The 2020 Update of the European Particle Physics Strategy

Muon Collider Collaboration - July 2020

Halina Abramowicz
Tel Aviv University
Secretary of the Strategy Update

Perspective on the outcome of the 2020 Strategy update
2020 Strategy Update

Reminder - organisation of the Update Process

• Decision making body - CERN Council as coordinating body of European Particle Physics (23 Member States)

• Drafting of the Strategy Update document - responsibility of the European Strategy Group (ESG) (23 MS representatives, LDG - National Lab’s Directors Group, Strategy Secretariat; Invitees: Associate MS, Observer States,... - see backup slide)

• Scientific Input to the Strategy Update - responsibility of the Physics Preparatory Group (PPG) (nominations 4 from ECFA, 4 from SPC, 4 from ICFA, 1 CERN, SUS - see backup slide)
  ➢ Call for input and processing of the input
  ➢ Open Symposium with outcome summarized in the Briefing Book

• Coordinating body - the Strategy Update Secretariat (SUS) (Secretary elected by Council, chairs of SPC, ECFA, LDG)

• Strategy implementation - purview of CERN DG, under scrutiny of CERN Council
2020 Strategy Update

Timeline

Documents submitted to CERN Council
1. Draft Update of the European Strategy for Particle Physics (with preamble, statements, conclusion) for feedback
   CERN/SPC/1137/RA CERN/3486/C2
2. Deliberation Document (with in addition rational behind the statements) for information
   CERN/SPC/1136/RA; CERN/3485/C
2020 Strategy Update

General Introduction

20 Strategy Statements unanimously adopted by the ESG in Jan. 2020

- 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

Derived based on

- Granada Symposium
- National Inputs
- Working Group 1: Social and career aspects for the next generation (chair: Eric Laenen)
- Working Group 2: Issues related to Global Projects hosted by CERN or funded through CERN outside Europe (chair: Mark Thompson)
- Working Group 3: Relations with other groups and organisations (chair: Tatsuya Nakada)
- Working Group 4: Knowledge and Technology Transfer (chair: Leandar Lisov)
- Working Group 5: Public engagement, Education and Communication (chair: Sijbrand de Jong)
- Working Group 6: Sustainability and Environmental impact (chair: Dirk Ryckbosch)
European vision

The European vision is thus 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.

Major developments from the 2013 Strategy (2)
- HL-LHC; neutrinos

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

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

Other essential scientific activities for particle physics (4)
- Scientific diversity programme; theory; detector R&D; SW and computing

Synergies with neighbouring fields (2)
- Astroparticle physics; nuclear physics

Organisational issues (3)
- Global projects; relations with EC; open science

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

The updated Strategy is visionary and ambitious, but also realistic and prudent. It lays the foundations for a bright future for particle physics in Europe, within the global context of the field.

On June 19, 2020 CERN’s Council decided unanimously to update the Strategy.
# 2020 Strategy Statements

## Guide through the statements

<table>
<thead>
<tr>
<th>2 statements on Major developments from the 2013 Strategy</th>
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<tbody>
<tr>
<td>a) Focus on successful completion of HL-LHC upgrade remains a priority</td>
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<tr>
<td>b) Continued support for long-baseline $\nu$ experiments in Japan and US and the Neutrino Platform</td>
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<table>
<thead>
<tr>
<th>3 statements on General considerations for the 2020 update</th>
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<tbody>
<tr>
<td>a) Preserve the leading role of CERN for success of European PP community</td>
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<tr>
<td>b) Strengthen the European PP ecosystem of research centres</td>
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<tr>
<td>c) Acknowledge the global nature of PP research</td>
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<tr>
<th>2 statements on High-priority future initiatives</th>
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<tr>
<td>a) Higgs factory as the highest-priority next collider and investigation of the technical and financial feasibility of a future hadron collider at CERN</td>
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<td>b) Vigorous R&amp;D on innovative accelerator technologies – through roadmap</td>
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<th>4 statements on Other essential scientific activities</th>
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<tr>
<td>a) Support for high-impact, financially implementable, experimental initiatives world-wide</td>
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<tr>
<td>b) Acknowledge the essential role of theory</td>
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<td>c) Support for instrumentation R&amp;D – through roadmap</td>
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<td>d) Support for computing and software infrastructure</td>
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<tr>
<th>2 statements on Synergies with neighbouring fields</th>
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<tr>
<td>a) Nuclear physics – cooperation with NuPECC</td>
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<td>b) Astroparticle – cooperation with APPEC</td>
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<th>3 statements on Organisational issues</th>
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<tr>
<td>a) Framework for projects in and out of Europe</td>
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<td>b) Strengthen relations with European Commission</td>
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<td>c) Support active role in supporting Open Science</td>
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<th>4 statements on Environmental and societal impact</th>
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<tr>
<td>a) Mitigate environmental impact of particle physics</td>
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<td>b) Invest in next generation of researchers</td>
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<tr>
<td>c) Support knowledge and technology transfer</td>
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<td>d) Cultural heritage: public engagement, education and communication</td>
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Letters for itemizing the statements are introduced for identification, do not imply prioritization.
High-priority future initiatives

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

Where is the muon collider?
### 2020 Strategy Update

#### Precision physics with the Higgs

H as a scalar couples to all the fundamental particles

### Comparison of Colliders: kappa-framework

**Some observations:**
- HL-LHC achieves precision of ~1-3% in most cases
- In some cases model-dependent
- Proposed $e^+e^-$ and $ep$ colliders improve w.r.t. HL-LHC by factors of ~2 to 10
- Initial stages of $e^+e^-$ colliders have comparable sensitivities (within factors of 2)
- $ee$ colliders constrain $BR \rightarrow untagged$ w/o assumptions
- Access to $\kappa_c$ at $ee$ and $eh$

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arXiv:1905.03764
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### Higgs self-coupling

Higgs@FC WG
- FCC-ee/FCC-sh/ILC-hh
- FCC-ee/GC/FCC-sh
- FCC-4e/4f
- CLIC
- CLIC[e, CLIC100, CLIC300]

Kappa-5, May 2019
- CLIC
- ILHC
- ILHC+hLHC
- CLIC
- LHC (100 < $\kappa_+ < 1$)
- ILHC (300 < $\kappa_+ < 1$)
- ILHC (600 < $\kappa_+ < 1$)

All future colliders combined with IL-LHC
2020 Strategy Update

**BSM at colliders**

- Higgs compositeness scale
- New resonant states
- Extended scalar sector
- Direct searches: pp: main LHC result ZZ; hadron colliders: extrapolate \( e^+e^- \rightarrow \nu\bar{\nu}; \phi \rightarrow hh \rightarrow bbbb 
- Sensitivity for ee colliders enhanced for couplings \( \gtrsim 1 \)
- Searches for W' & charged fermion currents more effective at hadron colliders

And much more
Future developments

Very interesting R&D projects

- Muon collider:
  - from proton beam (rcooling success: MICE)
  - from e+e- production (LEMMA)
- Plasma wakefield acceleration:
  - High gradients possible: ~100 GV/m
  - R&D progressing well but many challenges

Muon-based technology represents a unique opportunity for the future of high energy physics research: the multi-TeV energy domain exploration.

AWAKE@CERN

Achieved 2 GeV over 10m
Gradient 200 MV/m

Plasma density
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 FCCChh (100 TeV) for the energy frontier
• The dramatic increase in energy possible with FCCChh 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.
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.
2020 Strategy Update

Flavour Physics and CP

- Study processes very unlikely or impossible in the SM
- Great sensitivity to Physics Beyond the Standard Model - scale beyond $10^2 - 10^5$ TeV
- Complementarity of low energy high-precision and high energy frontier

Fig. 5.1: Reach in new physics scale of present and future facilities, from generic dimension six operators. Colour coding of observables is: green for mesons, blue for leptons, yellow for EDMs, red for Higgs flavoured couplings and purple for the top quark. The grey columns illustrate the reach of direct flavour-blind searches and EW precision measurements. The operator coefficients are taken to be either $\sim 1$ (plain coloured columns) or suppressed by MFV factors (hatch filled surfaces). Light (dark) colours correspond to present data (mid-term prospects, including IL-LHC, Belle II, MEG II, Mu3e, Mu2e, COMET, ACME, PIK and SNS).
2020 Strategy Update

Dark matter/Dark sector

- **Dark Matter**
  - What if dark matter is light?

- **Dark Sector**
  - Search for dark photon

**Axion/ALP searches: Mature Key Techniques**

- **Helioscopes**
  - Build on success of CAST hosted by CERN
  - Proposed BabyAxio leads to IAXO, with large discovery potential

- **Helioscopes**
  - ADMX (US) is leading the field
  - In Europe, MadMax is new key player
  - Smaller efforts developing new techniques

- **Light-shining-through-walls**
  - ALPS II is well underway
  - STAR is a new idea RF based
  - JURA is long term plan

From MACHOs searches

**BEAM DUMP PROJECTS AT CERN**

<table>
<thead>
<tr>
<th>EXPERIMENT</th>
<th>PERIOD</th>
<th>BEAM</th>
<th>PARTICLES ON TARGET</th>
<th>SIGNATURE</th>
<th>MODELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA64++(e)</td>
<td>2015-24</td>
<td>e 100 GeV</td>
<td>~5 10^{12}</td>
<td>invisible &amp; visible e-e'</td>
<td>DP, ALPs</td>
</tr>
<tr>
<td>eSPS/LDMX</td>
<td>&gt; 2026</td>
<td>e 16 GeV</td>
<td>10^{18}</td>
<td>invisible</td>
<td>DP, ALPs</td>
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<tr>
<td>AWAKE++</td>
<td>&gt; 2026</td>
<td>e ~50 GeV</td>
<td>~10^{15}</td>
<td>visible e-e'</td>
<td>DP, ALPs</td>
</tr>
<tr>
<td>NA62++</td>
<td>&gt; 2022</td>
<td>p 400 GeV</td>
<td>10^{18}</td>
<td>visible</td>
<td>DP, DS, HNL, ALPs</td>
</tr>
<tr>
<td>SHIP</td>
<td>&gt; 2026</td>
<td>p 400 GeV</td>
<td>2 10^{20}</td>
<td>recoil &amp; visible</td>
<td>DP, DS, HNL, ALPs</td>
</tr>
<tr>
<td>NA64++(μ)</td>
<td>&gt; 2022</td>
<td>μ 160 GeV</td>
<td>5 10^{13}</td>
<td>invisible</td>
<td>DZ₂, ALPs</td>
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**NB**: CERN offers unique opportunities with both lepton and hadron beams.
LHCb and LHC-LP dedicated projects (FASTER, milliQan, CODEX-b, MATHUSLA) have also sensitivity in similar mass range.
4. Other essential scientific activities for particle physics

Summary of “Physics Beyond Colliders” (PBC) study - aimed at exploring opportunities offered by the accelerator infrastructure of CERN and European research centres
4. 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 $10^5 \text{M}_\odot$
- Observed pattern of masses and mixings of quarks and leptons, remains a puzzle
- Physics Beyond Colliders study identified many high impact options with modest investment
- Larger scale new facilities such as the Beam Dump Facility, and later LHeC option at CERN, difficult to resource within the CERN budget, considering the other recommendations of this Strategy
- 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 Electron Ion Collider (CDDO) in BNL
- 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 (ex. axions at DESY, rare muon decays in PSI, dark photon in Frascati)

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.*
Concluding remarks

This 2020 update of the European Strategy for Particle Physics has focused 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.

My own perspective (what we have achieved with the EPPSU)

- We have a plan for the post-LHC era for CERB (plan A and plan B)
- CERN has to be more opened to the desiderates of the community
- CERN needs to cooperate and coordinate closer with National Labs
- In spite of budgetary constraints, CERN needs to invest in more than “just” superconducting magnets
- One issue not completely resolved: CERN DG responsible for the realization of the Strategy – might generate a conflict of interest when large projects are outside CERN/Europe