Future Circular Collider
Study status and implementation aspects

13 January 2024

J. Gutleber (CERN)

STUDY SCOPE, GOALS, MID-TERM REVIEW AND STUDY REPORTS

Objectives of the study

Demonstrate geological, technical, environmental, and administrative feasibility of subsurface and surface elements and optimise the placement of the ring.

Together with the Host States, **identify and address administrative processes** required for project approval.

Advance collider and injector design.

R&D for key technologies.

Consolidate physics case.

Develop detector concepts.

Develop a sustainable operational model (environmental, financial, societal).

Consolidate cost estimates.

The integrated programme

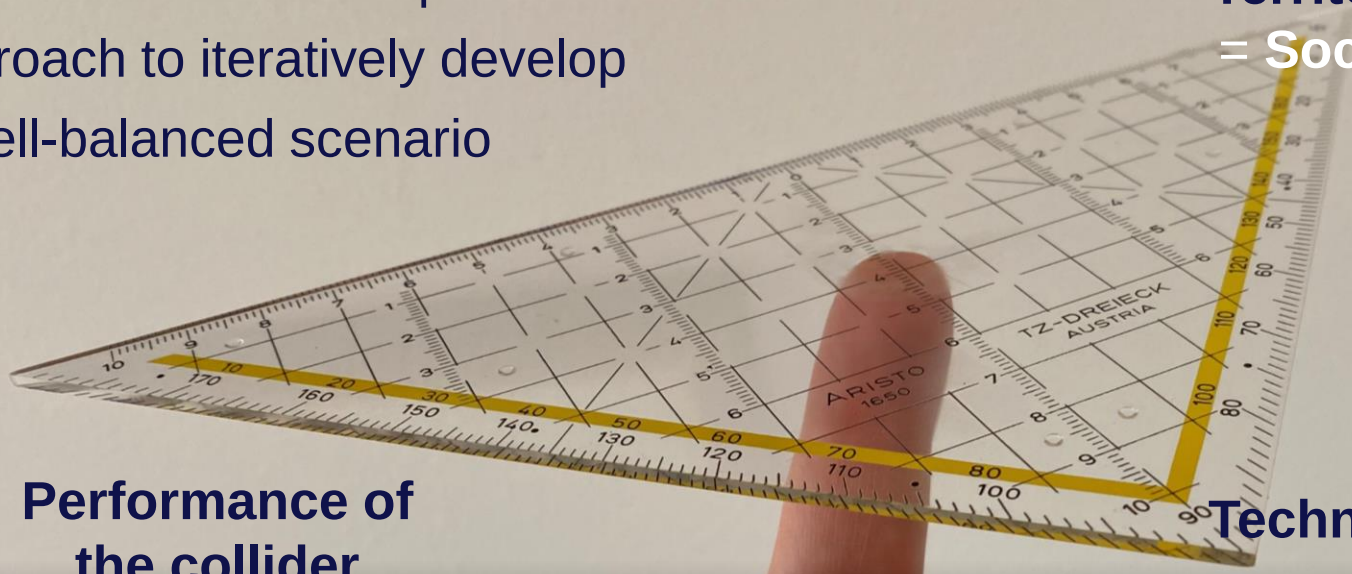
Long-term programme to fully exploit the infrastructure for a complementary physics programme.

A high energy e^+e^- injector offers additional physics research opportunities.

Scenario development: A balance of stakes

« **A**void-**R**educe-**C**ompensate »
approach to iteratively develop
a well-balanced scenario

Territorial impacts
= Societal license



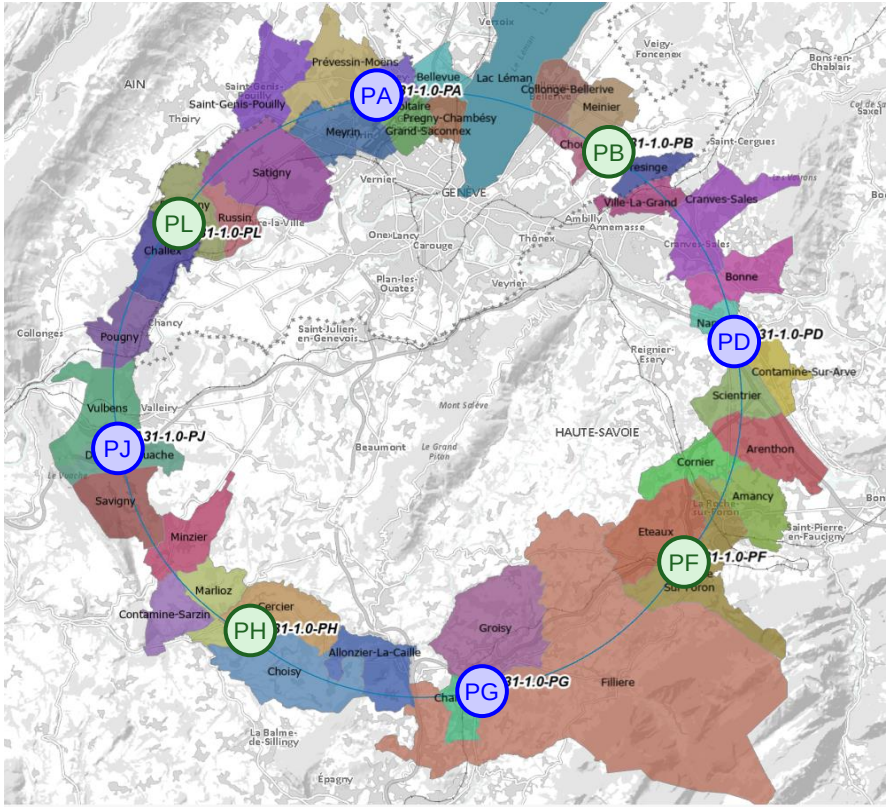
Performance of the collider
= Scientific excellence

Technical feasibility and cost
= Acceptable risks

Reference scenario PA31: 8 sites, 4 IPs

1. **PA – Ferney Voltaire** (FR, 01) – experiment
2. **PB – Choulex** (CH) – technical
3. **PD – Nangy** (FR, 74) – experiment
4. **PF – Etaux** (FR, 74) – technical
5. **PG – Charvonnex/Groisy** (FR, 74) - experiment
6. **PH – Cercier/Marlioz** (FR, 74) – technical
7. **PJ – Vulbens/Dingy en Vuache** (FR, 74) – experiment
8. **PL – Challex** (FR, 01) – technical

LSS@IP (PA, PD, PG, PJ)	1400 m
LSS@TECH (PB, PF, PH, PL)	2032 m
Arc length	9.6 km
Sum of arc lengths	76.9 m
Total length	**90.7 km**



Eight new surface site locations: 7 FR and 1 CH


PA


PB


PD


PF


PG


PH


PJ


PL

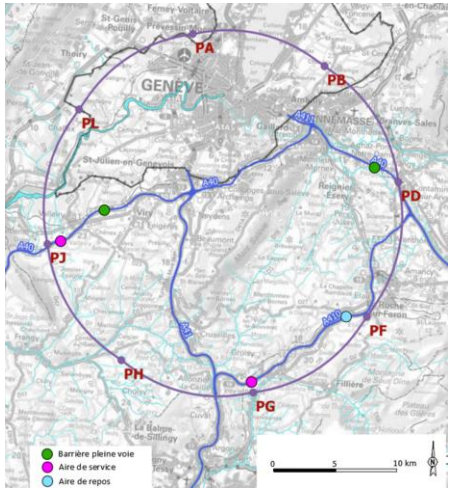
Integration with territorial networks

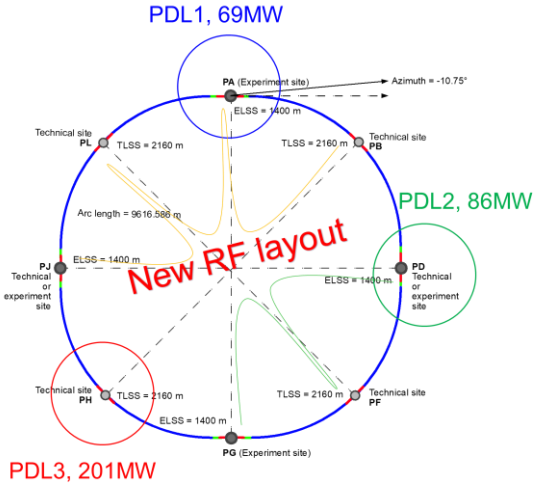
Accessibility:

Road accesses for all 8 sites conceived

4 possible motorway connections studied

Less than 4 km of new roads or road improvements.





Electricity:

Construction: 7 local connections in France and 1 in Switzerland.

Operation: 2 new connections to French electricity grid.

Concept developed with RTE (French grid operator).

Load has no significant impact on grid stability and resource needs.

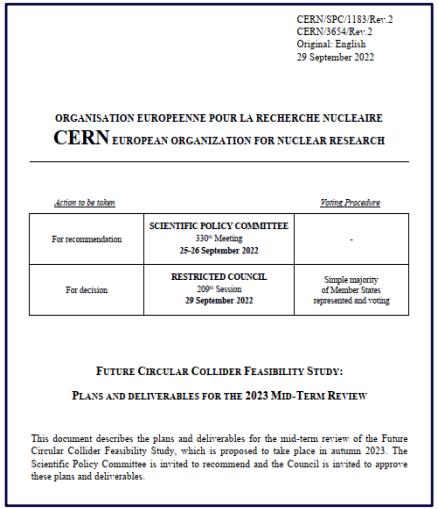
Further efforts are required to reduce energy needs and develop an “adaptive operation scheme” for both, FCC-ee and FCC-hh for increased economic and societal performance.

Mid-term review defined in CERN/SPC/1183/Rev.2

Assess the progress of the study towards the final report.

Scientific and technical results be reviewed by the FCC FS Scientific Advisory Committee, augmented by additional experts as needed.

Cost and financial feasibility with focus on the first-stage project (tunnel, technical infrastructure, FCC-ee machine and injectors), reviewed by a committee including external experts, as proposed in CERN/3588.



CERN/SPC/1183/Rev.2
CERN/3654/Rev.2
Original: English
29 September 2022

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Action to be taken		*Voting Procedure*
For recommendation	SCIENTIFIC POLICY COMMITTEE 330th Meeting 25-26 September 2022	-
For decision	RESTRICTED COUNCIL 209th Session 29 September 2022	Simple majority of Member States represented and voting

FUTURE CIRCULAR COLLIDER FEASIBILITY STUDY:
PLANS AND DELIVERABLES FOR THE 2023 MID-TERM REVIEW

This document describes the plans and deliverables for the mid-term review of the Future Circular Collider Feasibility Study, which is proposed to take place in autumn 2023. The Scientific Policy Committee is invited to recommend and the Council is invited to approve these plans and deliverables.

FCC Scientific Advisory Committee:

Riccardo Bartolini (DESY), Alain Chabert (Société Française du Tunnel Routier Fréjus), Heinz Ehrbar (HEP), Brigitte Fargevieille (Électricité de France), Belen Gavela Legazpi (UAM), Gudrun Hiller (Dortmund), Srinivas Krishnagopal (BARC), Peter Krizan (Ljubljana), Philippe Lebrun (CERN, retired), Peter McIntosh (STFC), Michiko Minty (BNL), **Andrew Parker** (**Chair**, Cambridge), Kyo Shibata (KEK), Roberto Tenchini (Pisa)

FCC Cost Review Panel:

Carlos Alejaldre (Fusion for Energy), Austin Ball (CERN, retired), Umberto Dosselli (INFN), Heinz Ehrbar (HEP) Vincent Gorgues (CEA), **Norbert Holtkamp** (**Chair**, Stanford), Christa Laurila (National Audit Office, Finland), Ursula Weyrich (German Cancer Research Centre), Jim Yeck (BNL), Thomas Zurbuchen (ETH Zürich)

Review successfully completed!

- **Review process between October 2023 and February 2024**
- **All deliverables approved by Council**
- **No technical showstoppers identified**
- **80 recommendations provided**

Deliverables:
D1 : Definition of the baseline scenario
D2 : Civil engineering
D3 : Processes and implementation studies with the Host States
D4 : Technical infrastructure
D5 : FCC-ee accelerator
D6: FCC-hh accelerator
D7: Project cost and financial feasibility
D8: Physics, experiments and detectors

3 report volumes are inputs for the Update of the European Strategy for Particle Physics

Volume 1: Physics and Experiments

Physics case, detector requirements and concepts, software and computing, energy calibration, polarisation, monochromatisation, community building.

Volume 2: The integrated project

Particle accelerators, technical infrastructures and safety.

Volume 3: Implementation

Civil engineering, territorial implementation, environmental aspect and sustainability/

Other documents under preparation:

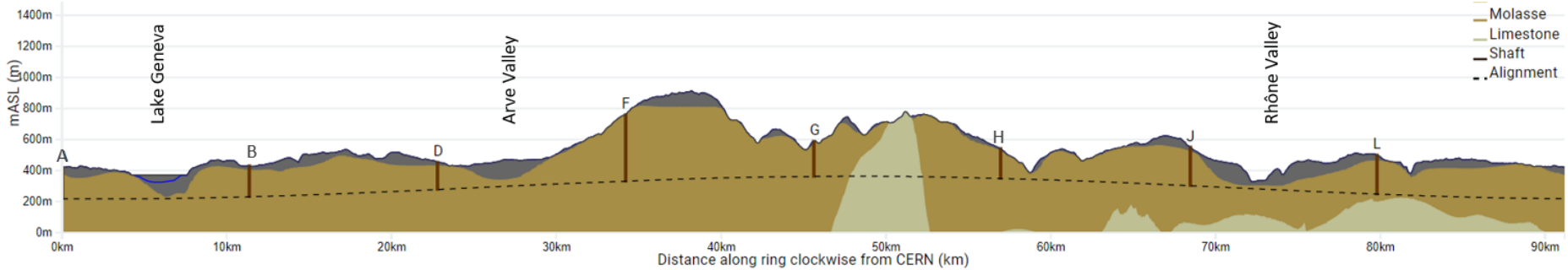
- **Cost estimate and funding models**
- **Environmental reports** volume I and II.
- **Socio-economic impact study**
- **Territorial opportunities and constraints**

Volumes will be completed by 17 March 2025 for submission to the European Strategy Update by Monday 31st March, 2025.

Volumes 1 to 3 will be **published by Springer-Nature in the EPJ series**: requires further reviews, copy editing and quality management to become valuable and lasting references for the community.

CIVIL ENGINEERING

Tunnel alignment



Tunneling mainly in molasse, soft rock layer, well suited for fast, low-risk TBM construction.

6 million m^3 excavated volume in situ, 8.5 million m^3 excavation material on surface

Management of excavated materials is a project-management and territorial topic for which a specific plan needs to be presented in a subsequent preparatory phase as part of the authorisation process.

CE designs of all underground structures developed.

To freeze the vertical position of the tunnel, interfaces between geological layers have to be better known.

Baseline conceptual design for study report

Evolution since mid-term:

Linac and **new transfer tunnel** alignments

Bypass tunnels removed at technical areas

Alcoves part of klystron galleries at PH and PL

Connection tunnels reduced at technical areas

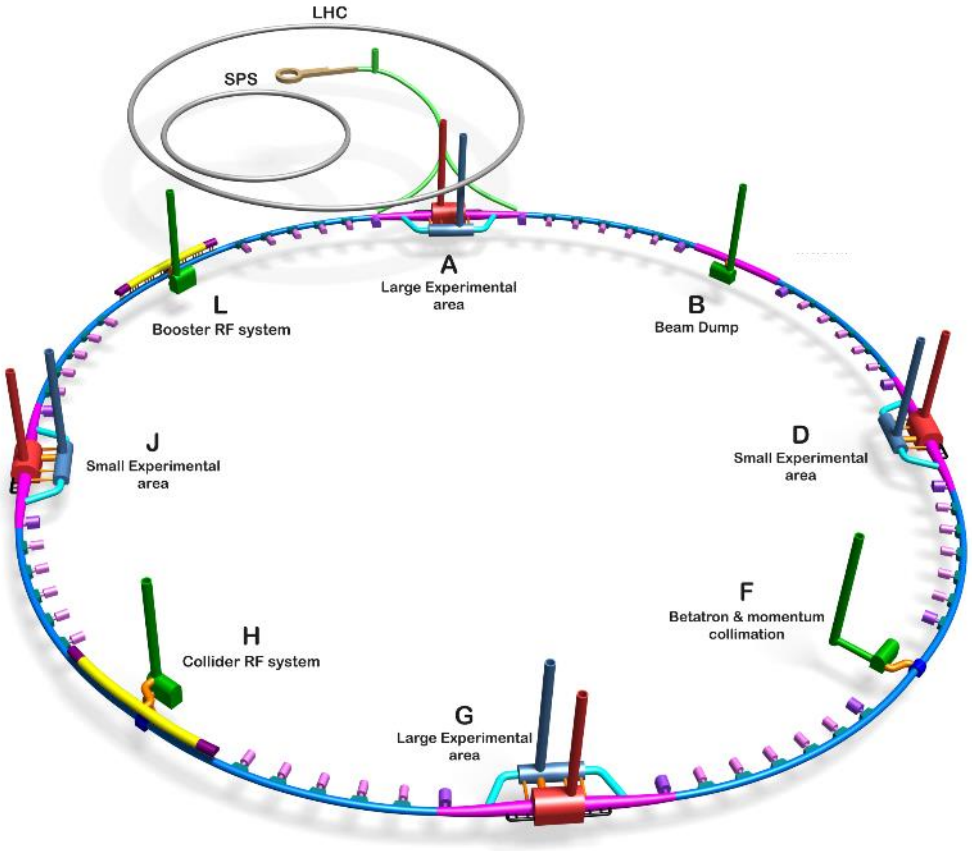
18 m **circular shafts** at experimental areas

Tunnel enlargements modified at IP locations

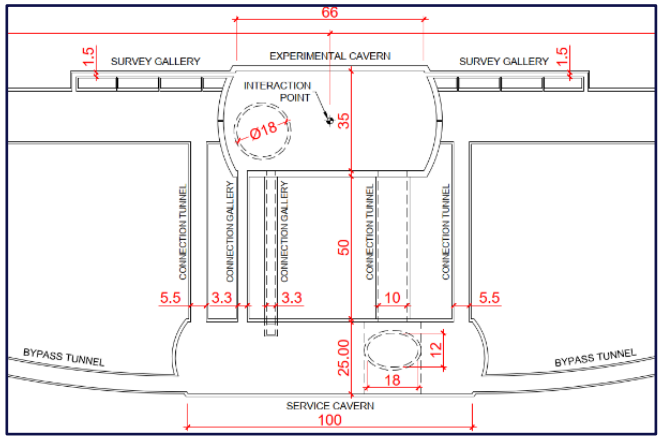
Shorter bypass tunnels at experimental areas

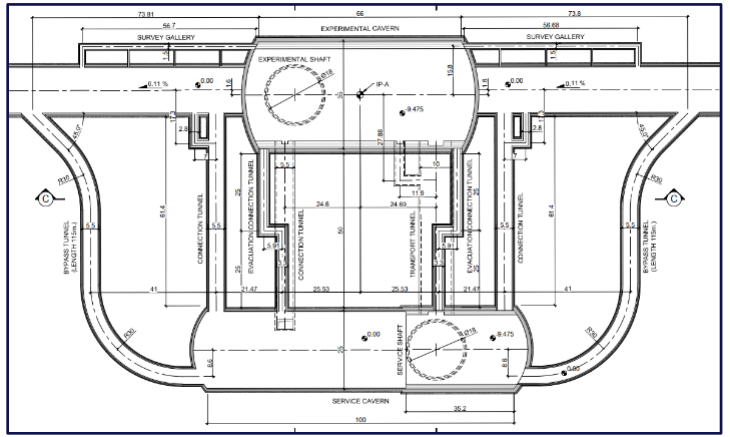
Beam dump tunnel enlargements at PB

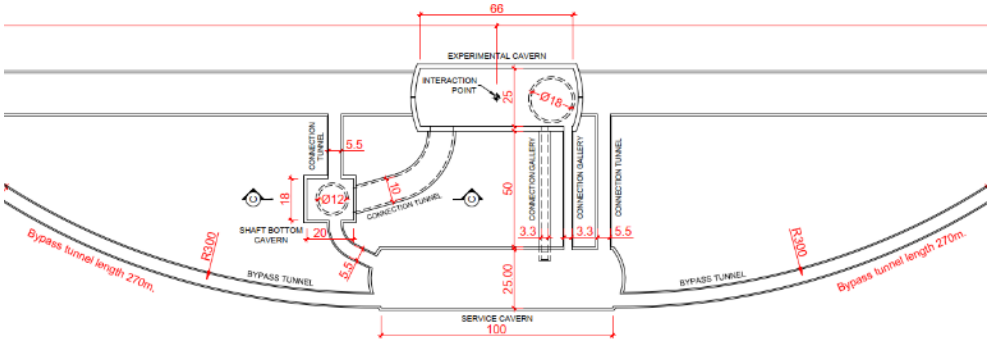
Improved level of details of drawings & models

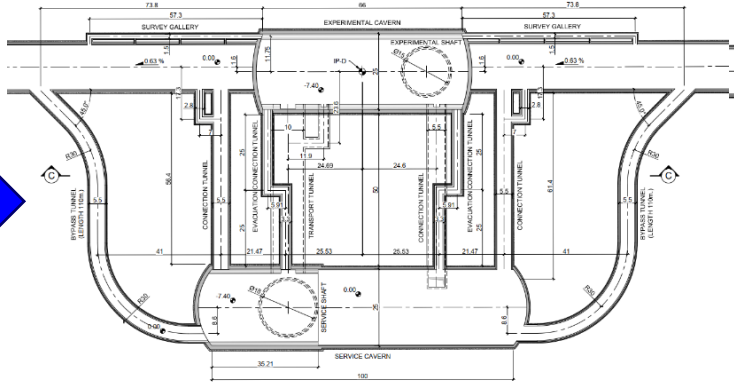


Examples for changes (PA, PD)







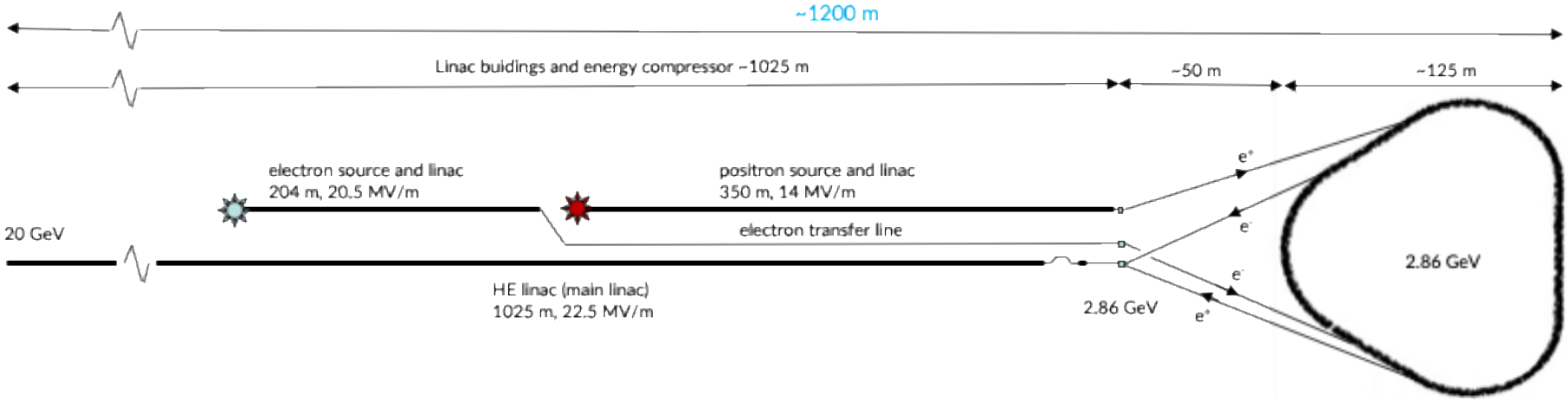


INJECTOR

Consolidated concept for linac

Considers the recommendations emerging from the mid-term review:

- Reduction of energy need by factor 3
- Reduced gradients: 29.5 to 20.5 MV/m
- No common linac with double repetition rate
- Reduced repetition rate: 200/400 to 100 Hz
- Damping ring at higher energy: 2.86 GeV

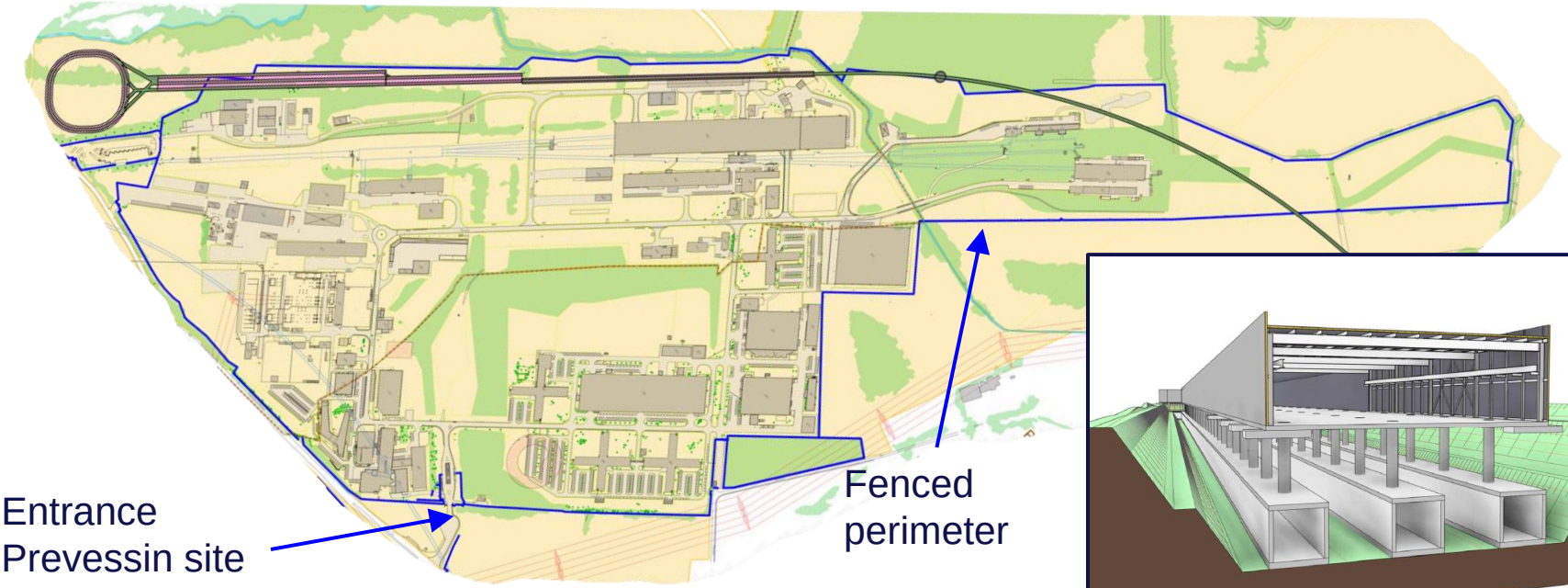


Injector at Prevessin site

Goal to stay as much as possible within fenced domain and to assure reduced visibility form outside.

Optimise connection to exiting experiment halls / facilities to exploit the new machine.

Choose location with good construction conditions



Opportunities to exploit the facility

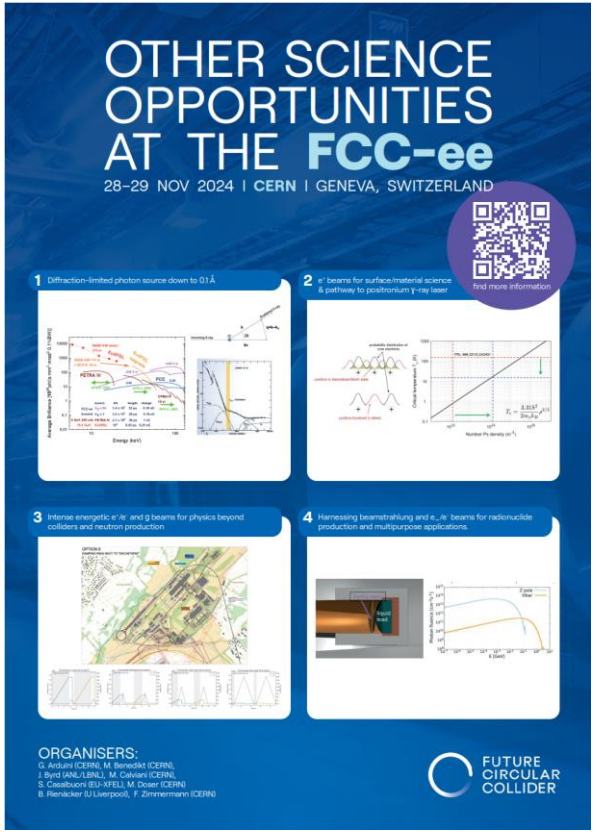
Assure that the entire FCC programme including injector and booster represent an attractive long-term platform for science.

Provide opportunities before the collider enters in operation.

- Non-collider science opportunities at FCC-ee (August 2024)
- Other science opportunities at the FCC-ee (November 2024)

Examples:

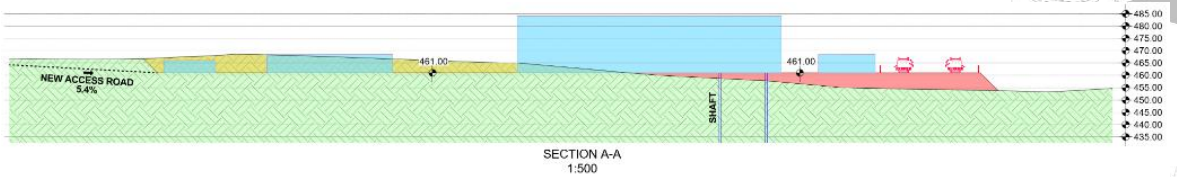
Photon science with high beam current (, positron source for materials science, testbeds for muon colliders, plasma acceleration of positrons, physics beyond colliders and much more.



SURFACE SITES

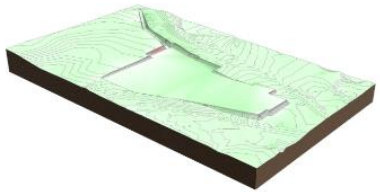
Concurrent : engineering & architecture concepts

Continuation of technical work on envelopes and costing based on the reference placement locations and their constraints.

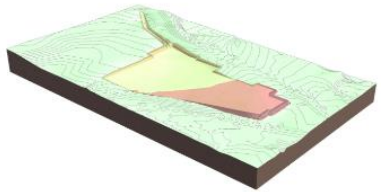


SECTION A-A
1:500

3D VIEW
CURRENT STATUS



3D VIEW
PROJECT STATUS



3D VIEW
CUT & FILL

Societal acceptance is different than in the past

Toolkit for dialogue based on existing projects

Green roofs



Facade expression



Innovative methods and materials



Toolkit for dialogue based on existing projects

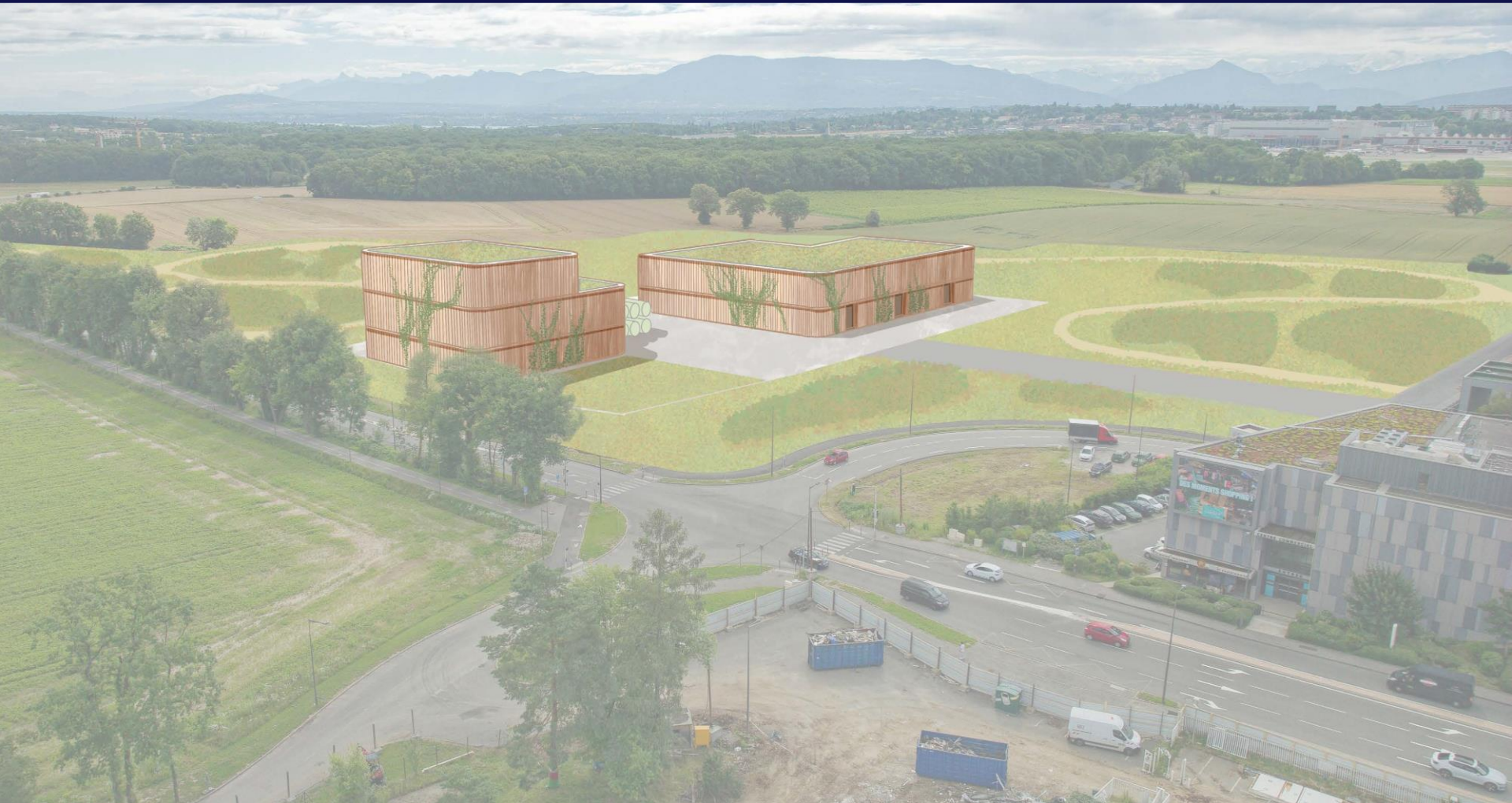
Nature restoration

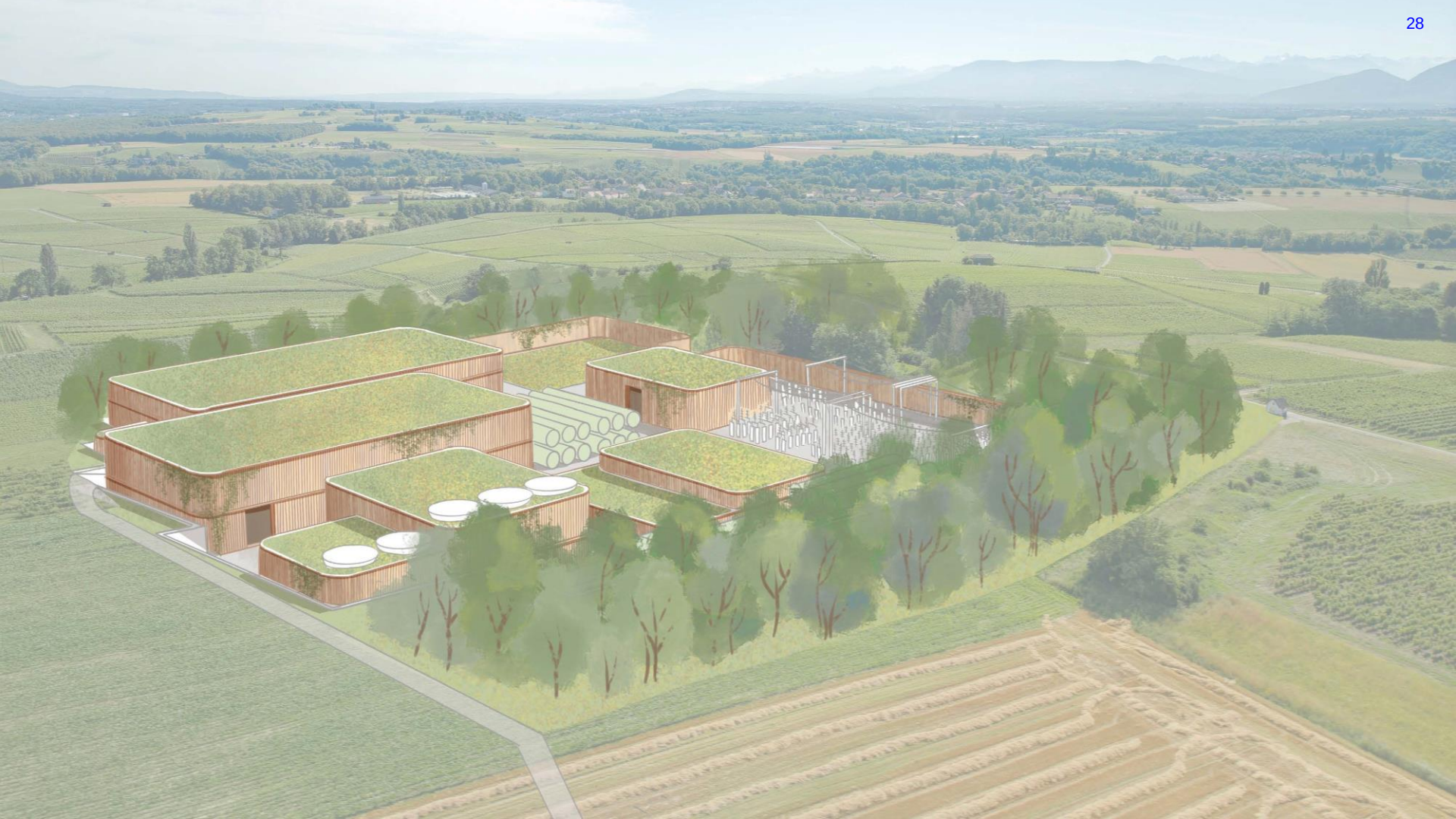
Utilising terrain

Green buffer

Uninterupted landscape

Caution: this image is not a design. It represents architectural concept opportunities only.





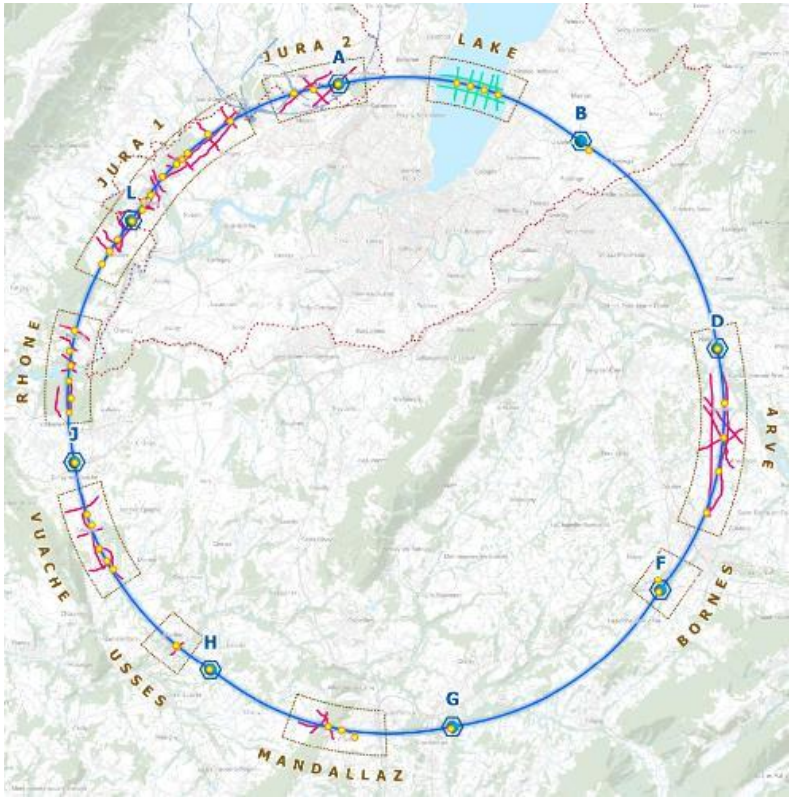
SUBSURFACE INVESTIGATIONS

Key achievement: start of subsurface investigations

Continusouly incoming results of initial subsurface investigations in areas with lack of information or particular challenges:

- optimise alignment depth and inclination.
- get a better understanding for the choice of the most adapted construction techniques.
- Increase the cost reliability and control.
- Gain experience with permitting and environmental impact assessments and associated schedule management.
- Prepare the project for subsequent, more detailed subsurface investigations.

28 boreholes between 10/24 and 12/25
80 km of geophysics between 10/24 and 10/25



Advancement by December 2024

North:

Awaiting for permits in Switzerland.

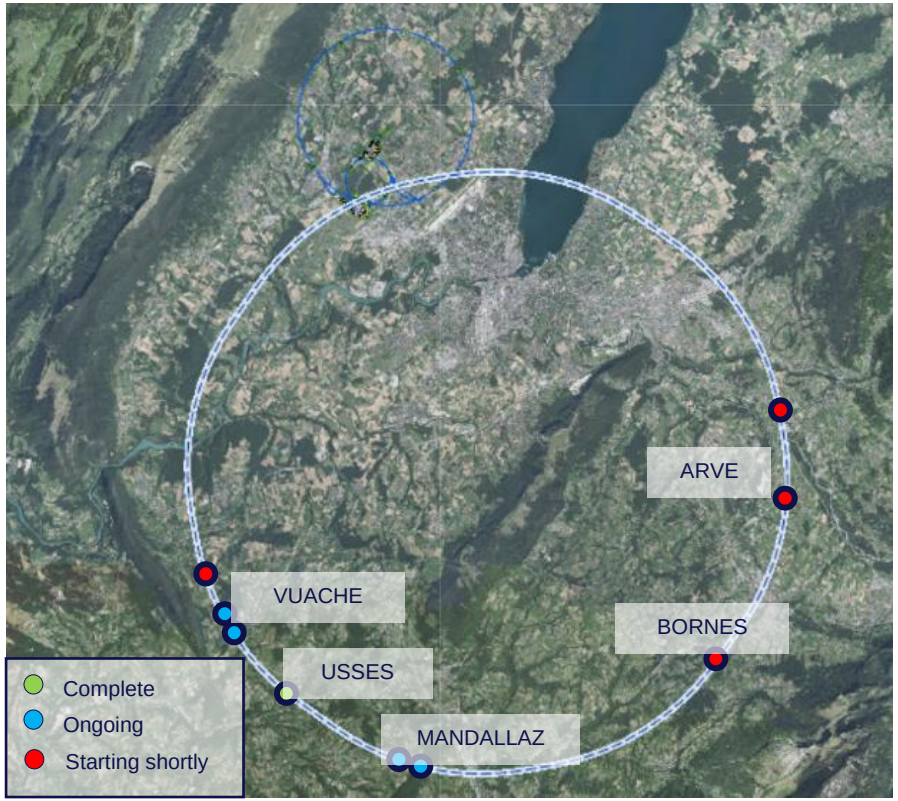
Expected end February 2025

South:

Geophysics in sections Arve, Mandallaz, Usses and Vuache complete: 40 km.

Geophysical interpretation in progress.

Drilling 50% complete



Planning for March 2025

South: complete

North:

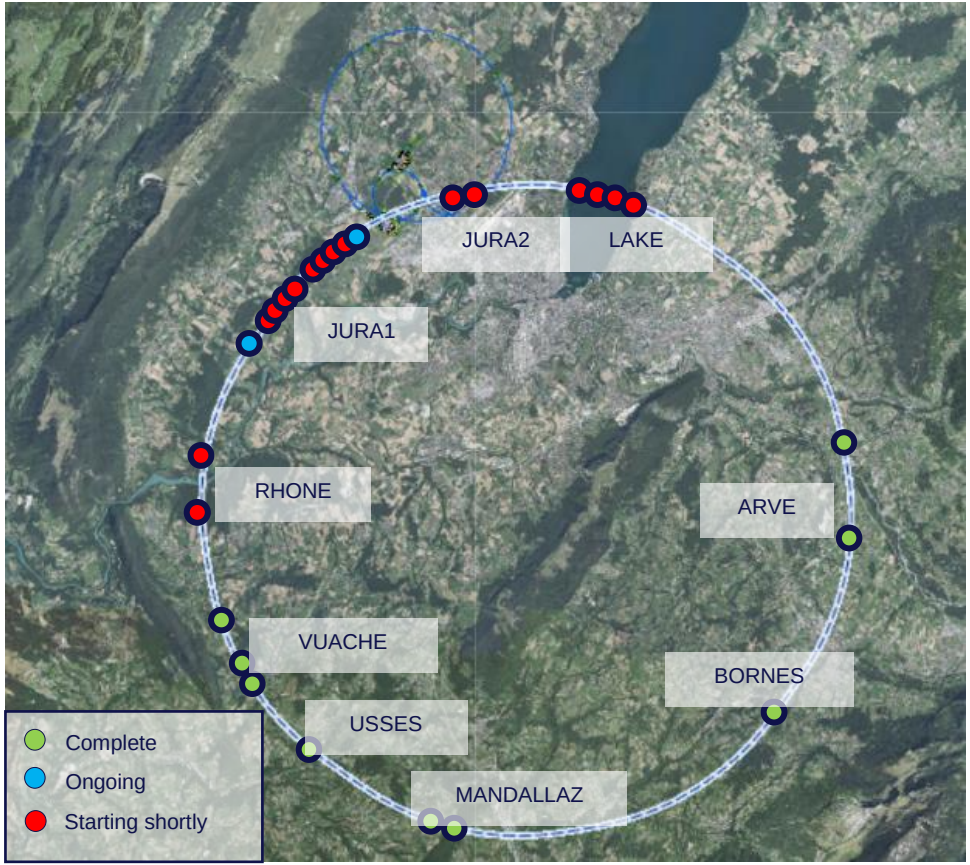
Geophysics and drilling in Jura 1 in progress.

Reprocessing of existing SIG 3D seismic campaign for Lake and Jura in cooperation with UNIGE complete.

Prepare drilling in lake for start in April 2025

Rhône: No drilling before September due to environmental impact constraints.

Finalisation of all activities by December 2025



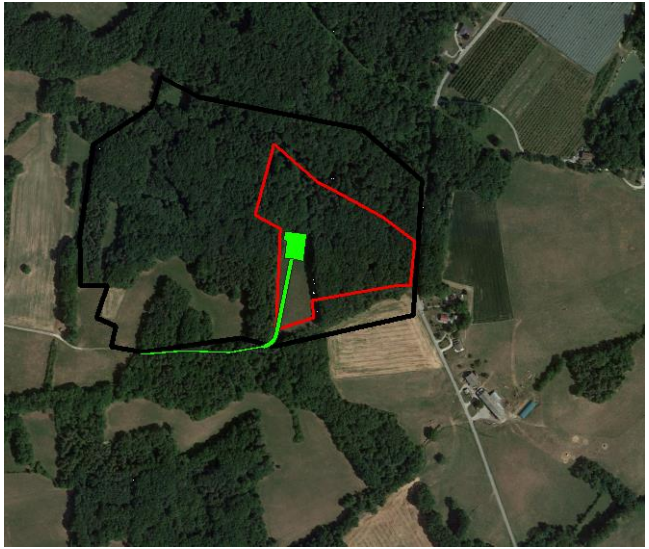
Geotechnical investigations: impressions

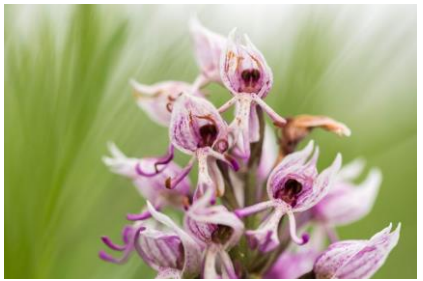
Geophysical investigations and limestone cores

ENVIRONMENT STUDIES

Environmental study coverage

- Soil
- Landscape
- Forest and agricultural performance
- Background noise
- Air quality
- Traffic
- Topography and relief
- Wetlands
- Biodiversity, habitats, fauna and flora
- Aerial imaging
- Technical risks
- Urbanisation
- Economy and social topics





Work performed

4 season field investigations 2023 and 2024.

Recorded the current environmental conditions at the surface site locations.

Complemented map and database information.

Selected preferred locations and adjust perimeters.

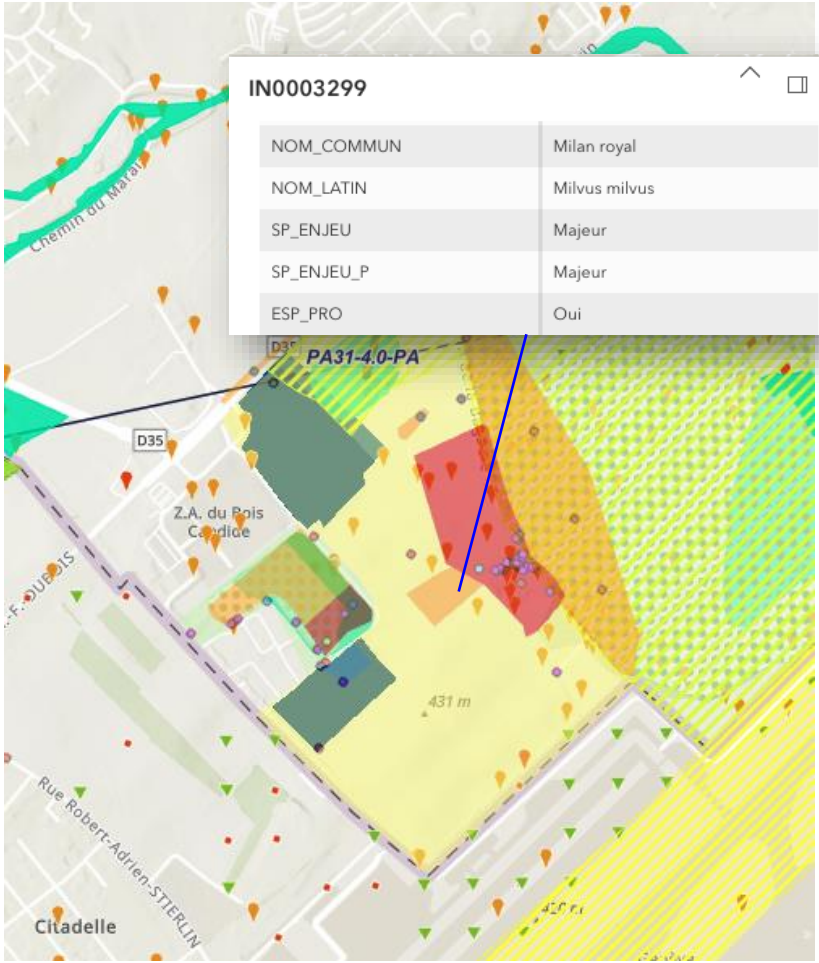
Confirmed in-principle territorial feasibility.

Comply with regulatory requirement to identify and document the environmental issues.

Created a documentation baseline for the environmental impact assessment:

Report, on-line and Environmental Information System

Leads to a report in French language in early 2025.



Compilation of environmental aspects

Non-technical description of the project with a focus on environmental aspects.

Aspect = any element that interacts with the environment, and leads to potentially relevant impacts.

Catalogue of all project elements and phases

- Subsurface construction
- Surface site elements
- Technical infrastructures
- Particle accelerators
- Experiment detectors

Systematic identification and prioritisation as required by regulatory frameworks.

Preparatory work for environmental impact assessment tendering and technical design integrating the eco-design approach.

Report in french towards the end of 2025.

Contents structure per system

Purpose of the system

Functional description of the system

System capacities and unit multiplicities

Resource needs (raw materials, processed materials, equipment, energy, water)

Energy transformation

Emissions

Efficiency and losses

Space requirements

Aspects and und normal conditions

Aspects under degraded / accidental conditions

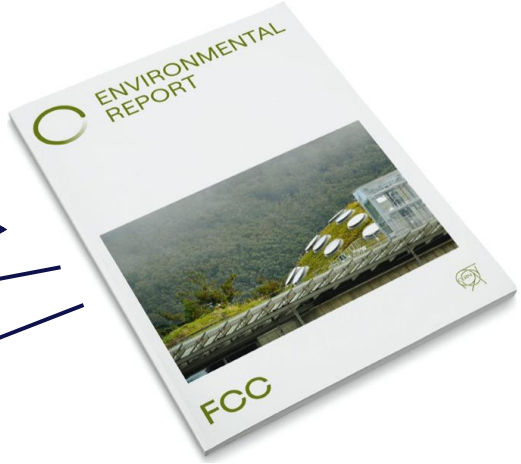
Durable references of data origins

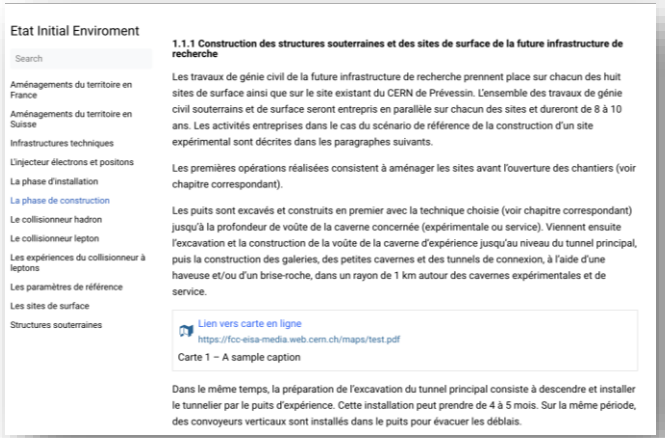
Product line for multi-media environment reports

LaTeX

ArcGIS Enterprise

http://





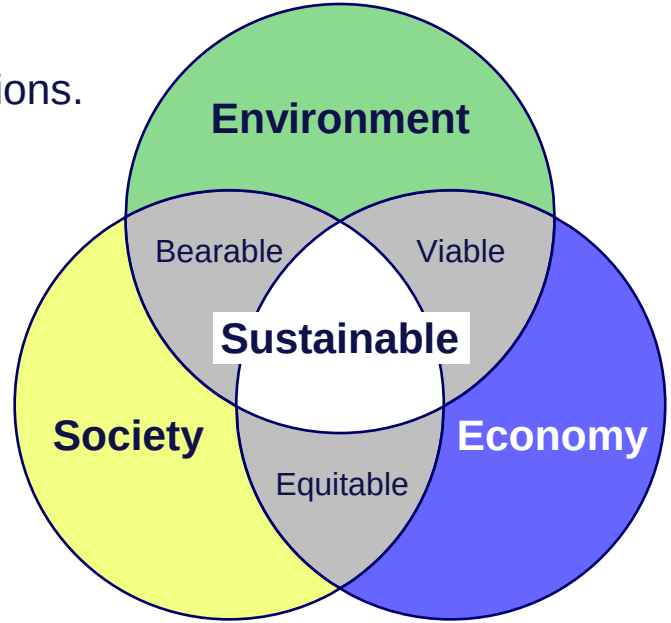
SUSTAINABILITY

Sustainability: an equilibrium of factors

- **The ability to be maintained at a certain rate or level.**
- Requires the consideration of 3 factors:
  biosphere (environment), economy and society dimensions.

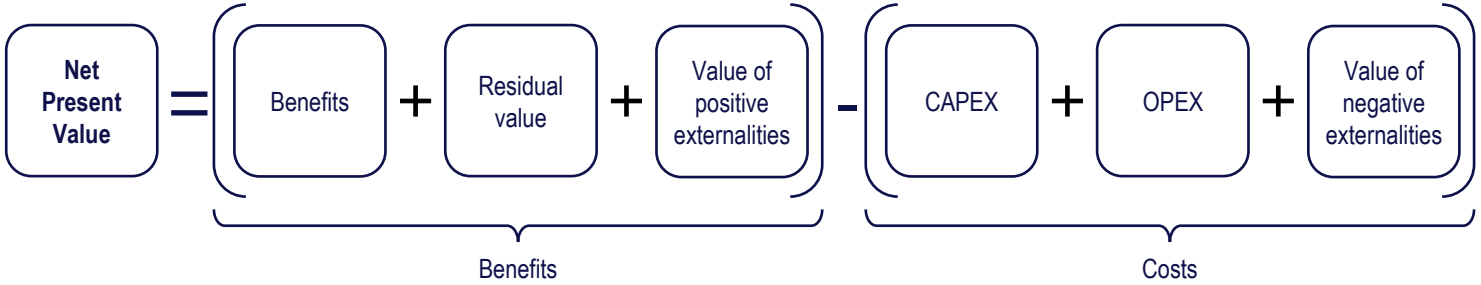
Environment considers among many others:

- Negative externalities such as the depletion of natural resources, loss of biodiversity, loss of land, contribution to climate change.
- Benefits such as production of clean water, use of waste heat and excavated materials, creation of green spaces, refurbishment of wastelands, creation of habitats.



Application of standardised methods

- International and national guidelines define sustainability analysis and criteria



- Explicitly requested by the host states: wider socio-economic assessment
- Impact study carried out, currently additional work to integrate some negative externalities and some environmental benefits:
  - Shadow cost of carbon, noise, loss of biodiversity, loss of agricultural income
  + waste heat supply, improvement and creation of habitats, re-creation of spaces

Electricity needs

On average 1.3 TWh/year.
Current CERN consumption: 1.2 TWh/year.

To be able to leverage renewable energy sources, be cost efficient and societally more acceptable:

Design and operation model should foresee an “adaptive” model foreseeing possibilities to function when on a long time horizon renewable energy sources are abundant and affordable, when the environmental condition are favourable to exploit waste-heat supply and work conditions are advantageous.

1.3 TWh per year corresponds to …

1 large “Meta” data centre in the US
(Facebook, Instagram, WhatsApp).

*https://sustainability.atmeta.com/wp-content/uploads/2024/08/Meta-2024-Sustainability-Report.pdf

1/4 of a chemical production plant in Ludwigshafen (DE, 5.3 TWh per year).

Waste heat supply

Techno-economic feasibility studied with industrial partner Ginger Burgeap.

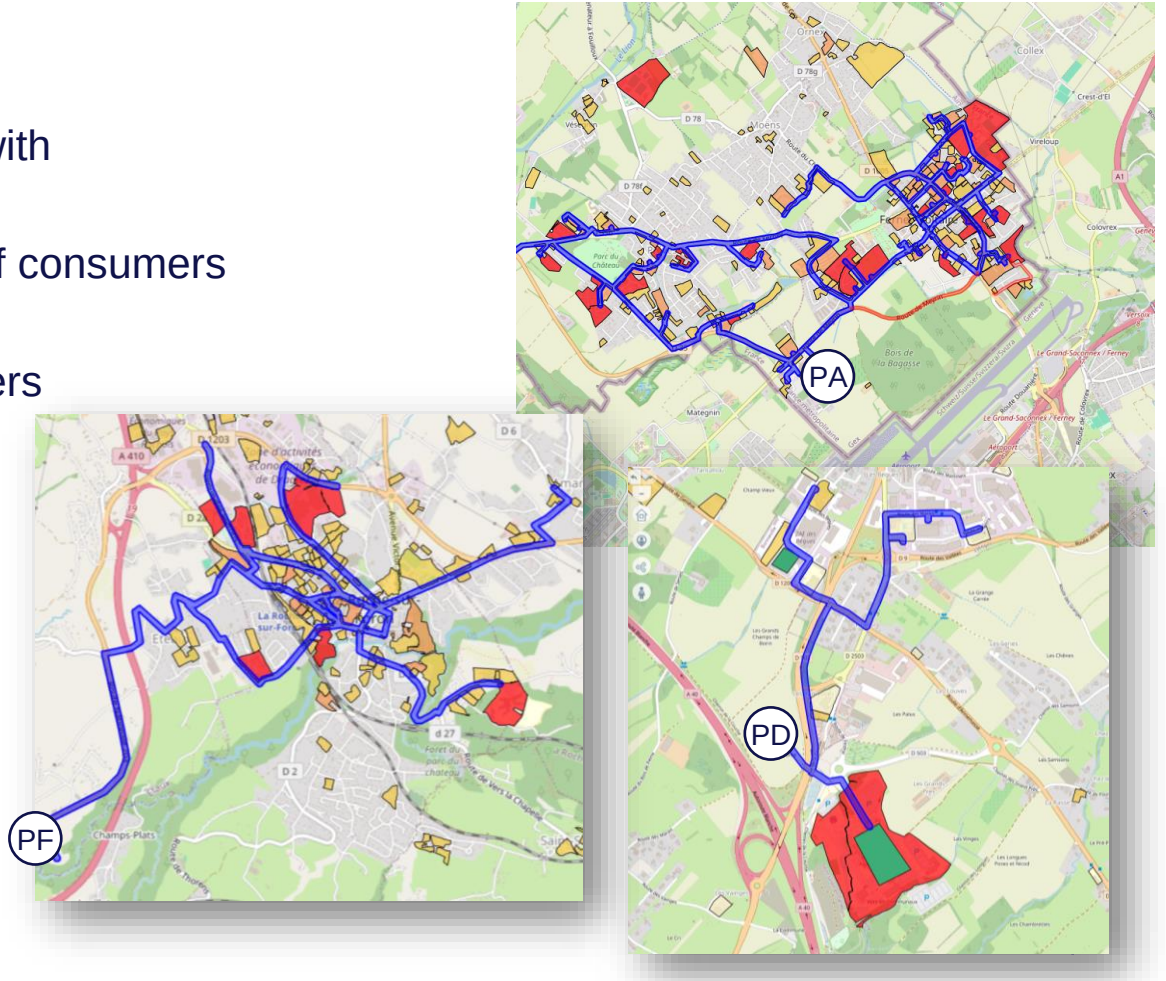
Identified 300 to 400 GWh per year of consumers around surface sites.

Large scale and institutional consumers are easier to serve than individual households.

Reduces cooling water needs.

Can compensate carbon footprint.

Requires adaptation of the operation schedule to times when more heat is required.



Raw water needs

Less than 3 millions de m^3 per year

- CERN needed 3.2 millions de m^3 in 2022
- No new intake required.
- No use of water bearing layers.
- No impacts on water streams.
- Sustainability study project: treatment of STEP released water for cooling purposes.

For comparison

➔ 3.5 millions m^3 per year released by STEP SRB Scientrier into the Arve.

Land consumption

Scenario development led to land use reduction:

From 12 to 8 sites
From 100 to 45 ha

-55%

➔ **4,5 ha par an,**
limited to 10 years of construction.

Note:
- **Re-use of LHC Pt8 spaces in Ferney-Voltaire needs to be maximized.**
- Re-naturalisation projects around sites still need to be developed, but are foreseen.

For comparison:
➔ France artificialises 66 ha per day
➔ Switzerland artificialises 13 ha per day

Construction carbon footprint:

530 000 $tCO_2(eq)$

- Studied with industrial partner WSP applying European Norms EN 17472, EN15804+A2
- Comparable to **3 years of CERN operation**
- Corresponds to **0,11 kg** (115 g) **per capita in Member States per year of construction**
- **Note: Paris Agreement goal for 2050 is 2 000 kg per person per year.**

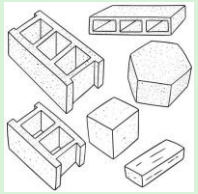
For comparison

- ➔ Channel tunnel: 13 million tCO_2
- ➔ Lyon-Turin tunnel: 10 million tCO_2
- ➔ Gotthard tunnel: 24 million tCO_2

Excavated materials management challenge

- Manage 8.5 million m^3 of excavated materials.
- A project management and territorial implementation topic and **part of the authorisation conditions**.
- **Deposit** in quarries is in principle **feasible, but is expensive** (> 500 million euro) and possibilities are reducing from year to year.
- 95% is molasse, a heterogeneous, sedimentary rock for which no re-use scenario exists today.
- Typically conventional construction projects (tunnels, roads, appartment house projects, public works) are too small and have too tight schedules to engage innovation actions for this type of material.

Identified credible re-use pathways being studied



Traditional channels

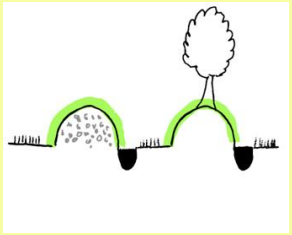
- Use of sand and limestone for concrete production
- Innovative construction materials

Use inside and in vicinity of the project

- Landscape design
- Unpaved tracks, rural and forest paths

Creation of new land

- Wasteland refurbishment
- Polluted soil treatment
- Creation of leisure areas and parks
- Improvement of acid soils



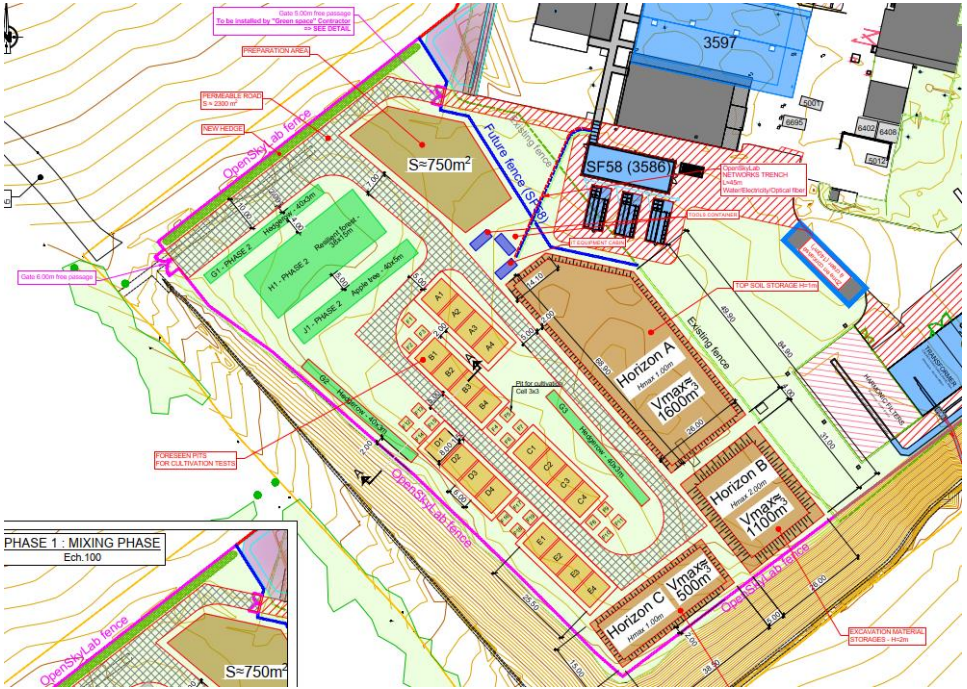
Territorial developments

- Quarries renaturation
- Noise barriers
- Raised hedges
- Covered road tranches

Trials for pathways with a potential of **2 million m^3** planned at OpenSkyLab

OpenSkyLab

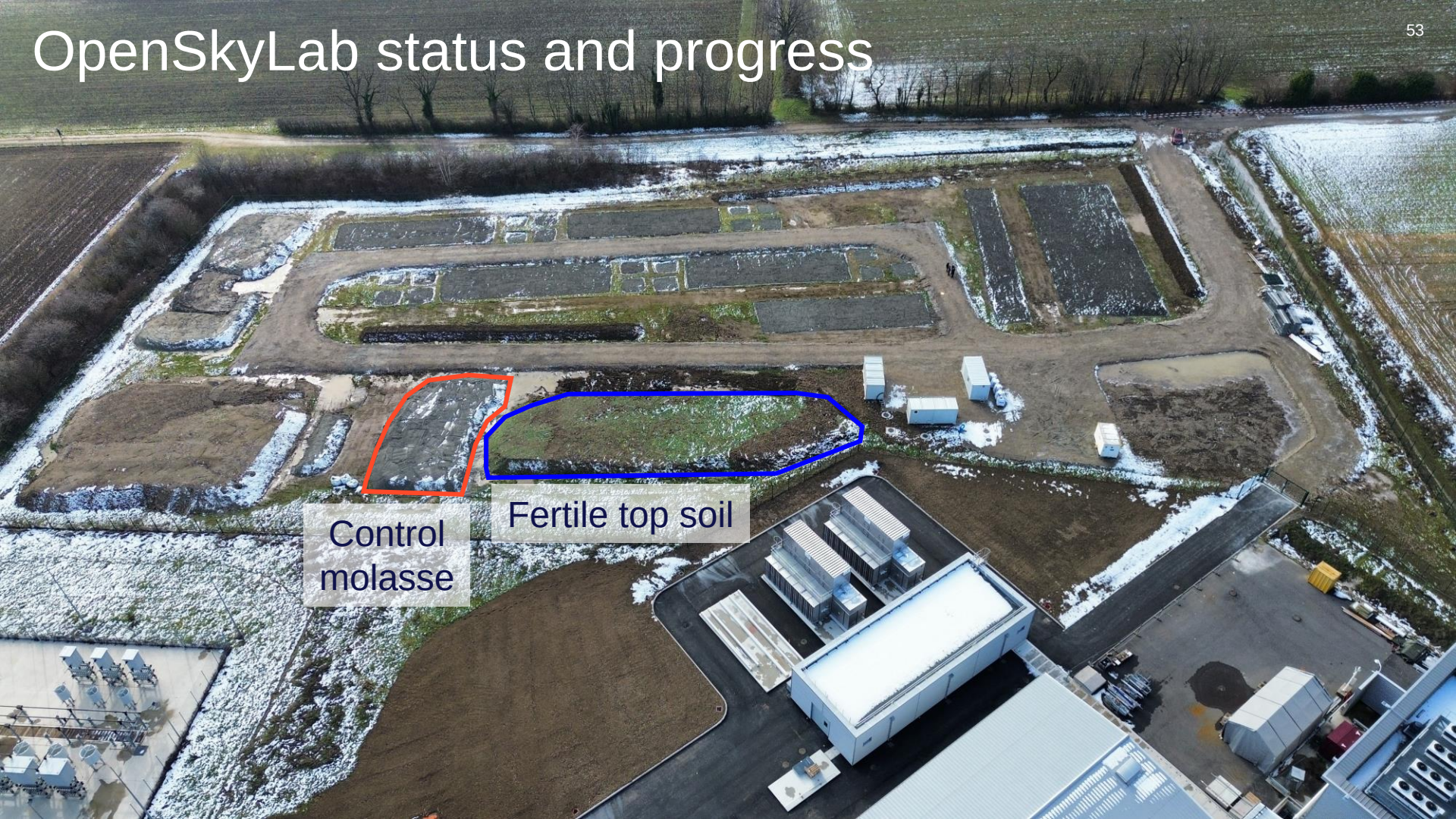
- Academic and industrial **collaboration**
- **Location: CMS Pt5, Cessy, 1 ha of land**
- **Materials: Molasse from the HL-LHC construction**
- **Duration: 4+ years (2024 -)**
- **Budget: Approximately 4 MCHF**
- **Trials with 5 000 t molasse**
- **Field monitoring system with sensors and drone to permit comprehensive and systematic process of the development of methods and products as required by regulatory frameworks.**
- **<u>Note:</u> agreements need to be established with offtakers before the materials are produced!**



hepia Haute école du paysage, d'ingénierie et d'architecture de Genève
brgm Géosciences pour une Terre durable
EDAPHOS
BOKU UNIVERSITY
micro humus Ingénierie des sols
MONTAN UNIVERSITÄT LEOBEN
BECC EST 2018
BG

OpenSkyLab status and progress

OpenSkyLab status and progress



Pre-treated molasse for trials

Preparation for trials and field monitoring

Preparation for trials and field monitoring

Complementary socio-economic studies

The delivery of a socio-economic assessment **is requested by swiss and French host states.**

In France it is part of the environmental authorisation process that leads to the unique construction permit.

An **initial assessment was published on Zenodo**:

https://doi.org/10.5281/zenodo.10653395

Based on 2 experiments and does not include negative environmental externalities.

Since October 2024 complementary studies have been engaged:

- Consideration of updated total costs
- 4 experiments
- Updated waste-heat supply potentials
- New results from tourism spending survey
- Pathways to increase returns to participating nations

Consideration of environmental externalities:

- Shadow cost of carbon
- Noise, ionising radiation, traffic
- Loss of habitats and biodiversity
- Lost of agricultural income and forestry

Eco-design strategic recommendation & guide

- https://zenodo.org/records/14336970
- Defines the **ambition** of the project owner.
- Outlines the **priority** stakes.
- Provices a high level **framework** for the work
- It applies to **all phases** of the project.
- It considers **transnational** aspects.
- It defines **responsibilities**.
- The contents will **evolve**.
- **High level directions** for 3 periods (p. 7)
  - 2024-2030, 2030-2040+, 2040+

The strategy and guidelines are **aligned with** and **compatible with CERN's established environmental objectives**.

The document is intended **to be adopted by all participants of the FCC study and subsequent design**, irrespective if works are occuring at CERN, at partner institutes or companies.

It serves as a **principal strategy and guide**.

Further recommendations have to be compatible with the contents of this document.

The document **should be widely distributed**.

The document **should be attached to certain procurement actions** as an annex.

IMPLEMENTATION WITH HOST STATES

FUTURE CIRCULAR COLLIDER

FCC – SYNTHESE DES CONTRAINTES ET OPPORTUNITES D'IMPLANTATION

10.5281/zenodo.7569138

13/12/2023

Grant Agreement number: 951754 — FCCIS — H2020-INFRADEV-2018-2020 / H2020-INFRADEV-2019-3

Future Circular Collider
Futur Collisionneur Circulaire

RAPPORT LIVRABLE

SYNTHESE DES CONTRAINTES ET OPPORTUNITES D'IMPLANTATION

Identifiant du document	FCC-2107150900-CER 10.5281/zenodo.7569138
Date de la version	11/12/2023
Groupe de travail	FCCIS – WP3 Intégrer l'Europe
Organisation	Cerema - CERN - LD
Version	V 2.0
Statut	Publié
Domaine	Implémentation
Mots clés	FCC, implémentation, impacts environnementaux, opportunités territoriales

Ce projet a reçu, de l'Union Européenne, une subvention du programme d'aide de recherche et d'innovation Horizon 2020 sous le numéro d'agrément : 951754.

Page 1 sur 579

Single source of information for the implementation scenario

- Periodically updated via editorial process
- **V3.0 published in October 2024**
- **V4.0 in time for submission to European Strategy Update**
- 120 persons contributed to this work

https://doi.org/10.5281/zenodo.10369593

Work with host states on project-related matters

France:

Meeting with **Interministerial FCC Evaluation Committee** to walk through the french feedback on the MTR.

Received requirements, suggestions and recommendations on the completion of the feasibility study documents.

Work with **Commission Nationale du Debat Public (CNDP)** on a "**counseling mission**" concerning their accompanyment in first public information meetings and the preparation of subsequent informal and formal public engagement processes.

Reception of **list of generally applicable administrative procedures** until start of construction.

Switzerland:

Federal and cantonal authorities completed their work on the sector plan development.

Meeting with **Committee Suisse Evaluation FCC (CSEF**, composed by 23 participants from federal offices, the canton Geneva, PSI and Univ. Zürich) to walk through the swiss feedback on the MTR.

Received requirements, suggestions and recommendations on the completion of the feasibility study documents and further studies and development works.

Engagement with the public

After a slow start, CERN insisted on a swift ramp up of public information meetings to assure that the process of the subsurface investigations would not be jeopardized.

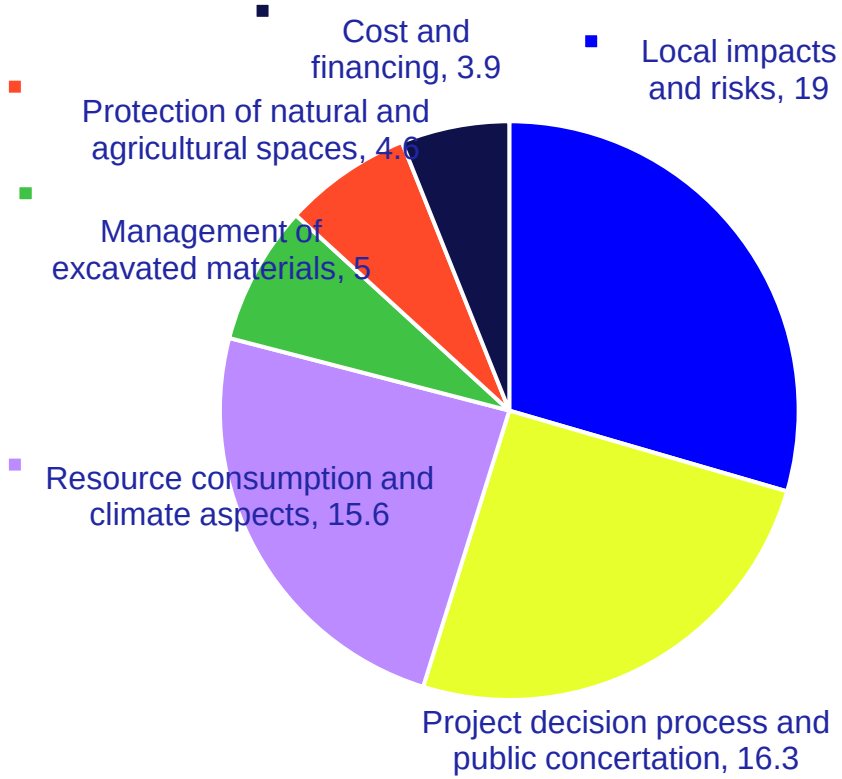
7 information meetings between 10 and 19 december.

All meetings are structured, recorded and analysed.

A formal system to receive questions concerning FCC and provide answers is in place.

A formal stakeholder management system is in place to assure the quality of the subsequent processes.

Public information meetings will now continue with “topical” focus to respect the need for further information and improved dialogue.



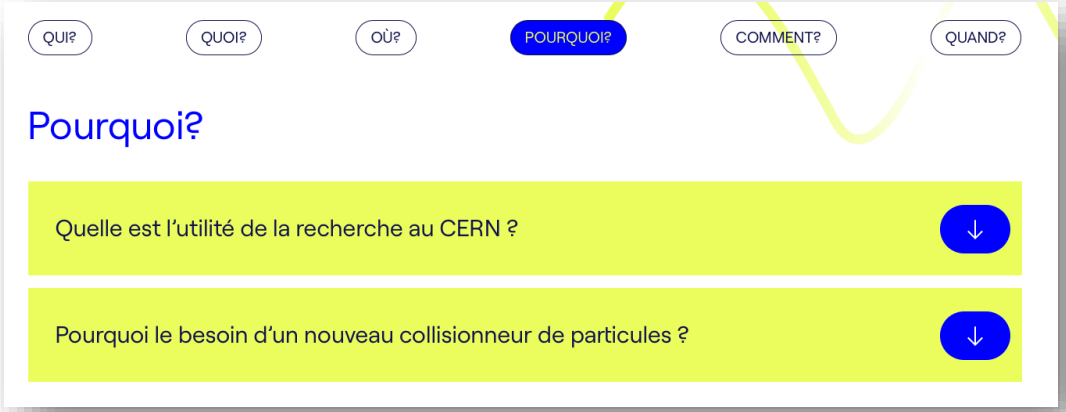
Impressions from meetings: 20 to 250 participants

Thanks to the participation of theoretical and experimental physics colleagues. This is essential!

We need much more science ambassadors to be involved in assuring the public of the interest of the interest and commitment of the science community for such an infrastructure!

Source of information: **fcc-faisabilite.eu**
Official contact channel: **fcc-info@cern.ch**

Follow on social media: **linktr.ee/FCC_study**
Engage on BlueSky:
https://bsky.app/profile/fccstudy.bsky.social



CONCLUSIONS

Conclusions

Mid-term review successfully completed.

Recommendations from review taken into account for study and further design phase.

Host states provided feedback that is incorporated into subsequent works.

The continued accompaniement of the host states is a key to success and is very much appreciated.

Final reports are on track for submission to Update of the European Strategy for Particle Physics.

Environmental initial state analysis, engagement with the public, socio-economic assessment and sustainability studies carried out as pre-requisites for the authorisation processes.

Structured and managed process to be set up to carry out requirements and design works in an overall integrated way to support the authorisation processes in a subsequent phase.

Technical feasibility is not to be confused with a societal and territorial licsense. This topic is to be tackled without interruption between phases if the intended start construction is to be maintained.

Demonstration of a committed engagement of a large and gloval science community is important.

Any new project at CERN with territorial development needs requires studies and works akin to the ones carried out in the frame of the FCC studies (investment so far 8 years).

FCC Week Vienna, Austria, 2025

Strong participation from all FCC collaborators worldwide is encouraged for this final event of the Feasibility Study!

Vienna, Austria

Monday 19 to Friday 23 May 2025

Hofburg Palace (a historical and cultural landmark).

Presentation of the Feasibility Study reports and review of its findings and opportunities for future R&D projects