The 2020 Update of the European Particle Physics Strategy

ICHEP2020

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Secretary of the 2020 European Strategy Update

Outline
- General Introduction
- Preamble
- Short guide to all 20 statements
- Selected Strategy Statements: introduction and formulation

European Strategy Update

2020 Strategy Update

Organisation of the Update Process

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

- Update coordination – the Strategy Update Secretariat (SUS) (Secretary elected by Council, ex-officio chairs of the Scientific Policy Committee of CERN (SPC), of the European Committee for Future Accelerators (ECFA), of the National Lab's Directors (LDG))

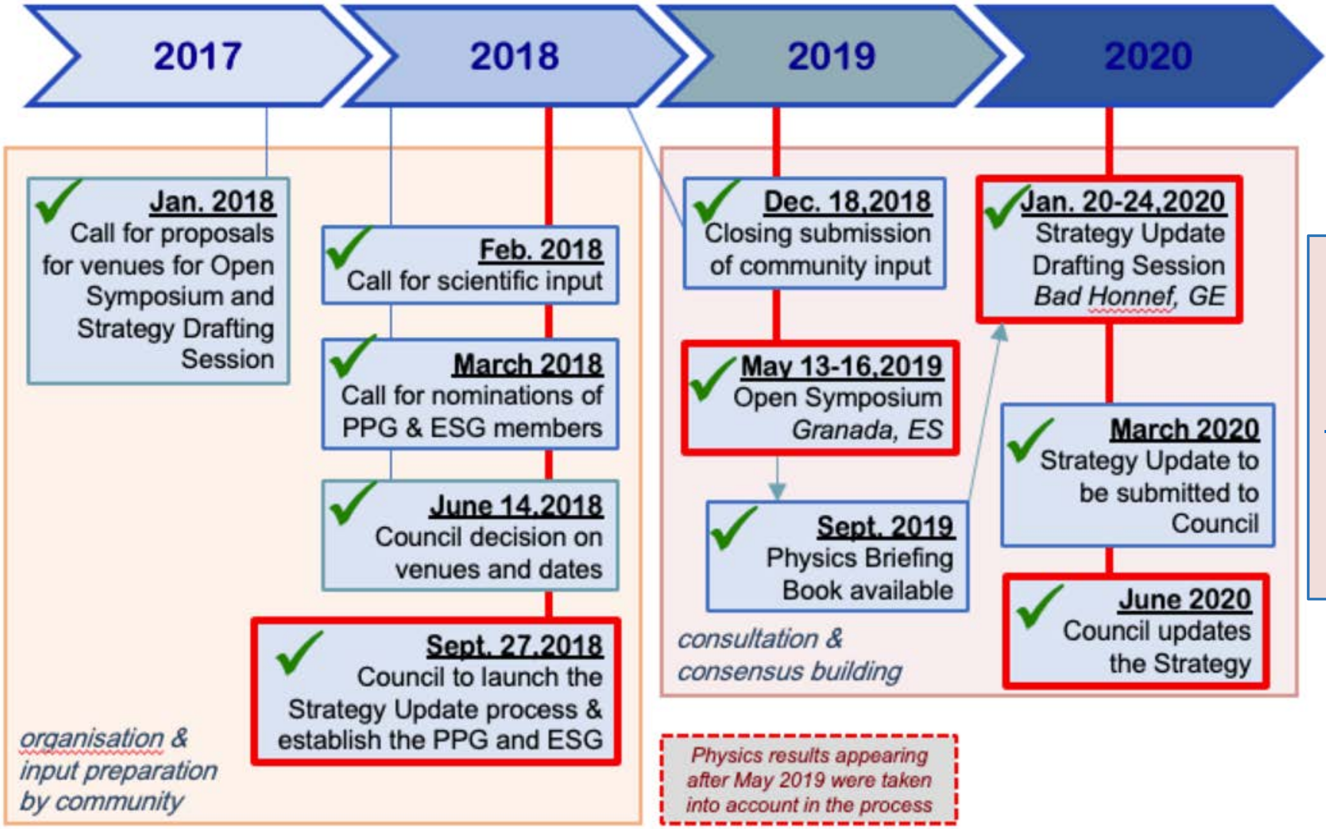
- Drafting of the Strategy Update document – responsibility of the European Strategy Group (ESG) (23 MS representatives, LDG members, SUS; Invitees: Associate MS, Observer States,… - see backup slide)

- 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)
  - Processing of the submitted input
  - Open Symposium with outcome summarized in the Briefing Book

- Strategy implementation – purview of CERN DG, under scrutiny of CERN Council

2020 Strategy Update

Timeline



2 Documents submitted to CERN Council

- 2020 Update of the European Strategy for Particle Physics (with preamble, statements, conclusion) (brochure)

- Deliberation Document (with in addition rational behind the statements) for information (brochure)

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

Preamble

Scientific background

- Many mysteries about the universe remain to be explored: **nature of dark matter, preponderance of matter over antimatter, origin and pattern of neutrino masses**
- Particle Physics develops technologies to probe ever smaller distance scales (higher energies)
- **Higgs** is a **unique particle** that raises profound questions about the fundamental laws of nature
  - ✓ measurement of Higgs properties is in itself a powerful tool to look for answers
    → **electron-positron collider as Higgs factory**
  - ✓ Higgs boson pair-production study is key to understanding the fabric of the universe
    → **collider with significantly higher energies than a Higgs factory**
- New realm of energies is expected to lead to new discoveries and provide answers to existing mysteries

European perspective

- It is essential for particle physics in Europe and for CERN to be able to propose a new facility after the LHC
- The 2020 Strategy update should aim to significantly extend knowledge beyond current limits and to drive innovative technological developments

2020 Strategy Statements

Guide through the statements

2 statements on **Major developments from the 2013 Strategy**

a) Maintain focus on successful completion of HL-LHC upgrade
b) Maintain 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 viable, 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) Play active role in supporting Open Science

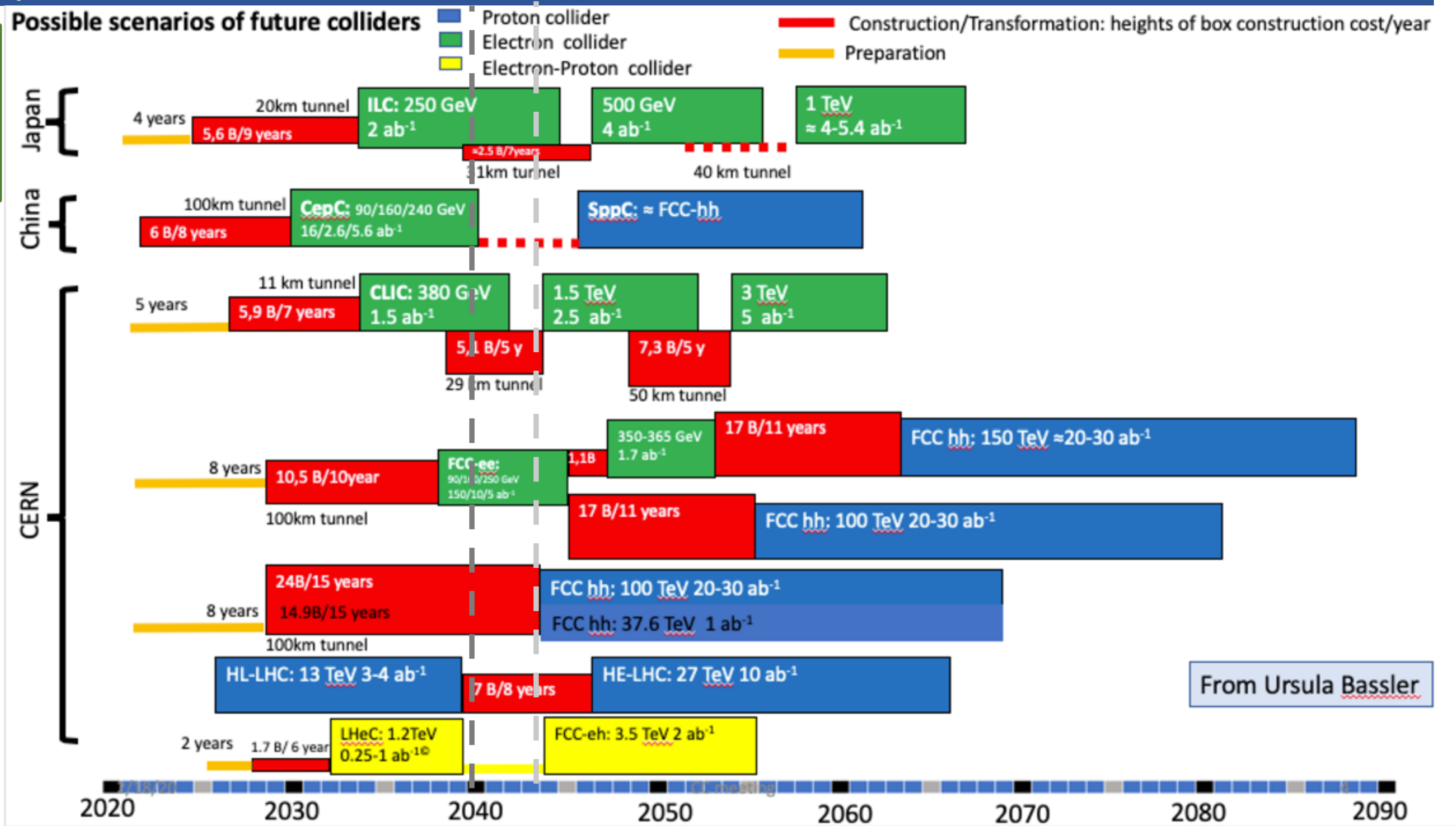
4 statements on **Environmental and societal impact**

a) Mitigate environmental impact of particle physics
b) Invest in next generation of researchers
c) Support knowledge and technology transfer
d) Spread 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



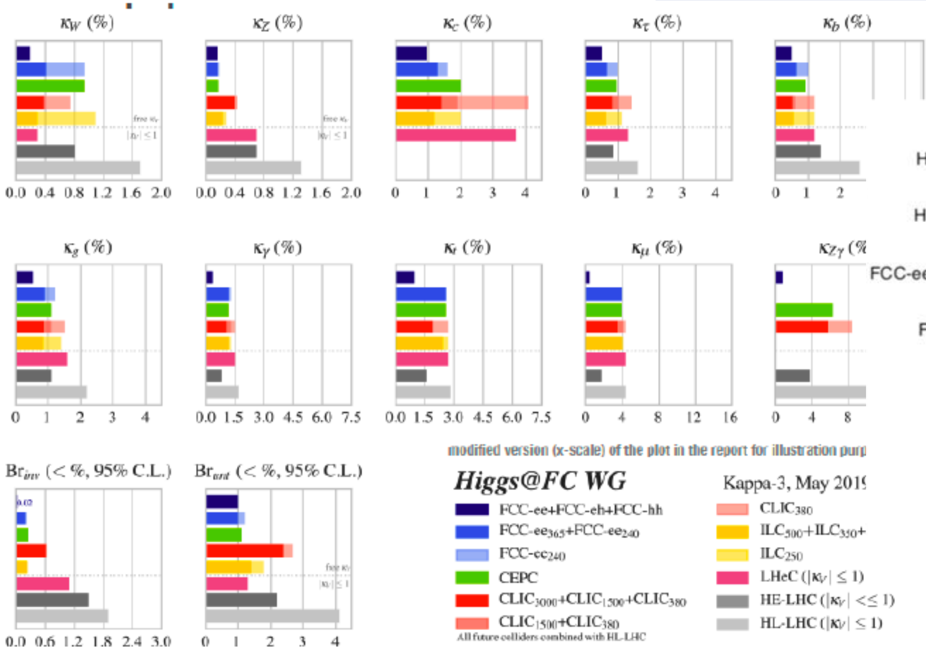
Precision physics with the Higgs

Comparison of Colliders: kappa-framework

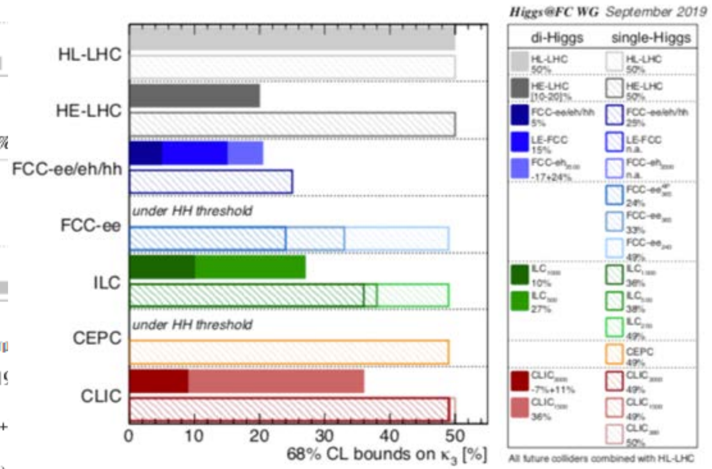
Some observations:

- **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



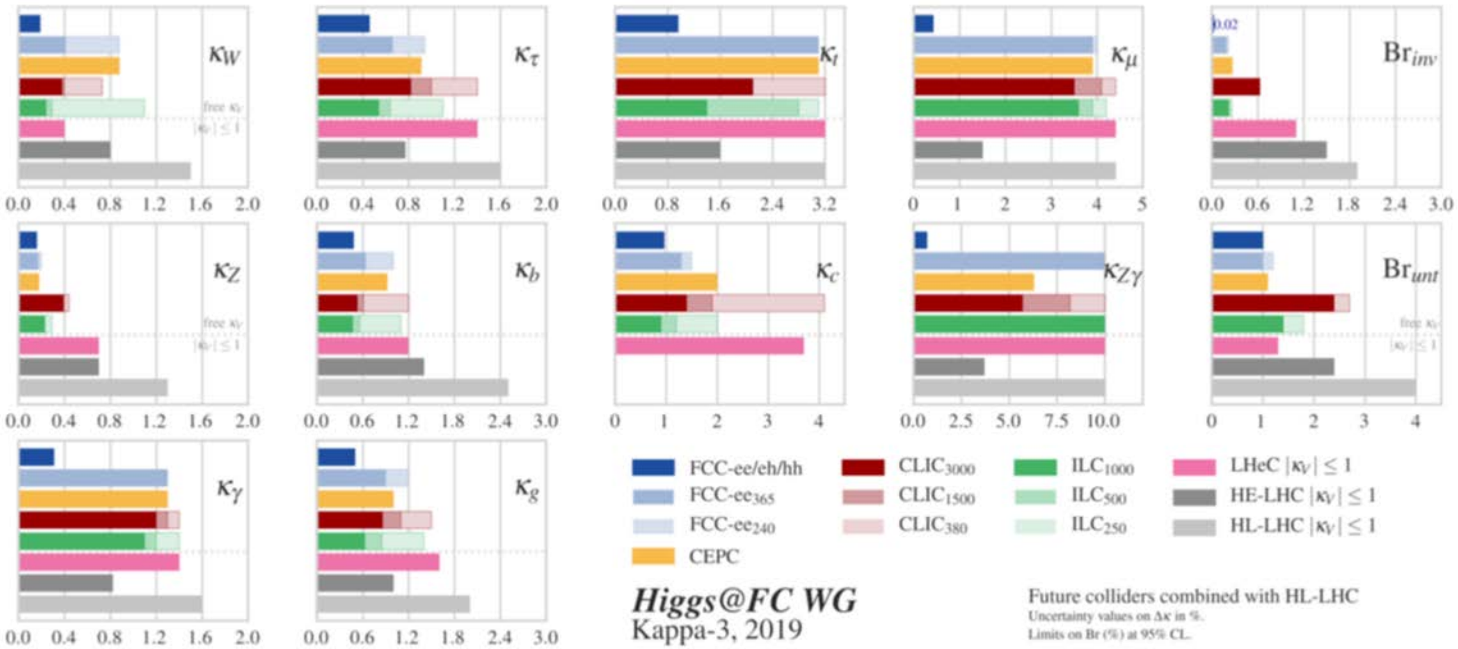
Higgs self-coupling



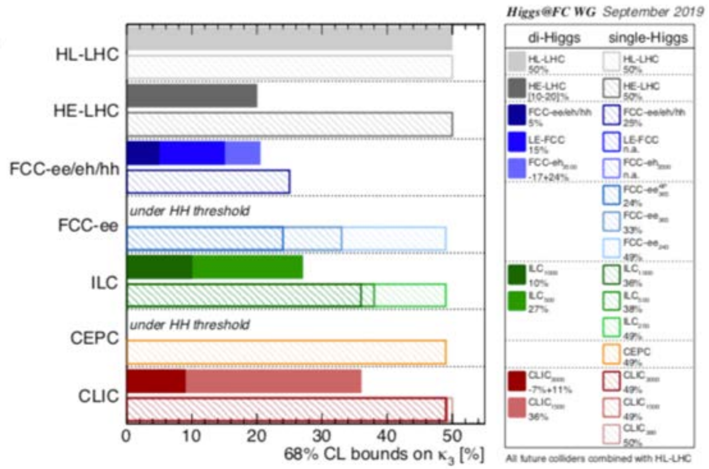
> ➢ A Higgs factory is needed, even if the ultimate goal would be the FCC-hh

Precision physics with the Higgs

Higgs couplings at different colliders arXiv 1905.03764



Higgs self-coupling

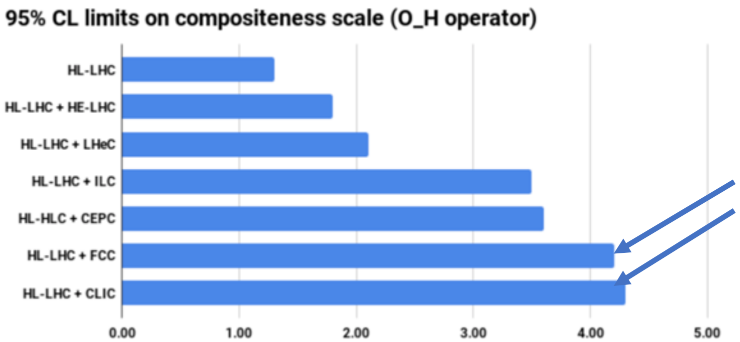


HL-LHC: 1 to 3%; proposed colliders improve by factor 2 to 10; Higgs factories comparable within factor 2;

➢ A Higgs factory is needed (BR untagged w/o assumptions), even if the ultimate goal is the FCC-hh

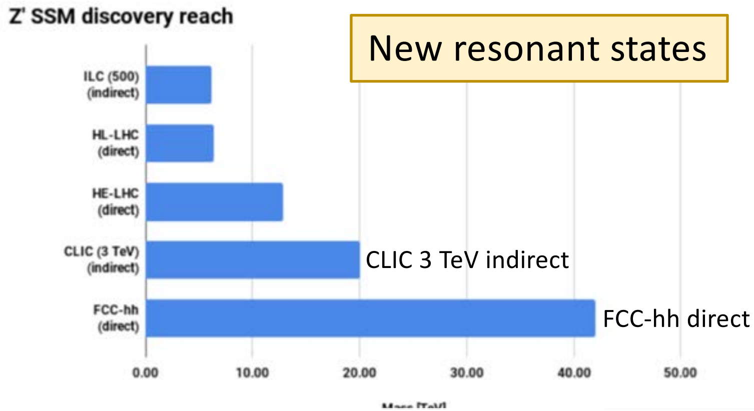
BSM at colliders

Higgs compositeness scale

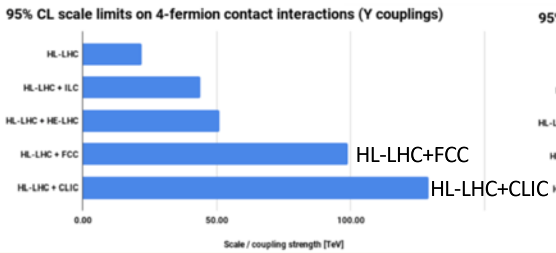


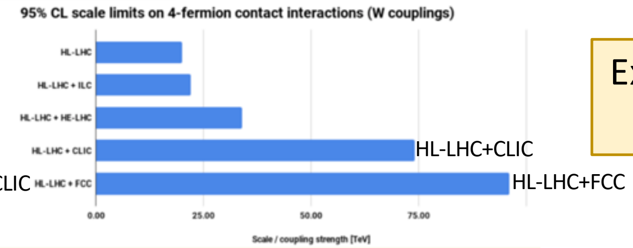
Maximum sensitivities from CLIC and FCC(ee+eh+hh)

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

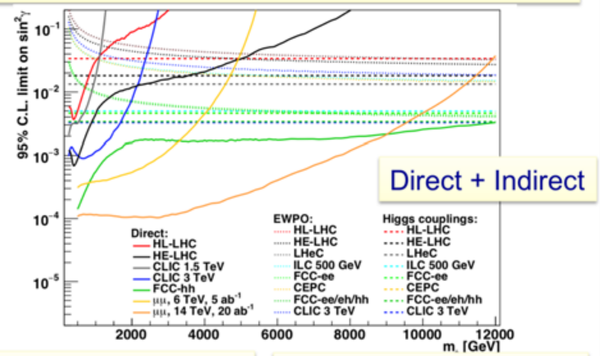
Extended scalar sector

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

FCC

CLIC

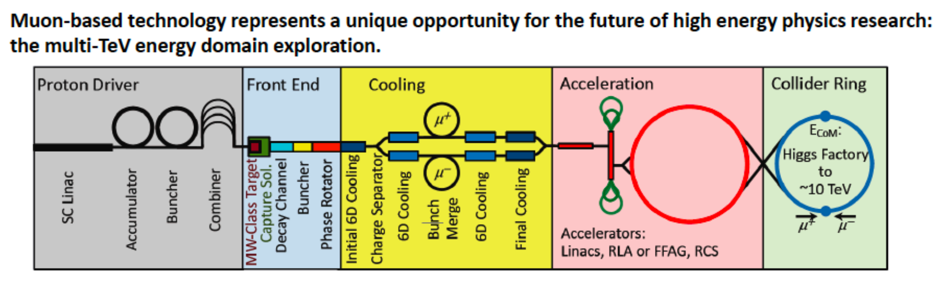
$\mu\mu$

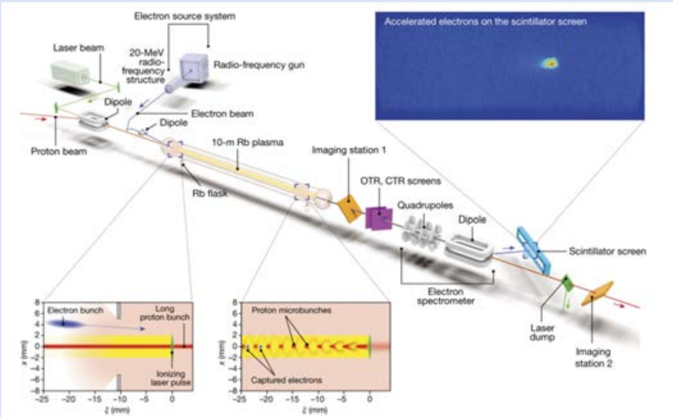


Future developments

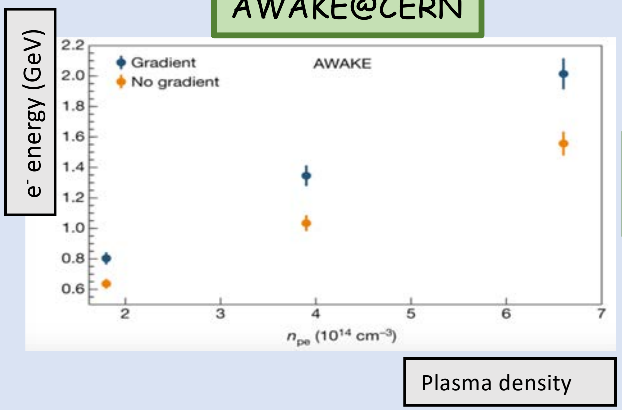
Very interesting R&D projects

- 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





AWAKE@CERN



Achieved 2 GeV over 10m
Gradient 200 MV/m

2020 Strategy Statements

High-priority future initiatives

- There are two clear ways to address the remaining mysteries: Higgs factory and exploration of the energy frontier
- Europe can 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 most promising for a future facility at the energy frontier.
- It is important therefore to launch a feasibility study for FCC 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

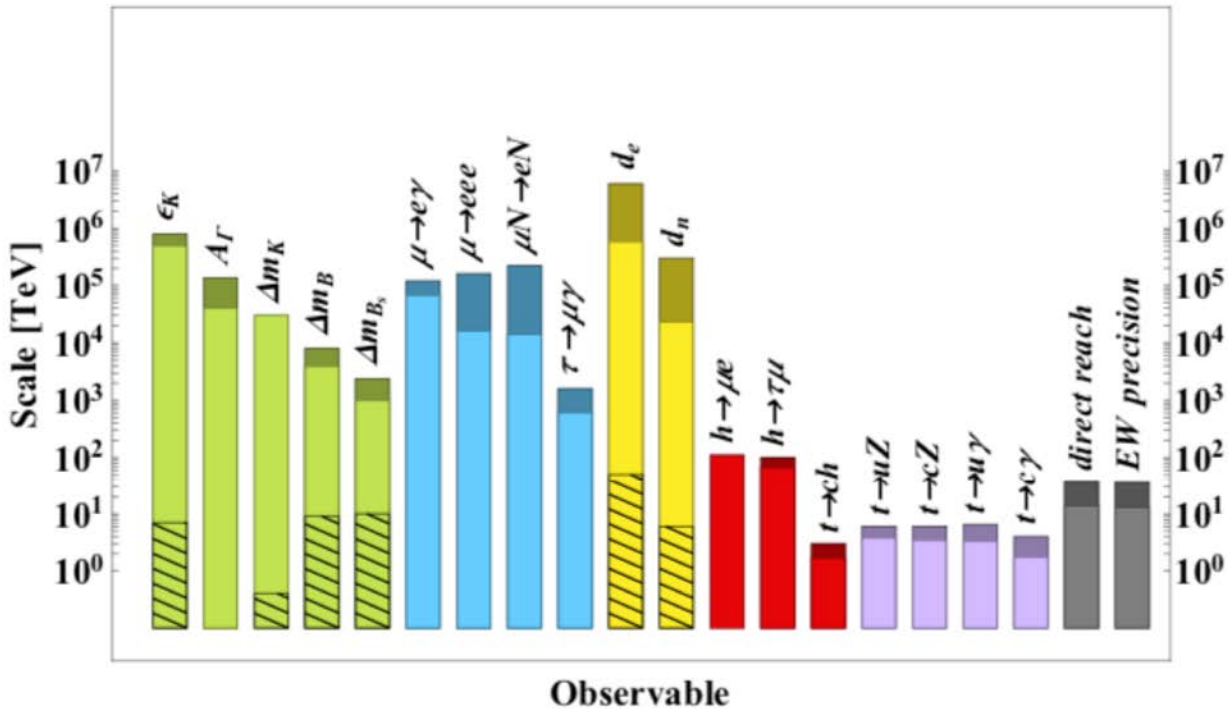
- The European particle physics community should develop an accelerator R&D roadmap focused on the critical technologies needed for future colliders, maintaining a beneficial link with other communities such as photon or neutron sources and fusion energy
- The roadmap should be established as soon as possible
- 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



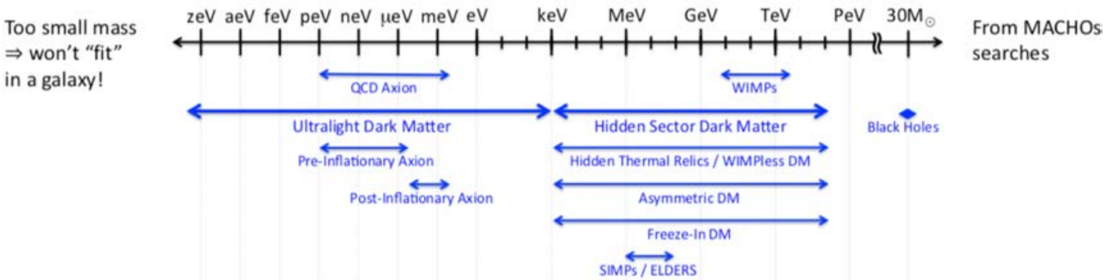
Reach in new physics scale from generic dimension 6 operators

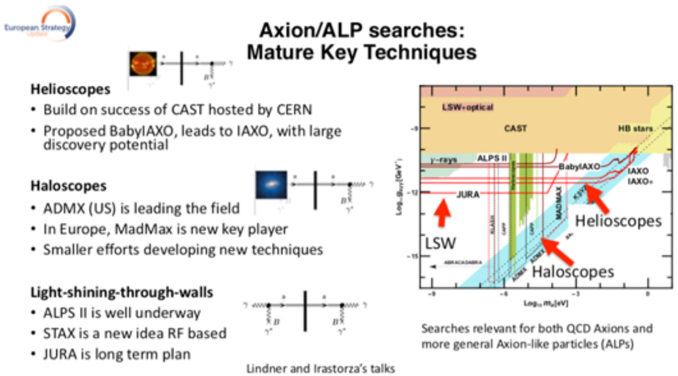
Fig. 5.1: Reach in new physics scale of present and future facilities, from generic dimension six operators. Colour coding of observables is: green for mesons, blue for leptons, yellow for EDMs, red for Higgs flavoured couplings and purple for the top quark. The grey columns illustrate the reach of direct 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





BEAM DUMP PROJECTS AT CERN

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

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

European Strategy Update

2020 Strategy Update

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

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
- 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.*

European Strategy Update

2020 Strategy Statements

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.*

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 long-term projects, the European plan needs to be coordinated with other regions of the world
- To remain attractive and dynamical, the field needs to meet the environmental and societal challenges as well as the aspirations of the next generation of researchers
- 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

The European 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 societal challenges. The updated Strategy is visionary and ambitious, but also realistic and prudent

On June 19, 2020 CERN's Council unanimously decided to update the Strategy
The updated Strategy is visionary and ambitious, but also realistic and prudent
It lays the foundations for a bright future for particle physics

2020 Strategy Statements

Back-up slides

Strategy Secretariat

- H. Abramowicz (Chairperson)
- J. D'Hondt (ECFA Chairperson, *ECFA: European Committee for Future Accelerators*)
- K. Ellis (SPC Chairperson, *SPC: Science Policy Committee @ CERN*)
- L. Rivkin (European LDG Chairperson, *LDG: Lab Directors Group*)

Contact: EPPSU-Strategy-Secretariat@cern.ch

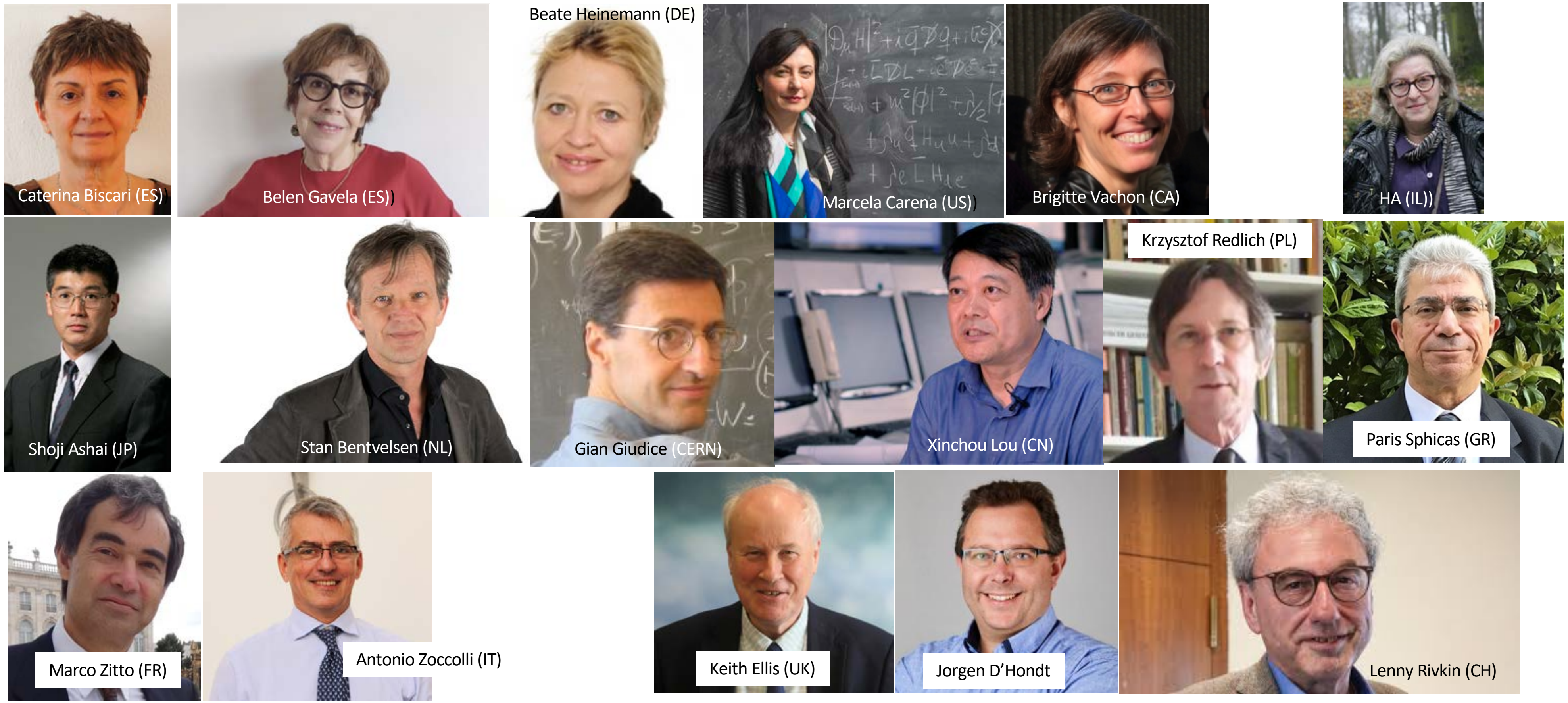
Physics Peparatory Group

- *Strategy Secretariat*
- Caterina Biscari (ES), Belen Gavela (ES), Beate Heinemann (DE), Krzysztof Redlich (PL) – *delegates nominated by SPC*
- Stan Bentvelsen (NL), Paris Sphicas (GR), Marco Zito (FR), Antonio Zoccoli (IT) – *delegates nominated by ECFA*
- Gian Giudice (*CERN*) – *nominated by CERN*
- Shoji Asai (Japan) and Xinchou Lou (China) - *delegates from Asia nominated by ICFA*
- Marcela Carena (US) and Brigitte Vachon (Canada) - *delegates from the Americas nominated by ICFA*

Responsible to organize the Open Symposium and to deliver to the European Strategy Group (ESG) a Briefing Book.

2020 Strategy Update

Faces behind the Strategy science – Physics Preparatory Group



European Strategy Update

Names at
http://europeanstrategyupdate.web.cern.ch/composition-esg

2020 Strategy Update

Composition of the ESG

European Strategy Group (ESG) composition, adopted by Council, December 2013:

- the Strategy Secretary (acting as Chairperson),
- one representative appointed by each CERN Member State,
- one representative for each of the Laboratories participating in the major European Laboratory Directors' meeting, including its Chairperson,
- the CERN Director-General,
- the SPC Chairperson,
- the ECFA Chairperson.

Responsible to deliver a draft Strategy Update to Council.

Invitees

- the President of the CERN Council,
- one representative from each of the Associate Member States,
- one representative from each Observer State,
- one representative from the European Commission and JINR,
- the Chairpersons of ApPEC, FALC, ESFRI, and NuPECC,
- the members of the Physics Preparatory Group.