Ingredients for building our particle accelerator future

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2. From today to the next decades: vision and a strategy
3. CERN environmental commitments
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Our mission and ‘raison d’être’

CERN is the world’s biggest laboratory for particle physics.

Our goal is to understand the most fundamental particles and laws of the universe.
The fundamental questions

What is the universe made of?
We study the elementary building blocks of matter and the forces that control their behavior.

How did the universe begin?
We reproduce the conditions a fraction of a second after the Big Bang, to gain insight into the structure and evolution of the universe.
3 main technical ingredients

1. The largest machines to study the smallest particles in the universe – relying on technology innovation and R&D to advance the limits of what is possible.

2. Detectors - giant 3D cameras

3. Computing power - Worldwide Computing Grid
3 main technical ingredients

Accelerate particles to almost the speed of light.
Giant detectors record the product of the beam collisions in the heart of the four experiments.
Worldwide LHC Computing Grid.
A lot of successes and still many opportunities ahead of us to answer remaining questions

Numerous and giant steps forward …

Several CERN scientists have received Nobel Prizes for key discoveries in particle physics.

The Higgs boson was discovered in 2012; without it fundamental particles would be massless and atoms could not form.

… and still many unanswered questions in fundamental physics

Why is the universe made only of matter, with hardly any antimatter?

95% of the mass and energy of the universe is unknown.

Why is gravity so weak compared to the other forces?

Is there only one Higgs boson, and does it behave exactly as expected?
CERN’s technological innovations have applications in many fields

And there are many more examples
Medical imaging, cancer therapy, material science, cultural heritage, aerospace, automotive, environment, health & safety, industrial processes.
CERN's technological innovations have important applications in the fields of medicine and health.

Technologies applied at CERN are also used in PET, for medical imaging and diagnostics.

Pixel detector technologies are used for high resolution 3D colour X-ray imaging.

CERN produces innovative radioisotopes for nuclear medicine research.

Accelerator technologies are applied in cancer radiotherapy with protons, ions and electrons.
Preparing the future: CERN scientific programme

1- LHC exploitation: RUN3 & HL-LHC

- RUN3: 2022-25; 13.6 TeV c.d.m, 250 fb\(^{-1}\) (ATLAS and CMS), 25-30 fb\(^{-1}\) (LHCb), 7 nb\(^{-1}\) (ALICE, Pb-Pb);
- HL-LHC: 2029-2042, ~3000 fb\(^{-1}\) (ATLAS and CMS).

2- Scientific program complementary to the LHC experiments

- Experiments at the Booster, PS, SPS;
- Participation in accelerator-based neutrino projects (LBNF/DUNE) through the CERN Neutrino Platform;
- Other opportunities discussed as part of the 'Physics Beyond Colliders' working group.

3- Preparing for the future of CERN

- Intense R&D program for accelerators (incl. high field superconducting magnets, radio frequency, plasma field waves...);
- The Feasibility Study for a Future Circular Collider (FCC) (final report expected Dec. 2025);
- R&D and design studies for other scenarios: e.g. CLIC, Muon colliders.

Based on the 2020 update of the European Strategy for Particle Physics => 3 pillars CERN

New contributions expected at the end of 2025 for an update of the strategy towards 2026-2027
The heritage: a unique accelerators complex

- **AD/ELENA**: Antiproton Decelerator for antimatter studies
- **CAST, OSQAR**: axions
- **CLOUD**: impact of cosmic rays on clouds \( \rightarrow \) implications on climate
- **COMPASS**: hadron structure and spectroscopy
- **ISOLDE**: radioactive nuclei facility
- **NA61/Shine**: heavy ions and neutrino targets
- **NA62**: rare kaon decays
- **NA63**: interaction processes in strong EM fields in crystal targets
- **NA64**: search for dark photons
- **NA65**: \( \tau \)-neutrino production from \( D_s \) decays
- **Neutrino Platform**: \( \nu \) detectors R&D for experiments in US, Japan
- **n-TOF**: n-induced cross-sections
- **UA9**: crystal collimation
A diverse and rich scientific programme

Theoretical Particle Physics

Nuclear Physics (ISOLDE)

Antimatter Research (Antiproton Decelerator)

Cosmic rays and cloud formation (CLOUD)

Fixed-target experiments, which include searches for rare phenomena

Contribution to the Long Baseline Neutrino Facility in the USA (LBNF)
The Large Hadron Collider LHC

- 27 km in circumference
- About 100 m underground
- 2 beams of trillions of protons travelling at 0.9999999991 times the speed of light in opposite directions
- Superconducting radiofrequency system to accelerate the beams
- NbTi Superconducting magnets operating at -271.3 °C to bend them in a circle
- Largest beam vacuum system worldwide
- Advanced powering, machine protection systems, beam diagnostics & control
- 4 Large experiments
Provide users with the beams of today while preparing those of tomorrow.

### Ambitious target values for the beam parameters expected at the gates of the HL-LHC:

<table>
<thead>
<tr>
<th>Beam parameters @ LHC entrance</th>
<th>$N_b \times 10^{11}$ p/b</th>
<th>$\varepsilon_{x,y}$ (µm)</th>
<th>Bunch spacing</th>
<th>Bunch number</th>
</tr>
</thead>
<tbody>
<tr>
<td>HL-LHC targets</td>
<td>2.3</td>
<td>2.1</td>
<td>25 ns</td>
<td>4x72 per injection</td>
</tr>
<tr>
<td>Pre LS2 targets</td>
<td>1.3</td>
<td>2.7</td>
<td>25 ns</td>
<td>4x72 per injection</td>
</tr>
</tbody>
</table>

LHC Injectors Upgrade project - 2011-2021:

- Define the modifications needed to overcome beam performance limitations in all injectors so that the required parameter set can be achieved;
- Make the identified changes;
- Bring the injectors back into service at pre-LS2 performance then gradually at the ‘LIU’ target values.

In 2022, the SPS extracted $1.8e11$ p/b with the required luminosity and packet length, in line with the LIU ramp-up plan.

2.3e11 p/b are now stable on the injection energy plateau.
Upgrade to the High-Luminosity LHC under way

The HL-LHC will use new technologies to provide 10 times more collisions than the LHC.

It will provide greater precision and discovery potential.

It will start operating in 2029, and run until 2042.
Scientific priorities for the future: a fertile ground of ideas

Implementation of the recommendations of the 2020 Update of the European Strategy for Particle Physics:

- Fully exploit the HL-LHC
- Build a Higgs factory to further understand this unique particle
- Investigate the technical and financial feasibility of a future energy-frontier 100 km collider at CERN
- Ramp up relevant R&D
- Continue supporting other projects around the world
Scientific priorities for the future

- A Future Circular Collider – feasibility study underway – completed by end 2025
  - Goal: to push the energy frontier of particle colliders to reach 100 TeV
  - A ~100km ring linking to the existing CERN accelerator complex
  - Sustainable operational model being elaborated
  - Key engineering challenges include:
    - Civil engineering the tunnel & related infrastructure
    - Magnet technology to reach much higher field
    - Improved superconducting RF
Scientific priorities for the future

- A Compact Linear Collider – technical design report under preparation
  - For the era beyond HL-LHC – horizon of 2040
  - Novel two-beam accelerating technique using high-gradient, room temperature, X-band RF cavities
    - Proof of principle experiment completed at CERN
  - Expandable, staged programme (11 – 50 km) with collision energies up to the energy frontier
  - Engineering challenges include:
    - Avoiding breakdown in any of the 140000 accelerating structures, high precision alignment & stability, minimising power consumption.
Scientific priorities for the future: R&D Concepts

- A Muon Collider – Study underway
  - Promises to reach higher energy and luminosity than linear colliders
- Global Challenges:
  - Muons are not stable (lifetime only 2.2 μs at rest) so acceleration needs to be quick
    - At relativistic speeds their lifetime is much longer as time slows down for the muon!
  - Muons decay to produce neutrinos leading to radiation issues at the surface
- Engineering challenges
  - high-field magnets
  - efficient RF
  - robust targets
Scientific priorities for the future – R&D Concepts

- **Plasma Wakefield Acceleration – Experimental studies underway**
  - Novel acceleration concept being studied by the AWAKE experiment at CERN
  - Replaces traditional radiofrequency cavities with a plasma cell for acceleration
  - Plasma waves generated by an intense proton bunch
  - An electron bunch can then be injected onto these waves to be accelerated to high energy
  - Capable of generating accelerating gradients an order of magnitude higher than current radiofrequency systems allowing for much more compact accelerators
Geodetic Metrology

• Challenges
  • Scale from nm to 100km
  • Range in size of components
  • Environment - radiation, cryogenic, limited access, ...
  • Accuracy & Precision required

• Position Monitoring & Adjustment
  • HL-LHC
    • Monitoring of magnet inside cryostat at micrometer level
    • Alignment over all components over 200m better than ~250µm
  • CLIC
    • Component alignment at ~10µm
    • Stabilisation of critical components at nanometre level

Permanent monitoring

Geodetic aspects

R&D

Georeferenced scans

Structured laser beam

Frequency Scanning Interferometry (FSI)
For a research which respects the environment: context

A long-term approach that originates from the creation of the laboratory in 1954

- 1980-1990: integration of environmental concerns into impact studies of new accelerators
- Since then, greater consideration of environmental issues in CERN's activities according to the evolution of the theme in the Host States and on an international scale - breakthrough of key subjects such as energy and greenhouse gas emissions tight

Establishment:
- of the Tripartite Environment Committee in 2007 (CERN – Authorities of the Host States France and Switzerland)
- of a Tripartite Agreement on the protection against ionizing radiation and the safety of the Organization's facilities in 2010
- a CERN committee dedicated to energy in 2015 and creation in 2017 of a CERN committee dedicated to all environmental issues
- an ISO 50001 certification process for energy management, started in 2021 with completion at the end of 2022.

Publication:
- the first 2017-2018 environmental report in September 2020 according to the GRI (Global Reporting Initiative) standard, available to the public, and the second 2019-2020 report in November 2021
- Publication of MASTERPLAN 2040 in December 2021 for the development of CERN sites, integrating framework objectives for the protection of the environment
For a research which respects the environment: strategy

1. Minimize the impact of laboratory activities on the environment through priority actions defined by 2025

2. Pursue actions and the development of technologies to consume less, improve efficiency and recover more

3. Continue to identify and develop CERN technologies that would help to mitigate society’s impact on the environment
Energy – consume less, improve efficiency and recover more: the numbers

1. Heat recovery from CERN-P8 (Ferney Voltaire) to be injected into an “anergy” local loop (ZAC Zone d’Aménagement Concerté, Ferney-Voltaire innovation) - 20 GWh/year

2. Renovation of the Prévessin boiler room (F) including heat recovery from the new Computing Center (PCC) planned to heat the buildings on the site from 2024 – reduction of emissions from the gas boiler room located on the site (up to ~1900 tCO2e/year).

3. Ongoing studies to recover heat from the CERN cooling towers at LHC point 1 to heat the buildings of the Meyrin site (CH) – reduction of emissions from the gas-fired boiler room located on the site (from ~2000 tCO2e/year).
Energy – consume less, improve efficiency and recover more: the numbers

- Main feeding point from a 400kV line (interconnection F-CH)
- Mandatory for CERN accelerators (capacity and stability)
- Back-up from 130kV (limited capacity).

Energy per origin, yearly average "Beams"

- Fuel: 4 GWh, 0.3%
- Gas: 67 GWh, 5.2%
- Electricity: 1’220 GWh, 94.5%

~90% for accelerators, detectors and test facilities
Energy efficiency and savings related to scientific and technical facilities

- Savings of ~100 GWh/year in place since 2010
- Energy efficiency, energy savings taken into account in each renovation/optimization project of the CERN accelerator infrastructure
- New metric developed for the Large Hadron Collider (LHC) to illustrate the amount of energy used per unit of luminosity delivered

Energy efficiency standards are systematically applied for new constructions at CERN and in the building renovation master plan.
Energy – consume less, improve efficiency and recover more

FCC power being evaluated by machine configuration- Jean-Paul Burnet, ESS WK, 29-30 September 2022, Grenoble

Electricity supply 2036 - 2060

Electricity supply for FCC-ee from 2036 to 2060

Schedule of the annual consumption during the FCC-ee lifetime.

<table>
<thead>
<tr>
<th>Year</th>
<th>Type</th>
<th>Beam GeV</th>
<th>Min power MW</th>
<th>Max power MW</th>
<th>Annual consumption TWh</th>
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<tr>
<td>2036</td>
<td>Construction</td>
<td>20</td>
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<tr>
<td>2037</td>
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<td>0.2</td>
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<tr>
<td>2038</td>
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<td>20</td>
<td>50</td>
<td>0.2</td>
<td>0.2</td>
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<tr>
<td>2039</td>
<td>Construction</td>
<td>20</td>
<td>50</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>2040</td>
<td>Construction</td>
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<td>0.3</td>
<td>0.3</td>
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<tr>
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<td>Construction</td>
<td>20</td>
<td>50</td>
<td>0.4</td>
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<td>2043</td>
<td>Construction</td>
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<td>2044</td>
<td>Construction</td>
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<td>0.6</td>
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<tr>
<td>2045</td>
<td>Z operation</td>
<td>45.6</td>
<td>65</td>
<td>237</td>
<td>1.30</td>
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<tr>
<td>2046</td>
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<td>65</td>
<td>237</td>
<td>1.30</td>
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<tr>
<td>2047</td>
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<tr>
<td>2048</td>
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<td>65</td>
<td>237</td>
<td>1.30</td>
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<tr>
<td>2049</td>
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<td>80</td>
<td>68</td>
<td>263</td>
<td>1.43</td>
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<tr>
<td>2050</td>
<td>W operation</td>
<td>80</td>
<td>68</td>
<td>263</td>
<td>1.43</td>
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<tr>
<td>2051</td>
<td>H operation</td>
<td>120</td>
<td>69</td>
<td>292</td>
<td>1.58</td>
</tr>
<tr>
<td>2052</td>
<td>H operation</td>
<td>120</td>
<td>69</td>
<td>292</td>
<td>1.58</td>
</tr>
<tr>
<td>2053</td>
<td>H operation</td>
<td>120</td>
<td>69</td>
<td>292</td>
<td>1.58</td>
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<tr>
<td>2054</td>
<td>Long shutdown</td>
<td>65</td>
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<td>0.57</td>
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<tr>
<td>2055</td>
<td>TT operation</td>
<td>182.5</td>
<td>78</td>
<td>385</td>
<td>2.07</td>
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<tr>
<td>2056</td>
<td>TT operation</td>
<td>182.5</td>
<td>78</td>
<td>385</td>
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<tr>
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<td>TT operation</td>
<td>182.5</td>
<td>78</td>
<td>385</td>
<td>2.07</td>
</tr>
<tr>
<td>2060</td>
<td>Upgrade</td>
<td>50</td>
<td>50</td>
<td>0.44</td>
<td>0.44</td>
</tr>
<tr>
<td>2061</td>
<td>Upgrade</td>
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<td>0.44</td>
<td>0.44</td>
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<tr>
<td>2062</td>
<td>Upgrade</td>
<td>50</td>
<td>50</td>
<td>0.44</td>
<td>0.44</td>
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<tr>
<td>2063</td>
<td>Upgrade</td>
<td>50</td>
<td>50</td>
<td>0.44</td>
<td>0.44</td>
</tr>
<tr>
<td>2064</td>
<td>Upgrade</td>
<td>50</td>
<td>50</td>
<td>0.44</td>
<td>0.44</td>
</tr>
<tr>
<td>2065</td>
<td>HH operation</td>
<td>50</td>
<td>500</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Next steps

➢ Define the electrical infrastructure based on these numbers for the feasibility study
➢ Work on the reduction of the energy consumption
➢ Study energy production, energy recovery and sustainability

CERN 1.3TWh/yr
LHC 0.6TWh/yr
Swiss railways 3TWh/year
French railways 7TWh/year
Electricity production in France 510TWh/year
FCC – environmental initial state analysis

**Heritage and landscape**
viewpoints and sites of cultural, natural importance and historical importance

**Human environment**
agricultural economic study, transport infrastructures, constructed areas strategic infrastructures of national interest, demography and development, analysis of risks relating to technical infrastructures

**Services**
public health and emergency services, security, education, housing, industry and commerce

**Natural environment**
flora, fauna, biodiversity, presence and relevance of habitats, presence and conditions of forests, existence and evolution of protection zones

**Physical environment**
climatic and meteorological conditions, sites topography, geology

**Light**
artificial light pollution, source, type, intensity, direction, places of occurrence and duration

**Noise**
level, frequency and places of occurrence

**Soil and water**
surface water, hydrology, soil profile, land cover and land use and existing soil pollution

**Vibration**
source, type, level, frequency, places of occurrence and duration

**Air**
air quality and types of pollutants

**Ionisation and non-ionising radiation**
source, type, level
Our future: the next generations, from the early age

Be a scientist
- Since 2011
- In collaboration with the educational institutions
- Discovery of the scientific approach through group activities in class (9-12 years old)
- CERN schools visits
  - https://voisins.cern/en/be-scientist

Django Girls in ICT
- In 2018, 2019 and 2021
- Computer discovery workshops for girls
  - voisins.cern/fr/day-ict-workshops-girls-globe

Women and Girls in Science and Technology
- Since 2017
- 11 February is the International Day of Women and Girls in Science. On this occasion and for the whole of the week, UNIGE Scienoscope, EPFL, LAPP and CERN offer local schools the opportunity to welcome a female scientist / engineer to present her work to (mixed) classes.
- They are invited to tell their story, reveal some mysteries of science and, if they wish, to conduct some small demonstrations.
## Countless training possibilities offered at CERN

<table>
<thead>
<tr>
<th>Opportunities for students</th>
<th>Field</th>
<th>Duration</th>
<th>Eligibility</th>
<th>Features</th>
<th>Open to applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interns (100/an)</td>
<td>Applied Physics, Engineering, Computer Science</td>
<td>Max. 6 months</td>
<td>Full-time undergraduate student</td>
<td>Project with CERN supervisor</td>
<td>11/2022</td>
</tr>
<tr>
<td>Technical students (200/an)</td>
<td>Applied Physics, Engineering, Computer Science</td>
<td>4 to 12 months</td>
<td>Have completed 18 months of undergraduate studies</td>
<td>Project with CERN supervisor</td>
<td>08/2022 to 7/11/2022</td>
</tr>
<tr>
<td>Summer students (300/an)</td>
<td>Physics, Engineering, Computer Science</td>
<td>8 to 13 weeks in summer</td>
<td>Have completed 3 years of undergraduate studies</td>
<td>Conferences, visits, workshops</td>
<td>11/2022 to 01/2023</td>
</tr>
<tr>
<td>Doctoral students (80/an)</td>
<td>Applied Physics, Engineering, Computer Science</td>
<td>6 months to 3 years</td>
<td>Enrolled in a doctoral program</td>
<td>Project leading to a thesis, 2 thesis supervisors (University / School and CERN)</td>
<td>08/2022 to 7/11/2023</td>
</tr>
</tbody>
</table>
Endless career opportunities at CERN

**ORIGIN**
Give a real boost to your career.
Continue learning with a job offering support and guidance from the supervisor and a CERN team.

**Duration:** 6 – 36 months
**Selection committee:** November – March – May – August

**Eligibility:**
- Candidates from Member States and Associate Member States
- Specialized studies/technician's diploma or Bachelor's or Master's degree; less than 2 years of experience

**QUEST**
Deepen your knowledge and expertise.
Work on a specific proposed project, under expert supervision, within a team.
Development of the professional network in the areas of interest. Ability to supervise a student.

**Duration:** 6 – 36 months
**Selection committee:** March – October

**Eligibility:**
- Candidates from Member States and Associated Member States - (exceptionally for candidates from non-Member States)
- Master 2 to 6 years of experience
- PhD with maximum 3 years of experience

**Research Fellows**
Build international visibility and develop a network in the scientific community.

**Duration:** 6 – 36 months
**Selection committee:** November – May

**Eligibility:**
- Postdoctoral research topic to be submitted (particle physics, applied physics, engineering)
- Candidates from Member States and Associated Member States - (exceptionally for candidates from non-Member States)
- PhD with up to 6 years of experience

CERN recruits around 250 new graduates every year
CERN Science Gateway

CERN’s new education and communication center for the general public, everyone from 5 years old

Opening scheduled for summer 2023

Immersive exhibitions, educational laboratories, events and shows
Concluding remarks

CERN has a vast and exciting scientific programme:
- With the LHC running until ~2042;
- With the facilities and experiments of the injector complex, complementary to the collider, at the service of a large community;
- Through vigorous R&D and design studies for future installations.

The ESPP 2020 program has identified the Future Circular Collider as the preferred option at CERN for an upcoming post-LHC collider.
- An immense physical potential, but also a very difficult and ambitious project;
- The feasibility study has started and will be completed by the end of 2025;
- The focus is on FCC-ee and magnet R&D;
- Other options are also being studied.

To maintain interest in CERN and motivate the community (especially younger generation), it is crucial to:
- Avoid too much time between the end of the HL-LHC around 2042 and the start of physics in a new installation (around ~2045);
- Build a new facility alongside the operation of the HL-LHC where the next generation can work on HL-LHC data analysis and R&D for the construction of the new facility.

Today’s accelerators form our heritage and our foundation for tomorrow.

There will be no future large-scale scientific project without a thoughtful energy management policy, including a strong incentive for energy efficiency and energy recovery among the major objectives.

Any future projects will have challenging ‘alignment and survey’ specification. Your expertise is integrally part of the success of our future programmes.
THANK YOU