Photo Trevor Sherwin

Implementation of the 2020 update of the European Strategy

Fabiola Gianotti (CERN), ESPP Open Symposium, Venice, 23 June 2025

Main tools/committees to monitor the ESPP implementation

CERN Medium-Term Plan (MTP)

Rolling 5-year plan approved by Council in June of each year → allows regular assessment by Council and its subordinate bodies of compliance of CERN's scientific and financial strategy with ESPP recommendations.

Large Particle Physics Laboratories Directors Group (LDG)

Directors of major European Laboratories: CERN, CIEMAT, DESY, IJCLab, IRFU, LNF, LNGS, Nikhef, PSI, STFC-RAL, STFC-Daresbury.
Chair (M. Seidel) is member of Strategy Secretariat, representatives of these Labs are members of the European Strategy Group.
LDG discusses ESPP implementation in the various Labs and matters of common interest; forum for general coordination among European Labs in the field (e.g. for joint applications for EU funding).
Since 2020 ESPP: leading role in overseeing the development of the Accelerator R&D Roadmap and monitoring its implementation.

Plenary ECFA (European Committee for Future Accelerators) and Restricted ECFA (RECFA)

Plenary ECFA brings together representatives of CERN Member and Associate Member States to discuss the landscape of the field in Europe, in particular ESPP-related matters.
RECFA visits to countries (~ 4/year): opportunities to review status of the field and ESPP implementation in the countries, and help the community with recommendations to the country's political authorities on issues of concern.
Chair (P. Sphicas) is member of Strategy Secretariat.
Since 2020 ESPP: leading role in overseeing the development of the Detector R&D Roadmap and monitoring its implementation.

ICFA (International Committee for Future Accelerators)

Discusses regional strategies (ESPP, US P5, etc.) in wider worldwide context.
ICFA panels (Instrumentation, Sustainable Accelerators, Advanced and Novel Accelerators, etc.) promote synergic efforts and provide opportunities to discuss some ESPP recommendations in the global context.

2020 ESPP update: 20 recommendations

2 : Major developments since the 2013 Strategy
HL-LHC; neutrinos

3 : General considerations for the 2020 update
Europe's leadership role; collaboration CERN-European labs; collaboration with global partners

2 : High-priority future initiatives
Future colliders; accelerator R&D

4 : Other essential scientific activities for particle physics
Diverse scientific programme; theory; detector R&D; SW and computing

2 : Synergies with neighbouring fields
Astroparticle physics; nuclear physics

3 : Organisational issues
Global projects; relations with EC; open science

4 : Environmental and societal impact
Environmental protection; early-career scientists; technology transfer; public engagement

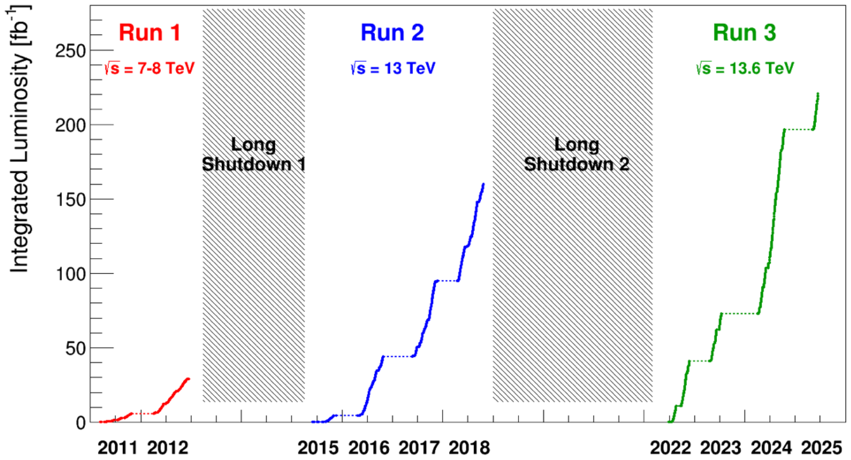
Note: only **some highlights here** → more in dedicated talks during the week (role of national labs, relations with other fields, sustainability, etc.)

Major developments since the 2013 Strategy (I): LHC and HL-LHC

The successful completion of the high-luminosity upgrade of the machine and detectors should remain the focal point of European particle physics, together with continued innovation in experimental techniques.
The full physics potential of the LHC and the HL-LHC, including the study of flavour physics and the quark-gluon plasma, should be exploited.

Full exploitation of the LHC

Integrated luminosities delivered to ATLAS and CMS



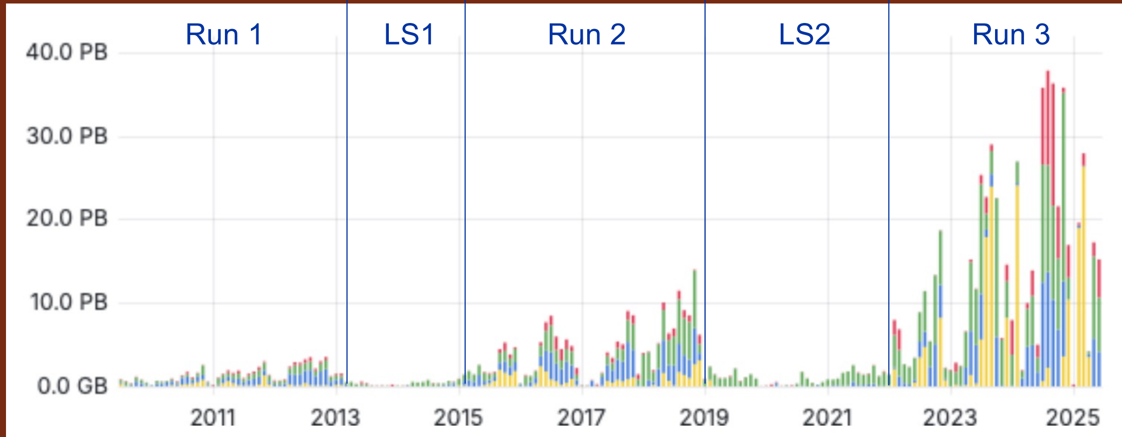
Total integrated luminosity to ATLAS and CMS since LHC start: **410 fb^{-1}**, of which **380 fb^{-1}** at $\sqrt{s} \geq 13$ TeV

4 large experiments and growing number of smaller experiments with complementary goals (forward physics, neutrinos, monopole searches, etc.)

Experiment	Number of papers on collision data accepted for publication until 10/6/2025	Number of papers on collision data accepted for publication from 1/7/2020 to 10/6/2025
ALICE	502	221
ATLAS	1355	458
CMS	1346	371
LHCb	767	243

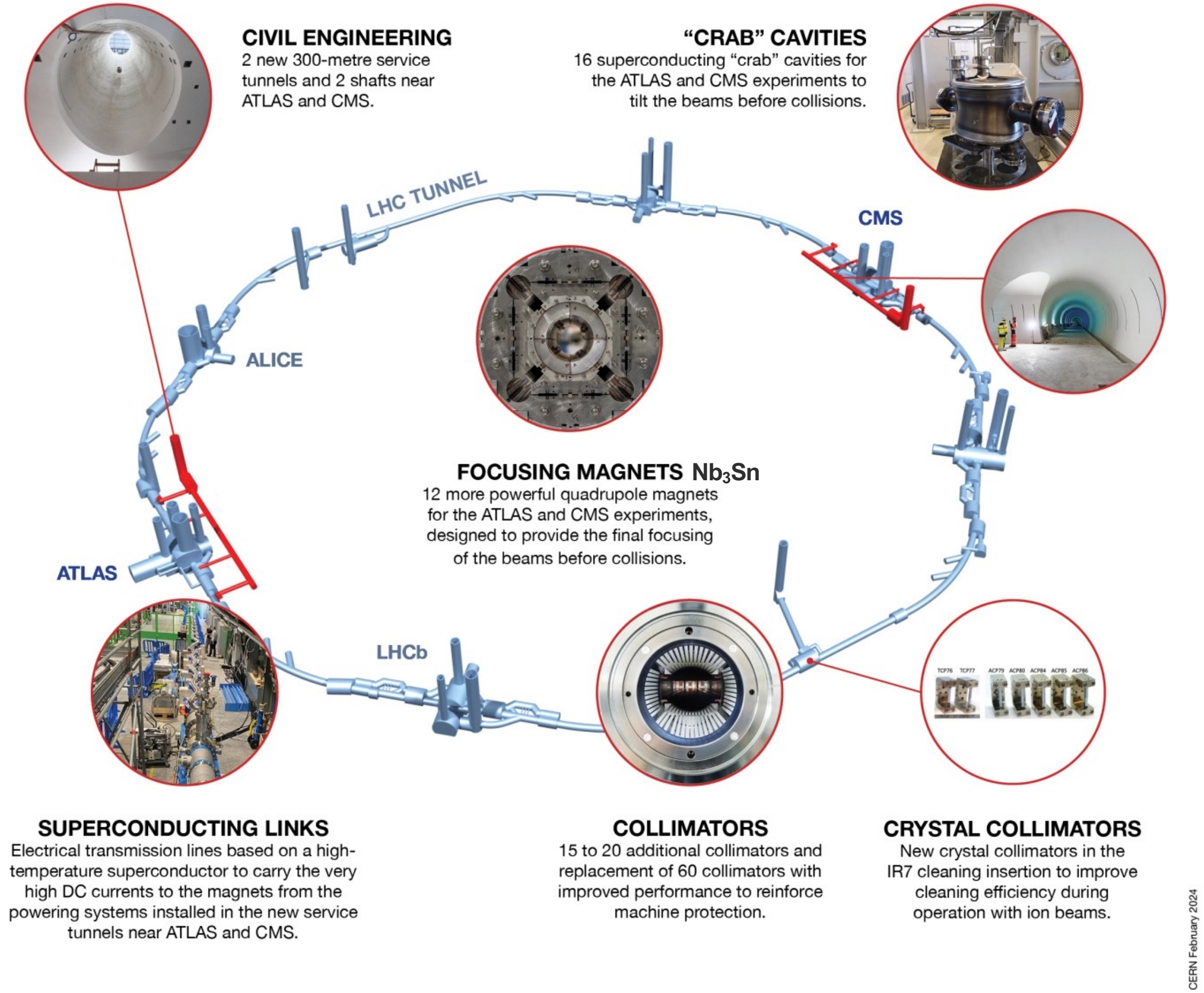
Experiment	Fraction of delivered luminosity used for analysis (2024 pp data)
ALICE	76%
ATLAS	88%
CMS	89%
LHCb	86%

Data archived monthly at CERN by LHC experiments (PB)



HL-LHC : accelerator upgrade

- ~ 1.2 km of accelerator replaced
- variety of new technologies
- > 80% of budget committed



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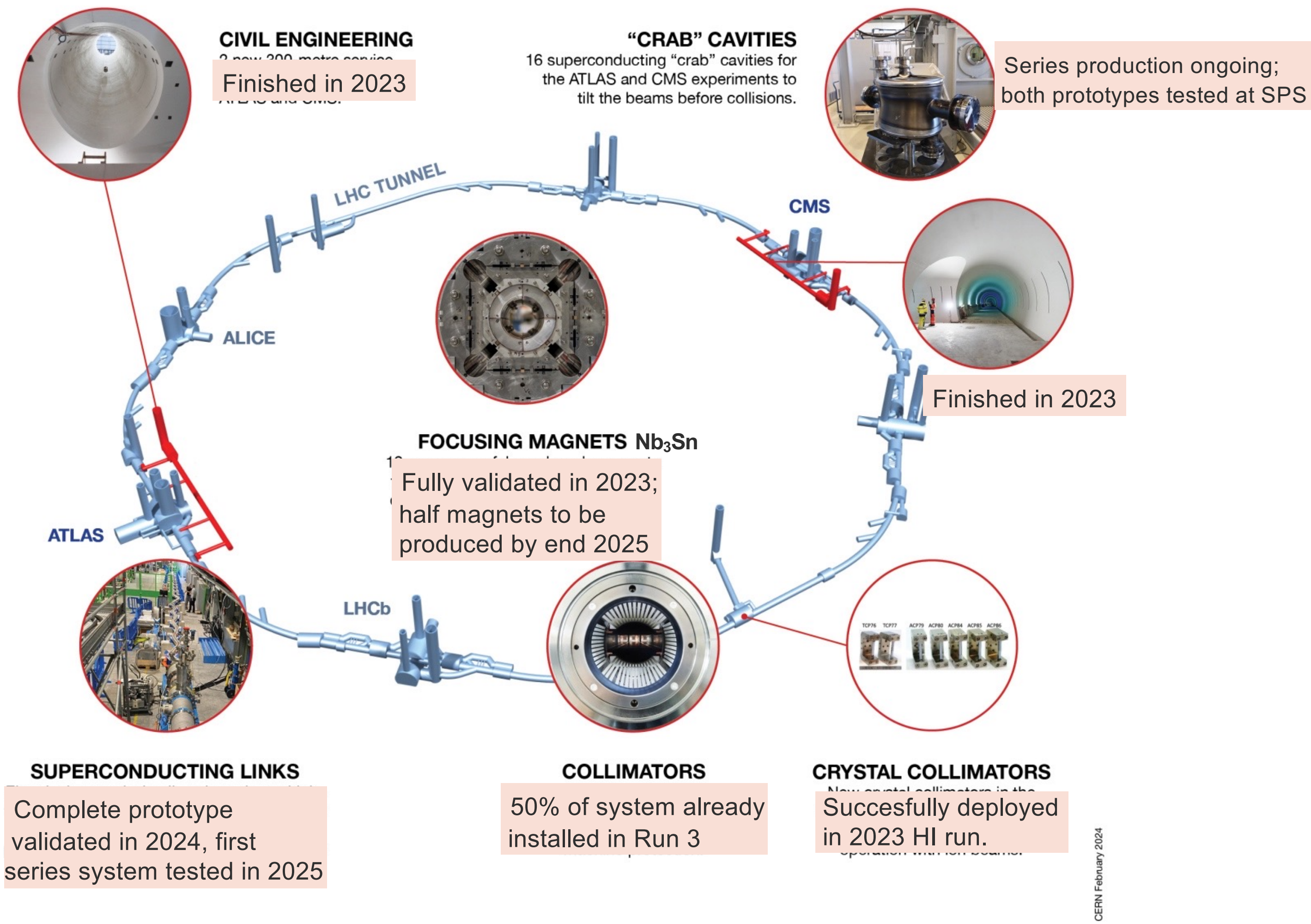
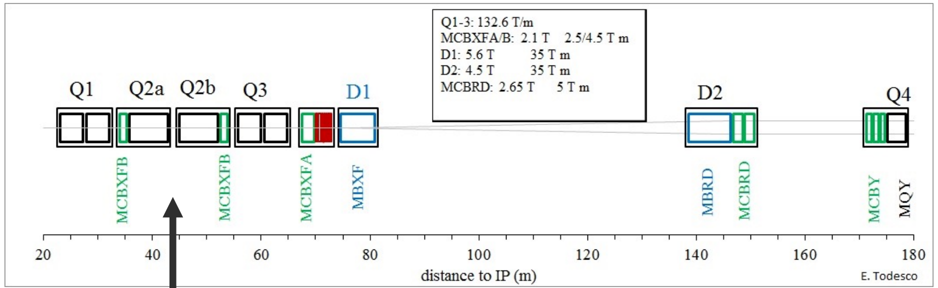
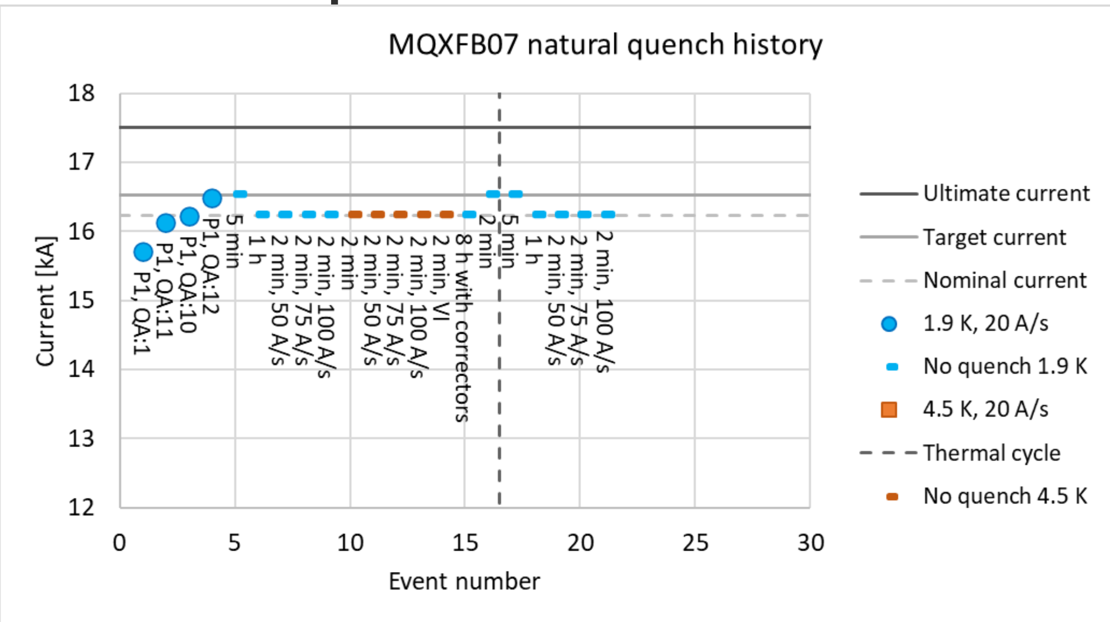
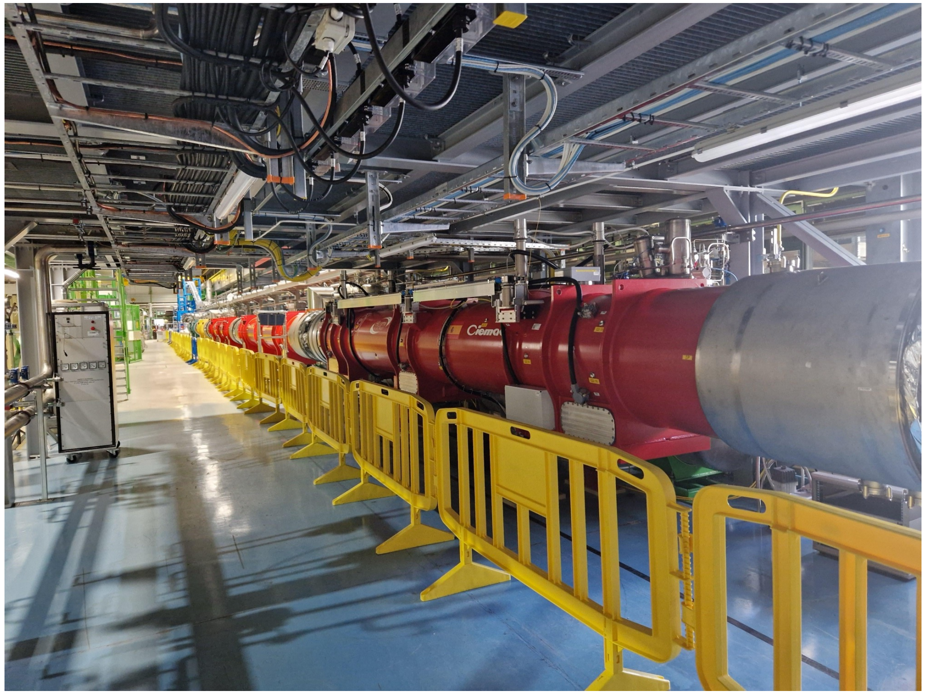






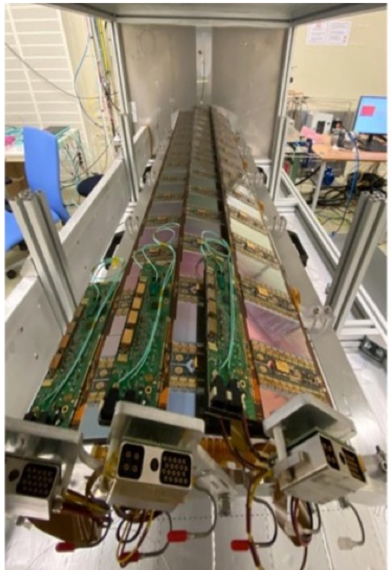
Nb_3Sn technology for high-field superconducting magnets demonstrated in the US and at CERN

Inner Triplet (IT) string: test to start in October



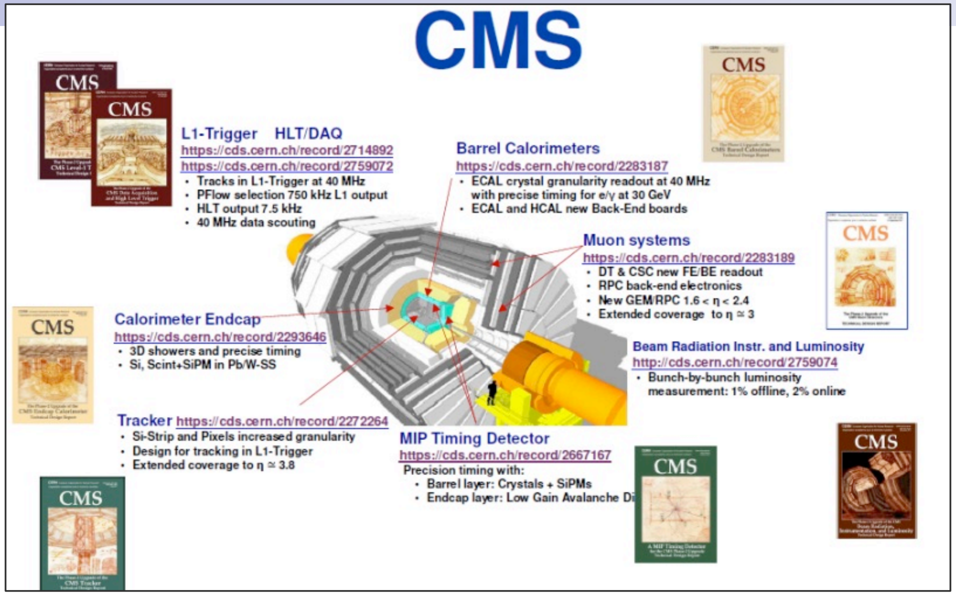
HL-LHC : Phase 2 upgrades of ATLAS and CMS

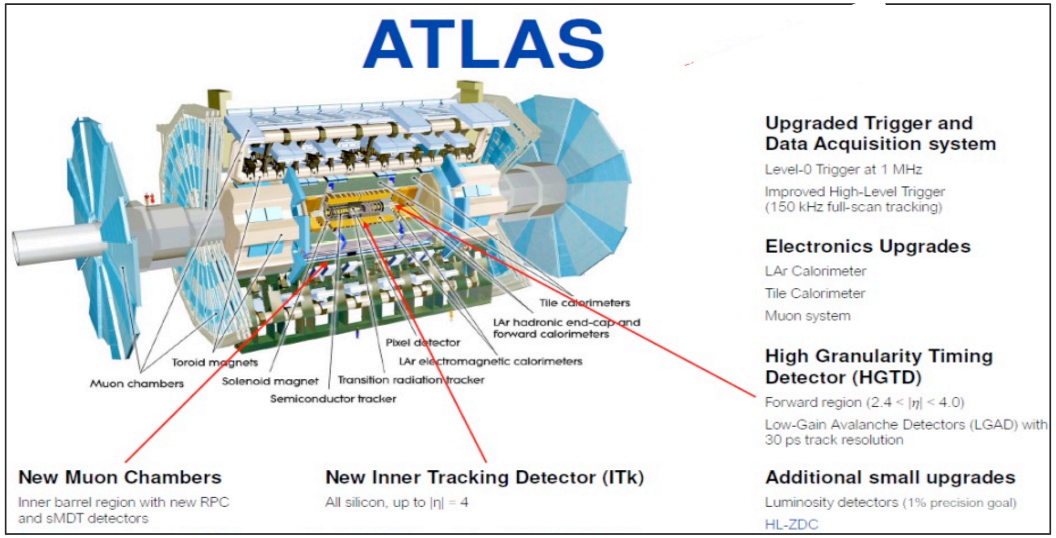
- ❑ Very ambitious; several new technologies; heroic efforts of the collaborations
- ❑ Production started for most sub-systems; ATLAS ITk and CMS Outer Tracker and HGCAL have lowest time contingency
- ❑ Ultimately, upgraded detectors will work wonderfully and will boost the technical advances in the field



ATLAS ITk barrel system tests

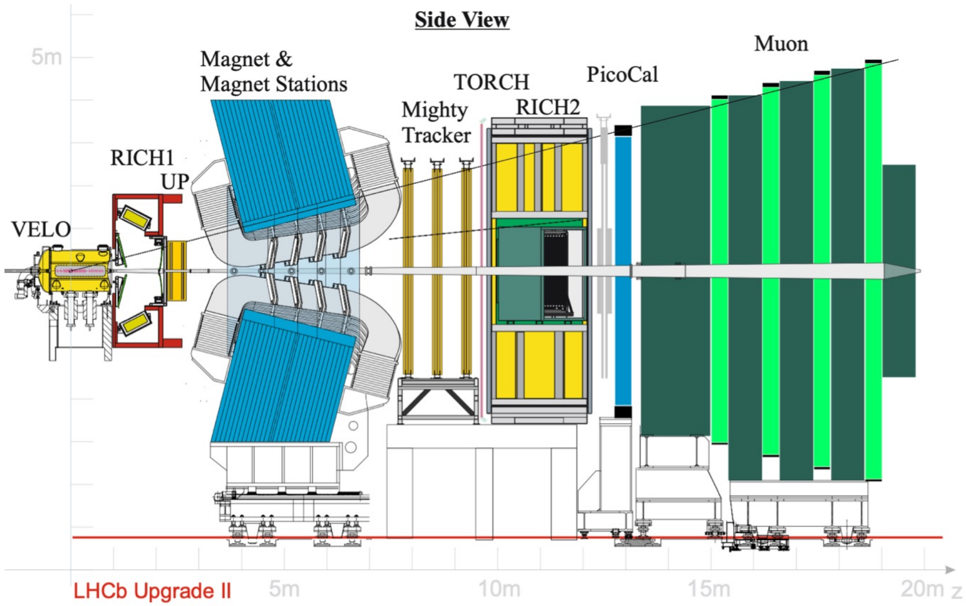
CMS HGCAL end-cap absorber

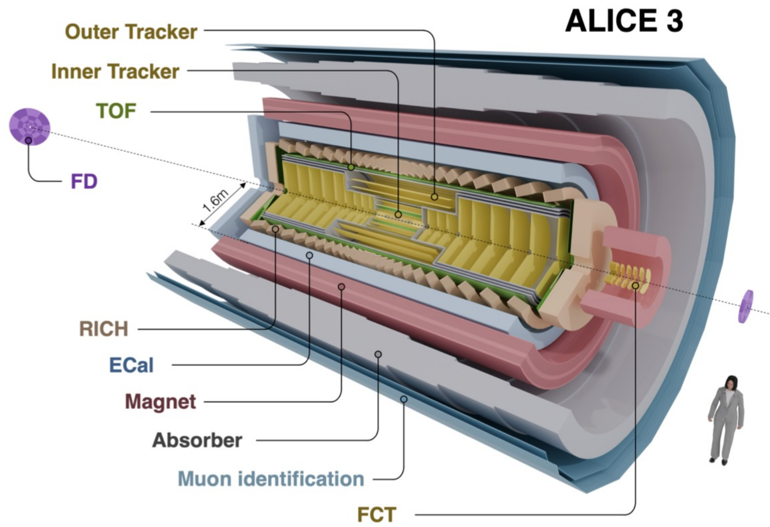




Unfortunately, due to technical challenges with both accelerator and detectors, and external circumstances (COVID, war in Ukraine, etc.), HL-LHC start delayed by 3 years since 2020 ESPP (now starts mid-2030)

HL-LHC: further upgrades of ALICE (ALICE3) and LHCb (Upgrade II) in LS4





- ❑ Goal is to operate at L = 1×10^{34} cm^{-2} s^{-1}(2×10^{33} today) and record 300 fb^{-1} by end of HL-LHC (cfr 50 fb^{-1} before LS4).
- ❑ Full replacement of tracking detectors (high-granularity, radiation-hard detectors with fast timing capability), new readout for ECAL and RICH.
- ❑ Significant improvements in precision, world-best sensitivity to most key flavour physics observables plus broad programme beyond flavour

- ❑ Goal is to record ~ 35 nb^{-1} in Run 5 (cfr 13 nb^{-1} before LS4)
- ❑ Fully new detector, based on CMOS silicon tracker, monolithic time-of-flight sensors, a RICH, and a new superconducting magnet providing 1-2 T.
- ❑ Significant improvement in pointing precision and acceptance. Unprecedented studies of quark-gluon plasma using in particular heavy flavour hadrons and di-electron mass spectra

Proposals being reviewed by relevant committees and discussed with Funding Agencies. Approval expected by the end of the year

Major developments since the 2013 Strategy (II) : neutrinos

Europe, and CERN through the Neutrino Platform, should continue to support long baseline experiments in Japan and the United States.
In particular, they should continue to collaborate with the United States and other international partners towards the successful implementation of the Long-Baseline Neutrino Facility (LBNF) and the Deep Underground Neutrino Experiment (DUNE).

CERN Neutrino Platform

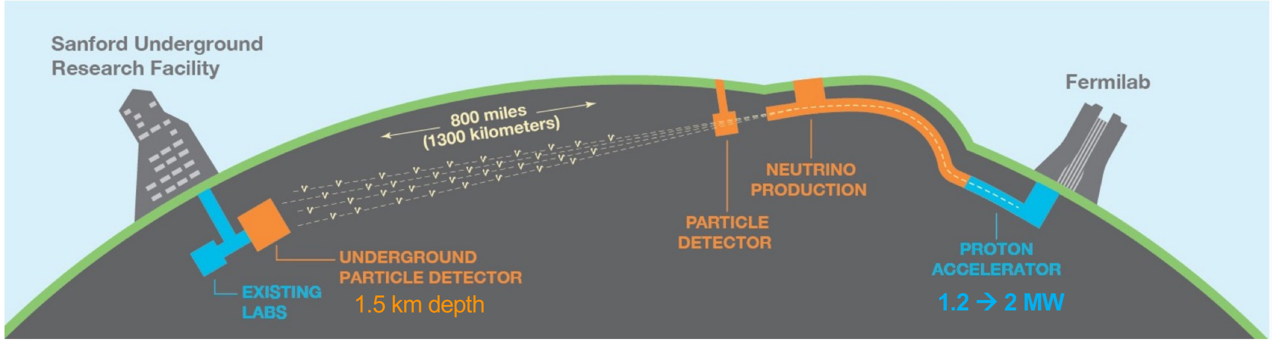
Established in 2014, following 2013 update of ESPP:
"*CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.*"

Main activities and accomplishments at the NP

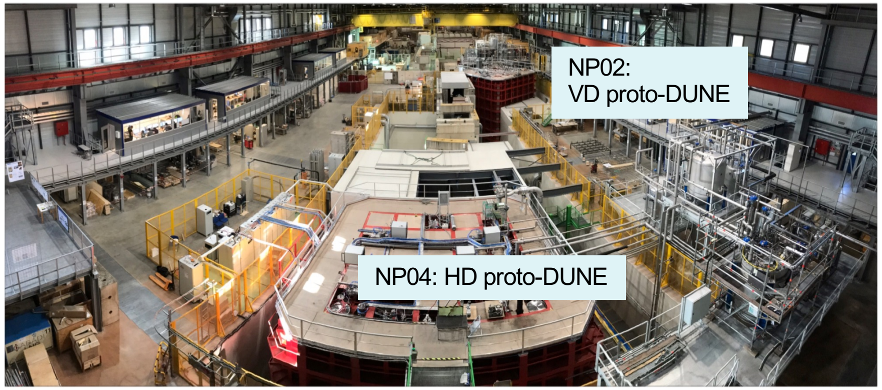
- ❑ Extensions of EHN1 hall at North Area to provide space and beam facility for (big) ν detectors
- ❑ Refurbishment of ICARUS detector for short-baseline neutrino programme at Fermilab
- ❑ Development and test of a series of prototypes for DUNE detector → crucial to validate technology, establish detector feasibility, and finalise technical choices for the horizontal-drift (HD) and vertical-drift (VD) modules
- ❑ Construction of two cryostats for DUNE detector modules
- ❑ Construction of Baby-Mind and ND280 upgrade detectors for T2K experiment in Japan; support for test of Hyper-K electronics

~ 900 collaborators from ~30 countries

Large European participation in DUNE (~ 600 out of ~ 1500 collaborators)
Beam-based science expected to start mid-2031

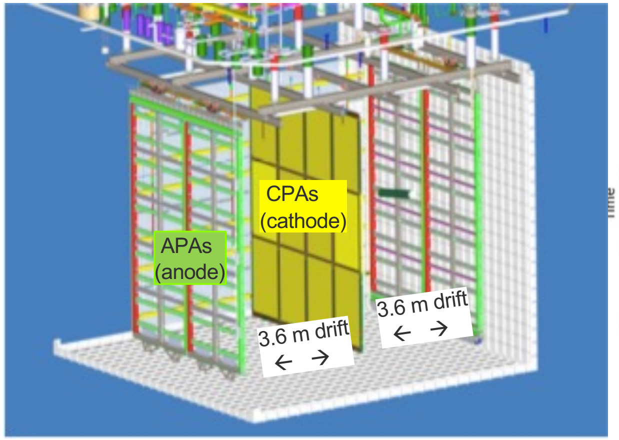


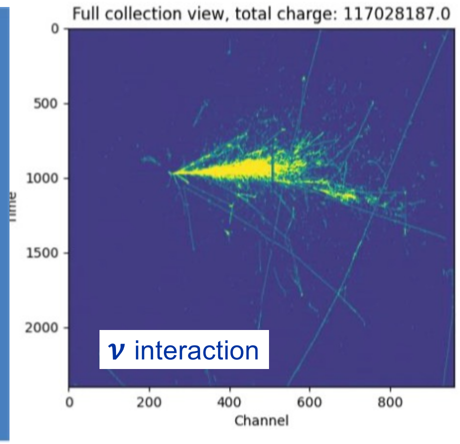
1 DUNE module: x 20 proto-DUNE

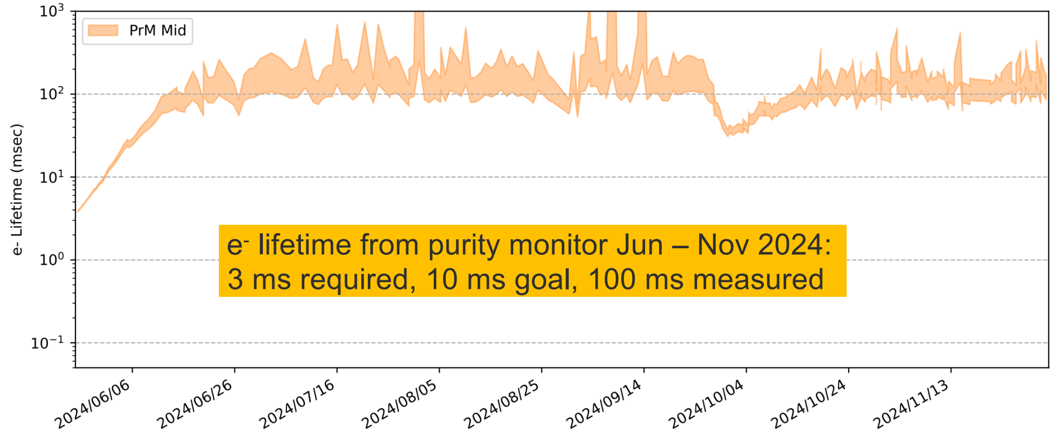


CERN Neutrino Platform

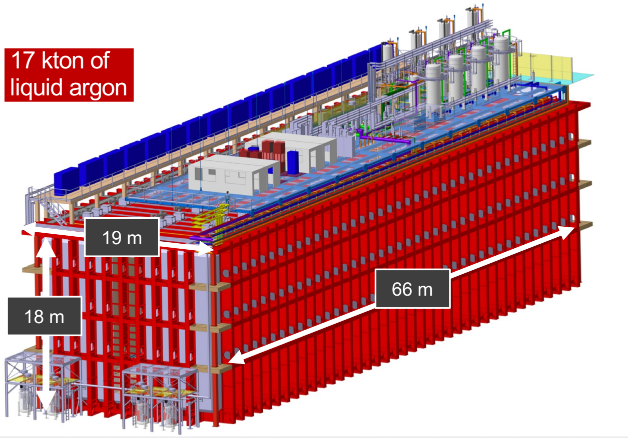
Construction and beam-test of HD "module-zero" completed in 2024 (VD module-zero tests to be completed in 2025)

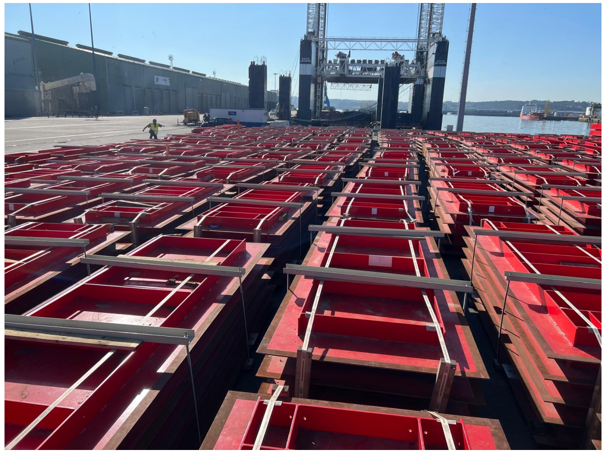






Warm structure of both cryostats (~ 7000 tons of steel) delivered to South Dakota → underground installation at SURF starts beg. 2026





General considerations for the 2020 update

This Strategy update should be implemented to ensure Europe's continued scientific and technological leadership.

The particle physics community must further strengthen the unique ecosystem of research centres in Europe. In particular, cooperative programmes between CERN and these research centres should be expanded and sustained with adequate resources in order to address the objectives set out in the Strategy update.

The implementation of the Strategy should proceed in strong collaboration with global partners and neighbouring fields.

Numerous examples of progress in these areas in previous and following slides …

High-priority future initiatives (I): future colliders

An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy.

Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage. Such a feasibility study of the colliders and related infrastructure should be established as a global endeavour and be completed on the timescale of the next Strategy update.

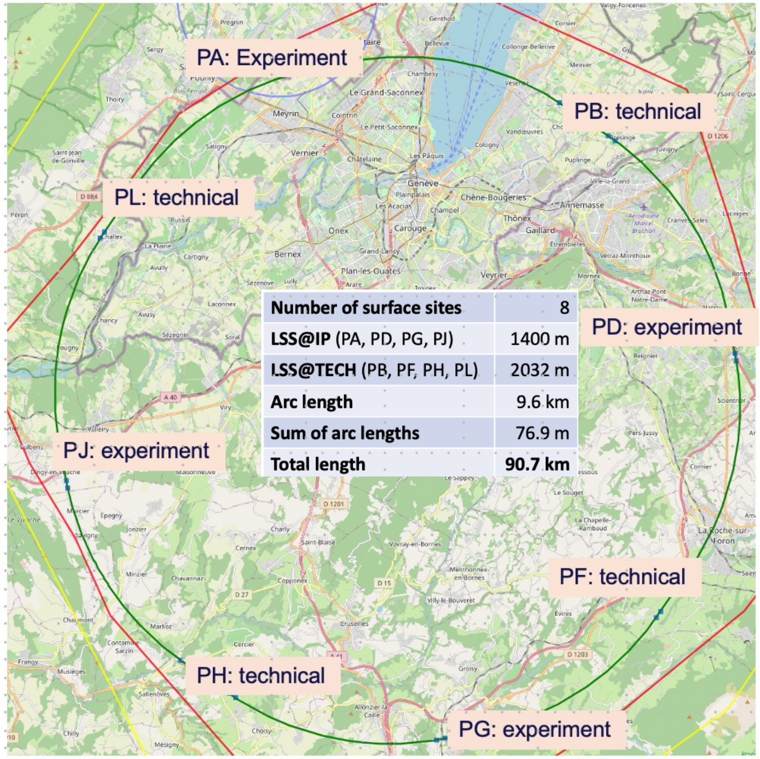
FCC Feasibility Study

- Started in 2021 → Report completed in March 2025, earlier than initially planned, to align with ESPP input submission deadline

- It covers the geological, technical, environmental and territorial feasibility of a 91-km ring and its infrastructure in the Geneva basin, and scientific potential and required technologies for FCC-ee and FCC-hh.
  Good progress also on financial aspects (→ see later)

- Total cost-to-completion: 83 MCHF

Vol. 1: Physics, Experiments and Detectors (~ 260 pages)
Vol. 2: Accelerators, Technical Infrastructure and Safety (~ 600 pages)
Vol. 3: Civil Engneering, Implementation and Sustainability (~ 330 pages)

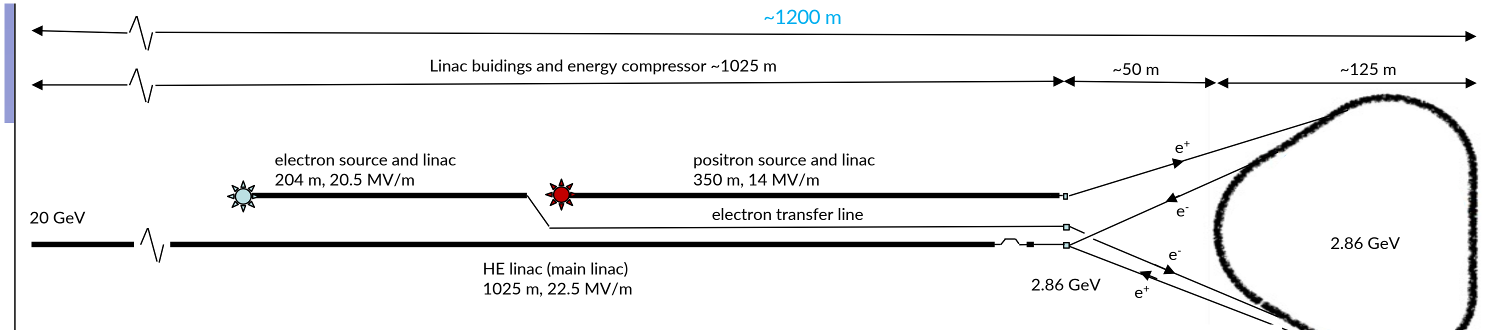


An extraordinary collective effort by the FCC community, involving some 1500 contributors from 162 institutions in 38 countries

The **breadth and depth of the results are unprecedented for a project at this stage of development.**

Report being reviewed by expert committee, and then by Council and its subordinate bodies before end of year.

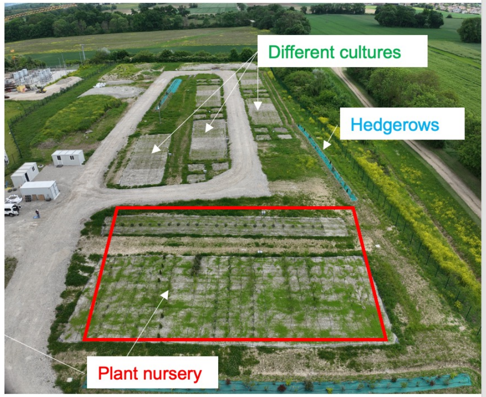
Ring placement selected out of ~ 100 variants taking into account geological, environmental, surface (land availability, access to roads, etc.), infrastructure (water, electricity, transport) constraints, machine performance, etc.



Optimised layout for FCC-ee injectors: lower gradient/repetition rate/power consumption

Geological site investigations:
28 drillings; ~80 km seismic lines

de 125 ml (surface plateforme estimée : 12 x 12 m soit environ 150 m²)



OpenSkyLab: to transform molasse into fertile soil; applicable to any tunnel excavated in North Alpine basin

Communications campaign targeting local population

Environmental initial state analysis

Direct discovery reach (5σ) of FCC-hh at various collision energies

Resonance	100 TeV	80 TeV	120 TeV
Q^*	40	33	46
$Z'_{\mathrm{TC2}} \to t\bar{t}$	23	20	26
$Z'_{\mathrm{SSM}} \to t\bar{t}$	18	15	20
$G_{\mathrm{RS}} \to WW$	22	19	25
$Z'_{\mathrm{SSM}} \to \ell\ell$	43	36	50
$Z'_{\mathrm{SSM}} \to \tau\tau$	18	15	20

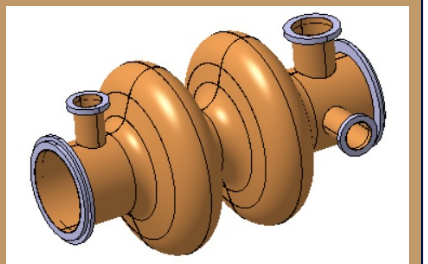
Single 400 MHz 2-cell cavity for Z, W, ZH operation

Niobium thin film on Copper

Operation at 4.5 K

Max. accel. gradient 13 MV/m

Quality factor Q_0 = 3.3 x 10^9



Building a viable financial path

Updated project cost for FCC-ee up to and including operation at ZH and 4 experiments
t-tbar upgrade requires additional 1.3 BCHF

Domain	Cost [MCHF]
Civil engineering	6160
Technical infrastructures	2840
Injectors and transfer lines	590
Booster and collider	4140
CERN contribution to four experiments	290
FCC-ee total	**14 020**
+ Four experiments (non-CERN part)	1300
FCC-ee total, including four experiments	**15 320**

Funding of FCC (or any other major future collider project) expected to come from two main sources:

- ❑ CERN Budget (i.e. revenues from Member and Associate Member States): would cover more than 50% of FCC investment cost
- ❑ External contributions:
  - additional voluntary contributions (in-cash or in-kind) from Member and Associate Member States
  - contributions from non-Member States
  - exploring possible contributions from the European Union in the next Multiannual Financial Framework (MFF 2028-2034)
  - exploring possible contributions of private donors (→ in Dec 2024, Council approved "*Policy for fundraising from private donors for scientific activities at CERN*")

→ good progress over the past months

Several funding scenarios developed, based on different assumptions (e.g. constant or slightly increased CERN Budget)
→ ongoing discussions in Council

High-priority future initiatives (II): accelerator R&D

The particle physics community should ramp up its R&D effort focused on advanced accelerator technologies, in particular that for high-field superconducting magnets, including high-temperature superconductors.

The European particle physics community must intensify accelerator R&D and sustain it with adequate resources. A roadmap should prioritise the technology, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry. Deliverables for this decade should be defined in a timely fashion and coordinated among CERN and national laboratories and institutes.

Roadmap developed under the oversight of the LDG and completed end 2021

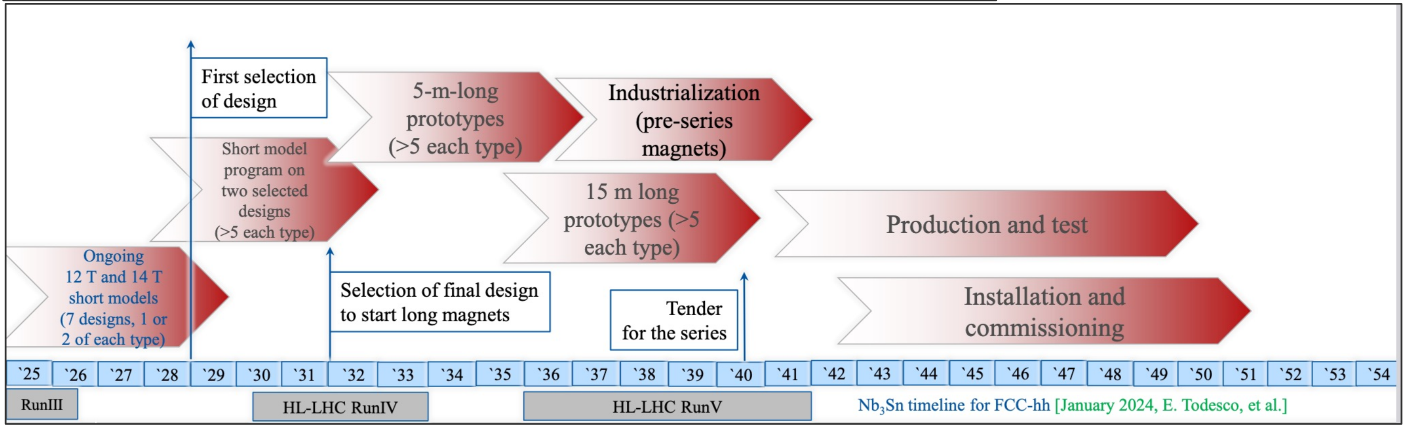
https://cds.cern.ch/record/2800190/files/2201.07895.pdf

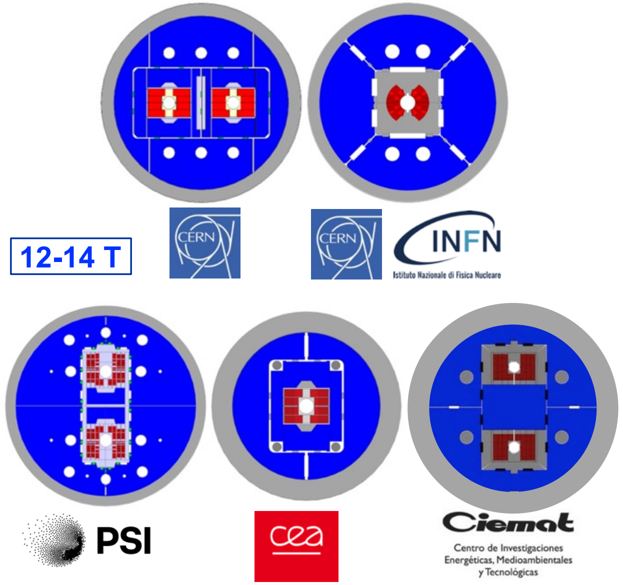
5 key areas:

- ❑ High-field magnets (HFM)
- ❑ High-gradient RF structures and systems
- ❑ High-gradient plasma and laser accelerators
- ❑ Bright muon beams and muon colliders
- ❑ Energy-recovery linacs

In addition: Sustainability Assessment of Future Acceleratros WG established in 2024

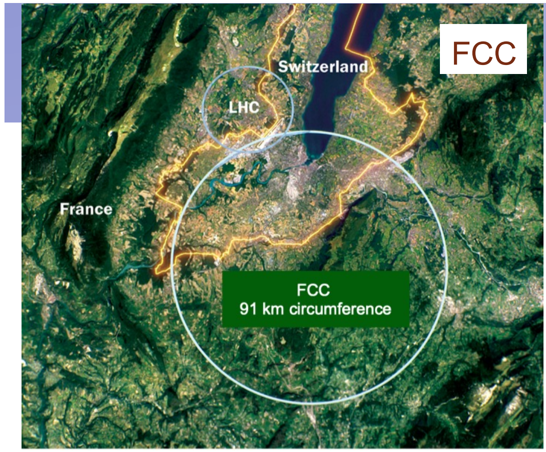
Example: HFM timeline and deliverables targeting FCC-hh
Current baseline is Nb_3Sn, 14 T, 1.9 K → 85 TeV in 91 km tunnel

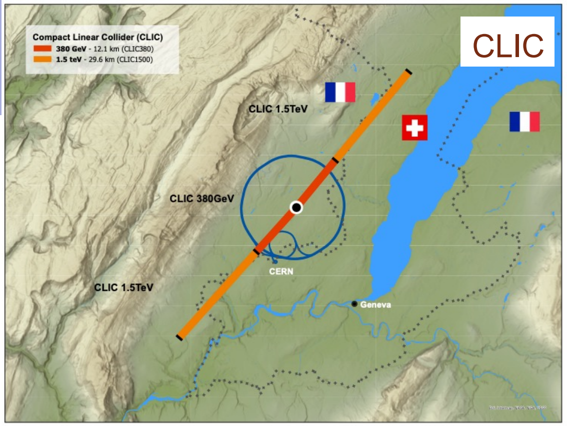


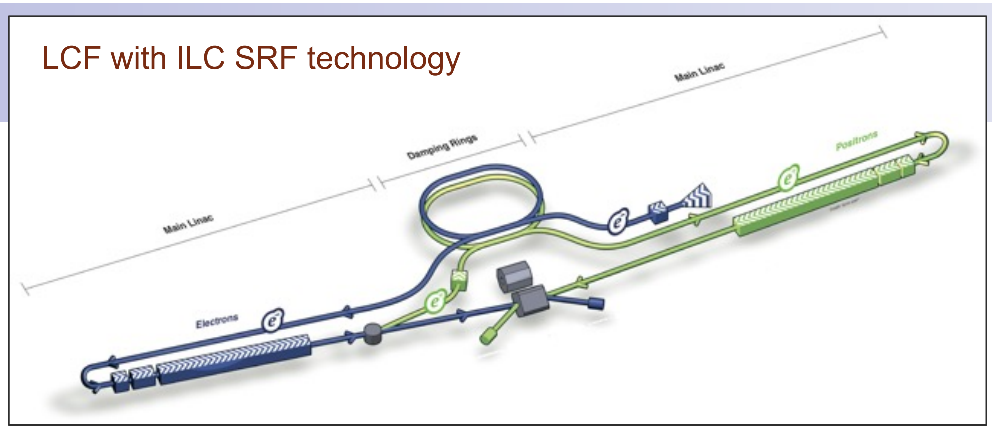


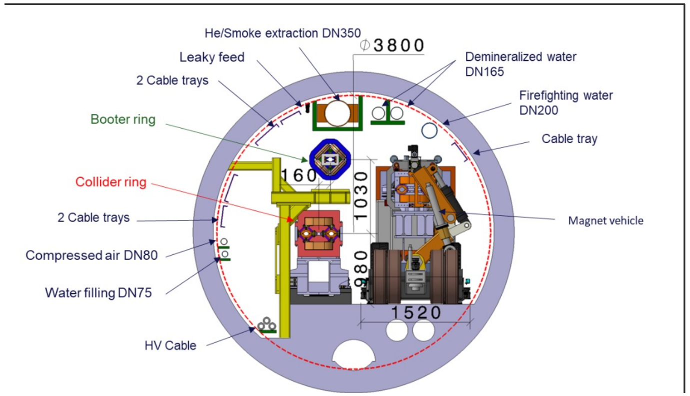
REBCO coated-conductor R&D line at KIT.

In parallel: HTS developments, aiming at 20 T. Goal is short dipole ≥ 14 T by 2035



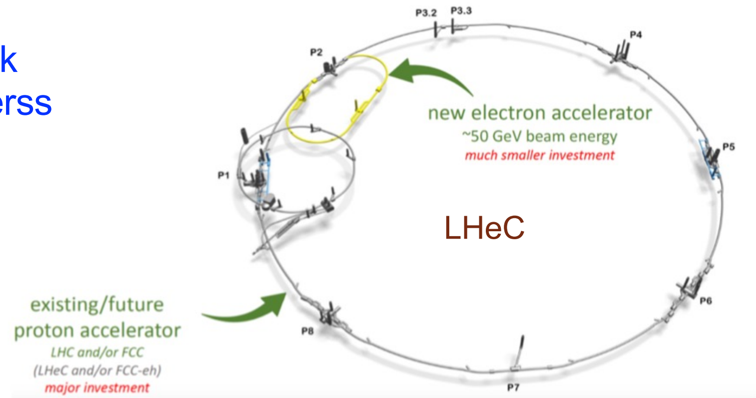


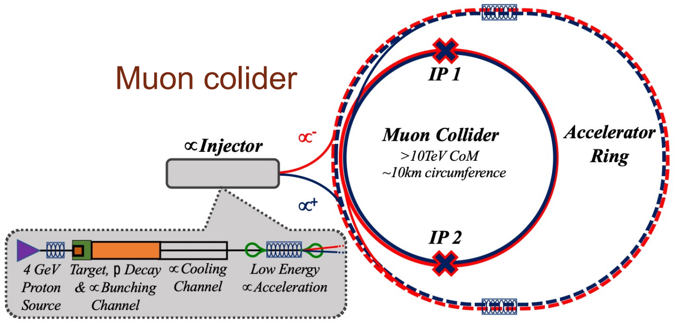


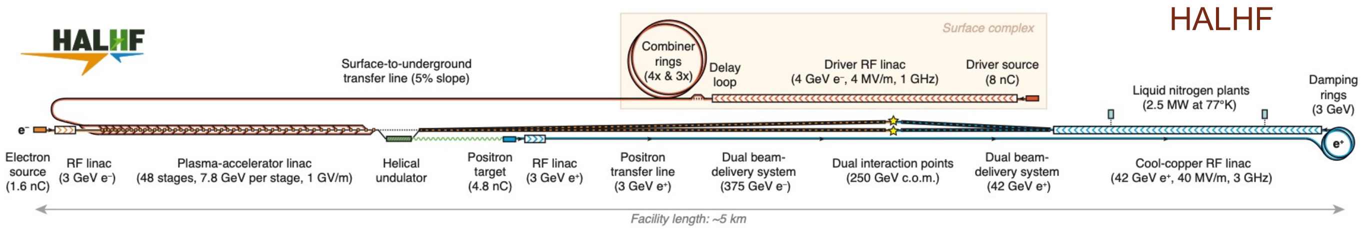


Huge amount of R&D and design work on a variety of proposed future colliderss

(varying levels of maturity, time scale, cost, physics reach/performance)





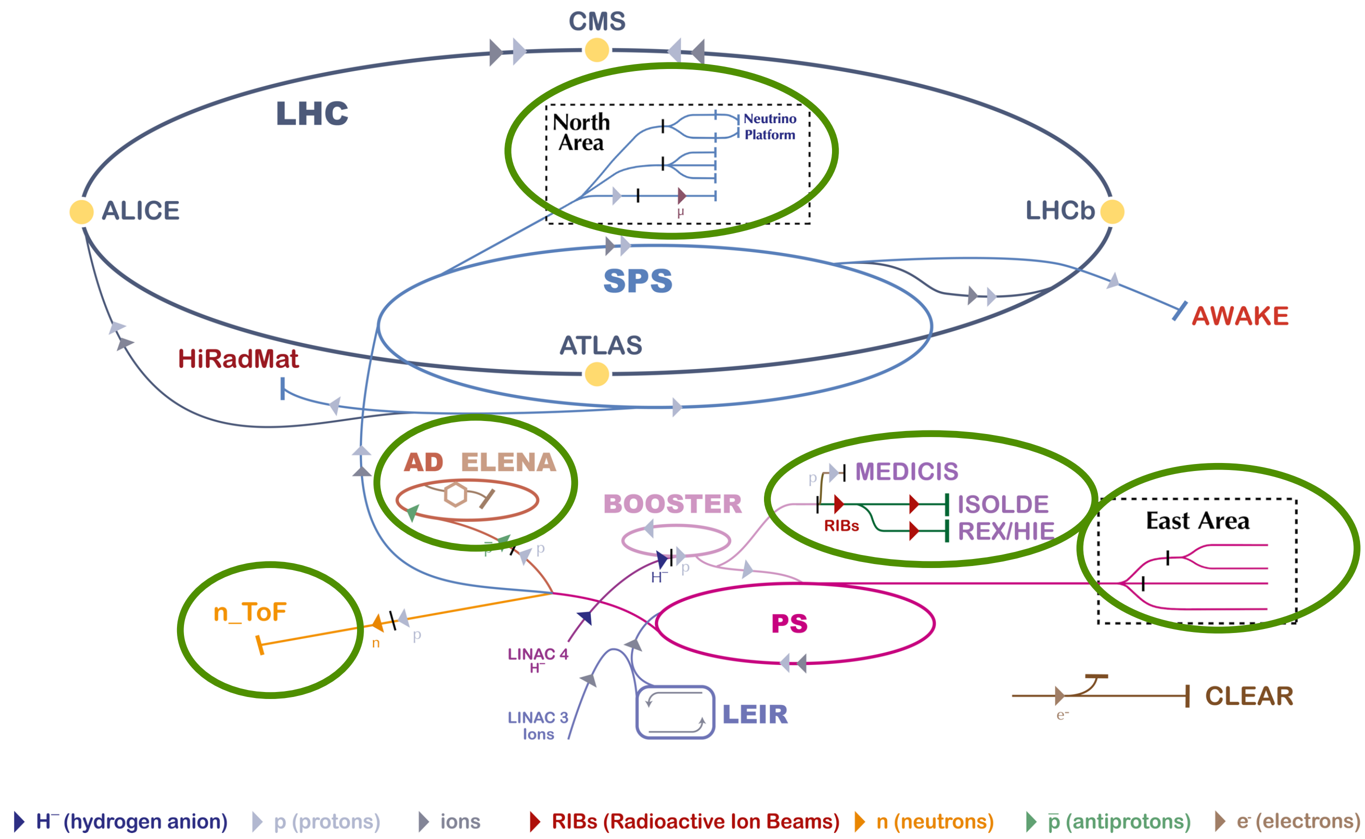


Other essential scientific activities for particle physics (I): other experiments

The quest for dark matter and the exploration of flavour and fundamental symmetries are crucial components of the search for new physics. This search can be done in many ways, for example through precision measurements of flavour physics and electric or magnetic dipole moments, and searches for axions, dark sector candidates and feebly interacting particles. There are many options to address such physics topics including energy-frontier colliders, accelerator and non-accelerator experiments. A diverse programme that is complementary to the energy frontier is an essential part of the European particle physics Strategy.

Experiments in such diverse areas that offer potential high-impact particle physics programmes at laboratories in Europe should be supported, as well as participation in such experiments in other regions of the world.

Pursuing a compelling scientific programme complementary to high-energy colliders



ISOLDE: radioactive nuclei facility

n-TOF: n-induced cross-sections

CLOUD: impact of cosmic rays on aeorosols and clouds

AD / ELENA: Antiproton Decelerator for antimatter studies

COMPASS → AMBER: hadron structure and spectroscopy

NA61/SHINE: ions and neutrino targets

NA62: rare kaon decays

NA64: search for dark photons

NA65: study of tau neutrino production

Neutrino Platform: ν detector R&D for experiments in the US and Japan

SHiP: future beam dump experiment with high-intensity beams

Etc. etc.

Exploiting the unique capabilities of CERN accelerator complex
~ 20 projects, ~ 3 500 scientists

Pursuing a compelling scientific programme complementary to high-energy colliders

Physics Beyond Colliders Study Group

Bold: running or approved experiments

Neutrino physics

SHiP
SBN@CERN (ENUBET/NuTAG)
FASER, FPF, ***SND@LHC***

QCD related and other SM precision measurements:

AMBER, SMOG2, LHCspin, ALADDIN, ***TWOCRYST***
DICE/NA60+, ***NA61/SHINE***
(***FASER***, FPF, ***SHiP***, ***SND@LHC)***
MUonE, FAMU
EDMs (ALADDIN, cpEDM, @ISOLDE)
Strong-field QED (PAX, @AWAKE, @FCC-ee/LC)
Gravitational field of LHC beam

Hidden sector with "beam dump"

NA62, NA64, SHiP
BD@AWAKE
NA64@FCC-ee(injector), BD@LC
REDTOP

The Physics Beyond Colliders Study Group, established in 2016 and supported by the 2020 ESPP update, explores scientific opportunities offered by CERN accelerator complex that are complementary to LHC main programme.
Also wide support to similar efforts in other Member State laboratories.

New long-lived particles from LHC:

ANUBIS, CODEX-B, MAPP-2,
MATHUSLA40, SHIFT
FASER, FPF, ***SND@LHC***

Non-accelerator projects:

Exploit CERN's technology (RF, vacuum, magnets, optics, cryogenics) for experiments at CERN or at other laboratories.

AION-100, axion heterodyne detection, ***BabyIAXO***, FLASH, RADES

Other facilities

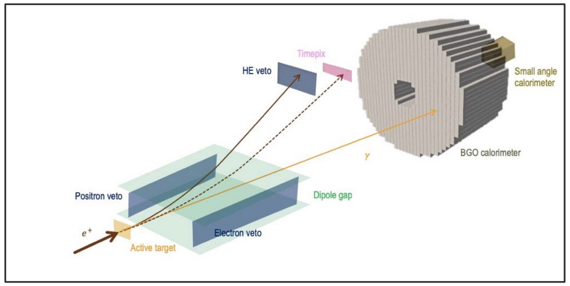
cpEDM
γ-factory from partially stripped ions
SBN@CERN (ENUBET/NuTAG)

Courtesy G. Schnell

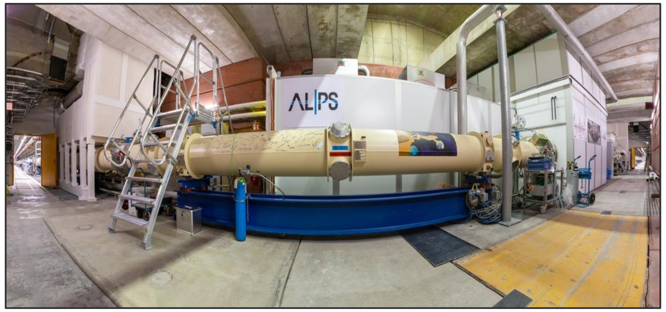
Pursuing a compelling scientific progaramme complementary to high-energy colliders

A multitude of activities in Europe (and beyond) using a large variety of technologies
→ here only a very few examples from different areas, technologies and countries

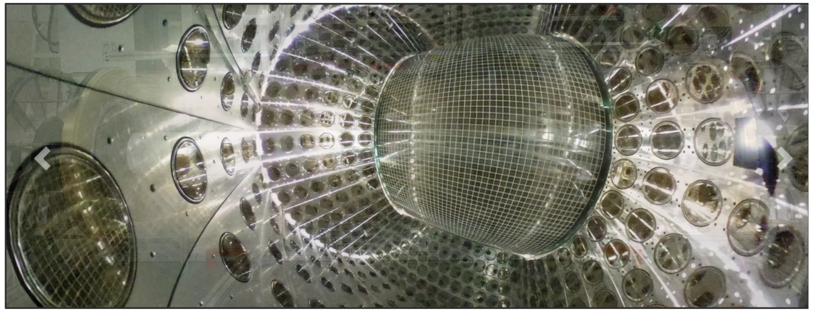
PADME, dark photons, Frascati



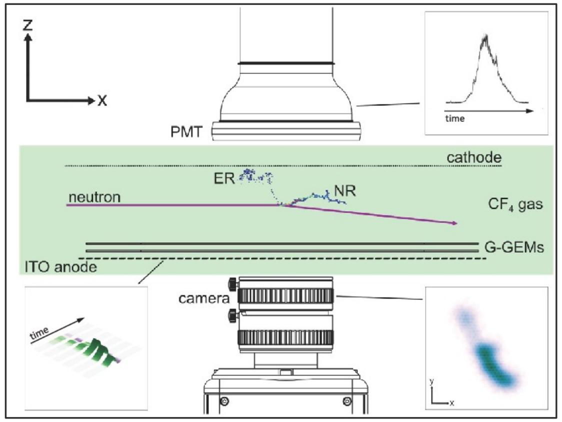
ALPS II, axion-like particles, DESY



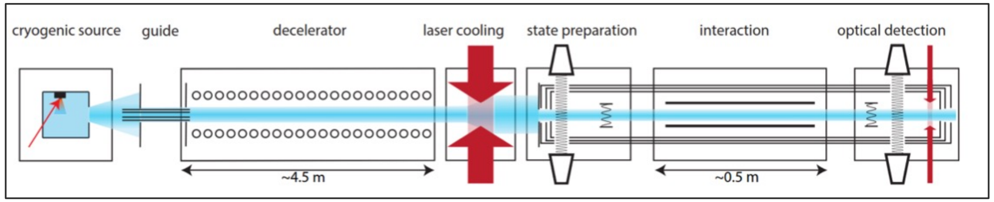
MEG, μ→ eγ, PSI



MIGDAL, dark matter, RAL



NL-*e*EDM, electron electric dipole moment in molecules, Nikhef-Groningen



Other essential scientific activities for particle physics (II) : theory

Europe should continue to vigorously support a broad programme of theoretical research covering the full spectrum of particle physics from abstract to phenomenological topics. The pursuit of new research directions should be encouraged and links with fields such as cosmology, astroparticle physics, and nuclear physics fostered. Both exploratory research and theoretical research with direct impact on experiments should be supported, including recognition for the activity of providing and developing computational tools.

→ see talk by E. Laenen

Other essential scientific activities for particle physics (III) : detector R&D

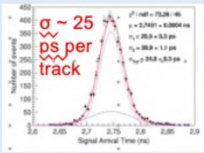
Detector R&D programmes and associated infrastructures should be supported at CERN, national institutes, laboratories and universities. Synergies between the needs of different scientific fields and industry should be identified and exploited to boost efficiency in the development process and increase opportunities for more technology transfer benefiting society at large. Collaborative platforms and consortia must be adequately supported to provide coherence in these R&D activities. The community should define a global detector R&D roadmap that should be used to support proposals at the European and national levels.

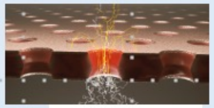
Detector R&D

Roadmap developed under the oversight of the ECFA and completed end 2021:
https://indico.cern.ch/event/1090779/contributions/4592538/attachments/2335809/4036993/ ECFA%20Detector%20R%26D%20Roadmap%20Main%20File.pdf

Implemented through Detector R&D (DRD) collaborations hosted at CERN, with review and oversight provided by DRD Committee (DRDC) and ECFA Detector Panel

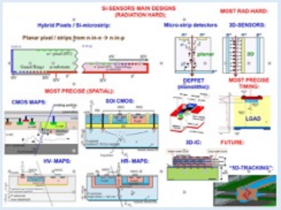
DRD1: Gaseous Detectors
Large · Fast · eco-friendly gases · MPGD, e.g. GEMs



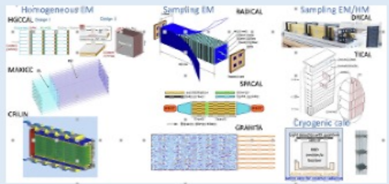


PICOSEC: NIMA903 (2018) 317

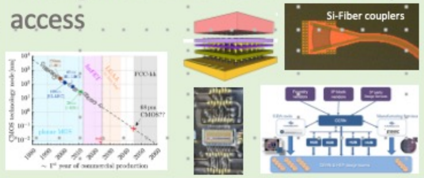
DRD3: Semiconductor Det.
Monolithic CMOS · LGADs · radiation hardness · interconns.



DRD6: Calorimetry
Energy resolution · High granularity · dual readout · particle flow · sandwich · optical

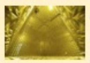


DRD7: Electronics
ADC/TDC IP Blocks · Opto-electronics · packaging · power · extreme environments · COTS · intelligence on detector · foundry access



DRD2: Liquid Detectors
for Neutrinos · Dark Matter · 0vbb

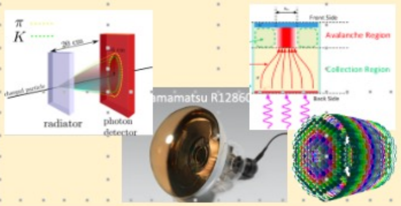
Noble Elements
- Argon & Xenon
- Ionisation charge & transport
- VUV Scintillation, light propagation & detection



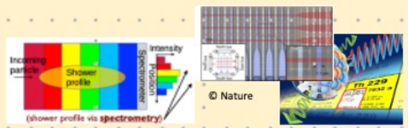
Liquid Scintillators
- Visible Scintillation, light propagation
- Scintillator properties
- Isotope loading

Water Cherenkov
- Cherenkov light, light propagation
- Doping for n-capture

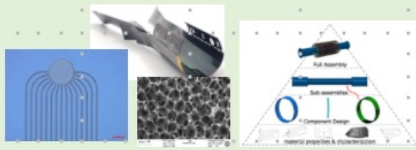
DRD4: Photon detectors
vacuum, solid-state (SiPM), hybrid single-photon and SciFi detectors · applications in PID and RICH



DRD5: Quantum Sensors
Quantum dots · supercondut. nanowires · bolometers · TES · MMC · nuclear clocks
First applications for DM, first projects in HEPP happening



DRD8: Mechanics
Ultra-thin beam pipes · CF foam and new materials · curved, retractable sensors · air & micro-channel cooling · eco-friendly cooling fluids · robots · augmented reality



Courtesy T. Bergauer

Other essential scientific activities for particle physics (IV) : computing

The community must vigorously pursue common, coordinated R&D efforts in collaboration with other fields of science and industry to develop software and computing infrastructures that exploit recent advances in information technology and data science. Further development of internal policies on open data and data preservation should be encouraged, and an adequate level of resources invested in their implementation.

Example of computing R&D with industry

CERN openlab is a PUBLIC-PRIVATE partnership that since 2001 has been creating innovative R&D collaborations to shape the future of computing for fundamental research and society

Sponsored R&D collaborations with leading companies, research labs, universities

More than 150 projects in 20 years in distributed computing, large-scale storage, control systems, AI, quantum technologies

Sponsorship from industry and foundations allows students and researchers to work at CERN to develop cutting-edge technology

The CERN Quantum Technology Initiative

QUANTUM TECHNOLOGY INITIATIVE

CERN QTI main goals:
- **Evaluate potential advantage of quantum technologies** for HEP
- **Use CERN technology capabilities to support** quantum R&D

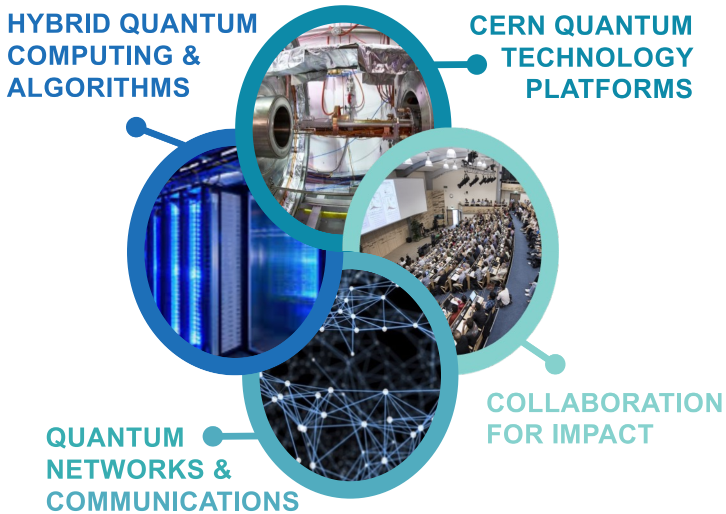
Phase1 (2020-2023): Technology Exploration

Phase 2 (2024-2028): Consolidation for impact

Current results:
- **Quantum computing** evaluation in realistic settings (anomaly detection, …)
- **Quantum sensors** sensitivity for new physics searches (axions, GW, …)
- **Innovative CERN technologies** for quantum (WhiteRabbit, RF cavities, …)

Phase 2 objectives:
- Development of **next generation detectors**
- Integrate quantum computing services in **HEP computing model**
- Integrate CERN with **European network infrastructure**

QTI2 Centers of Competence:



A collaborative initiative:
- **Advisory Board** from CERN Member States, **Technical Expert Group** from broader expert community
- Unified **QTI collaboration framework** across CERN Member States and beyond (academia and industry)
- **QC4HEP working group**, which includes >100 researchers in CERN Member States and beyond

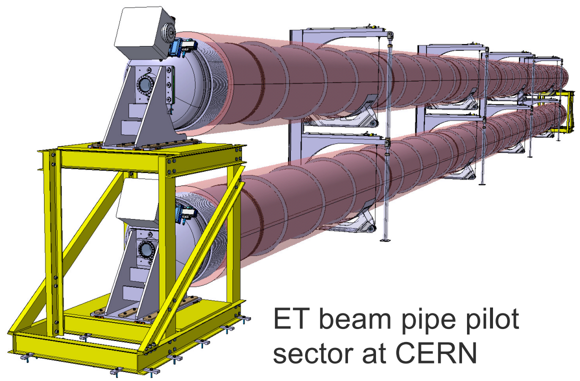
Synergies with neighbouring fields

Europe should maintain its capability to perform innovative experiments at the boundary between particle and nuclear physics, and CERN should continue to coordinate with NuPECC on topics of mutual interest.

Synergies between particle and astroparticle physics should be strengthened through scientific exchanges and technological cooperation in areas of common interest and mutual benefit.

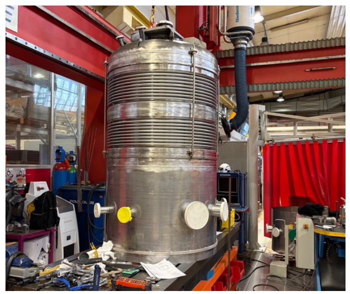
CERN has a strong nuclear physics programme, with experiments and facilities that are regularly consolidated and upgraded:
ISOLDE/HIE-ISOLDE, n_TOF, AD/ELENA, SPS fixed target (NA61, AMBER), ALICE

Recognized by NuPECC (Nuclear Physics European Coordination Committee), of which CERN is associated member
2024 Long-Term Plan:
“Nuclear physics opportunities at CERN constitute a world-leading research programme. The construction of ALICE 3 as part of the HL-LHC plans is strongly recommended. Continued support for exploitation and new developments are recommended to maximise the scientific output of ISOLDE, n_TOF, SPS fixed-target program and AD/ELENA. As the roadmap for the post-LHC future of CERN is developed, a strategy should be prepared to secure future opportunities for continuing world-leading nuclear-physics programmes that are unique to CERN.”


ET beam pipe pilot sector at CERN

Astroparticle physics projects (APPEC - Astroparticle Physics European Consortium)
- ❑ CERN contributes through its technologies
  (e.g. vacuum system, safety and civil engineering for Einstein Telescope; cryostat for DarkSide-20k, etc.)
- ❑ CERN is central hub of the European Consortium for Astroparticle Theory (EuCAPT)
- ❑ CERN hosts the AMS Payload Operations Control Centre

JENAS (Joint ECFA-NuPECC-APPEC)
Brings the three communities together to explore synergies and discuss common challenges




Organisational issues (I) : global projects

An ambitious next-generation collider project will require global collaboration and a long-term commitment to construction and operations by all parties.

CERN should initiate discussions with potential major partners as part of the feasibility study for such a project being hosted at CERN. In the case of a global facility outside Europe in which CERN participates, CERN should act as the European regional hub, providing strategic coordination and technical support. Individual Member States could provide resources to the new global facility either through additional contributions made via CERN or directly through bilateral and multilateral arrangements with the host organisation.

Remarks:

- ILC IDT (International Development Team): CERN facilitates the European participation and coordinates the European contributions to the common fund and in-kind contributions.
- Since 2020 ESPP: very good progress on reflections about the governance of a global project hosted at CERN, in CERN/3786 and more recent discussions in Closed Council

Joint Statements of Intent signed with Canada and the US

Joint Statement of Intent between The United States of America and The European Organization for Nuclear Research concerning Future Planning for Large Research Infrastructure Facilities, Advanced Scientific Computing, and Open Science, signed April 2024

Statement of Intent between Canada and the European Organization for Nuclear Research (CERN) concerning collaboration on future planning for large research infrastructure facilities, and on novel and advanced techniques and tools, signed March 2025

"Should the CERN Member States determine the FCC-ee is likely to be CERN's next world-leading research facility following the high-luminosity Large Hadron Collider, the United States / Canada intends to collaborate on its construction and physics exploitation, subject to appropriate domestic approvals."

Organisational issues (II): European Commission

The relationship between the particle physics community and the European Commission should be further strengthened, exploring funding-mechanism opportunities for the realisation of infrastructure projects and R&D programmes in cooperation with other fields of science and industry.

Relations with the EC

CERN and EC work together in many areas (MoU, signed in July 2009): research infrastructures, detection and imaging technologies, e-infrastructures, medical technologies, international cooperation, researcher careers and mobility, promoting gender equality in research, knowledge transfer and IP management, open science, science communication and education, fusion/ITER.

Since last ESPP: 85 projects co-funded by EC; most contributed to the ESPP implementation; most involve participants from CERN Member States and European industry; total EC funding ~ 440 M€ (some 85% of this goes to CERN Member States; ~46 M€ to CERN)

Future collider at CERN
FCC study: FCC-IS (2020-2024, coordinated by CERN, 3 M€ EC funding, 7.5 M€ full costs)

Accelerator R&D
- I.FAST (2021-2025, coordinated by CERN, 10 M€ EC funding, 19 M€ full costs)
- RADNEXT (2021-2026, coordinated by CERN, 5 M€ EC funding, 9 M€ full costs)
- HEARTS (2023-2026, coordinated by CERN, 3.6 M€ EC funding)
- Muon collider study: MuCol (2023-2027, coordinated by CERN, 2.2 M€ EC funding, 10.0 M€ full costs)

Detector R&D
- AIDAinnova (2021-2025, coordinated by CERN, 10 M€ EC funding, 23 M€ full costs)

Cooperation between nuclear and particle physics
EUROLABS (2022-2026, coordinated by INFN, 14.2 M€ EC funding)

Computing and data science
20 EU projects supporting the EOSC and Zenodo started since 2021 (coordinated by CERN or by other institutes, 11.6 M€ EC funding for CERN)

Diverse scientific programmes
4 ERC grants and 3 Marie-Sklodowska Curie projects since 2021 (12.8 M€ EC funding)

Knowledge transfer and societal impact
- ATTRACT Phase 2 (2021-2025, coordinated by CERN, 35 M€ EC funding)
- Radionuclides for medical applications: PRISMAP (2021-2025, coordinated by CERN, 5 M€ EC funding)
- Heavy-ion cancer therapy: HITRIplus (2021-2025, coordinated by CNAO, 5 M€ EC funding, 9 M€ full costs)

Theoretical physics
4 ERC grants and 21 Marie-Sklodowska Curie Post-doctoral fellowships started since 2021 (10.4 M€ EC funding)

Organisational issues (III) : Open Science

The particle physics community should work with the relevant authorities to help shape the emerging consensus on Open Science to be adopted for publicly-funded research, and should then implement a policy of Open Science for the field.

Open Science

Open Science[1]

- CERN established a comprehensive Open Science Policy[2] in 2022
  - Aligned with the UNESCO Recommendations on Open Science
  - Covers all relevant aspects, including open access to publications, open data, open-source software/hardware, research assessment, education, and more
- CERN's Open Source Program Office[3] (OSPO) was launched in 2023
  - First institutional OSPO to cover software and hardware
  - Two key roles: internal (advice and monitoring) and external (showcase CERN contributions, promote CERN as open-source lab, establish collaborations)

[1] https://openscience.cern
[2] http://dx.doi.org/10.17181/CERN.RTIF.Z8BO
[3] https://opensource.cern

Open Data and Data Preservation

- CERN Open Data portal[4] continues to grow in scope (experiments) and total data and associated material made available - now exceeds 5 PB
- New LHC Open Data policy for all LHC experiments published in 2020[5]

[4] https://opendata.cern.ch
[5] https://cds.cern.ch/record/2745133/files/CERN-OPEN-2020-013.pdf

European Open Science Cloud (EOSC)

CERN is member of the EOSC[6] Association, a digital infrastructure initiative in Europe that aims to create a single, accessible, and open environment for research data, tools, and services; it brings together > 250 members across all disciplines in the pursuit of open science practices; CERN selected as one of 13 organisations (from total 50) to form a node in the nascent EOSC federation[7]; node will build on existing open services, including Virtual Research Environment, Zenodo, INSPIRE, etc.

[6] https://eosc.eu
[7] https://home.cern/news/news/computing/cern-joins-build-phase-eosc-federation

Environmental and societal impact (I) : environment

The environmental impact of particle physics activities should continue to carefully studied and minimised. A detailed plan for the minimisation of environmental impact and for the saving and re-use of energy should be part of the approval process for any major project.
Alternatives to travel should be explored and encouraged.

Environmental protection: a **STRONG** commitment of our community

- Environmental protection awareness and sustainability now embedded in all activities, from operation of sites and technical infrastructures to development of new projects and dedicated R&D activities.
- Examples: Life Cycle Assessment of future colliders; development of energy-efficient technologies (klystrons, HTS, energy recovery linacs, computing, etc.), some of which with application to society; R&D for detector “eco-gases” with low GWP; waste heat reuse; policies (procurement, duty travel, etc.); net-zero buildings; mobility and commuting; public environment reports; etc.

We can and should aim at being a role model of a responsible and sustainable research field that respects the environment

Recovered heat from LHC cooling towers supplies heating to a nearby residential area in France (~ 8000 people)

Examples of CERN objectives for 2030

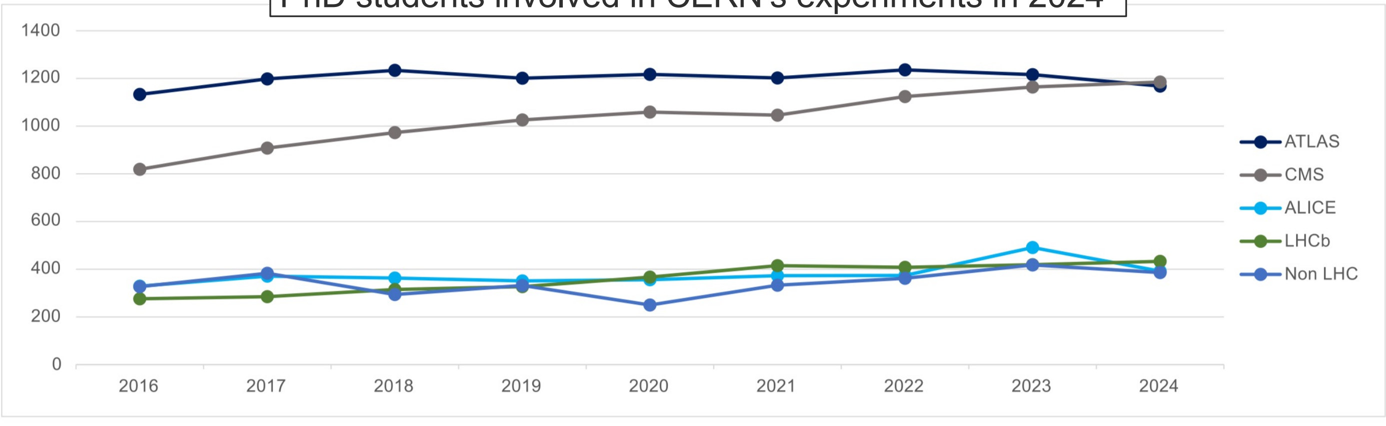
Domain	Value in reference year (2018)	Current status	Target for 2030
Scope 1 emissions (tCO_2e)	192 100	170 100 (2023)	➢ Reduce by 50% w.r.t. 2018
Electricity consumption (GWh)	1252	1142 (2023) 1290 (estimation 2024)	➢ Max 1500 ➢ 10% renewable PPA - photovoltaic
Gas consumption (GWh)	61 (average 2016-2018)	39 (2024)	➢ Reduce by 60% w.r.t. 2018

Environmental and societal impact (II) : early career researchers and DEI

For early-career researchers to thrive, the particle physics community should place strong emphasis on their supervision and training.
Additional measures should be taken in large collaborations to increase the recognition of individuals developing and maintaining experiments, computing and software. The particle physics community commits to placing the principles of equality, diversity and inclusion at the heart of all its activities.

Huge training efforts at CERN and collaborating institutes

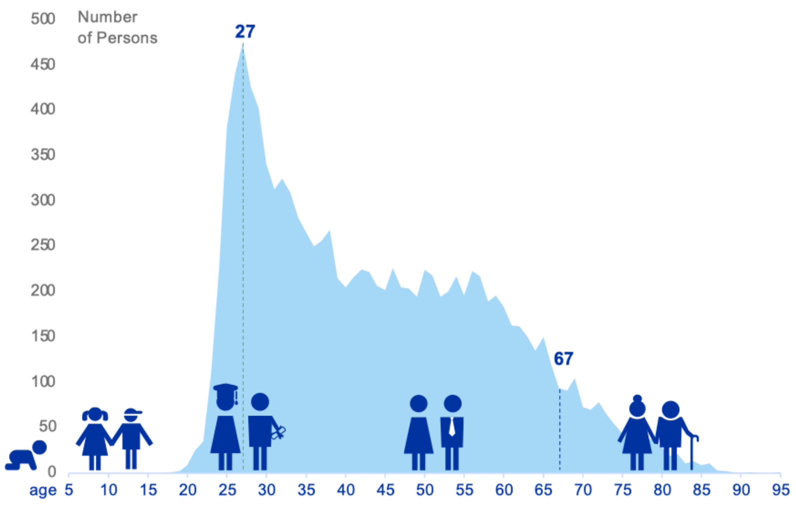
PhD students involved in CERN's experiments in 2024



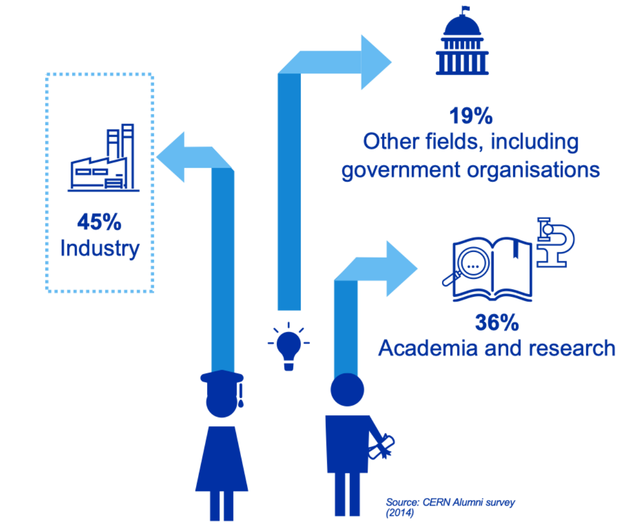
PhD students in CERN's experiments
3564

People trained by CERN's programmes (graduates, fellows, doctoral students, summer students, etc):
2262

Total (PhDs + CERN's programmes):
5830 (2024)



Age distribution of scientists working at CERN



PhD and technical students leaving CERN

Equality, diversity and inclusion

Since 2021: CERN “25 by‘25” initiative towards greater **gender and nationality** diversity

Since 2020: **gender inclusive language** in CERN Staff Rules and Rehulations

Since 2023: **disability** priority seats in all CERN rooms > 50 persons

Since 2023: **Pride flag** raised on CERN Esplanade on 18 Nov for LGBTQ+ STEM Day

Since 2024: network supporting **neurodiversity** at CERN

Women in Engineering, Graz, 2025

INFN STEM mentoring programme

Excellence & Diversity Scholarhsip, Weizmann Institute

9 Women in STEM video, 11 Feb. 2025, ESA

Initiatives at the European level with high-energy physics participation:

- GENERA (Gender Equality Network in the European Research Area)
- INSPIRE – Next Step Working Group
- EIROforum Diversity & Inclusion Working Group

Environmental and societal impact (III) : knowledge transfer

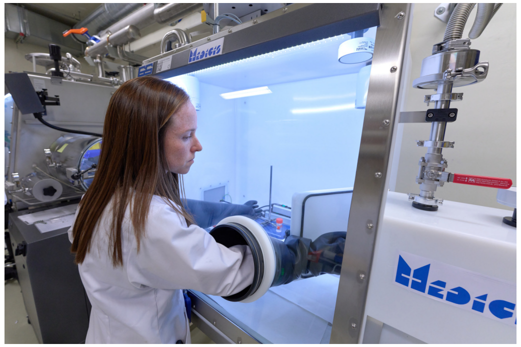
Particle physics research centres should promote knowledge and technology transfer and support their researchers in enabling it.

The particle physics community should engage with industry to facilitate knowledge transfer and technological development.

General positive trend across the whole community, increased awareness of importance of knowledge transfer (KT), multiplicity of activities:

- new initiatives to promote KT and support researchers (e.g. CERN Innovation Programme on Environmental Applications)
- engagement of industry at early stage becoming a focus in most activities (e.g. HFM, DRD, QTI, etc.)
- EC-funded projects (e.g. Aidainnova, HITRIplus, MEDICIS-PRISMAP, ATTRACT)
- platforms to bring research ideas to market: e.g. CERN Venture Connect, future DESY Innovation Factory, INFN R4I, PSI Park Innovaare, et

CERN and Airbus UpNext collaboration to explore how superconductivity developed at CERN can contribute to the decarbonisation of future aircraft systems



CERN-MEDICIS: accelerator-based production of innovative, mass-separated radioisotopes for medical research and clinical treatment

Medipix/Timepix: two decades of development and many successful applications in space dosimetry, cultural heritage, education, health

Environmental and societal impact (IV) : outreach

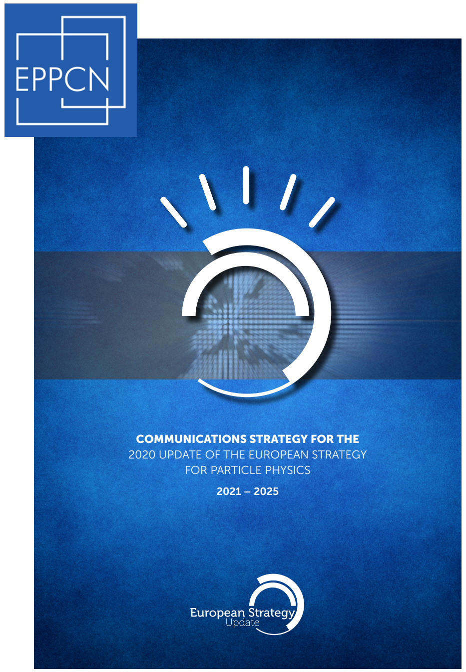
Public engagement, education and communication in particle physics should continue to be recognised as important components of the scientific activity and receive adequate support. Particle physicists should work with the broad community of scientists to intensify engagement between scientific disciplines. The particle physics community should work with educators and relevant authorities to explore the adoption of basic knowledge of elementary particles and their interactions in the regular school curriculum.

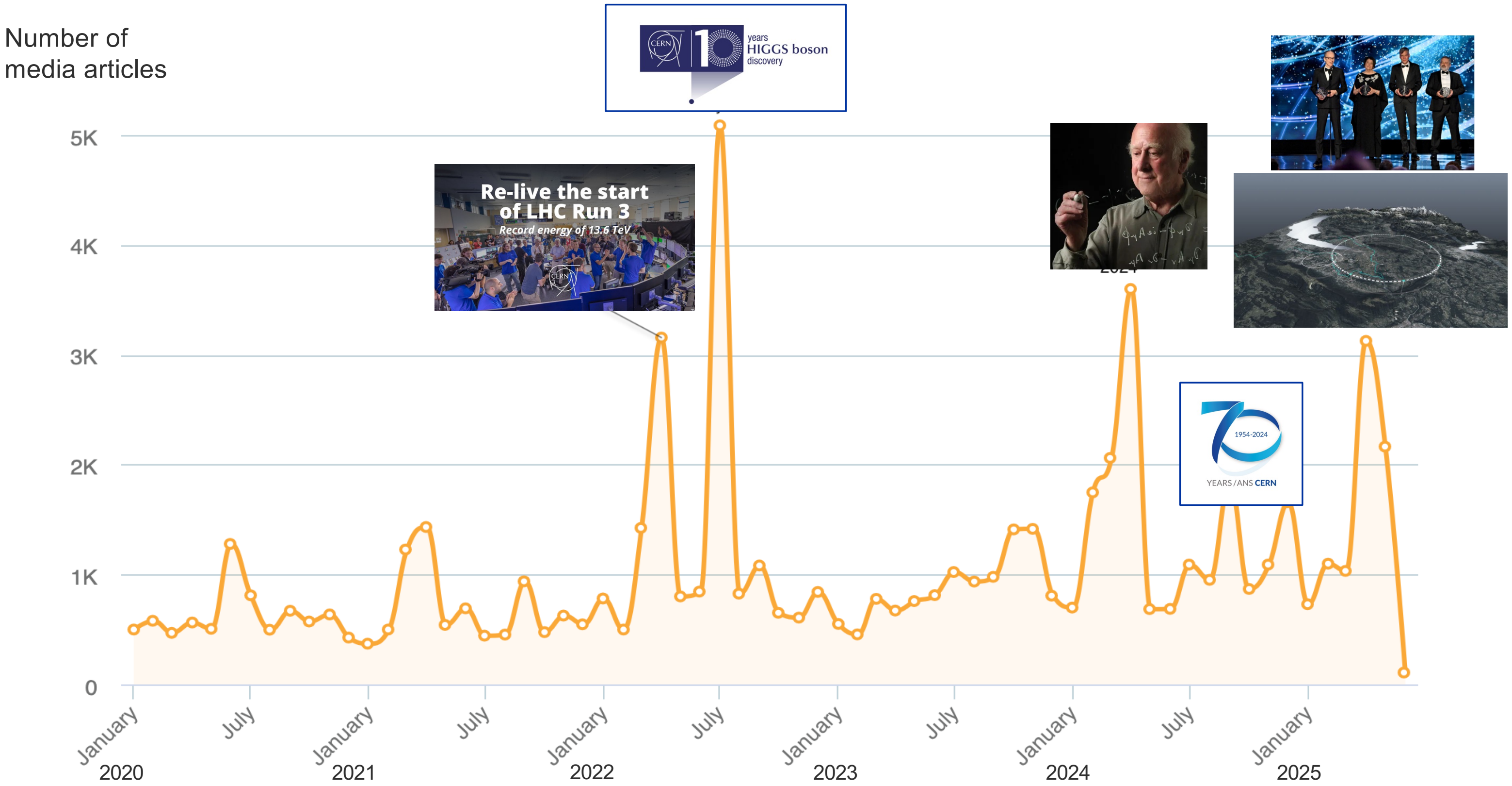
Public engagement, education and communication

CERN and EPPCN (European Particle Physics Communication Network, network of professional communication officers established by Council) developed common strategy, in line with the 2020 ESPP recommendations, and implemented coherent, long-term and impactful campaigns to support the field.

Specific working groups and campaigns successfully deployed: Higgs@10, start of LHC Run 3, CERN@70, environment, impact on society, etc.

Strong educational efforts at CERN and its Member States and beyond: teacher and school programmes, masterclasses, labs activities, etc.
Beamline for Schools, run by CERN and DESY, awarded the 2025 EPS-HEPP Outreach Prize: > 20,000 students took part, 25 winning teams





The resounding success of the **CERN Science Gateway**

-- 100 MCHF total cost, fully funded from donations
-- Built in less than 3 years (despite Covid and other crises)

-- Opened to the public on 8 October 2023
-- Number of visitors in 2024: > 390 000 (before SG: ~ 150 000 visitors/year)
-- Number of visitors until today: > 650 000 from 175 countries

TIME
WORLD'S GREATEST PLACES
2024

10 different lab workshops + 3 in preparation
Some 2060 sessions and 43 800 participants

CERN Science Gateway

Conclusions and main messages

Despite unprecedented global challenges - pandemic, invasion of Ukraine, and economic and geopolitical upheavals - the worldwide **CERN community's achievements in implementing the 2020 ESPP update** are **remarkable**

This success lays the **strongest foundation for the ongoing update of the ESPP.**

It also proves that **we are a strong, competent, enthusiastic, determined and resilient community, capable of designing, building and operating facilities of astounding complexity** - such as the LHC and its detectors and computing - that **consistently exceed expectations**.

This is our greatest asset as we prepare for even more ambitious projects.

We can be ambitious, **we must be ambitious.**

The time is ripe to forge a brilliant future for our field in Europe, together with our global partners

Many thanks to

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