Development of the European Strategy

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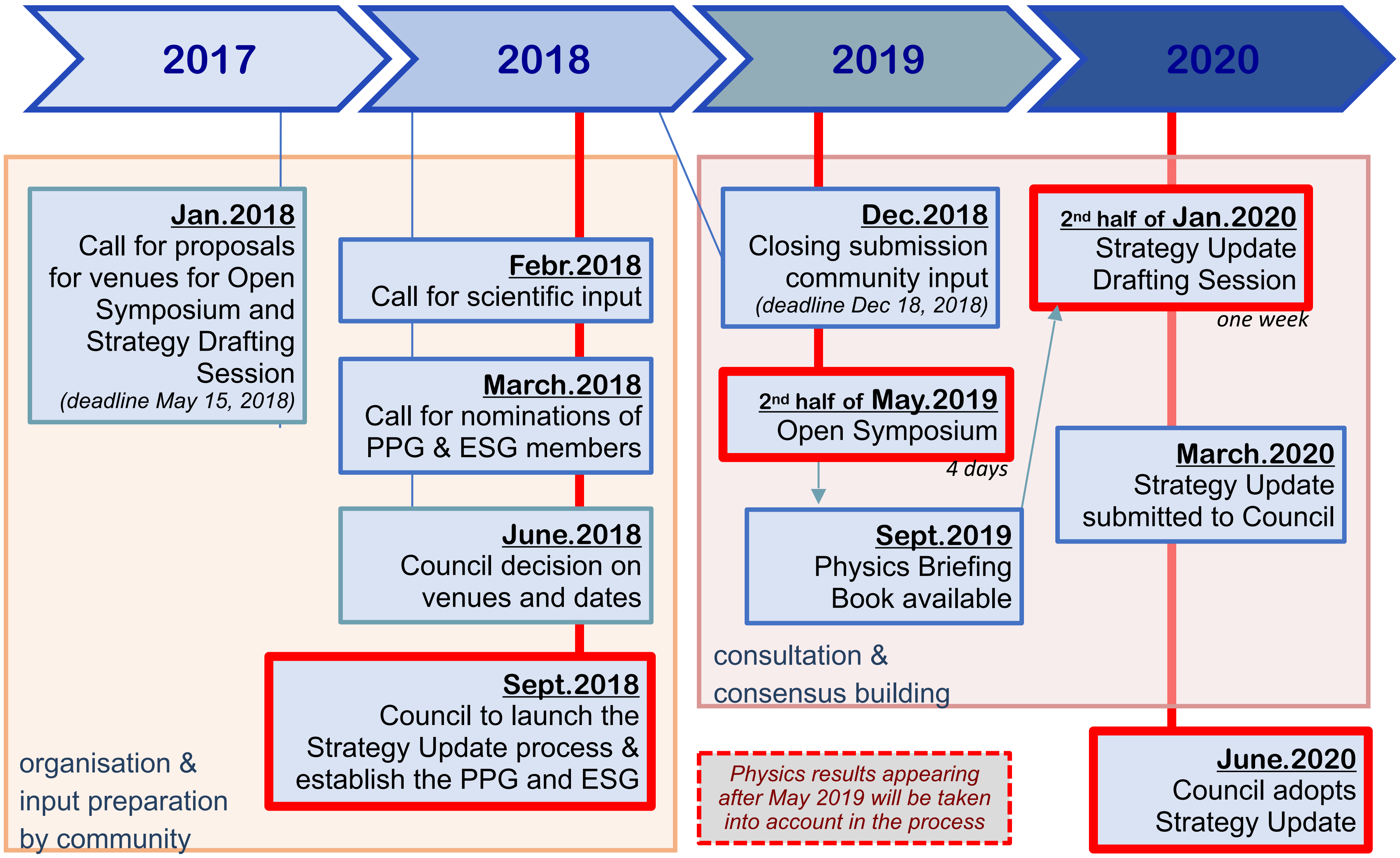
The strategy document is a 5-page document http://cds.cern.ch/record/2721370 comprising:-
General Introduction
Preamble
Strategy Statements (20): introduction and formulation

- 2 statements on **Major developments from the 2013 Strategy**
- 3 statements on **General considerations for the 2020 update**
- 2 statements on **High-priority future initiatives**
- 4 statements on **Other essential scientific activities for particle physics**
- 2 statements on **Synergies with neighbouring fields**
- 3 statements on **Organisational issues**
- 4 statements on **Environmental and societal impact**

Slides adapted from a report by Halina Abramowicz

Development of the European Strategy



Preamble — the lead story

- Many mysteries about the universe remain to be explored: nature of dark matter, preponderance of matter over antimatter, origin and pattern of neutrino masses
- Nature hides the secrets of the fundamental physical laws in the **tiniest nooks of space and time**
- PP develops technologies to probe ever smaller distance scales (higher energies)
- The 2020 Strategy update aims to significantly **extend knowledge beyond current limits**, to drive innovative technological developments, to maintain Europe's leading role
- The Higgs (discovered at the LHC) is a unique particle that raises profound questions about the fundamental laws of nature
- The study of Higgs properties is in itself a powerful experimental tool to look for answers
  → **electron-positron collider as Higgs factory**
- The study of Higgs boson pair production is key to understanding the fabric of the universe
  → **collider with significantly higher energies than Higgs factory**
- New realm of energies is expected to lead to new discoveries and provide answers to existing mysteries

The vision is to prepare a Higgs factory, followed by a future hadron collider with sensitivity to energy scales an order of magnitude higher than those of the LHC, while addressing the associated technical and environmental challenges.

The 2020 Strategy presents exciting and ambitious scientific goals that will drive technological and scientific exploration into new and uncharted territory for the benefit of the field and of society.

How was the strategy formulated?

- Granada Symposium
- National Inputs
- Working Group 1: Social and career aspects for the next generation;
- Working Group 2:Issues related to Global Projects hosted by CERN or funded through CERN outside Europe;
- Working Group 3: Relations with other groups and organisations;
- Working Group 4: Knowledge and Technology Transfer;
- Working Group 5: Public engagement, Education and Communication;
- Working Group 6: Sustainability and Environmental impact.

Output is 254-page Physics briefing book,
https://arxiv.org/abs/1910.11775

-ESU-004
uary 2020

Physics Briefing Book

Input for the European Strategy for Particle Physics Update 2020

Contents

1a Major developments from the 2013 Strategy

2013 Strategy identified 4 high-priority, large scale scientific activities (2 addressed later)

- LHC → upgrade to high luminosity (10 x LHC)
- Neutrino physics → Europe to participate in long-baseline experiments in Japan and the US (Neutrino Platform)

HL-LHC will challenge the understanding of particle physics at around the TeV scale, and indirectly at multi-TeV scales.

- Development of the essential short dipole magnets with Nb_3Sn superconductor to be tested in LHC Run3
- Upgrades of ATLAS and CMS documented in TDRs, to be commissioned 2027; emerging new technologies for trigger systems, computing and management of big data, reconstruction algorithms and analysis methods
- Upgrades considered by LHCb (flavour physics) and ALICE (heavy ion physics)

a) Since the recommendation in the 2013 Strategy to proceed with the programme of upgrading the luminosity of the LHC, the HL-LHC project, was approved by the CERN Council in June 2016 and is proceeding according to plan. In parallel, the LHC has reached a centre-of-mass energy of 13 TeV, exceeded the design luminosity, and produced a wealth of remarkable physics results. Based on this performance, coupled with the innovative experimental techniques developed at the LHC experiments and their planned detector upgrades, a significantly enhanced physics potential is expected with the HL-LHC. The required high-field superconducting Nb_3Sn magnets have been developed. *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.*

1b Major developments from the 2013 Strategy

Neutrino oscillations are a compelling sign of new physics, making neutrinos massive particles

- They are much lighter than charged leptons
- Not all oscillation parameters are yet fully known (observed very different mixing patter from quarks)
- Essential to pursue the exploration of the neutrino sector with accelerator, reactor, solar, atmospheric and cosmic neutrino experiments
- Two complementary approved programmes are in preparation with the DUNE (US) and Hyper-Kamiokande (Japan) experiments - strong participation of European physicists with CERN support through notably the Neutrino Platform
- The community is very keen for the Neutrino Platform to continue operation at CERN
- Balanced European support for this worldwide effort important to secure the determination of neutrino properties

b) The existence of non-zero neutrino masses is a compelling sign of new physics. The worldwide neutrino physics programme explores the full scope of the rich neutrino sector and commands strong support in Europe. Within that programme, the Neutrino Platform was established by CERN in response to the recommendation in the 2013 Strategy and has successfully acted as a hub for European neutrino research at accelerator-based projects outside Europe. *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).*

2a General considerations for the 2020 update

- With the construction and efficient operation of the LHC, CERN has established itself as the world's premier particle physics laboratory
- Cooperation between the Member, Associate Member and non-Member States and the concentration of the European particle-physics effort at CERN have created a unique resource in terms of scientific accomplishments, human capital, international collaboration, technical expertise, and research infrastructure.
- CERN and other accelerator-based laboratories worldwide use cutting-edge technologies (radiofrequency cavities to accelerate particles, superconducting magnets, cryogenics and high vacuum, management of large data volumes,etc.). shared throughout Europe for the benefit of the Member and Associate Member States.

a) Europe, through CERN, has world leadership in accelerator-based particle physics and related technologies. The future of the field in Europe and beyond depends on the continuing ability of CERN and its community to realise compelling scientific projects. *This Strategy update should be implemented to ensure Europe's continued scientific and technological leadership.*

2b General considerations for the 2020 update

European ecosystem for research in particle physics

- European National Laboratories collaborate, together with research institutes and universities, in large programmes at CERN and in activities performed locally and at other large laboratories
- European research centres provide a variety of large technical platforms dedicated to development, testing and production of accelerator and detector components
- European research centres afford fruitful synergies with other communities that go well beyond the boundaries of particle physics
- High visibility of European research centres in supranational large projects is essential for their sustainability

b) The European organisational model centred on close collaboration between CERN and the national institutes, laboratories and universities in its Member and Associate Member States is essential to the enduring success of the field. This has proven highly effective in harnessing the collective resources and expertise of the particle, astroparticle and nuclear physics communities, and of many interdisciplinary research fields. Another manifestation of the success of this model is the collaboration with non-Member States and their substantial contribution. *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.*

2a General considerations for the 2020 update

Global nature of particle physics research

- The increase in scale of the leading particle physics facilities and the resulting decrease in their number worldwide has led to the globalisation of the field
- The timely realisation of complementary, large-scale projects in different regions of the world, each of them unique in pushing further the frontiers of particle physics, remains essential for the progress of the field, as well as for the development of the key technologies
- Europe's long-term vision is to maintain its leadership in pushing the exploration of the energy frontier, and this vision is supported by the other regions.

c) The broad range of fundamental questions in particle physics and the complexity of the diverse facilities required to address them, together with the need for an efficient use of resources, have resulted in the establishment of a global particle physics community with common interests and goals. This Strategy takes into account the rich and complementary physics programmes being undertaken by Europe's partners across the globe and of scientific and technological developments in neighbouring fields. *The implementation of the Strategy should proceed in strong collaboration with global partners and neighbouring fields.*

European Strategy Update

Strategy process mirrored by a similar process in the USA

Snowmass process, https://snowmass21.org/ currently ongoing.

- Snowmass Kick-off Town-Hall meeting (virtual): April 18, 2020 (during the 2020 APS April Meeting)
- Snowmass Community Planning Meeting (virtual): October 5-8, 2020
- Snowmass Mid-term Assessment: during 2021 APS April Meeting (April 17-20, 2021)

  Snowmass Summer Study: July 11 - 20, 2021 at UW Seattle

- Energy Frontier
- Neutrino Physics Frontier
- Rare Processes and Precision
- Cosmic Frontier
- Theory Frontier
- Accelerator Frontier
- Instrumentation Frontier
- Computational Frontier
- Underground Facilities
- Community Engagement Frontier

3a High-priority future initiatives

It is essential for particle physics in Europe and for CERN to be able to propose a new facility after the LHC

- There are two clear ways to address the remaining mysteries: Higgs factory and exploration of the energy frontier
- Europe is in the privileged position to be able to propose both: CLIC or FCCee as Higgs factory, CLIC (3 TeV) or FCChh (100 TeV) for the energy frontier
- The dramatic increase in energy possible with FCChh leads to this technology being considered as the most promising for a future facility at the energy frontier.
- It is important therefore to launch a feasibility study for such a collider to be completed in time for the next Strategy update, so that a decision as to whether this project can be implemented can be taken on that timescale.

a) 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. Accomplishing these compelling goals will require innovation and cutting-edge technology:

- *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;*
- *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.*

The timely realisation of the electron-positron International Linear Collider (ILC) in Japan would be compatible with this strategy and, in that case, the European particle physics community would wish to collaborate.

3b High-priority future initiatives

Accelerator R&D is crucial to prepare the future collider programme

- The European particle physics community should develop an accelerator R&D roadmap focused on the critical technologies needed for future colliders, maintaining a beneficial link with other communities such as photon or neutron sources and fusion energy
- The roadmap should be established as soon as possible in close coordination between the National Laboratories and CERN
- A focused, mission-style approach should be launched for R&D on high-field magnets (16 T and beyond) including high-temperature superconductor (HTS) option to reach 20 T. CERN's engagement in this process would have a catalysing effect on related work being performed in the National Laboratories and research institutions
- The roadmap should also consider: R&D for an effective breakthrough in plasma acceleration schemes, an international design study for a muon collider and R&D on high-intensity, multi-turn energy-recovery linac (ERL) machines

b) Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders. It is also a powerful driver for many accelerator-based fields of science and industry. The technologies under consideration include high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures, bright muon beams, energy recovery linacs. *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.*

Higgs Physics @ Future Colliders

- Comparison using a single methodology of the potential of various future machines
- Using the inputs submitted to the update of the European Strategy for particle physics.

Higgs Boson studies at future particle colliders

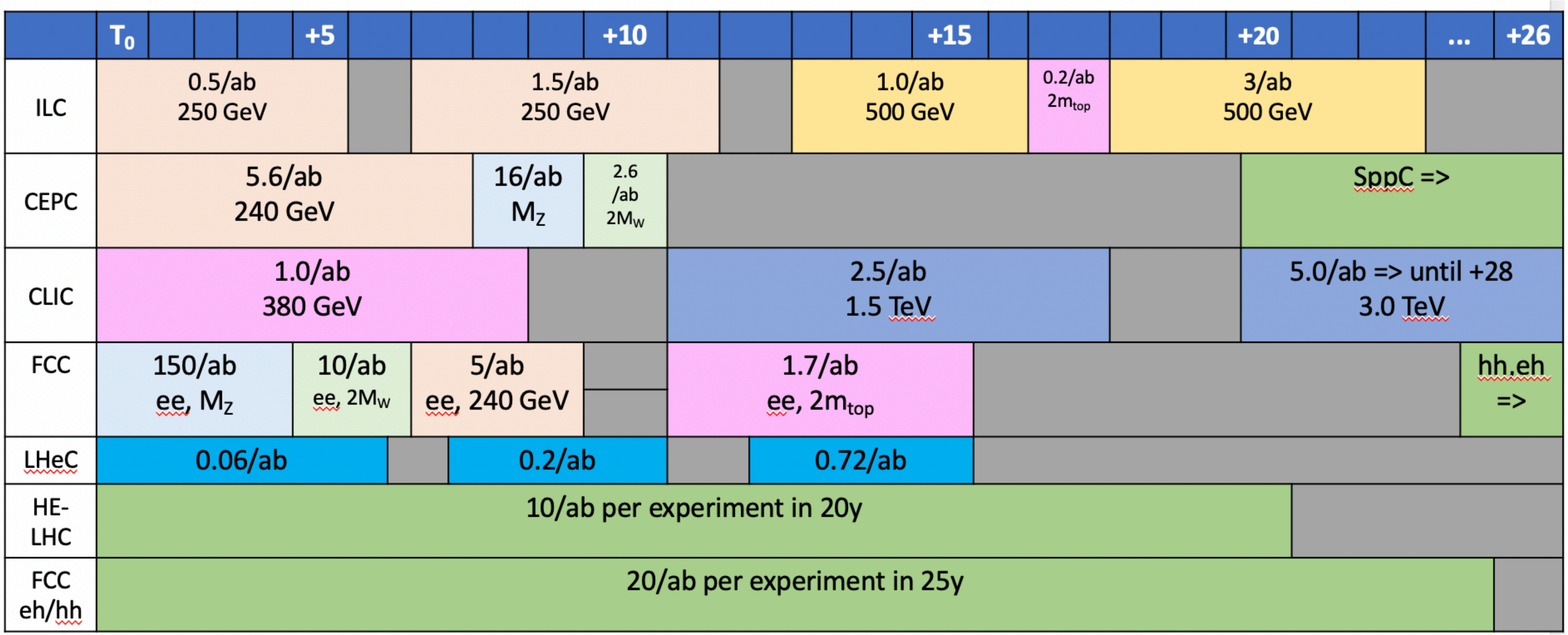
J. de Blas[1,2], M. Cepeda[3], J. D'Hondt[4], R. K. Ellis[5], C. Grojean[6,7], B. Heinemann[6,8], F. Maltoni[9,10], A. Nisati[11,*], E. Petit[12], R. Rattazzi[13], and W. Verkerke[14]

Contents

ABSTRACT

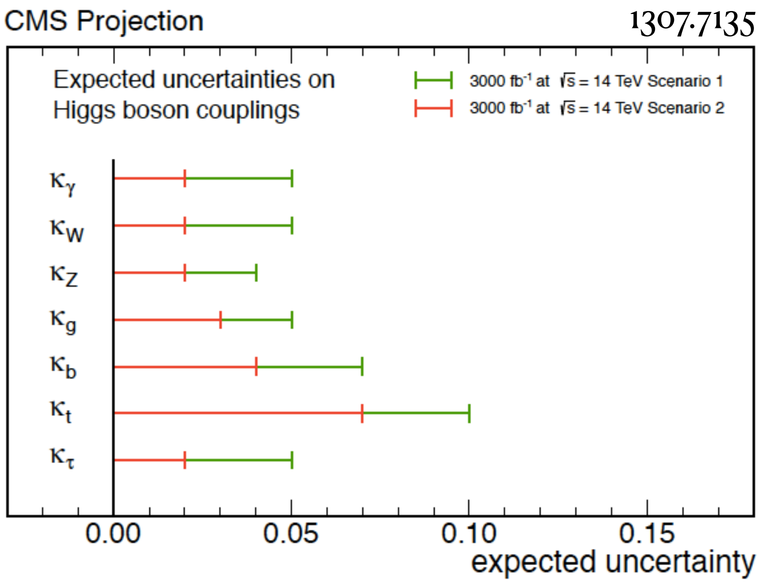
This document aims to provide an assessment of the potential of future colliding beam facilities to perform Higgs boson studies. The analysis builds on the submissions made by the proponents of future colliders to the European Strategy Update process, and takes as its point of departure the results expected at the completion of the HL-LHC program. This report presents quantitative results on many aspects of Higgs physics for future collider projects of sufficient maturity using uniform methodologies. A first version of this report was prepared for the purposes of discussion at the Open Symposium in Granada (13-16/05/2019). Comments and feedback received led to the consideration of additional run scenarios as well as a refined analysis of the impact of electroweak measurements on the Higgs coupling extraction.

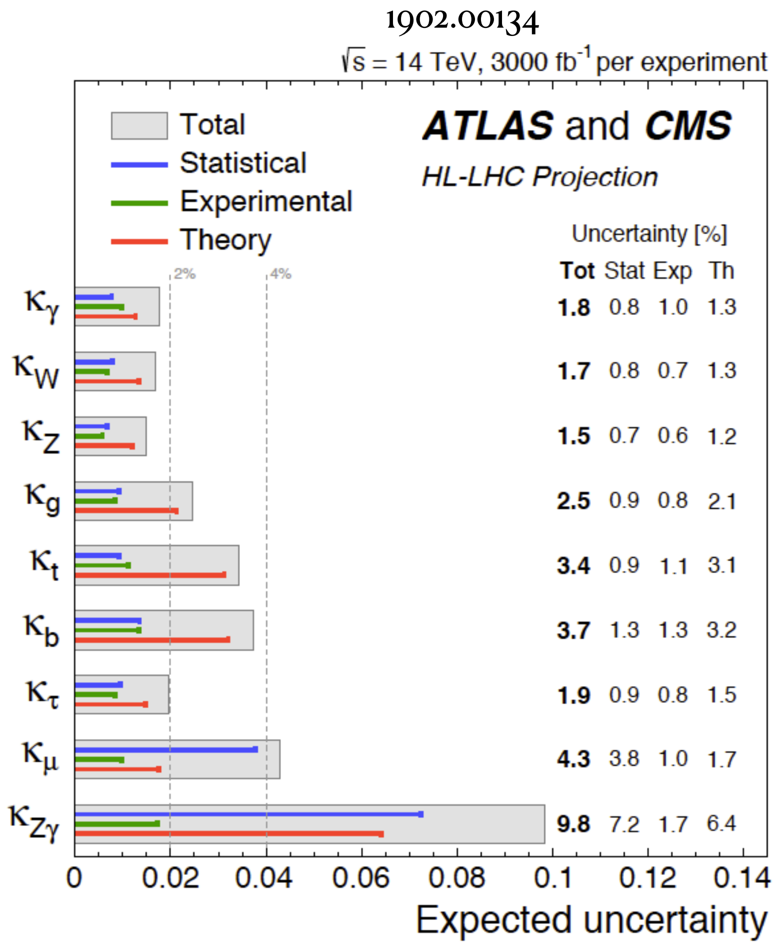
Timeline from T_0



- All first stage e+e- colliders have similar capabilities for Higgs physics, albeit with differing timescales.
- Polarization is worth about a factor of two in luminosity (increase in cross section ~45%, greater analyzing power).

Higgs Physics: start from the basis of HL-LHC

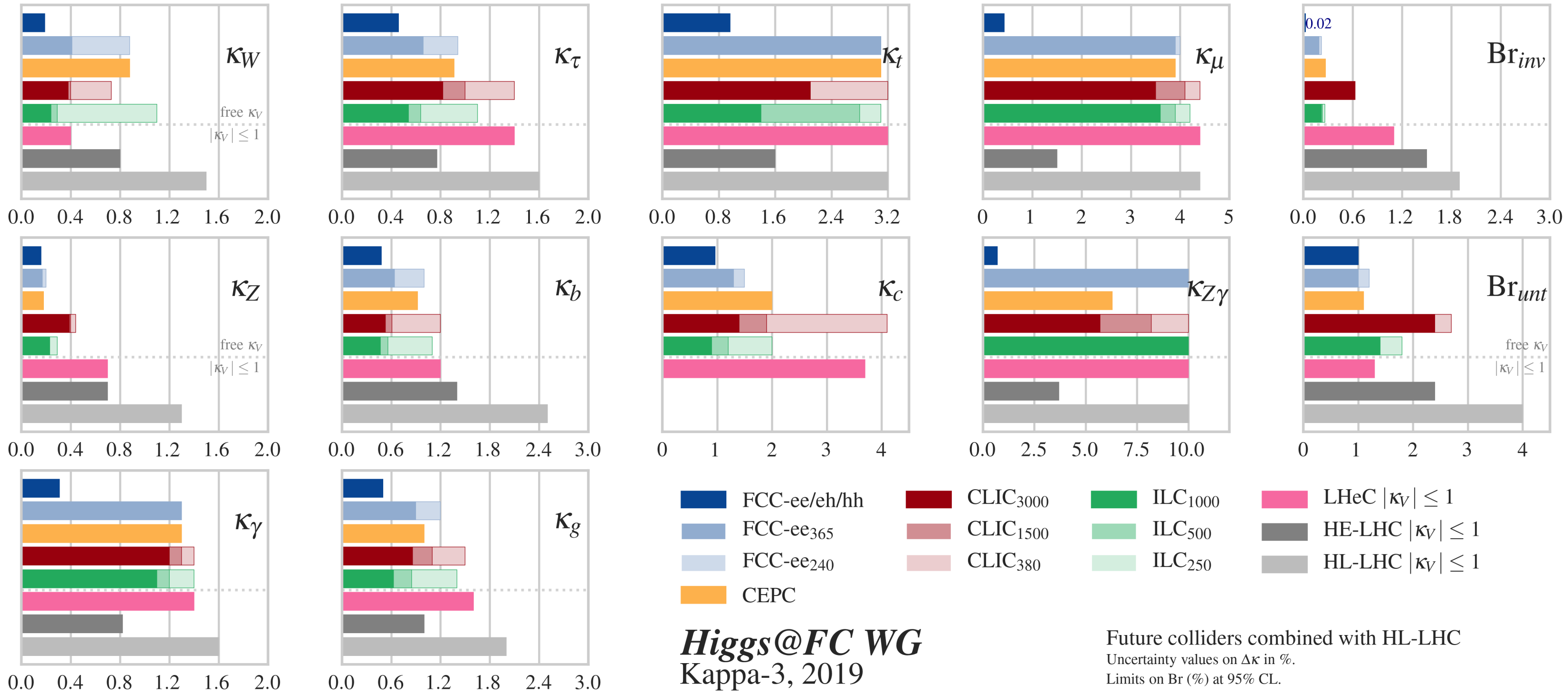




- Progress from 2013 to 2019
- With the availability of data, projections for the future have improved.
- Dominance of theoretical errors

Higgs:Physics: kappa Scenario

- κ has the advantage that it is simple;
- the effects of polarization are undervalued in this approach;
- Would give indications of deviations from the SM, but not necessarily diagnostic information to interpret deviation;
- In this kappa framework HL-LHC projections are included and the untagged and invisible branching ratios are constrained by the measurements.



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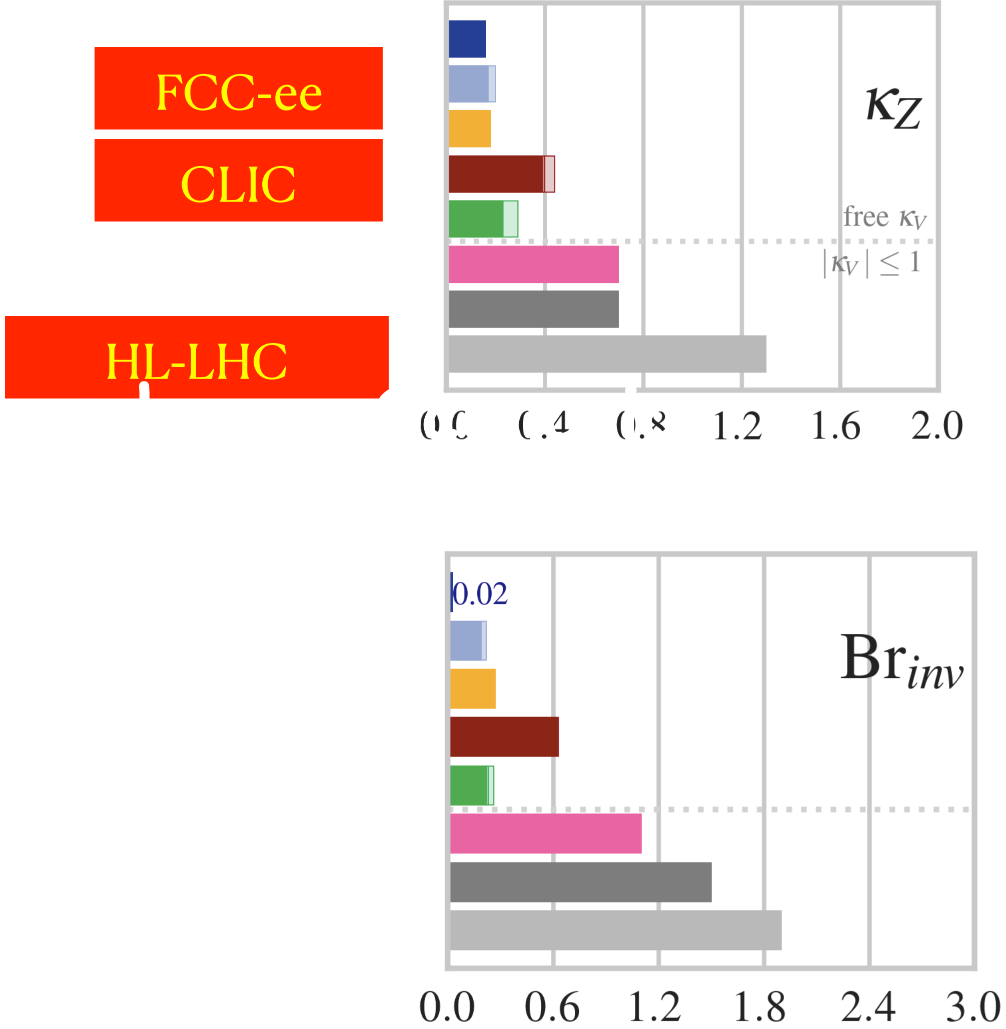
Higgs Physics: Look at a couple in more detail

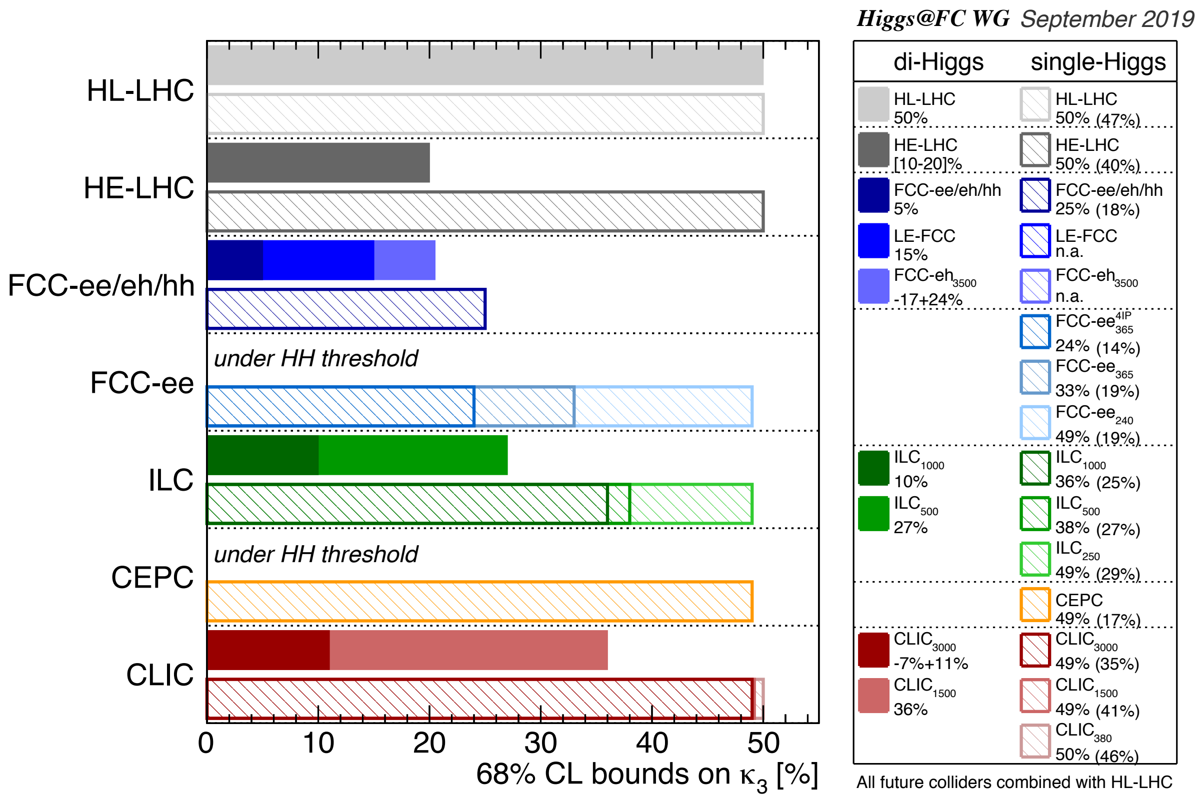
Focus on the first stage e+e- colliders

- Expected relative precision on kappa parameters in percent.



Higgs Physics: Sensitivity to λ via single-H and H production

- Di-Higgs
  - HL-LHC ~50%
  - Improved by HE-LHC(20%), LE-FCC(15%), ILC_{500}(25%)
  - Precisely by $CLIC_{3000}$(9%), FCC(hh)(5%)
  - Robust w.r.t. other operators
- Single Higgs
  - Global analysis FCCee_365 and ILC500 sensitive to ~35% when combined with LHC.
  - ~21% if FCC-ee has 4 detectors
-



Timescale for magnet devopment

Timeline	~ 5	~ 10	~ 15	~ 20	~ 25	~ 30	~ 35
Lepton Colliders – Linear and Circular:							
SRF-LC/CC	Proto/pre-series	Construction		Operation		Upgrade	
NRF–LC	Proto/pre-series	Construction		Operation		Upgrade	
Hadron Collier – Circular :							
14~16T Nb_3Sn		Short-model R&D		Prototype/Pre-series		Construction	
12~14T Nb_3Sn	Short-model R&D	Proto/Pre-series		Construction		Operation	
9~12T Nb_3Sn	Model/Proto/Pre-series	Construction			Operation		Upgrade
6~8T NbTi	Proto/ Pre-series	Construction		Operation			Upgrade

Note: **LHC experience: NbTi, 10 T** R&D started in 1980's and **8.3 T** Production started in late 1990's, after **~ 15 years**

A. Yamamoto, 190513b/updated:190628a

Yamamoto, Granada

4a Other essential scientific activities for particle physics

Diverse science at low energy: exploration of dark matter and flavour puzzle

- Change of paradigm for dark matter particles - could be as light as 10^{-22} eV to as heavy as primordial black holes of $10 \times M_{\odot}$
- The observed pattern of masses and mixings of quarks and leptons, remains a puzzle
- Physics Beyond Colliders study explored opportunities offered by the accelerator complex and infrastructure of CERN and European research centres – many high impact options with modest investment identified
- Improvements in the knowledge of the proton structure needed to fully exploit the potential of present and future hadron colliders. Added value from fixed target experiments and from EIC (CD0) in BNL
- Larger scale new facilities such a the Beam Dump Facility, and later LHeC option at CERN not a priority at present
- Given the challenges faced by CERN in preparing for the future collider, the role of the National Laboratories in advancing the exploration of the lower energy regime cannot be over-emphasised

a) 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.*

4b Other essential scientific activities for particle physics

Essential role of theory for advancement in particle physics

- European theoretical research spans a wide range of subjects, from abstract ideas of string theory to the detailed simulation of collider physics processes
- Results from neighbouring fields, such as cosmology, nuclear physics and astrophysics, condensed matter and atomic physics, computation and quantum information enrich the scientific dialogue
- Theory plays an essential role in assessing the strategic importance for future investments in accelerators and experimental infrastructure
- Calculation-intensive areas such as precision phenomenology at colliders, lattice field theory or the development of Monte-Carlo event generators and other software tools require long time scales to yield results
- Outreach activities benefit from the special perspective that theoretical physicists bring

b) Theoretical physics is an essential driver of particle physics that opens new, daring lines of research, motivates experimental searches and provides the tools needed to fully exploit experimental results. It also plays an important role in capturing the imagination of the public and inspiring young researchers. The success of the field depends on dedicated theoretical work and intense collaboration between the theoretical and experimental communities. *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.*

4c Other essential scientific activities for particle physics

Instrumentation R&D critical for present and future endeavours

- Delivering the near and long-term future research programme requires advances in instrumentation through focused and transformational R&D
- There is a clear need to strengthen existing R&D collaborative structures and to create new ones, and and to foster an environment that stimulates innovation and collaboration with industry
- The National Laboratories and research institutes in Europe play a central role by providing access to dedicated infrastructures and test facilities, specialised expertise and user support
- A roadmap should be developed by the community taking into account progress with emerging technologies in adjacent fields.

c) The success of particle physics experiments relies on innovative instrumentation and state-of-the-art infrastructures. To prepare and realise future experimental research programmes, the community must maintain a strong focus on instrumentation. *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.*

4d Other essential scientific activities for particle physics

Computing and software infrastructure

- There is a need for strong community-wide coordination for computing and software R&D activities, and for the development of common coordinating structures that will promote coherence in these activities, long-term planning and effective means of exploiting synergies with other disciplines and industry
- A significant role for artificial intelligence is emerging in detector design, detector operation, online data processing and data analysis
- Computing and software are profound R&D topics in their own right and are essential to sustain and enhance particle physics research capabilities
- More experts need to be trained to address the essential needs, especially with the increased data volume and complexity in the upcoming HL-LHC era, and will also help in experiments in adjacent fields.

d) Large-scale data-intensive software and computing infrastructures are an essential ingredient to particle physics research programmes. The community faces major challenges in this area, notably with a view to the HL-LHC. As a result, the software and computing models used in particle physics research must evolve to meet the future needs of the field.
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.

5a Synergies with neighbouring fields

Particle and Nuclear Physics

- The synergies are driven by the ambition to achieve first-principle understanding of strong dynamics based on QCD.
- They share similar experimental tools.
- The CERN baseline programme includes ISOLDE and n_TOF facilities and the heavy-ion programme at SPS and LHC
- Future European facilities such as FAIR, NICA and ESS envisage research programmes that are of interest to particle physics.
- The nuclear physics roadmap in Europe is coordinated by the Nuclear Physics European Collaboration Committee (NuPECC) and there are well established communication lines between the two communities
- NuPECC has expressed strong support for the extension of the heavy-ion programme into the HL-LHC era and beyond

a) A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments and facilities. Europe has a vibrant nuclear physics programme at CERN, including the heavy-ion programme, and at other European facilities. In the global context, a new electron-ion collider, EIC, is foreseen in the United States to study the partonic structure of the proton and nuclei, in which there is interest among European researchers. *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.*

5b Synergies with neighbouring fields

Particle and Astroparticle Physics

- There synergies between particle and astroparticle physics exist at the level of infrastructure, detectors, computing, interaction models and physics goals (ex.: neutrinos, dark matter, cosmic rays and gravitational waves)
- The need to foster these synergies has been clearly identified in the national inputs
- The astroparticle physics roadmap in Europe is coordinated by the Astroparticle Physics European Consortium (APPEC)
- APPEC seeks strong cooperation with CERN
- The APPEC theory centre for astroparticle physics, EuCAPT, was established recently with CERN chosen as its first hosting hub
- It would be appropriate to establish a new procedure (like Recognised Experiments) for collaborations seeking CERN's technical support, which should be limited to providing technical expertise and infrastructure services in a cost-neutral way for CERN

b) Astroparticle physics, coordinated by APPEC in Europe, also addresses questions about the fundamental physics of particles and their interactions. The ground-breaking discovery of gravitational waves has occurred since the last Strategy update, and this has contributed to burgeoning multi-messenger observations of the universe. *Synergies between particle and astroparticle physics should be strengthened through scientific exchanges and technological cooperation in areas of common interest and mutual benefit.*

6a Organisational issues

Clobal projects, Europe and CERN

- Large future projects, because of their size, complexity, duration and cost, will need to be planned on a global scale
- Need to consider governance and funding around either CERN hosting a next-generation collider as a globally funded project or a European contribution to a next-generation collider constructed outside Europe, and specifically the role that CERN would play
- For the case of a new global facility hosted at CERN, long-term commitments are needed from non-European states and must take account of both construction and operating costs and must be compatible with the provisions of the CERN Convention, amendment of which is not desirable
- For the case of a European contribution to a new global facility outside Europe, CERN should, if so decided by the CERN Council, provide strategic coordination and technical support for European contributions
- The modalities of European participation in a global facaility outside Europe remain to be decided, as and when the need occurs.

a) 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.*

6b Organisational issues

European Commission and particle physics

- Participation in European networks devoted to development of future accelerator and detector technologies (AMICI, ARIES, EUROCIRCOL, TIARA, ATTRACT, AIDA2020, COMPACT XLS, EuPRAXIA, ALEGRO, LEAPS, LENS, etc.) has contributed to coherency of effort among CERN and the National Laboratories, and has facilitated success
- The European particle physics community should work with the European Commission to shape and establish the funding instruments that are required for the realisation of common R&D projects, e.g. in the Horizon Europe programme.

b) The particle physics community and the European Commission have a strong record of collaboration.
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.

6c Organisational issues

Open Science

- Open science comprises open access to scientific publications and research data, preservation and reuse of research outcomes, sharing of infrastructures, as well as participation in the research process.
- Open Science promotes the sharing of research-based knowledge and facilitates the wide use of research findings, data, methods and infrastructures in the research community and in society at large
- Open science policies are formed and implemented at the national and international levels by governments, international institutions, and research funders
- The particle physics community in Europe and CERN have been pioneers in several aspects of open science, such as the open-access publishing initiative SCOAP3, the Zenodo archive and, not least, by establishing the worldwide web

c) European science policy is quickly moving towards Open Science, which promotes and accelerates the sharing of scientific knowledge with the community at large. Particle physics has been a pioneer in several aspects of 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.*

7a Environmental and societal impact

Climate change and particle physics

- In a world with increasing demand on limited resources and undergoing climate change it is crucial to keep energy consumption, sustainability and efficiency in mind when discussing the future of particle physics
- In the discussion of the optimal choice for a new facility, the energy efficiency of the accelerator should be considered alongside factors such as cost, timescale and physics reach
- Research into environmentally-friendly alternatives for materials with high global warming potential for use in particle physics detectors should be strongly stimulated and supported
- The community should invest in both hardware and software efforts to improve the energy efficiency of its computing infrastructures
- The community is expected to be in the vanguard of alternatives to physical travel such as virtual meeting rooms and should support low-carbon forms of travel and carbon offsetting, whenever travel is unavoidable.

a) The energy efficiency of present and future accelerators, and of computing facilities, is and should remain an area requiring constant attention. Travel also represents an environmental challenge, due to the international nature of the field. *The environmental impact of particle physics activities should continue to be 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.*

7b Environmental and societal impact

Next generations of particle physicists

- The exploratory nature of particle physics and its fundamental questions about the universe fascinates many inside and outside the field and draws in talented students
- National laboratories, research institutes and universities worldwide provide the training ground of future young scientists. Education and training in key technologies are crucial for the needs of the field and society at large
- It is essential to make the research environment in particle physics as attractive as possible and in particular to consider the worries expressed by the early career researchers (document under the auspices of ECFA)
- The principles of equality, diversity and inclusion should be clearly and recognisably present in all of the field's activities

b) Particle physics, with its fundamental questions and technological innovations, attracts bright young minds. Their education and training are crucial for the needs of the field and of society at large. *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.*

7c Environmental and societal impact

Knowledge and technology transfer

- A large number of technologies developed or under development by the particle physics community exist with excellent potential to be transferred to other fields of science and industry
- It is important to recognise the potential impact of technological developments in accelerators and associated fields on progress in other branches of science, such as astroparticle physics, cosmology and nuclear physics
- Joint developments with applied fields in academia and industry have brought benefits to fundamental research and may become indispensable for the progress in the field, demonstrating that knowledge and technology transfer is not a one-way street

c) Particle physics has contributed to advances in many fields that have brought great benefits to society. Awareness of knowledge and technology transfer and the associated societal impact is important at all phases of particle physics projects. *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.*

7d Environmental and societal impact

Public engagement, education and communication

- The particle physics community is highly active and effective in public engagement. European funding agencies are urged to explicitly accompany research funding with resources for public engagement activities
- Good contacts between particle physicists and other research disciplines will lead to better mutual understanding of the importance and urgency of the open scientific research
- The International Particle Physics Outreach Group (IPPOG) has been established to streamline particle physics education at the high-school level and its mission could be expanded to provide public engagement material
- The well established effectiveness of the European Particle Physics Communication Network (EPPCN) would be further improved if the vacancies for EPPCN representatives for all Member and Associate Member States were filled
- The basic picture of fundamental constituents of matter and their interactions should become part of the regular school curriculum

d) Exploring the fundamental properties of nature inspires and excites. It is part of the duty of researchers to share the excitement of scientific achievements with all stakeholders and the public. The concepts of the Standard Model, a well-established theory for elementary particles, are an integral part of culture. *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.*

Concluding remarks

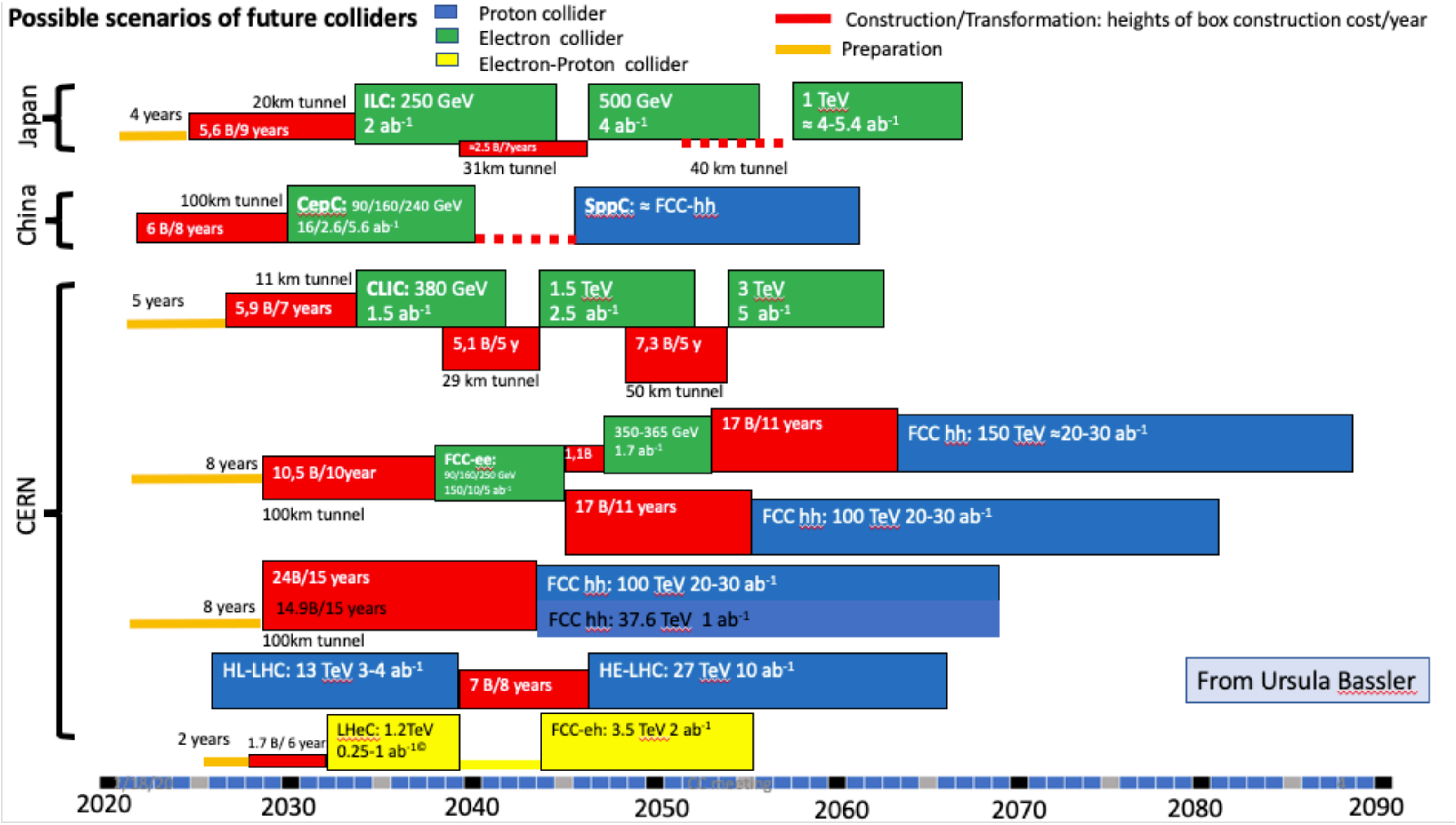
This 2020 update of the European Strategy for Particle Physics has focussed on both near and long-term priorities for the field. Given the scale of our long-term ambition, the European plan needs to be coordinated with other regions of the world. A further update of the Strategy should be foreseen in the second half of this decade when the results of the feasibility study for the future hadron collider are available and ready for decision.

Back-up slides

Draft 2020 Strategy Statements

Future Facilities

Map of possible future facilities submitted as input to the Strategy Update



Comparisons

Project	Type	Energy [TeV]	Int. Lumi. $[a^{-1}]$	Oper. Time [y]	Power [MW]	Cost
ILC	ee	0.25	2	11	129 (upgr. 150-200)	4.8-5.3 GILCU + upgrade
		0.5	4	10	163 (204)	7.8 GILCU
		1.0			300	?
CLIC	ee	0.38	1	8	168	5.9 GCHF
		1.5	2.5	7	(370)	+5.1 GCHF
		3	5	8	(590)	+7.3 GCHF
CEPC	ee	0.091+0.16	16+2.6		149	5 G$
		0.24	5.6	7	266	
FCC-ee	ee	0.091+0.16	150+10	4+1	259	10.5 GCHF
		0.24	5	3	282	
		0.365 (+0.35)	1.5 (+0.2)	4 (+1)	340	+1.1 GCHF
LHeC	ep	60 / 7000	1	12	(+100)	1.75 GCHF
FCC-hh	pp	100	30	25	580 (550)	17 GCHF (+7 GCHF)
HE-LHC	pp	27	20	20		7.2 GCHF

Essential Activities

Research activities essential for the field

- Diverse scientific programme – dark sector; flavour and CP violation; neutrinos
- Theory (formal, phenomenology, computational, MC)
- Accelerator R&D
- Detector R&D
- HL-LHC

			2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
		SPS	LS2						LS3						LS4				
		LHC	LS2		Run 3				LS3			Run 4			LS4				
North Area	NA64-electron	Operational	LS2		Data Taking										LS4				
	NA64-mu	< 1 MCHF	Studies		Test	Pilot	Phase 1												
	NA61/Shine	< 2 MCHF	Detector upgrade		Data Taking					Data Taking									
	MUonE	< 2 MCHF	Preparation		Pilot	Run 1	Data Taking												
	NA62-beamdump	< 1 MCHF	Studies		1e18 PoT in Run 3														
	KLEVER	~40 MCHF	EoI/proposal		R&D/Construction				Installation	Data Taking									
	COMPASS++	~10 MCHF	Studies/proposal		Phase1 Data Taking/Studies/R&D				Installation	Data Taking									
LHC	ALICE fixed target	<5 MCHF			Design/tests				Preparation/Construction			Data Taking							
	LHCb fixed target	<5 MCHF		Design	Construction and testing			Data	LS3			Data Taking							
	LHC Spin	~5 MCHF	Study		R&D				Production/Installation			Data Taking							
	FASER	~5 MCHF	Installation		Data Taking				Upgrade - phase 2			Data Taking							
	MATHUSLA	<100 MCHF		Funding to test design			Construction					Data Taking							
	CODEX-b	<5 MCHF	EoI		Beta		Beta data taking		Production/Installation			Data Taking							
	MilliQan	<5 MCHF	Demonstrator		Funding/Construction				Upgrade			Data Taking							
SPS	LDMX/eSPS	<10 MCHF			Studies		Production/Installation			Data Taking									
	SHiP	~70 MCHF	CDR		TDR/Prototypes			Production/construction			Installation		Data Taking						
	TauFV	tbc	Design		CDR	TDR/Prototypes		Production/construction			Installation		Data Taking						
	BabyIAXO (DE)	<5 MCHF		Production/construction			Commission	Data Taking											
	IAXO	~60 MCHF					Design, prototyping, construction, integration and commissioning (start tbc)												
	AWAKE	~15 MCHF	Prep/construction		AWAKE Run 2				LS3	AWAKE++?									
	eSPS	~80 MCHF	CDR		TDR		Preparation/Construction			Data Taking									
	Beam Dump Facility	~160 MCHF	CDR	TDR			Construction/Installation						Operation						
	Gamma Factory	~2 MCHF		CDR	SPS Proof of Principle/TDR				Preparation			LHC demo							
	nuSTORM	>160 MCHF	Study	CDR		TDR/Prototyping						Approval							
	CPEDM prototype (DE)	~20 MCHF	Study	CDR		TDR		Construction		Data Taking									

				2020					2025					2030					2035
Neutrino	DUNE/LBNF	O(1000)	Excavation		Installation of first module					Beam operation with the first two modules									
	HyperKamiokande	600 MCHF		Construction							Operation with beam								
	JUNO	300 MCHF	Installation		Data Taking														
	KM3NET/ORCA		Construction								Phase I Data Taking								
	ESSvSB (SE)	O(1000)	Design		CDR	Preparatory phase and TDR			Preconstruction		Construction								Data
	nuSTORM	>160 MCHF	Study	CDR		TDR/Prototyping						Approval							
	SBN (FNAL)			Data taking with 3 detectors															
	GVD (Baikal)	68 MCHF		Data taking with 8 clusters/Expansion to 1 km^3						Data taking with 20 clusters									
	NBNT (Baksan)	197 MCHF				Stage 2 data taking						Stage 3 data taking							

				2020					2025					2030					2035
	Muon collider			Baseline design				Design optimization							Project Preparation				Approval
	ANA scientific roadmap		Accelerator stages			x10 beam quality at higher energies					Reliable staged acceleration, 10 GeV module					Advanced Linear Collider CDR & TDR			
	ESSvSB (SE)		Design		CDR	Preparatory phase and TDR			Preconstruction		Construction								Data
	PERLE (FR)			TDR	Assembly & installation		Phase 1 OP	2nd cryo ins.	Phase 2 OP										
	HIBEAM/NNBAR (SE)		CDR (HB)		TDR/prototpying (HB)			Construction (HB), CDR (NNBAR)		Data taking(HB), TDR (NNBAR)		Construction and commissioning (NNBAR)			Data Taking (NNBAR)				