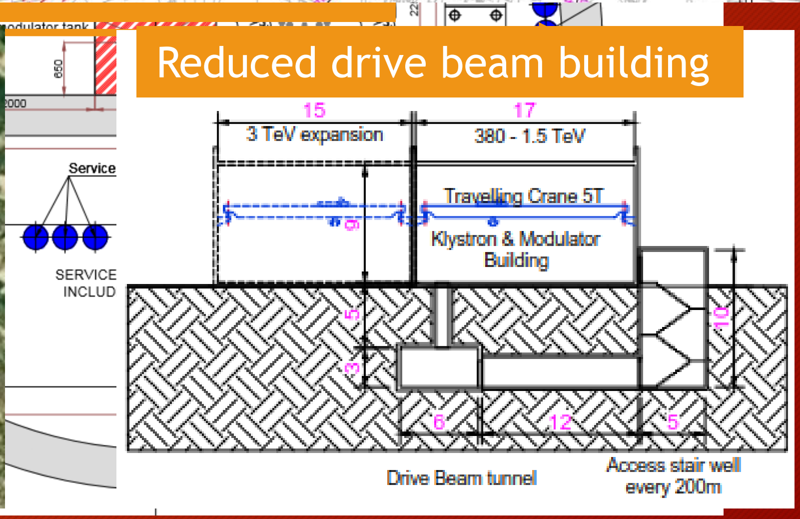


New Schedule Requirements

- A new schedule is required for the 380 GeV Klystron Design, key points are:
  - ➢ Larger diameter tunnel
  - ➢ Reduced surface buildings
  - ➢ Large shielding wall installation.
- Updates will be required to produce an edited schedule for a 380 GeV CDR design:
  - ➢ Tunnel lengths reduced.
  - ➢ Drive Beam Building significantly reduced.
  - ➢ One Pre-damping ring removed.
  - ➢ <u>**One detector cavern and all associated civil works Removed.**</u>



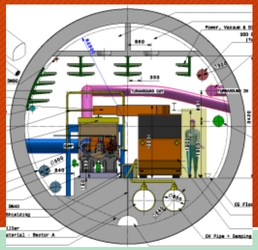


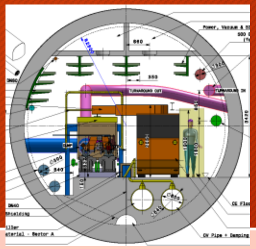


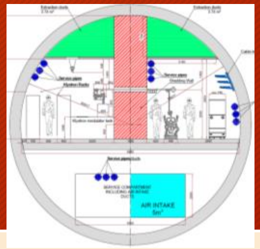
Cost Considerations

A consultant produced costing spreadsheet has been adapted to enable it to be used with CLIC parameters this allows us to:

- Compare the cost of multiple scenarios depending on geology.
- Analyse the cost of changing structural dimensions like tunnel width shaft depth etc…
- Allow us to compare the three tunnel options shown in the table.







	CDR 500 GeV	New 380 GeV Drive Beam	Klystron 380 GeV 10m TBM
Main Underground Site Length	13,736	10,280	10,061
Drive Beam Complex	Full drive beam complex required	Partial drive beam complex required	No drive beam complex required
Underground structures + drive beam cost	All cut and cover tunnels required	All cut and cover tunnels required	Removal of drive beam complex associated cut and cover tunnels

Further Study

Transport:

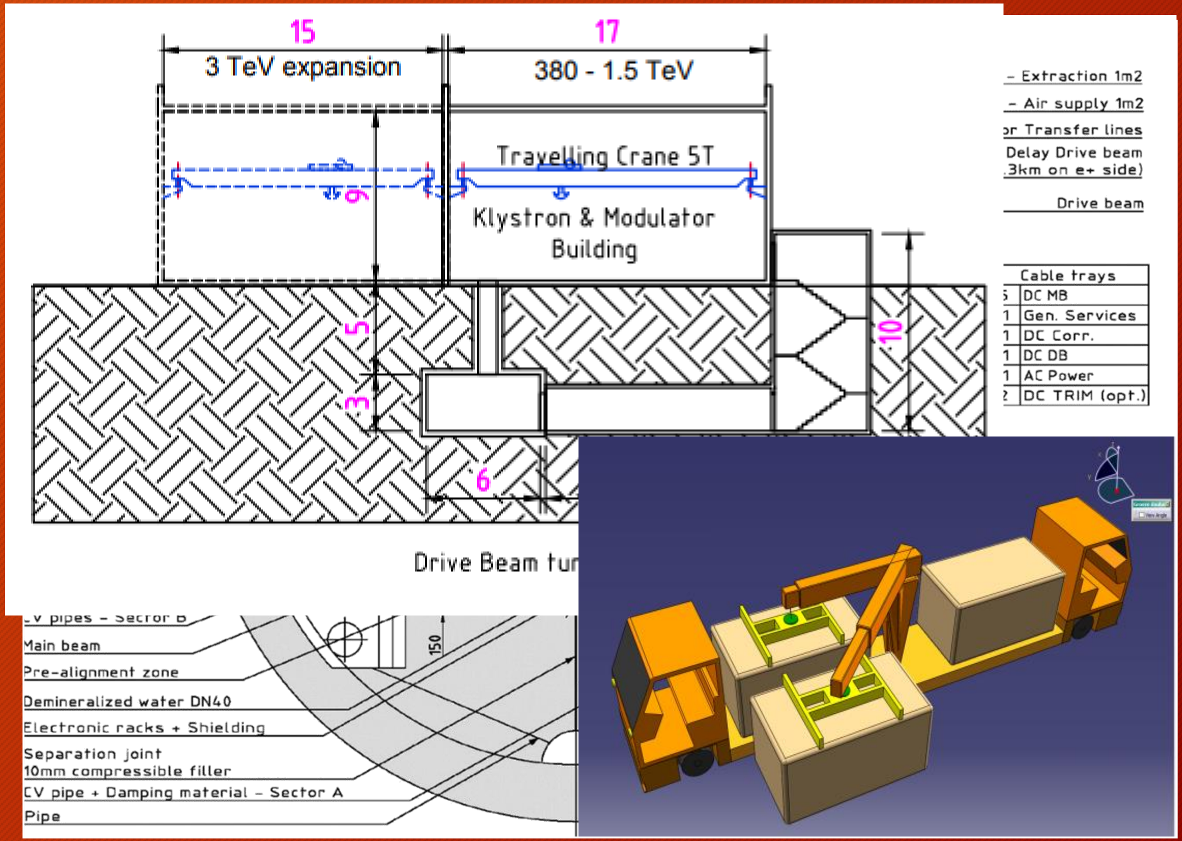
- An updated items list for transport is required for the Klystron and the Drive beam design.
- Transportation logistics need to be studied to allow a construction and installation schedule to be produced.

Cooling and Ventilation:

- Update of heat loads from ALL users is required to allow a solution to be implemented properly.
- Smoke extraction and radiation protection systems need to be integrated into the requirements (to be done with safety).
- Finalise the solutions for both <u>Cooling</u> and <u>Ventilation.</u>

Safety:

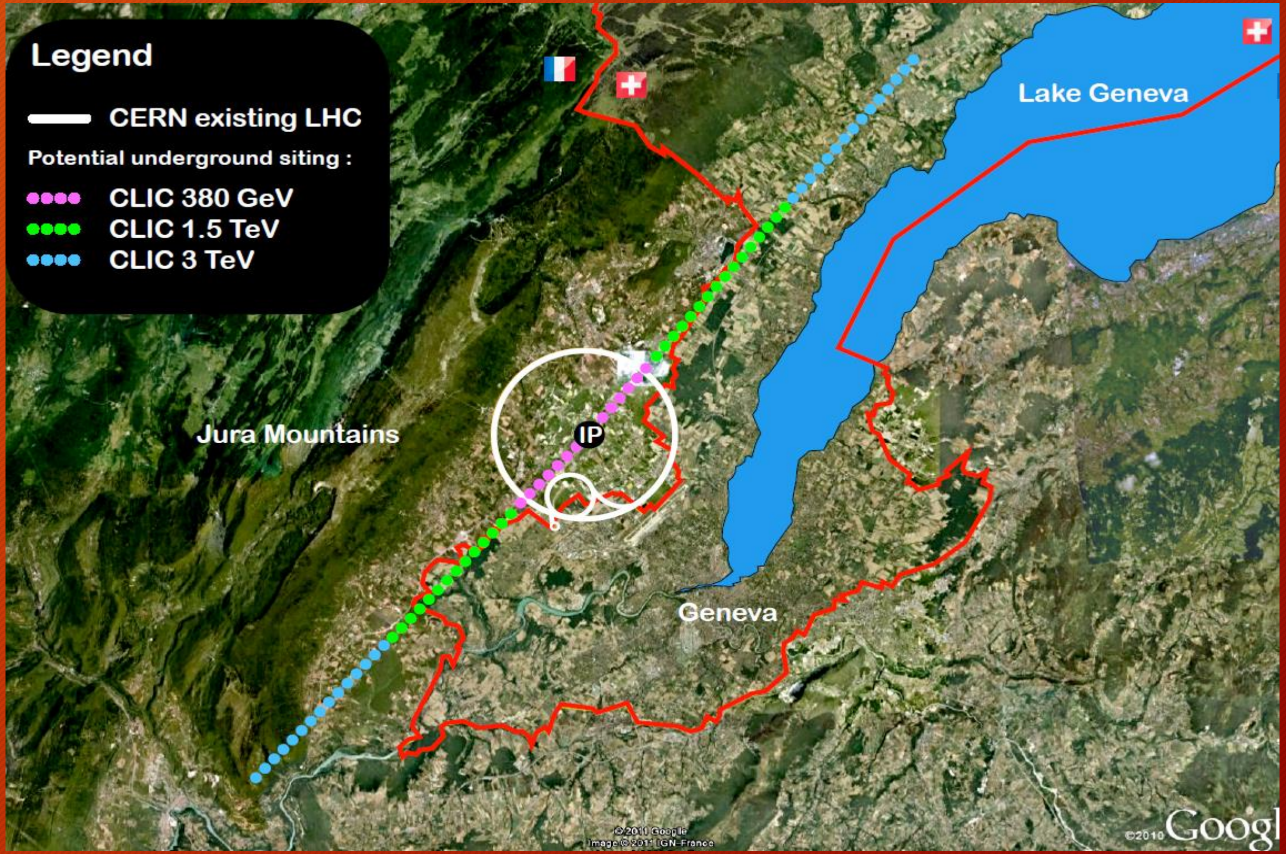
- Identification of hazards and mitigations that fall under standard procedure.
- Hazard register to be produced and populated by all disciplines.



Further Study

Civil Engineering
- Use CLIC TOT to optimise the position of the tunnel for the different energy stages.
- Continue to update and integrate all disciplines into the surface and tunnel layouts and designs.

Electrical:
- Electrical power distribution layouts and electrical infrastructure requirements for both the Drive beam and the Klystron design are to be studied and integrated into the accelerators layouts.
- The availability of the required electrical power for all different CLIC machine configurations and energy levels will have to be studied and optimized.



Summary

CEIS Working Group:

- Meetings for the CEIS Working Group are taking place every 5 weeks to ensure full integration of the work done by each discipline.
- Full Activity tracker updated at each meeting outlining the tasks for each discipline.

Updates since CDR:

- Civil Engineering Layouts have been updated and new Klystron layouts have been produced.
- CLIC TOT has been produced and is available to start optimising the position of the CLIC tunnels and surface locations.
- HVAC has been studied in more detail, the heat loads have been updated and new cooling and ventilation systems/solutions have been proposed.
- CLIC Power supply requirements have been proposed with an update on the substation requirements and the connection to the European grid.

Further Study:

- CLIC tunnel optimisation to be studied in detail.
- Solutions proposed for the cooling and ventilation require input from all disciplines responsible for heat loading so a more detailed design can be produced.
- Safety to produce and populate a hazard register for the CLIC Project.
- Transport design and schedule to be completed – requires an updated list of items that are to be transported throughout the shafts and tunnel.
- Survey and Alignment to provide lattice files for the 1.5 TeV and 3 TeV energy stages.

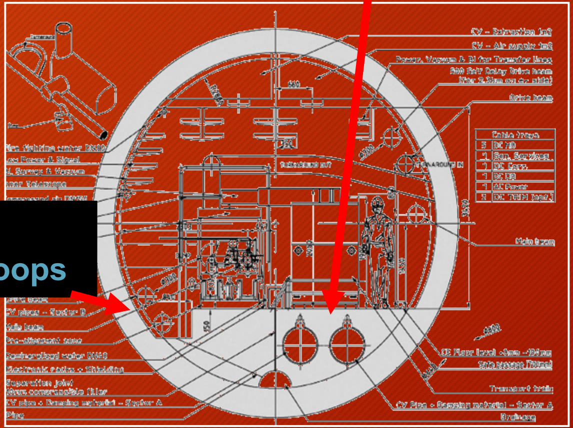
Thank You For Your Attention

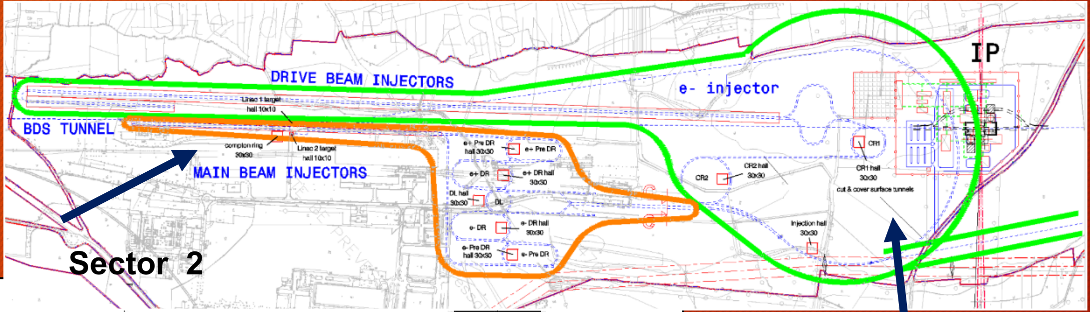
Thank you to all contributors from the CLIC CEIS Working Group

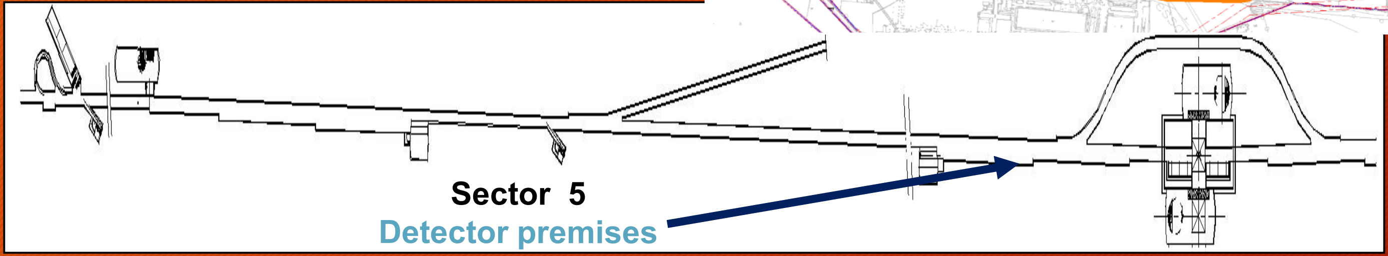
Cooling CDR Baseline

Facilities divided into 5 cooling sectors according to:

- Functional and operational requirements
- Thermal loads
- Dimensions & geographical distribution
  - Facilities (Drive beam injector building)
  - HVAC and cooling plants (keep reasonable size)
  - Environmental impact: no cooling towers on surface points -> centralised in Prévessin





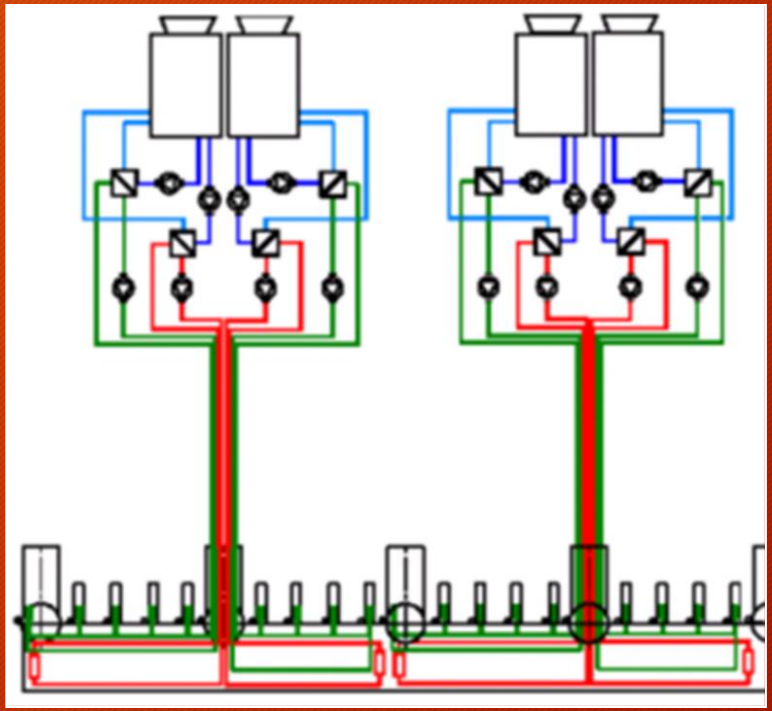


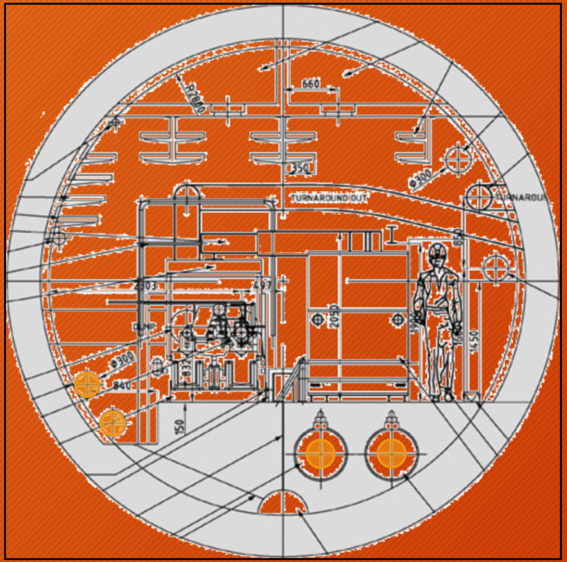
Cooling: proposed modification

Cooling towers in surface points: Pt 4, 5, 8, 9

Advantages:

- Smaller pipe diameters in tunnel
- Lower electrical power requested (25%)
- No need for booster pumps
- Bypass, connection to drain: simpler if still needed
- Easier operation (balancing of circuit, …)





Disadvantages:

- Stronger environmental impact (outside CERN)
- Bigger surface needed for installation
- Impact on shaft dimensions?

However: manifold issue still present

CDR Schedule Critical Path

Table 9.20: Construction and installation of CLIC Interaction Region (IR)

Year	Underground work	Surface work
1	Excavate two experimental shafts in parallel.	Construction of part (2/3) of two detector assembly halls in parallel, including services.
2	Excavate and carry out finishing of experimental caverns and transfer tunnel (2.5 years).	Assemble two detectors in their dedicated assembly halls (1st of 4 years). Construct service buildings (cooling & ventilation, electrics, gas, counting rooms, etc.).
3	Proceed with finishing of the two experimental Caverns and transfer tunnel.	Assemble two detectors in assembly halls (2nd of 4 years).
4	Finish the two experimental caverns and transfer tunnel. Install infrastructure and services in two experimental caverns and transfer tunnel (1.5 years). See details in Fig. 9.24.	Assemble two detectors in assembly halls (3rd of 4 years). Complete construction of last third of two assembly halls.
5	Complete installation of infrastructure and services in two experimental caverns and transfer tunnel.	Complete assembly of two detectors in assembly halls. Installation of heavy-load gantry crane for lowering detectors.
6	Connect two detectors to the caverns' on-detector services and cable chains (6 months).	Lower two detectors (6 months).
7	Perform magnet tests. Trial run with cosmic rays. Commission safety systems. Test push–pull system including forward shielding.	