The 2020 Update of the European Particle Physics Strategy

Muon Collider Collaboration – July 2020

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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)

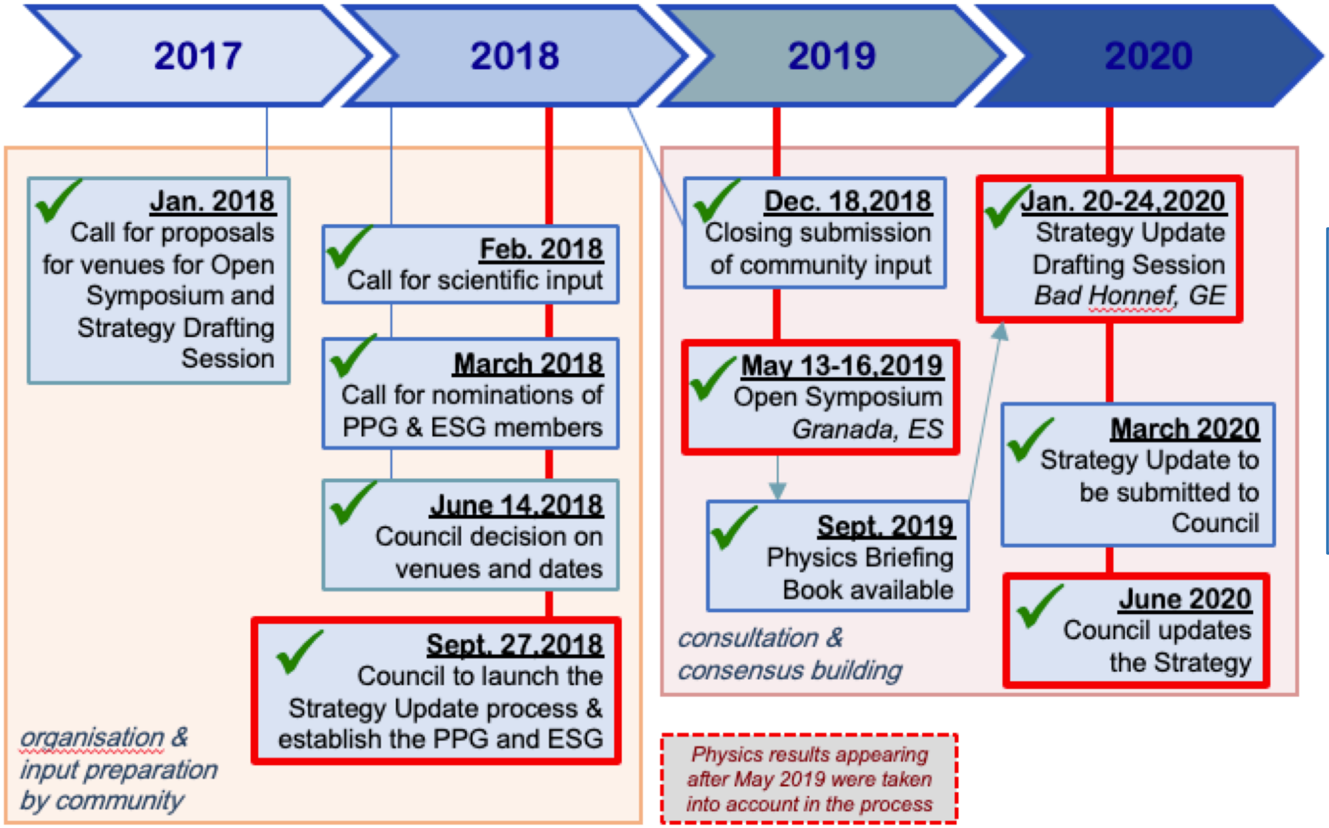
- Scientific Input to the Strategy Update – responsibility of the Physics Preparatory Group (PPG) (nominations 4 from ECFA, 4 from SPC, 4 from ICFA, 1 CERN, SUS – see backup slide)
  - Call for input and processing of the input
  - Open Symposium with outcome summarized in the Briefing Book

- 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)

2020 Strategy Update

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

2 statements on **Major developments from the 2013 Strategy**
a) Focus on successful completion of HL-LHC upgrade remains a priority
b) Continued support for long-baseline ν experiments in Japan and US and the Neutrino Platform

3 statements on **General considerations for the 2020 update**
a) Preserve the leading role of CERN for success of European PP community
b) Strengthen the European PP ecosystem of research centres
c) Acknowledge the global nature of PP research

2 statements on **High-priority future initiatives**
a) Higgs factory as the highest-priority next collider and investigation of the technical and financial feasibility of a future hadron collider at CERN
b) Vigorous R&D on innovative accelerator technologies – through roadmap

Letters for itemizing the statements are introduced for identification, do not imply prioritization

4 statements on **Other essential scientific activities**
a) Support for high-impact, financially implementable, experimental initiatives world-wide
b) Acknowledge the essential role of theory
c) Support for instrumentation R&D – through roadmap
d) Support for computing and software infrastructure

2 statements on **Synergies with neighbouring fields**
a) Nuclear physics – cooperation with NuPECC
b) Astroparticle – cooperation with APPEC

3 statements on **Organisational issues**
a) Framework for projects in and out of Europe
b) Strengthen relations with European Commission
c) Support active role in supporting Open Science

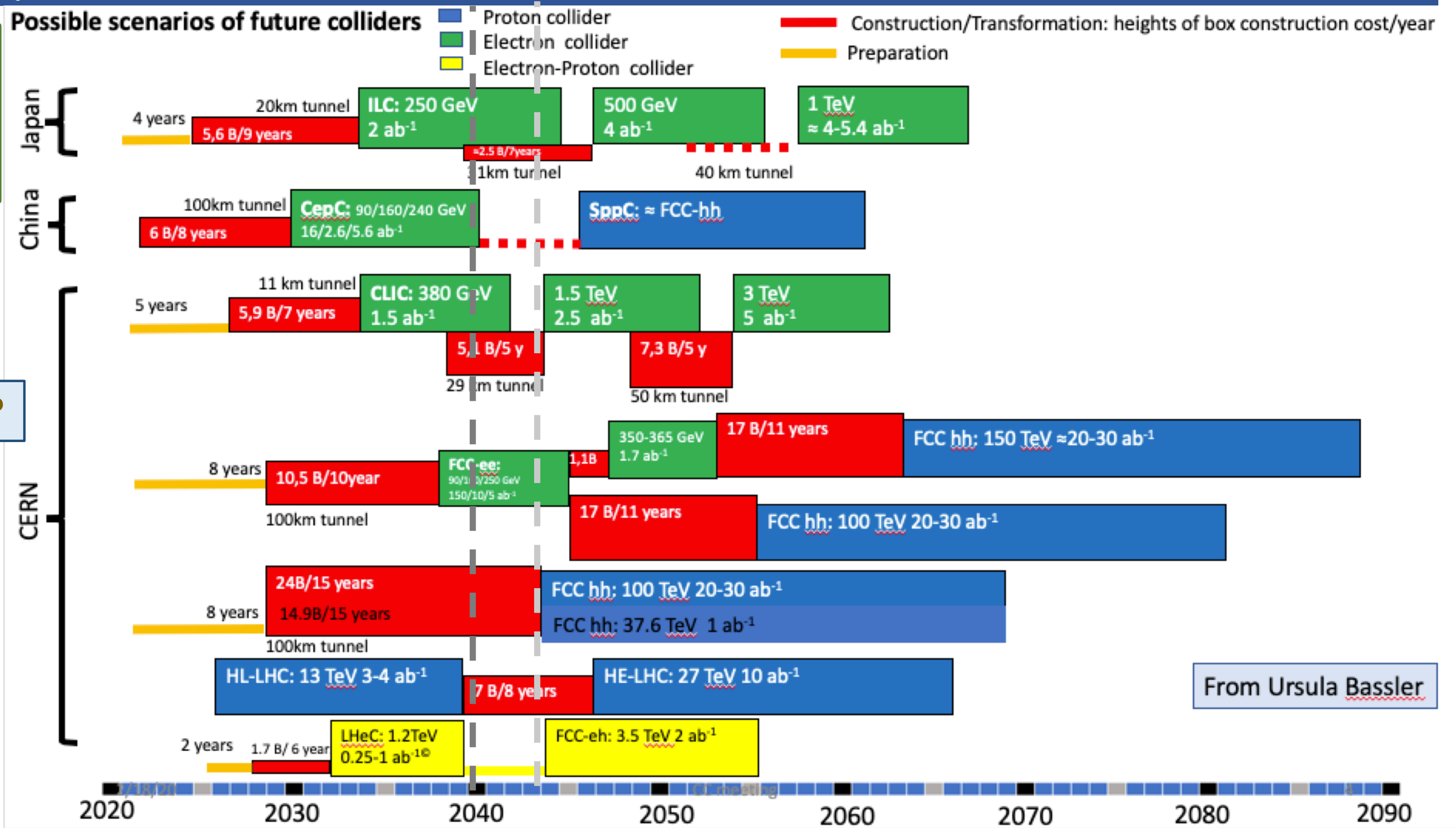
4 statements on **Environmental and societal impact**
a) Mitigate environmental impact of particle physics
b) Invest in next generation of researchers
c) Support knowledge and technology transfer
d) Cultural heritage: public engagement, education and communication

2020 Strategy Update

High-priority future initiatives

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

Where is the muon collider?



From Ursula Bassler

Precision physics with the Higgs

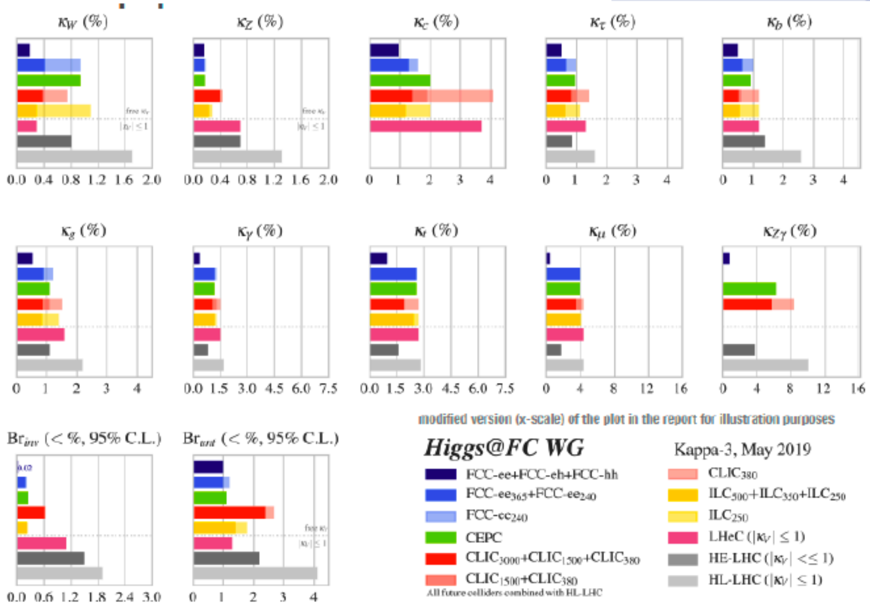
H as a scalar couples to all the fundamental particles

Comparison of Colliders: kappa-framework

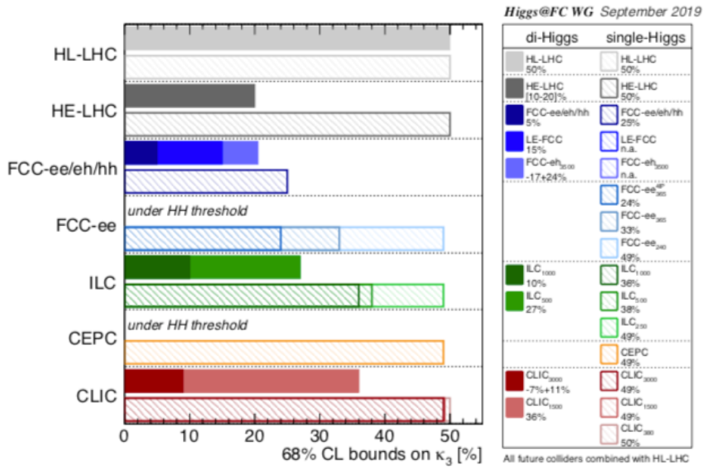
Some observations:

- **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 κ_c at ee and eh**

arXiv:1905.03764

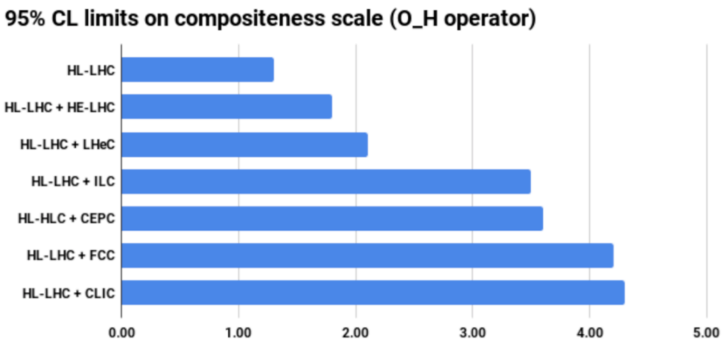


Higgs self-coupling



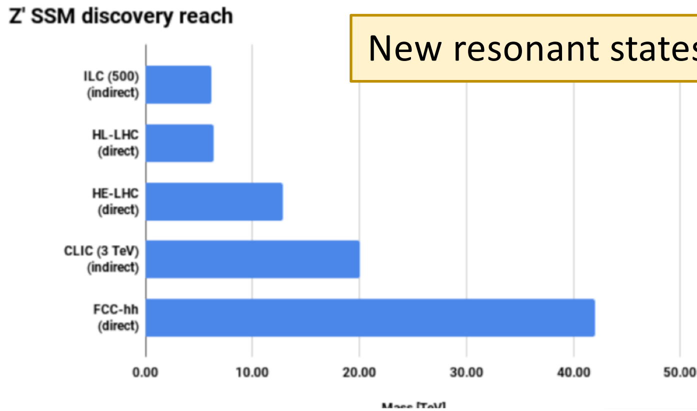
BSM at colliders

Higgs compositeness scale

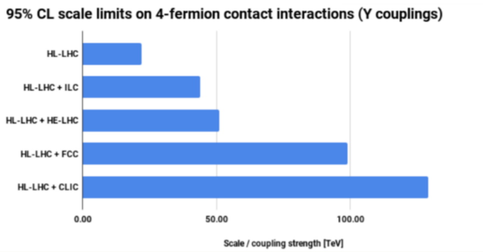


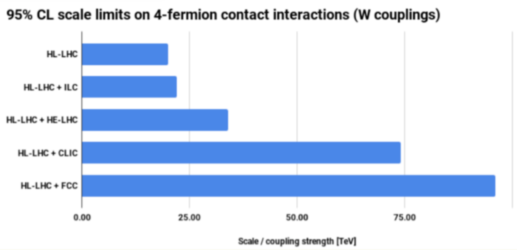
Maximum sensitivities from CLIC and FCC(ee+eh+hh)

New resonant states



Contact Interactions

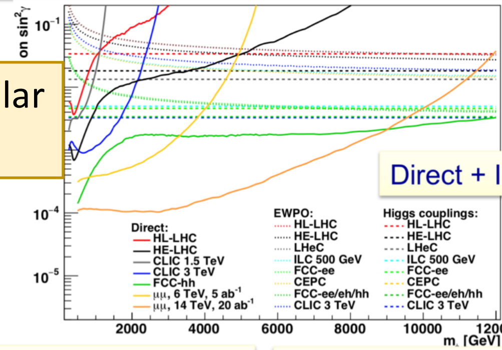




Sensitivity for ee colliders enhanced for couplings ≳ 1
(weak couplings → direct searches become more sensitive)
Searches for W' & charged fermion currents more effective at hadron colliders

Extended scalar sector

Direct searches: pp: main LHC result ZZ; hadron colliders: extrap in $\sqrt{s}$; $e^+e^- \to \nu\nu\varphi$; $\varphi \to hh \to bbbb$



Direct + Indirect

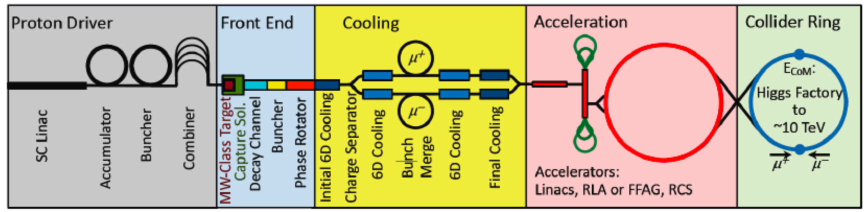
And much more

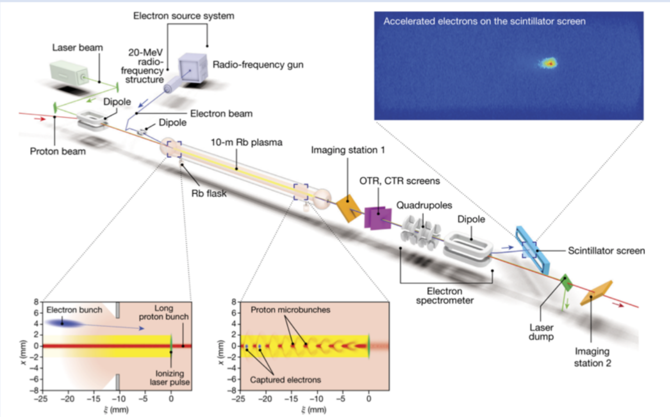
Future developments

Very interesting R&D projects

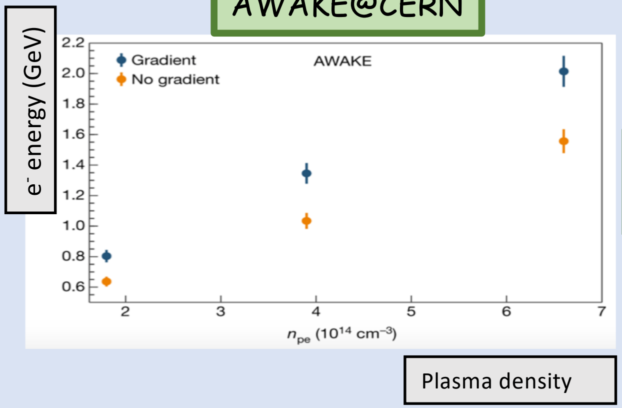
- Muon collider:
  - from proton beam (rcooling success: MICE)
  - from e+e- production (LEMMA)
- Plasma wakefield acceleration:
  - High gradients possible: ~100 GV/m
  - R&D progressing well but many challenges

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

2020 Strategy Statements

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.

2020 Strategy Statements

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.*

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

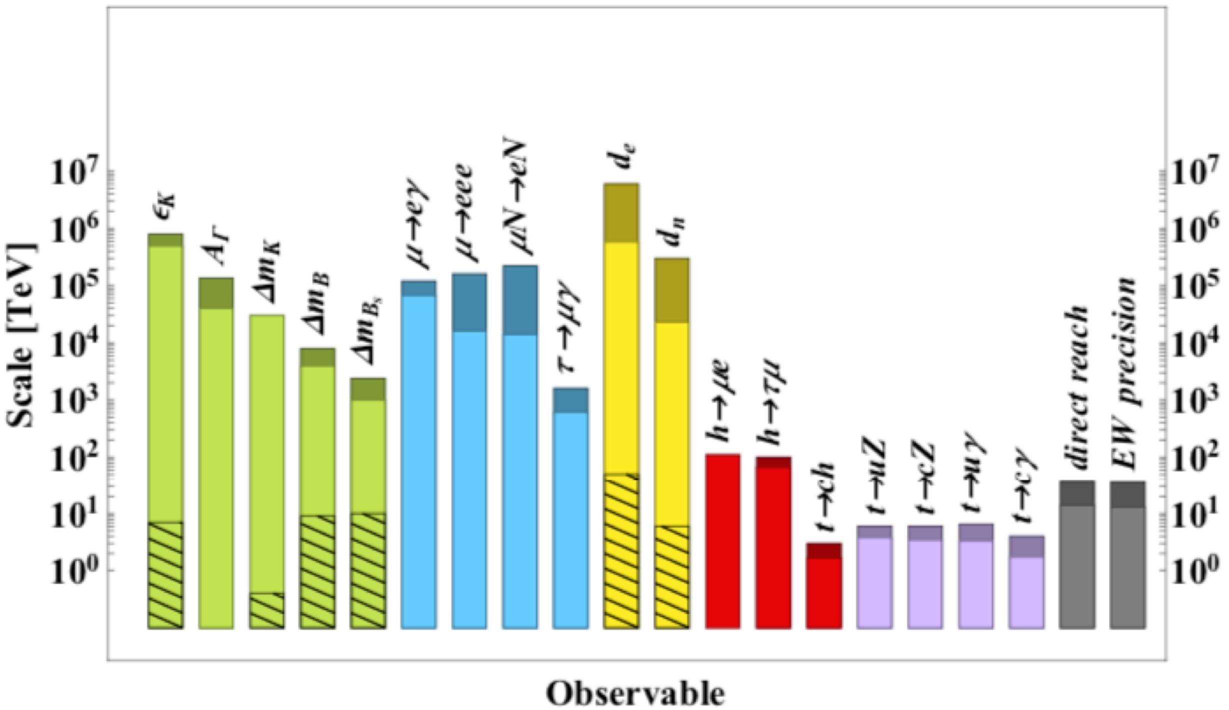


Fig. 5.1: Reach in new physics scale of present and future facilities, from generic dimension six operators. Colour coding of observables is: green for mesons, blue for leptons, yellow for EDMs, red for Higgs flavoured couplings and purple for the top quark. The grey columns illustrate the reach of direct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

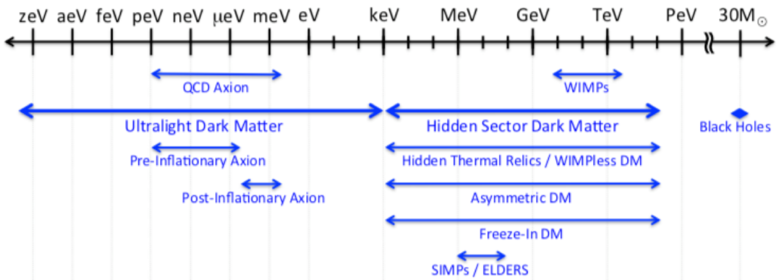
2020 Strategy Update

Dark matter/Dark sector

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

- Dark Sector
  - ➢ Search for dark photon

Too small mass ⇒ won't "fit" in a galaxy!



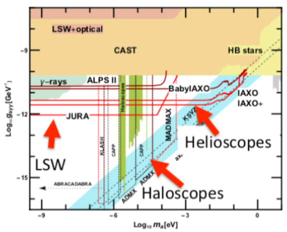
From MACHOs searches

Axion/ALP searches: Mature Key Techniques

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

Haloscopes
- 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
- STAX is a new idea RF based
- JURA is long term plan



Searches relevant for both QCD Axions and more general Axion-like particles (ALPs)

Lindner and Irastorza's talks

Standard Model → Portal → Dark Sector

DP = Dark Photon
DS = Dark Scalar
HNL = Heavy Neutral Lepton
ALP = Axion-Like Particle

BEAM DUMP PROJECTS AT CERN

EXPERIMENT	PERIOD	BEAM	PARTICLES ON TARGET	SIGNATURE	MODELS
NA64++(e)	2015-24	e 100 GeV	~5 10^{12}	invisible & visible e^+e^-	DP, ALPs
eSPS/LDMX	> 2026	e 16 GeV	10^{16}	invisible	DP, ALPs
AWAKE++	> 2026	e ~50 GeV	~10^{15}	visible e^+e^-	DP, ALPs
NA62++	> 2022	p 400 GeV	10^{18}	visible	DP, DS, HNL, ALPs
SHiP	> 2026	p 400 GeV	2 10^{20}	recoil & visible	DP, DS, HNL, ALPs
NA64++(μ)	> 2022	μ 160 GeV	5 10^{13}	invisible	DZ_{μ}, ALPs

NB: CERN offers unique opportunities with both lepton and hadron beams

LHCb and LHC-LLP dedicated projects (FASER, 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

			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								

Other activities essential for the field

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

European Strategy Update

2020 Strategy Statements

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 $10 \times M_{\odot}$
- 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 a 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 (CD0) 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.*

2020 Strategy Statements

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.

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