European Strategy on Particle Physics

XLVIII International Meeting on Fundamental Physics

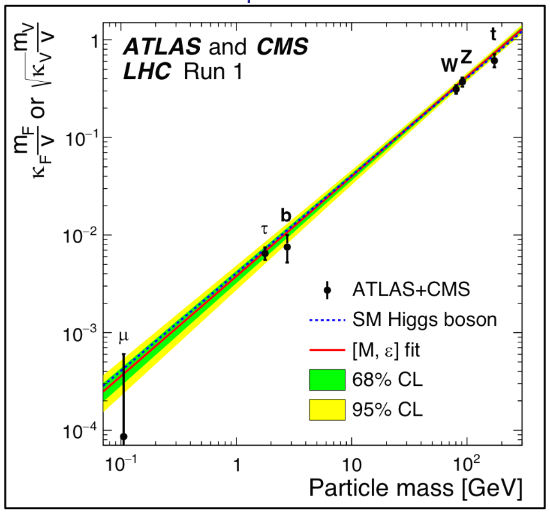
Benasque / Spain
6 – 11 September 2021

Karl Jakobs, ECFA Chair
University of Freiburg / Germany

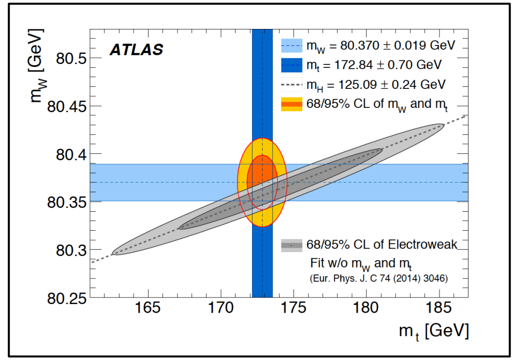
ECFA
European Committee for Future Accelerators

LHC: 10 Years at the Energy Frontier

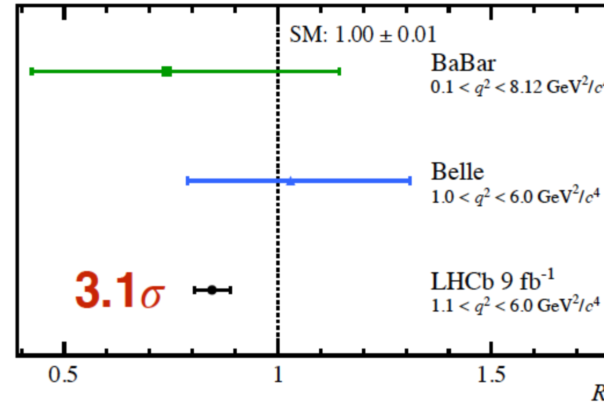
Discovery of the **Higgs boson** and precise measurement of its parameters



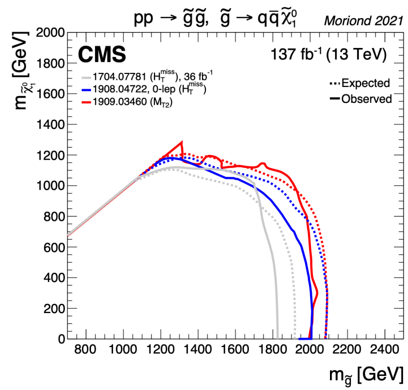
Precision tests of the Standard Model (SM)



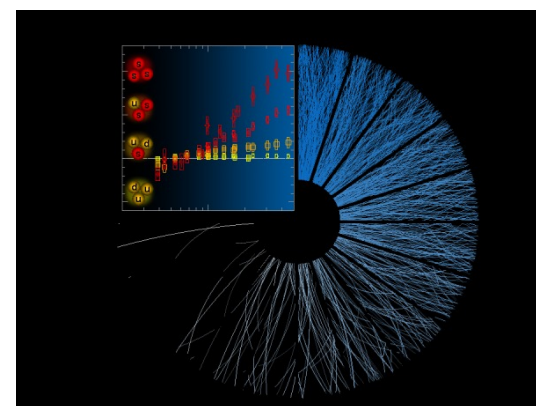
Challenging the SM in Flavour Physics



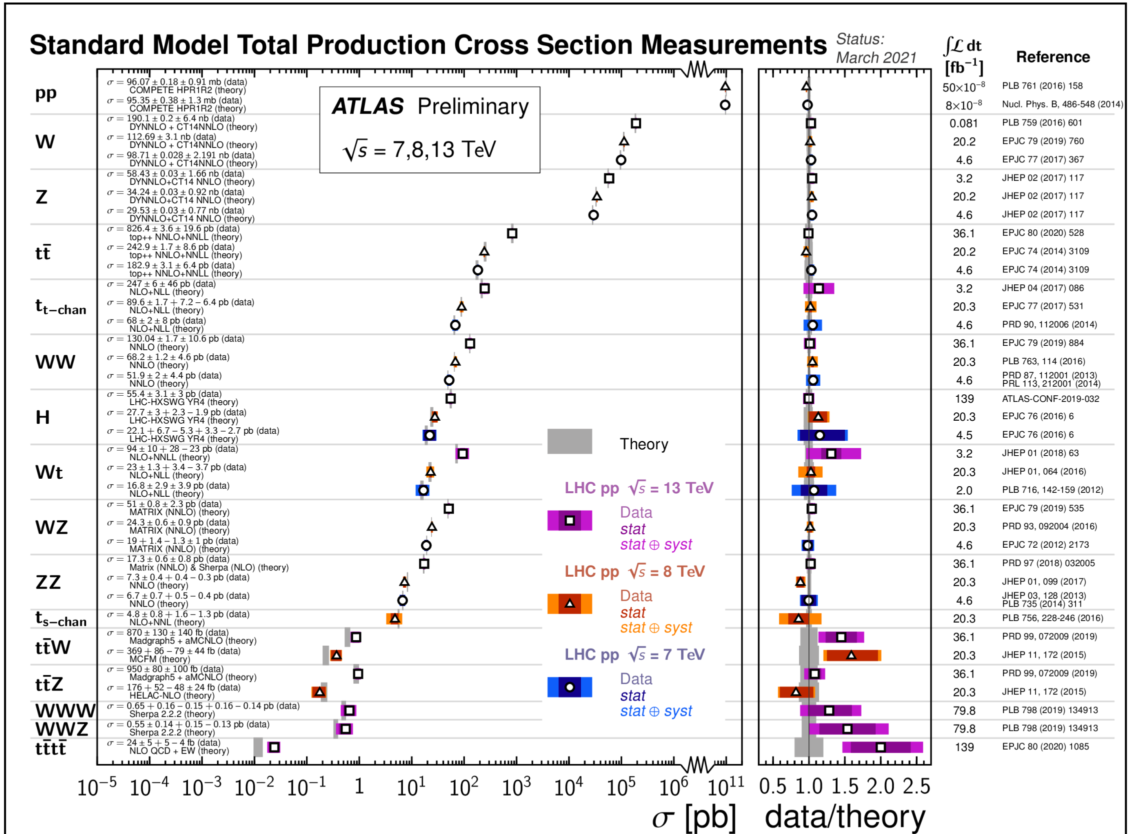
Constraints on **Physics Beyond SM**



Exploring **QCD at extreme conditions**



LHC: 10 Years at the Energy Frontier



- Triumph of **experiment** and **theory**
- The Standard Model provides a successful description of the data (except neutrino masses)

but:

- Increasing tension in the flavour sector
- Many open questions…

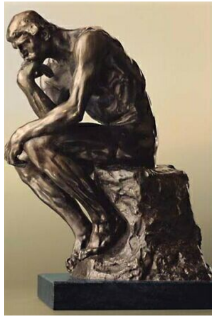
Open Questions

Higgs Sector
Explore the properties of this new particle with high precision!
It may be the key to understand physics Beyond the Standard Model → precision
Why is the Higgs boson so light (naturalness/hierarchy problem)?

Flavour
Why three fermion families?
Why do neutral leptons, charged leptons and quarks behave differently?
What is the origin of neutrino masses and oscillations?

Dark Matter
What is the nature of dark matter?

Cosmology and Gravity
What is the cause of the Universe's accelerated expansion ?
What is the origin of the universe matter-antimatter asymmetry?
Why is Gravity so weak ?

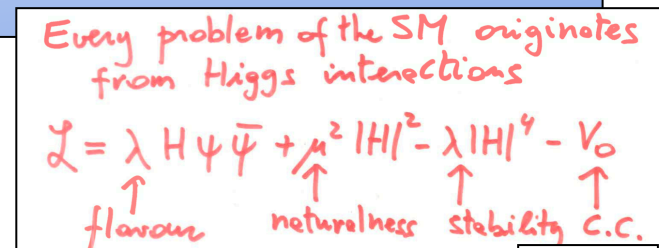


New physics required but no clear indication of the E-scale

Understanding the Higgs Sector

H is not just … "another particle":
- ❑ Profoundly different from all elementary particles discovered previously
- ❑ It got almost no properties; carries a different type of "force"
- ❑ Related to the most obscure sector of SM
- ❑ Linked to some of the deepest structural questions (flavour, naturalness, vacuum, ...)

→ It provides a unique door into new physics, and calls for a very broad and challenging experimental programme which will extend for decades



G. Giudice

↓

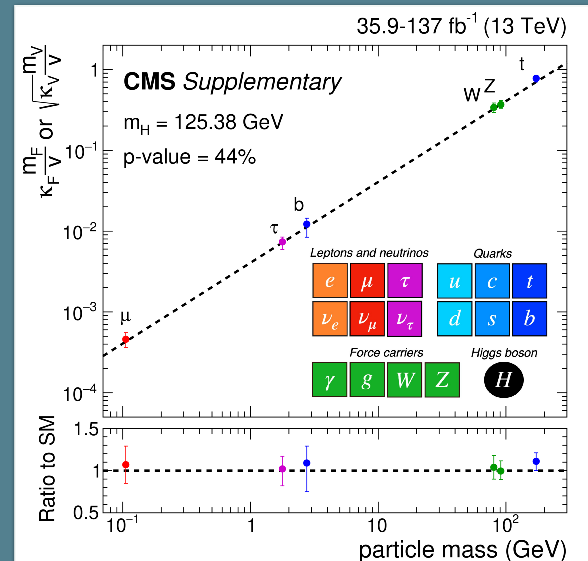
- ❑ Precision measurements of couplings (as many generations as possible, loops, …)
- ❑ Forbidden and rare decays (e.g. H→ τμ) → flavour structure and source of fermion masses
- ❑ H potential (HH production, self-couplings) → EWSB mechanism
- ❑ Exotic decays (e.g. H→ E_T^{miss}) → new physics ?
- ❑ Other H properties (width, CP, …)
- ❑ Searches for additional H bosons, etc.

F. Gianotti (LHCP 2021)

SO WHAT HAVE WE HAVE LEARNT?

•Let's recap:

- Measurements of Mass (to 0.11%!), Width, CP
- Main production modes explored in depth by now, with precise measurements of the signal strength/cross section (down to 10% precision)
- Coupling to the SM particles well established for the main decay modes, and already at evidence level for several of the statistically dominated ones (eg: muons)
- Measurements going differential, and towards precision in properties
- Interpretations in terms of Effective Field Theories (EFT) start to be the norm
- Rarer processes starting to become accessible

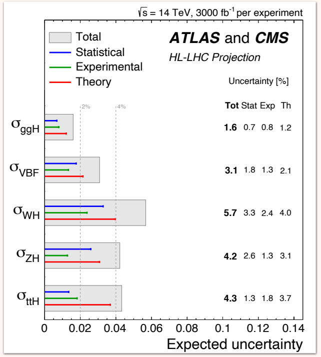


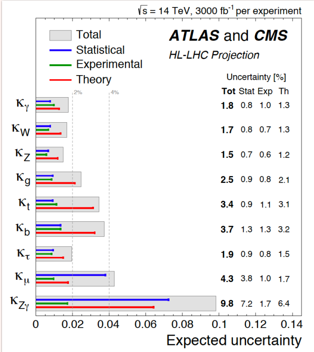
Can we put together all the information to have a global view of Higgs@LHC?

M. Cepeda, Benasque 2021

Large progress can be made at the (HL)-LHC

HOW WELL *CAN* WE KNOW THE HIGGS COUPLINGS?





- We've only tapped a small fraction of the LHC potential as a Higgs-Hunting machine
- Target at the end of the HL-LHC: cross sections, branching ratios and kappas to the few percent level (except for stat-dominated final states)

María Cepeda (CIEMAT) 32 Benasque, Septiembre 2021

… but we need even higher precision

HOW WELL *SHOULD* WE KNOW THE HIGGS COUPLINGS?

SMALL CORRECTIONS EXPECTED IN MANY BSM MODELS

If new physics is at 1 TeV:

	$\delta\kappa_V$	$\delta\kappa_b$	$\delta\kappa_\gamma$
Singlet	<6%	<6%	<6%
2HDM (large t_β)	~1%	~10%	~1%
MSSM	~.001%	~1.6%	~-.4%
Composite	~-3%	~-(3-9)%	~-9%
Top Partner	~-2%	~-2%	~1%

Patterns of deviations can pinpoint specific BSM physics

- Generically new physics effects on couplings $\sim \frac{v^2}{M^2} \sim \mathcal{O}(6\%)$ for M=1 TeV
- Only now are we approaching sensitivity where we expect deviations

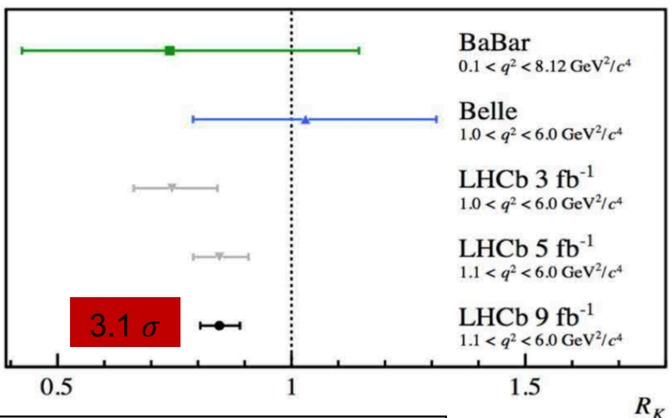
Sally Dawson

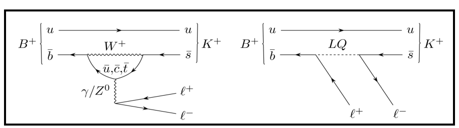
María Cepeda (CIEMAT) 33 Benasque, Septiembre 2021

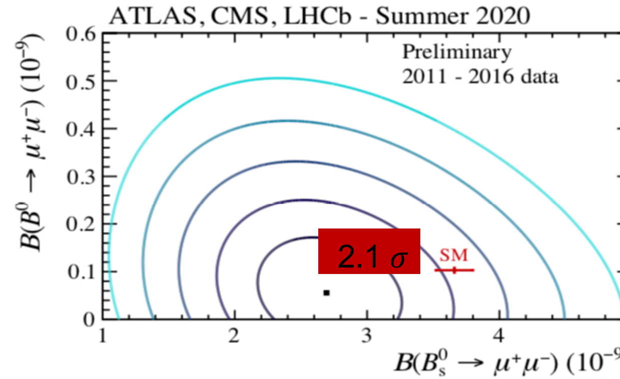
M. Cepeda, Benasque 2021

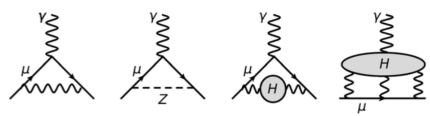
Flavour Anomalies

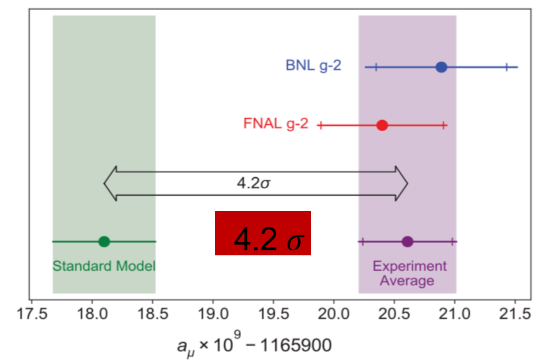
$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to J/\psi\,(\to \mu^+\mu^-)K^+)} \Bigg/ \frac{\mathcal{B}(B^+ \to K^+e^+e^-)}{\mathcal{B}(B^+ \to J/\psi\,(\to e^+e^-)K^+)}$$











Recent **anomalies, if** consolidated, may indicate (a close) **scale of new physics** (and drive a paradigm shift in particle physics)

see also talk by J.M. Camalich, Benasque 2021

The outstanding questions are compelling, difficult and interrelated → can only be successfully addressed through a variety of approaches (thanks also to strong advances in accelerator and detector technologies): particle colliders, neutrino experiments, cosmic surveys, dark matter direct and indirect searches, measurements of rare processes, dedicated searches (e.g. axions, dark-sector particles), etc.

	High-E colliders	Dedicated high-precision experiments	Neutrino experiments	Dedicated searches	Cosmic surveys
H, EWSB	x	x		x	
Neutrinos	x (ν_R)		x	x	x
Dark Matter	x			x	x
Flavour, CP, matter/antimatter	x	x	x	x	x
New particles, forces, symmetries	x	x		x	
Universe acceleration					x

F. Gianotti (LHCP 2021)

Historically, high-energy accelerators have been one of the best tools for exploration

1) Scientific diversity, and combination of complementary approaches, are crucial to explore directly and indirectly the largest range of E scales and couplings, and to properly interpret signs of new physics with the goal to build a coherent picture of the underlying theory

2) Global coordination and optimisation of the particle physics programme is necessary to maximise the opportunities of the field, given so many exciting physics questions and the cost and complexity of the projects

Main lines of research at present and future colliders

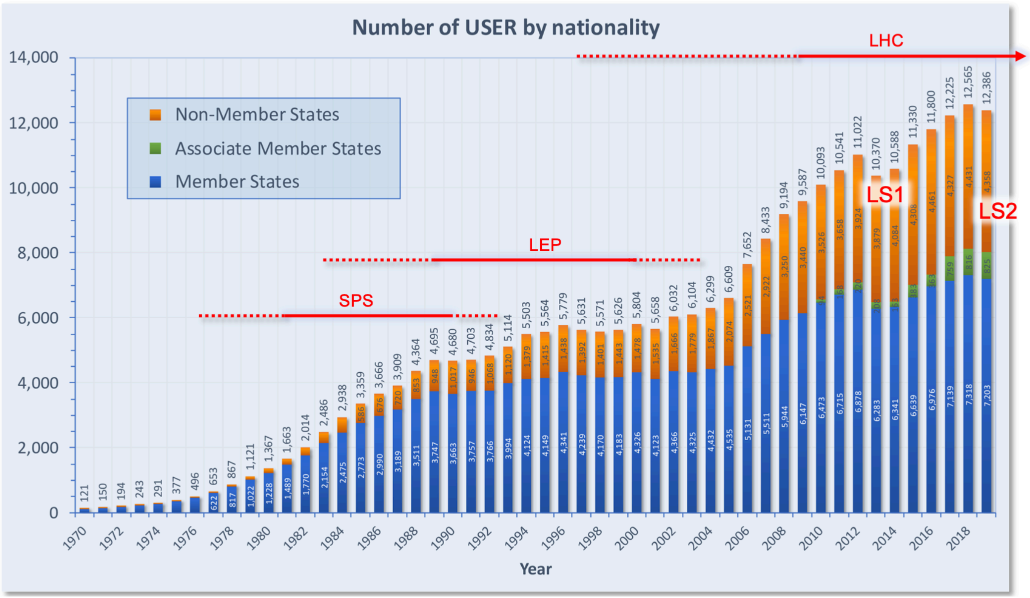
- **Detailed studies of the Higgs boson** (only possible at colliders)

  → *a "guaranteed deliverable"*

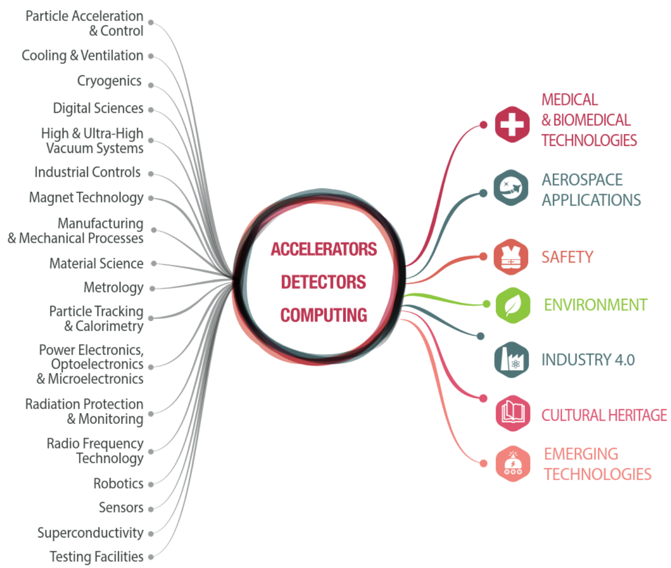
- **Searches for new physics**: directly through observation of new particles and indirectly through precise measurements revealing deviations from SM expectations

CERN’s Leading Role in Particle Physics

CERN leading role in particle physics, its innovative wide-ranging technologies, and its large community (~17’000 people) come primarily from its “flagship project” **LHC**



CERN’s Leading Role in Particle Physics



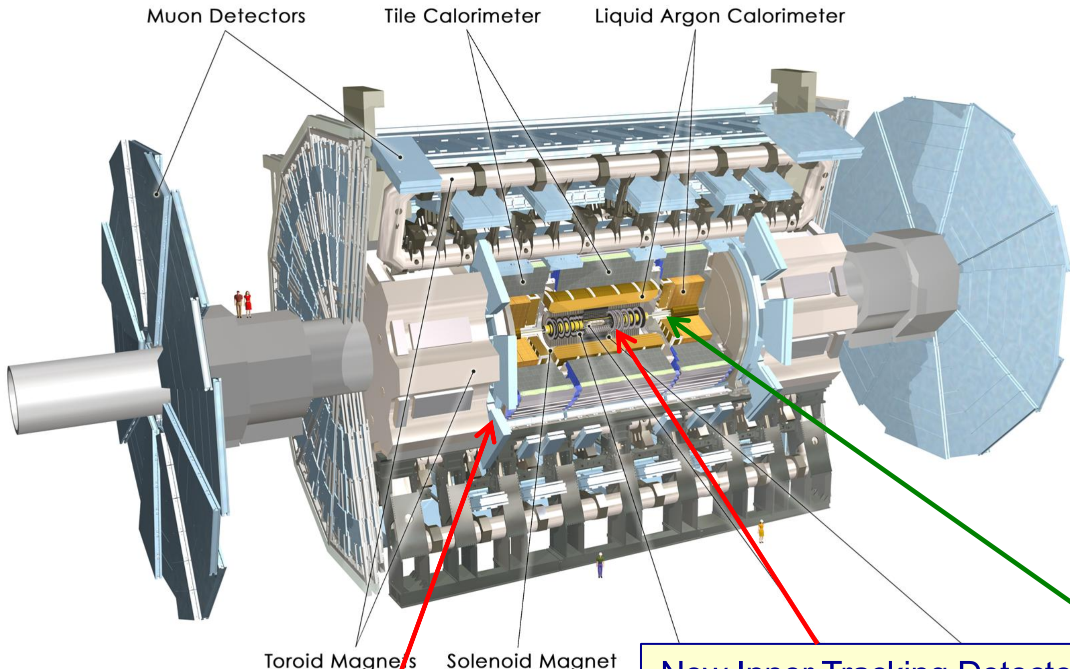
In addition, CERN has a huge technological innovation capability and is a prime example of a highly successful European Cooperation

To maintain CERN and its leading role a new flagship project, following the LHC and strongly motivated by physics is needed!

High-Luminosity LHC

The successful realisation of the HL-LHC machine and the challenging upgrades of the experiments keeps the CERN community busy for several years to come

Example: ATLAS Phase-II Upgrade



Upgraded Trigger and Data Acquisition System:

- L0: at 1 MHz
  (capable of evolving to a dual-level architecture with L0 at 4 MHz)
- Improved Event Filter
  (output rate of 10 kHz, hardware tracking as co-processor)

Electronics Upgrade :
- LAr Calorimeter
- Tile Calorimeter
- Muon system

New Inner Tracking Detector
(all silicon tracker, up to $|\eta| =4$)

High granularity timing detector
(forward region)

New muon chambers
in the inner barrel region

2020 Update of the European Strategy for Particle Physics

*A **two-year process involving the whole community** and **aiming at developing a common vision for the future of particle physics in Europe**.*

- Particle-physics community across universities, laboratories and national institutes was invited to submit written input by 18 December 2018.
- Scientific Open Symposium in Granada, Spain (13 - 16 May 2019), where the community was invited to debate the future orientation of European particle physics.
- Writing of a **"Briefing Book"** followed by a Strategy Drafting Session in Bad Honnef, Germany, in January 2020
- *Update of the Strategy by CERN Council in June 2020*

Update of the European Strategy for Particle Physics

1. Major developments from the 2013 Strategy

...

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.***

…

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).

Update of the European Strategy for Particle Physics

2. General considerations for the 2020 update

...
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.*

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

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

Update of the European Strategy for Particle Physics

3. High-priority future initiatives

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:

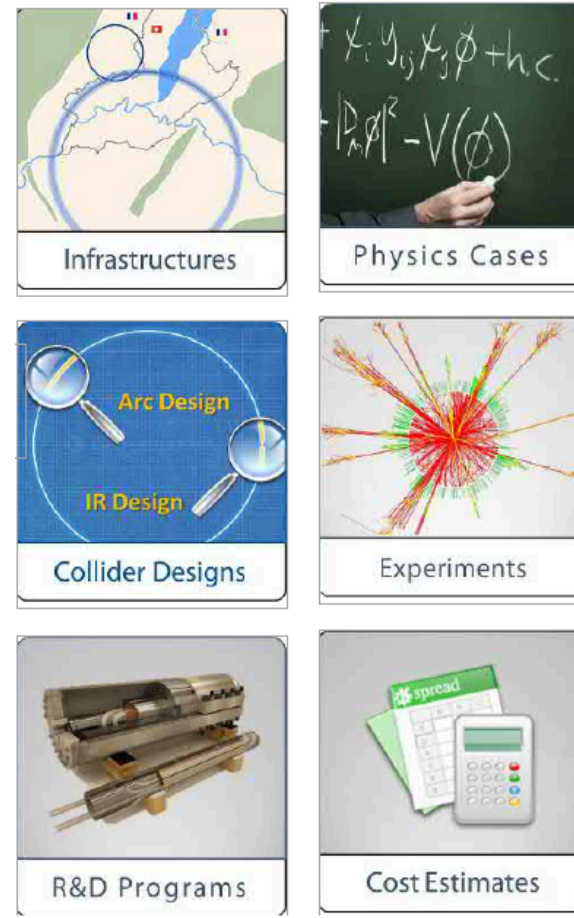
- *the particle physics community should ramp up its R&D effort focused on advanced accelerator technologies, in particular that for high-field superconducting magnets, including high-temperature superconductors;*
- *Europe, together with its international partners, should investigate the technical and 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.

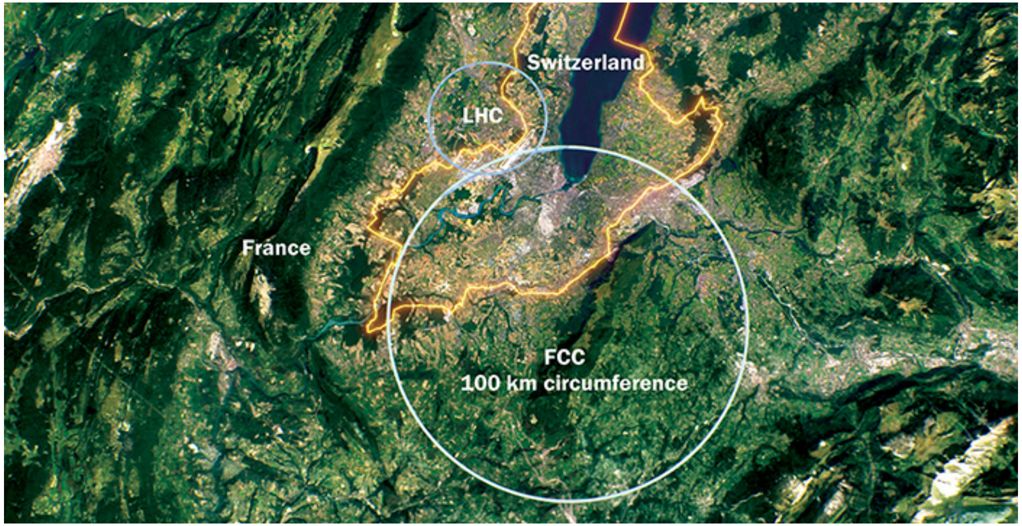
FCC Feasibility Study and its Major Goals

- Optimisation of placement and layout of the ring and demonstration of the geological, technical, environmental and administrative feasibility of the tunnel and surface areas;
- Pursuit, together with the Host States, of the preparatory administrative processes required for a potential project approval;
- Optimisation of the design of the colliders and their injector chains;
- Elaboration of a sustainable operational model for the colliders and experiments
(human and financial resources, environmental aspects and energy efficiency);
- Identification of substantial resources from outside CERN's budget for the implementation of the first stage of a possible future project;
- Consolidation of the physics case and detector concepts for both colliders.

Studies have started, approved by CERN Council in June 2021



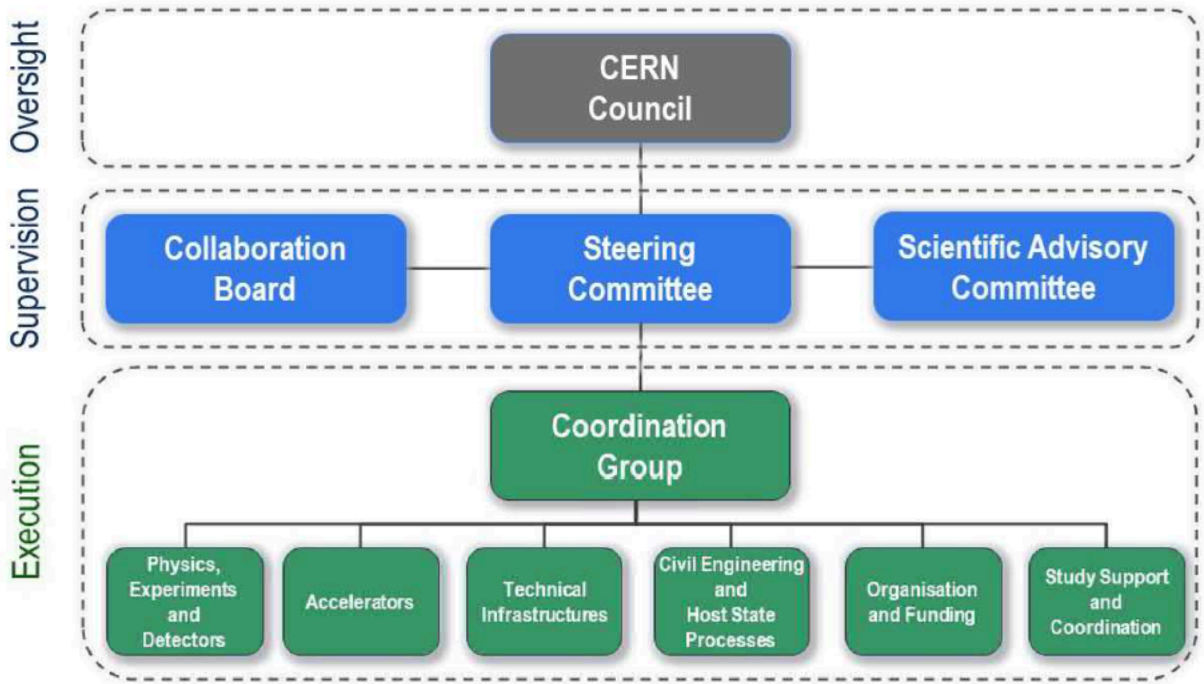
FCC Feasibility Study: Major Objectives



- Tunnel: assess geological, technical, administrative, environmental feasibility → aim is to demonstrate there is no show-stopper for ~100 km ring in Geneva region
- Technologies: superconducting high-field magnets and RF accelerating structures; high-efficiency power production; energy savings and other sustainable technologies
- Funding: development of funding model for first-stage machine (FCC-ee and the tunnel, total ~ 10 BCHF) and identification of substantial resources from outside CERN's budget
- "Consensus building": gathering scientific, political, societal support → communication campaign targeting scientists, governmental and other authorities, industry, general public

→ Release Feasibility Study Report by end 2025

Organisational Structure of the FCC Feasibility Study



Roadmap for Accelerator R&D

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.

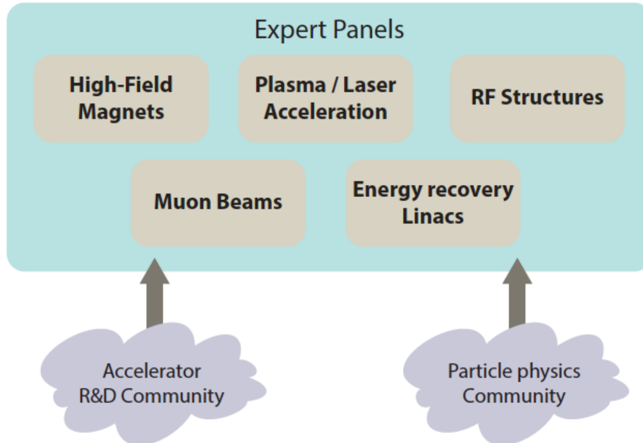
Lab Directory Group (LDG) has been Mandated to develop this roadmap
(LDG: Directors of the Large Particle Physics Laboratories and CERN)

LDG: European "Lab Directors Group" (10 labs)
- CERN, CIEMAT, DESY, IRFU, IJCLAB, NIKHEF, LNF, LNGS, PSI, STFC-RAL
- lab-to-lab communications with a view to address together the ESPP
- current chairperson: Dave Newbold (STFC-RAL)

Deliberation Document:
" … This roadmap should be established as soon as possible in close coordination between the National Laboratories and CERN."

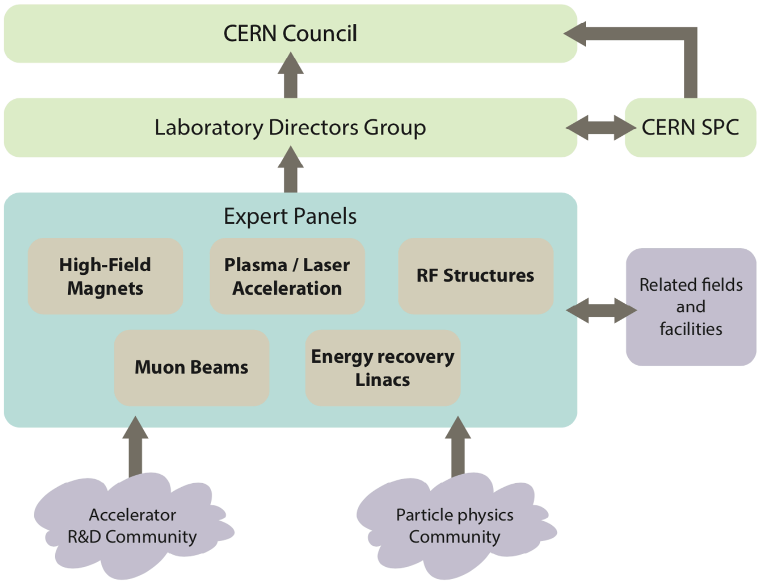
Roadmap for Accelerator R&D (cont.)

- Provide an agreed structure for a coordinated and intensified programme of particle accelerator R&D, including new technologies, **to be coordinated across national laboratories**
- Be based on the goals of the European Strategy, but defined in its implementation through consultation with the community and, where appropriate, through the **work of Expert Panels**
- Take into account, and coordinate with, international activities and work being carried out in other related scientific fields, including development of new large-scale facilities
- **Specify a series of concrete deliverables, including demonstrators, over the next decade;**
- **Designed to inform, through its outcomes, subsequent updates to the European Strategy**



Accelerator R&D Roadmap planned to be released by end of 2021

Roadmap for Accelerator R&D (cont.)



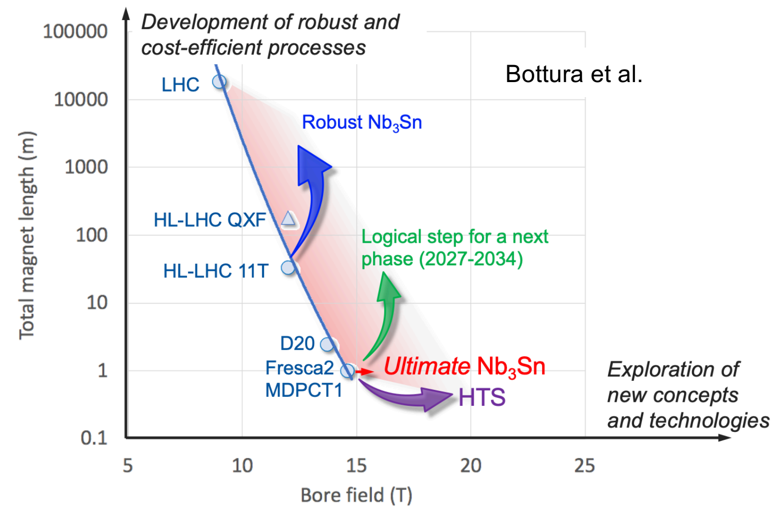
High-field Superconducting Magnets

- Key technology for future accelerators (hadron colliders, muon colliders, neutrino beams, …)
- To reach the required field strength of 16 – 20 T for FCC_hh, new technologies have to be **established and brought into industrial production**

Present candidates: Nb_3Sn or High-Temperature Superconducting (HTS), …)

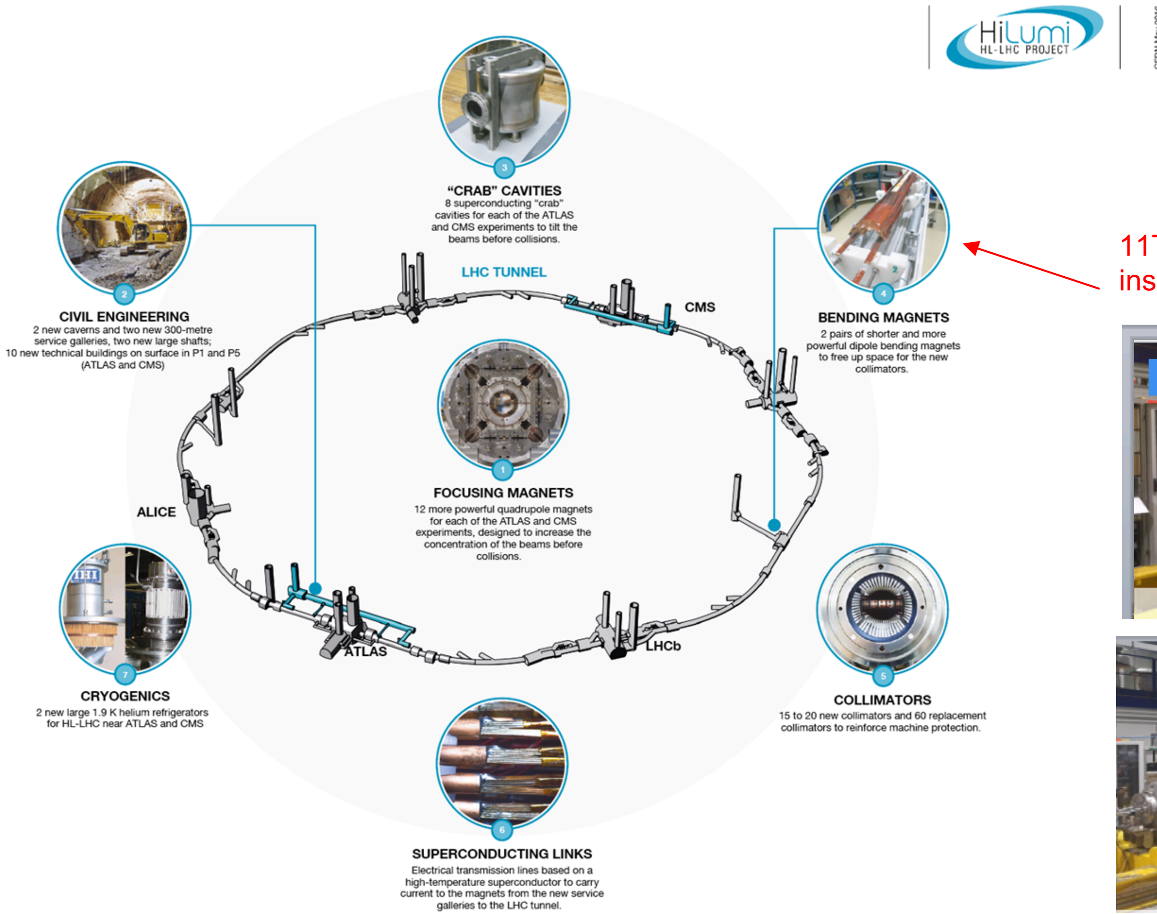
- So far small magnets have been successfully built and operated, however, scale up to longer magnets is a challenge!
  e.g. 11T Nb3Sn magnets will not be installed in Run 3, but needed for HL-LHC

  → a long way to go!
  Europe must intensify R&D (more resources (people, money,..), close cooperation with industry)



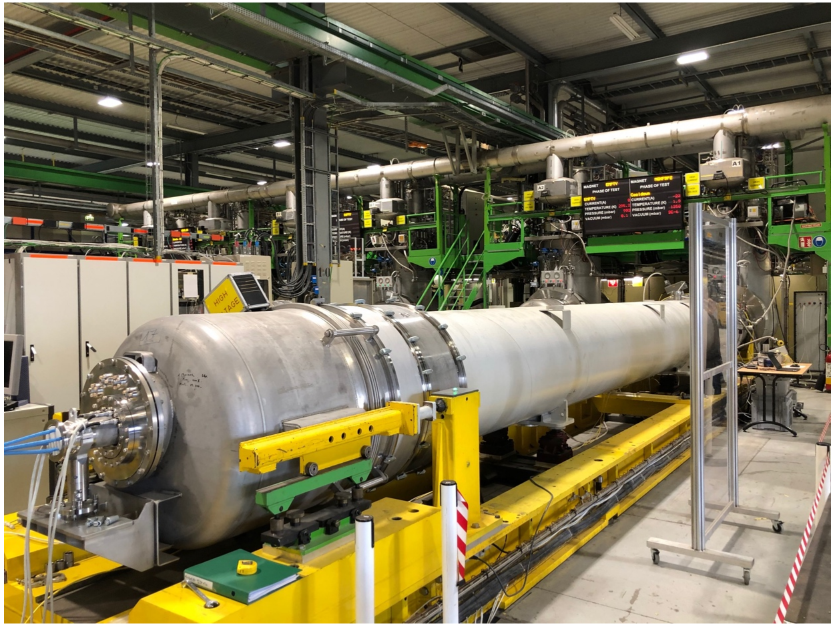
- HTS magnets interesting beyond HEP / industry
  (NMR, fusion, power applications for motors and generators)

HL-LHC as Stepping Stone (11T magnets)



11T prototype magnets will not be installed for LS2 in Run 3

High-field Superconducting Quadrupoles



First Prototype failed to reach nominal current, but nonetheless very positive results!

- First 2 CERN Prototypes built and tested
- First Horizontal MQXF cold-tests of Nb_3Sn magnets with new design
- First 7m long magnets tested
- B01 Reached 6.5 TeV equivalent without quench
- B02 Reached 7 TeV after slow and special training cycles
- CLIQ protection system worked as planned

➔ All main concepts have been proven up to 7 TeV equivalent!

➔ Prototype 1 showed limitation only in one coil and in one location [CERN plans 5 coils / magnet]

➔ **Prototype 2 reached nominal current, but only after special training and with indication of a weakness in one of the coils**

O. Brüning (EPS 2021)

High-field Superconducting Magnet Challenges

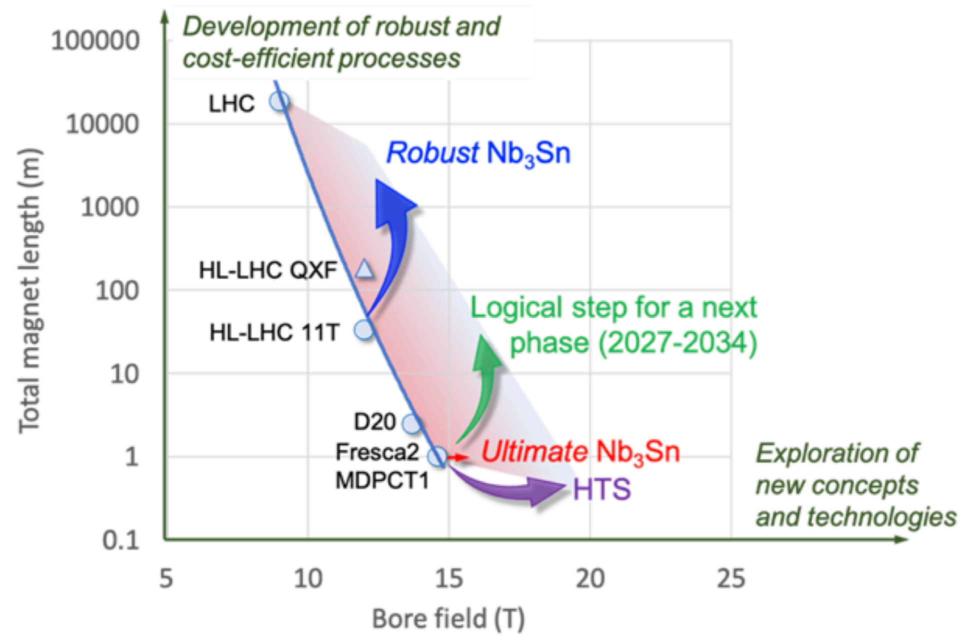
- Lead times for the development of high-filed magnets are long
- Development of novel SC magnets requires infrastructure, often of large size
  (Collaboration of CERN, European National Labs and interested universities with industry is essential);
  It would be even better to set this up in worldwide R&D Collaborations
- Development spans across many fields of science

Major Issues:

- Superconductor
  (sufficiently high current densities are needed to achieve high magnetic fields)
- Mechanics, design
  All known high-field superconductors (Nb_3Sn) and HTS are brittle;
  → of paramount importance that level of stress and strain is mastered and controlled throughout magnet fabrication and during operation (cycling)

Goals of a High Field Magnets R&D Program

- **Demonstrate Nb_3Sn magnet technology for large scale deployment**, pushing it to its practical limits, both in terms of maximum performance as well as production scale
  - Demonstrate Nb_3Sn full potential in terms of **ultimate performance** (**towards 16 T**)
  - Develop Nb_3Sn magnet technology for collider-scale production, through **robust design**, industrial manufacturing processes and cost reduction (benchmark 12 T)
- **Demonstrate suitability of HTS for accelerator magnet applications**, providing a proof-of-principle of HTS magnet technology beyond the reach of Nb_3Sn (**towards 20 T**)



- **Other key parameters:**
  - Cost of Magnets & R&D
  - Timeline of a realistic development

P. Vedrine (EPS 2021)

See EPS talk by P.Vedrine:
https://indico.desy.de/event/28202/contributions/105817/

P. Vedrine, EPS-HEP Conference, 30 July 2021

Physics, Experiments and Detectors at a Future Higgs/EW/Top Factory

ECFA Workshops towards an Higgs/EW/Top Factory

- *ECFA recognizes the need for the experimental and theoretical communities involved in physics studies, experiment designs and detector technologies at future Higgs factories to gather. **ECFA supports a series of workshops** with the aim to **share challenges and expertise, to explore synergies in their efforts** and to respond coherently to this priority in the European Strategy for Particle Physics (ESPP).*

Goal: bring the entire e^+e^- Higgs factory effort together, foster cooperation across various projects, collaborative research programmes are to emerge

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- **Studies started with a Kick-off meeting on 18th June 2021**

- Working Groups on: (i) Physics Potential
  (ii) Physics Analysis Methods
  (iii) Detector R&D

to prepare ECFA Workshops in 2022 and 2023

- Open for collaboration with other ongoing activities, e.g. Snowmass, ...
- Process is open for all interested physicists
- More information / updates on: https://indico.cern.ch/event/1044297/

Recommendations worked out by International Advisory Committee

- Extension to include **electroweak** and **top** factory
- Extend physics studies, where relevant (not all completed at time of EPPSU), however, focus on e^+e^- potential (no discussion of pros and cons of various machines or alternatives to e^+e^- Higgs factories)
- Understand better the interplay between (HL)-LHC and an e^+e^- Higgs/EW/Top factory
- Development of common tools important (software, simulation, fast simulation, ...)
- Development of common analysis methods of high interest
- Exploit synergies, discuss challenges, do not restrict to common items
- Need for theoretical accuracy and MC generator improvements ...
- …

International Advisory Committee:

- ECFA-chair would act as chair: Karl Jakobs
- From RECFA: Jean-Claude Brient, Tadeusz Lesiak, Chiara Meroni
- With (HL-)LHC experience: Jorgen D'Hondt, Max Klein, Aleandro Nisati, Roberto Tenchini
- For theory: Christophe Grojean, Andrea Wulzer
- For Linear Colliders: Steinar Stapnes, Juan Fuster, Frank Simon, Aidan Robson
- For Circular Colliders: Alain Blondel, Mogens Dam, Patrick Janot, Guy Wilkinson
- For CERN: Joachim Mnich

ECFA Working Groups

WG 1: Physics Potential
Convener: Juan Alcaraz (CIEMAT - Madrid), Jenny List (DESY), Fabio Maltoni (UC Louvain / Bologna) and James Wells (Univ. Michigan)

WG 2: Physics Analysis Methods
Convener: Patrizia Azzi (INFN-Padova / CERN), Fulvio Piccinini (INFN Pavia) and Dirk Zerwas (IJCLab)

Kick-off meeting to start WG1 and WG2 activities took place on 18th June:

https://indico.cern.ch/event/1033941/

WG 3: Detector R&D
Activities will be started once the ECFA Detector R&D Roadmap is defined

Update of the European Strategy for Particle Physics

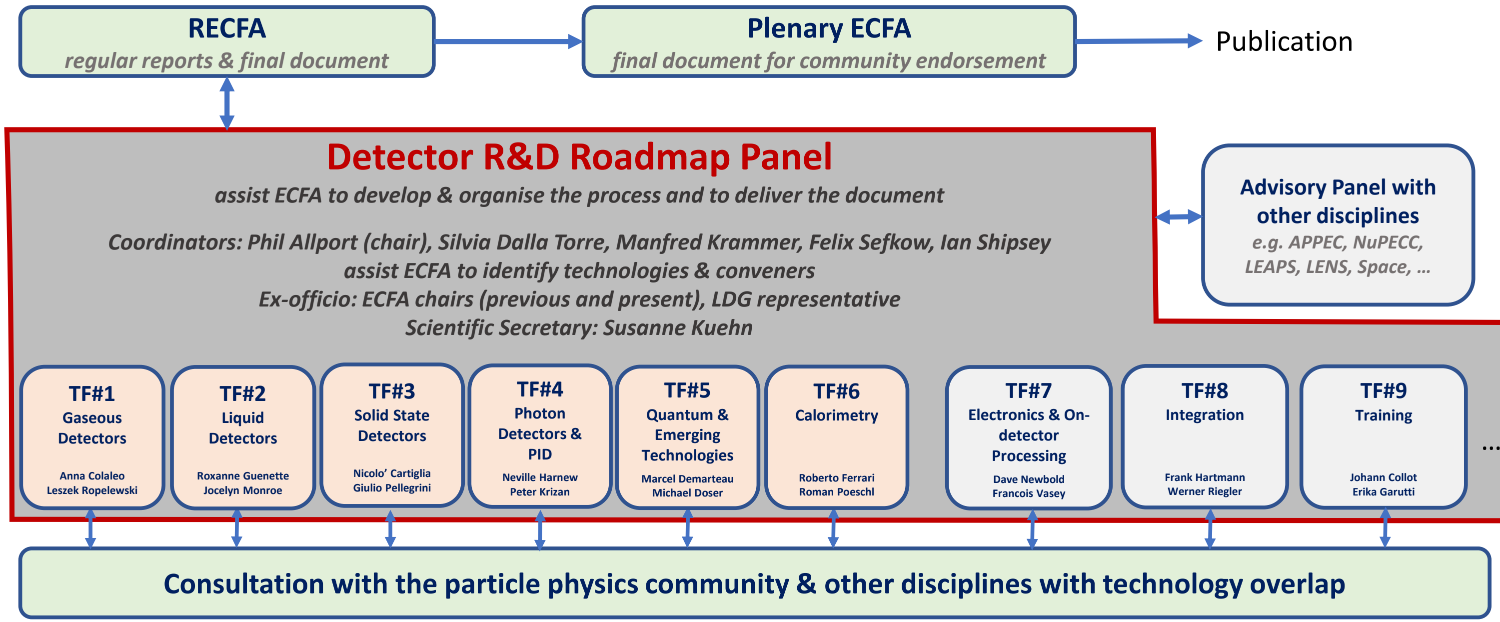
4. Other essential scientific activities for particle physics

…

*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.***

Organised by ECFA, a roadmap should be developed by the community to balance the detector R&D efforts in Europe, taking into account progress with emerging technologies in adjacent fields. The roadmap should identify and describe a diversified detector R&D portfolio that has the largest potential to enhance the performance of the particle physics programme in the near and long term. …

The Detector R&D Roadmap Process

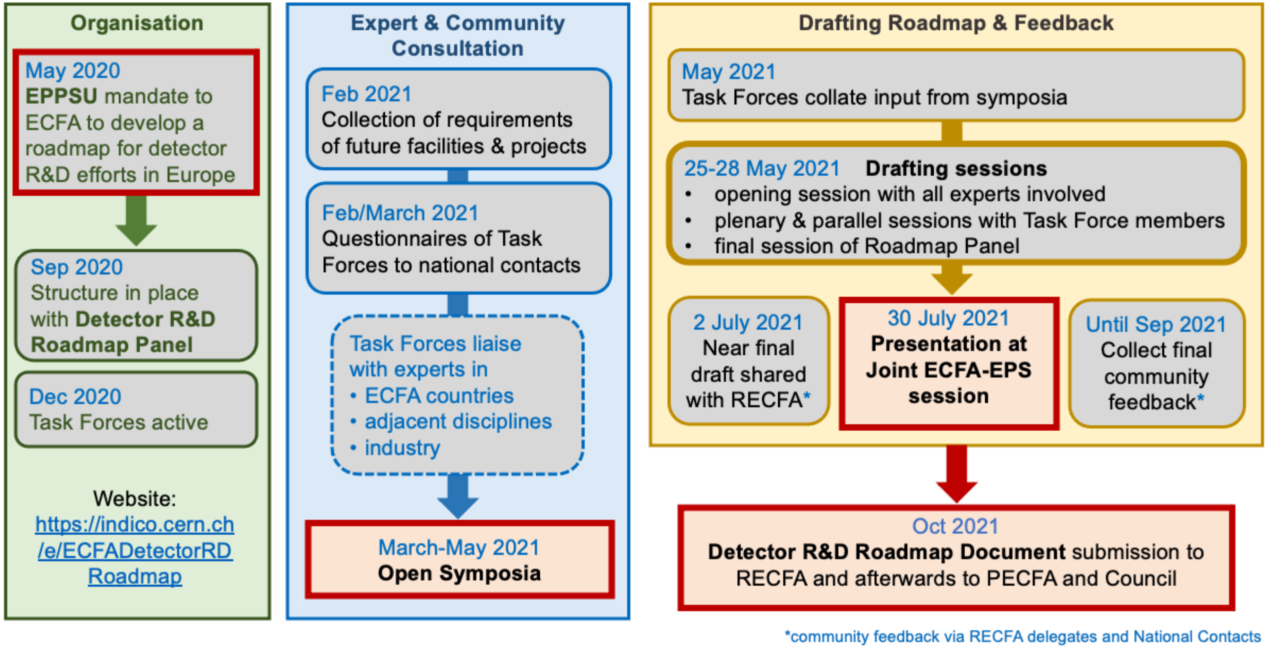


- ***Task forces*** *are composed of experts from the community covering key sub-topics in the relevant technology areas, including* ***two conveners*** *(who are part of the Roadmap Panel)*

- *Progress with emerging technologies in adjacent fields is provided through an* ***Advisory Panel with Other Disciplines*** *(→ expert contacts by Task Forces area)*

Information on the full process: [ECFA Detector R&D Roadmap]

The Detector R&D Roadmap Process



- Expert and Community consultation phase completed; major input at Open Symposia https://indico.cern.ch/event/957057/program
- First Open Presentation at the EPS Conference in the ECFA-EPS Session on 30th July 2021

Detector R&D Roadmap planned to be released by end of 2021

The Detector R&D Roadmap

- Principles: for the **earliest feasible start dates** of the proposed facilities:
  (including those which are still considered in the EPPSU, but mutually exclusive)

  - Basic detector R&D should not be the time-limiting step
    (started sufficiently early and prioritised correctly to meet the needs of the long-term programme in its global context)

  - Outcomes of the R&D should provide the necessary information on the feasibility and cost of future deliverables

- Task Forces have identified a set of detector R&D areas which are required if the physics programmes of experiments at these facilities are not to be compromised

  The most important drivers for research in each technology area are defined as **"Detector R&D Themes" (DRDTs)**

- It is also noted that in many cases, the programme for a nearer-term facility helps enable the technologies needed for more demanding specifications later, providing **stepping stones** towards these

- In addition to the Detector R&D Themes **General Strategic Recommendations** are made

Detector R&D Roadmap: Timeline for large accelerator-based experiments

The dates shown in the diagram have low precision, and are intended to represent the earliest 'feasible start date' (where a schedule is not already defined), taking into account the necessary steps of approval, development and construction for machine and civil engineering.

< 2030	2030-2035	2035-2040	2040-2045	> 2045
SPS Fixed Target	ALICE/LHCb (>LS4)	ILC	FCC-ee	FCC-hh
Other fixed target, FAIR (hep)	ATLAS/CMS (≥ LS4)		CLIC	FCC-eh
Belle II	EIC			Muon Collider
ALICE LS3	LHeC			
PIP-II/LBNF/DUNE/Hyper-K				

- The dates shown have deliberate low precision, and are intended to represent the **earliest 'feasible start date'** (where a schedule is not already defined), taking into account the necessary steps of approval, development and construction for machine and civil engineering.

- They do not constitute any form of plan or recommendation, and several options presented are mutually exclusive. Fine-tuning of time-ordering is also still under discussion with the Laboratories Directors Group.

- Furthermore, the projects mentioned here are limited to those mentioned in the EPPSU, although it should be noted that detector R&D for other possible future facilities is usually aligned with that for programmes already listed.

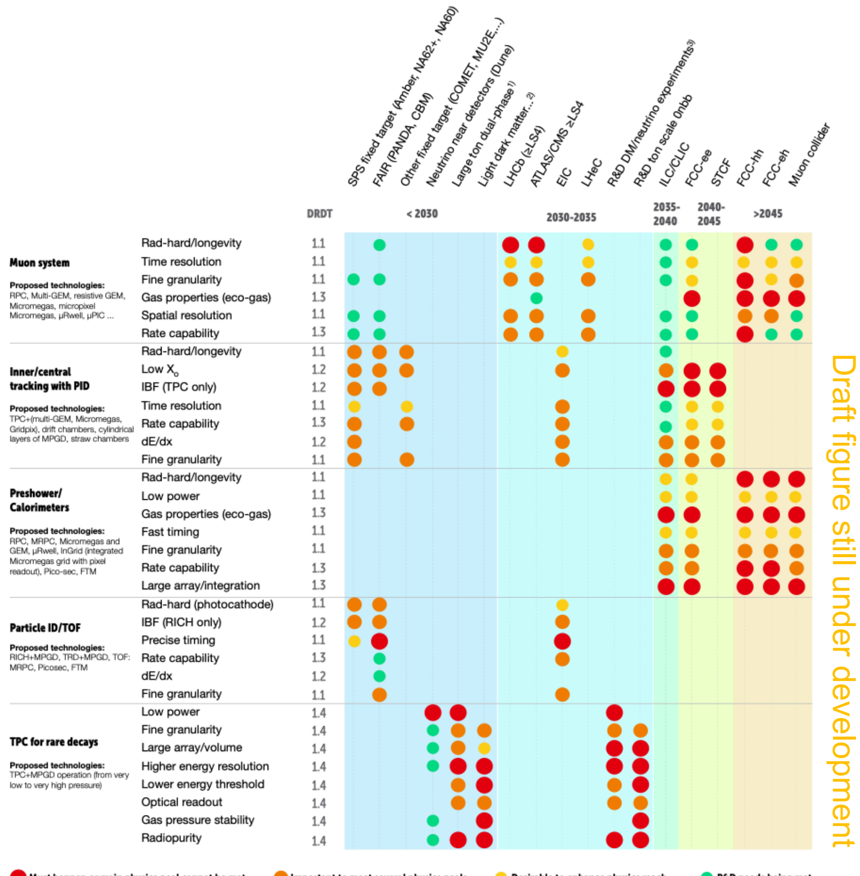
Timeline for representative* non-accelerator-based experiments

<2025						2025-2030									2030-2035								>2035		
Neutrino Telescopes (Km3)	Axions, ALPs, Dark Matter (DM)	Light DM Detectors	Multi-tonne scale DM Detectors	Tonne Scale 0nbb	100 m Atom Interferometry	Mu3e Phase II / COMET Phase II	Future muegamma experiment	Axions, ALPs, DM	Light DM Detectors	Hundred-tonne scale DM detectors	Tonne scale 0nbb	Proof of Principle Quantum Sensor HEP Detectors	Dark Radiation	Km scale Atom Interferometry	Future Mu3e Experiment	Light DM Detectors	Hundred-tonne scale DM detectors	Multi tonne scale 0nbb	Prototype Quantum Sensor HEP Detectors	Large scale quantum sensor networks	Space- based Quantum Sensors	Big Bang (CNB) Detectors	Space-based Quantum Sensor Networks	Functional Quantum Sensor HEP Detectors	PRISM

*Not intended to be an exhaustive list

- Focus has been on facilities targeting the properties and interactions of fundamental particles (including those that are undiscovered but theoretically motivated).
- It is noted that a number of particles increasingly play the role of cosmic messengers for phenomena happening far beyond our own galaxy which provides some of the exciting science opportunities in the neighbouring field of astroparticle physics, but the demanding detector requirements specific to this area are not generally within the scope

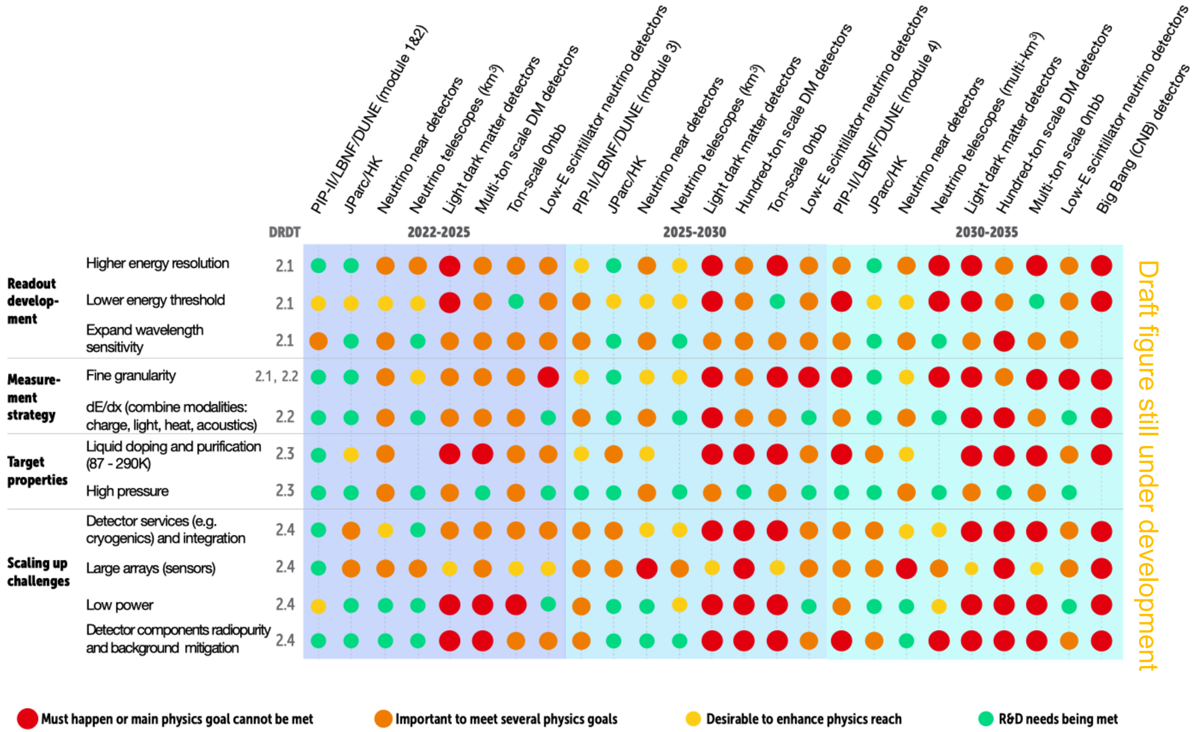
Detector R&D Roadmap: Example of requirements for Gaseous Detectors (TF1)



1) Large ton dual-phase (PandaX-4T, LZ, DarkSide -20k, Argo 200k, ARIADNE ...)
2) Light dark matter, solar axion, 0nbb, rare nuclei&ions and astroparticle reactions, Ba tagging)
3) R&D for 100-ton scale dual-phase DM/neutrino experiments

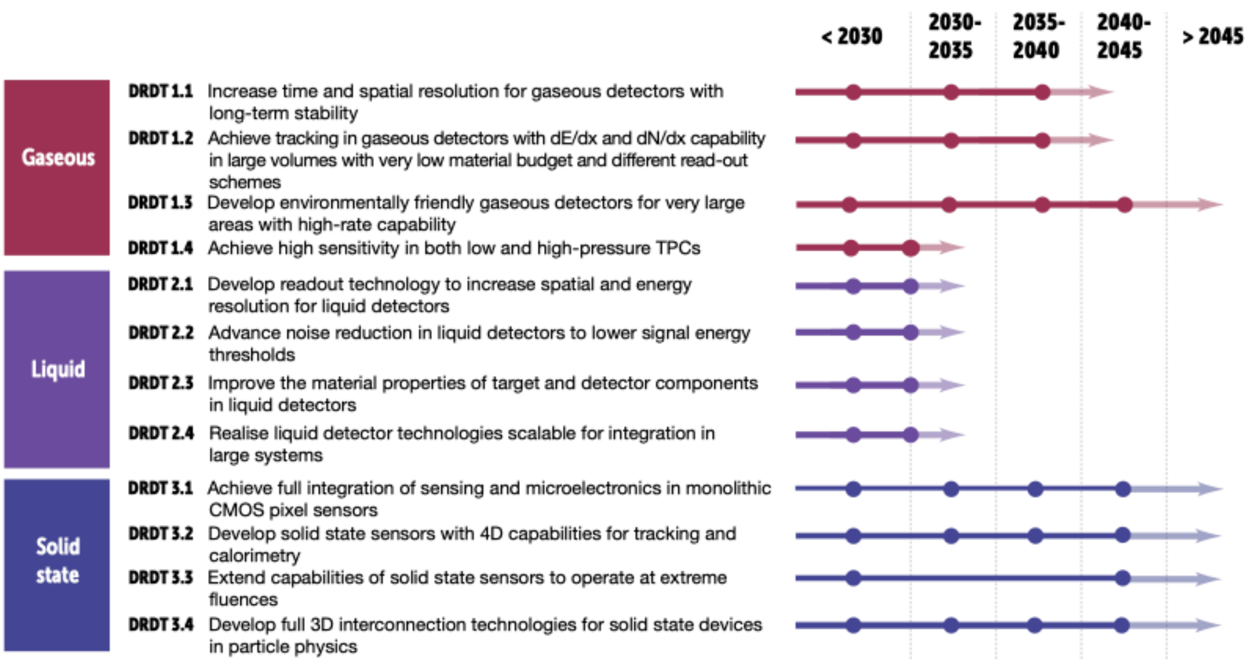
- For each technology these figures inform the development of the Detector R&D Roadmap with a view to set concrete target timelines for the readiness of the recommended R&D thematic programmes
- Ensure that the main physics goals of the updated strategy for particle physics do not risk being compromised by detector readiness

Detector R&D Roadmap: Example of requirements for Liquid Detectors (TF 2)



- For each technology these figures inform the development of the Detector R&D Roadmap with a view to set concrete target timelines for the readiness of the recommended R&D thematic programmes
- Ensure that the main physics goals of the updated strategy for particle physics do not risk being compromised by detector readiness

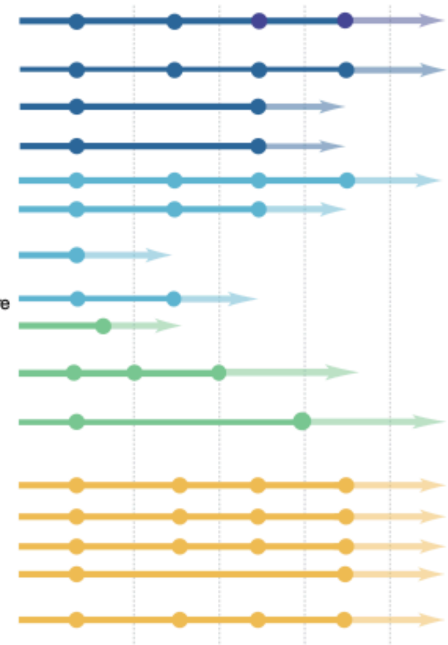
Detector R&D Roadmap: Detector R&D Themes (DRDTs)



- Stepping stones are shown to represent the R&D needs of facilities intermediate in time.
- The faded region acknowledges the typical time needed between the completion of the R&D phase and the readiness of an experiment at a given facility.
- Future beyond the end of the arrows is simply not yet defined, not that there is an expectation that R&D for the further future beyond that point will not be needed.

Detector R&D Roadmap: Detector R&D Themes (DRDTs)

PID and Photon	**DRDT 4.1**	Enhance the timing resolution and spectral range of photon detectors
	DRDT 4.2	Develop photosensors for extreme environments
	DRDT 4.3	Develop RICH and imaging detectors with low mass and high resolution timing
	DRDT 4.4	Develop compact high performance time of flight
Quantum	**DRDT 5.1**	Promote the development of advanced quantum sensing technologies
	DRDT 5.2	Investigate and adapt state-of-the-art developments in quantum technologies to particle physics
	DRDT 5.3	Establish the necessary framework and mechanisms to allow exploration of emerging technologies
	DRDT 5.4	Develop and provide advanced enabling capabilities and infrastructure
Calorimetry	**DRDT 6.1**	Develop radiation-hard calorimeters with enhanced electromagnetic energy and timing resolution
	DRDT 6.2	Develop high-granular calorimeters with multi-dimensional readout for optimised use of particle flow methods
	DRDT 6.3	Develop calorimeters for extreme radiation, rate and pile-up environments
Electronics	**DRDT 7.1**	Advance technologies to deal with greatly increased data density
	DRDT 7.2	Develop technologies for increased intelligence on the detector
	DRDT 7.3	Develop technologies in support of 4D and 5D techniques
	DRDT 7.4	Develop novel technologies to cope with extreme environments and required longevity
	DRDT 7.5	Evaluate and adapt to emerging electronics and data processing technologies



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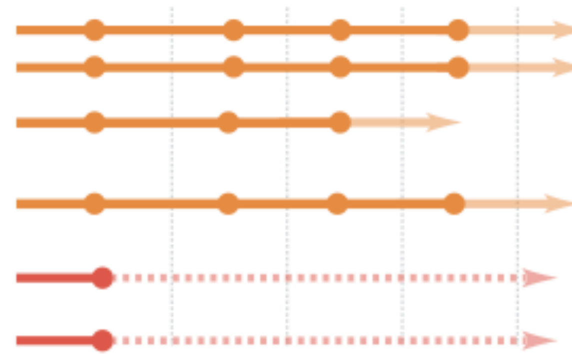
Detector R&D Roadmap: Detector R&D Themes (DRDTs)

Integration	**DRDT 8.1**	Develop novel magnet systems
	DRDT 8.2	Develop improved technologies and systems for cooling
	DRDT 8.3	Adapt novel materials to achieve ultra-light, stable and high precision mechanical structures. Develop Machine Detector Interfaces (MDI)
	DRDT 8.4	Adapt and advance state-of-the-art systems in monitoring including environmental, radiation and beam aspects
Training	**DCT 1**	Establish and maintain a European coordinated programme for training in instrumentation
	DCT 2	Develop a master's degree programme in instrumentation



Detector R&D Roadmap: General Strategic Recommendations

GSR 1 - Supporting R&D facilities

GSR 2 - Engineering support for detector R&D

GSR 3 - Specific software for instrumentation

GSR 4 - International coordination and organisation of R&D activities

GSR 5 - Distributed R&D activities with centralised facilities

GSR 6 - Establish long-term strategic funding programmes

GSR 7 - Blue-sky R&D

GSR 8 - Attract, nurture, recognise and sustain the careers of R&D experts

GSR 9 - Industrial partnerships

GSR 10 - Open Science

Detector R&D Roadmap: General Strategic Recommendations

GSR 1 - Supporting R&D facilities
It is recommended that the structures to provide Europe-wide coordinated infrastructure in the areas of: test beams, large scale generic prototyping and irradiation be consolidated and enhanced to meet the needs of next generation experiments with adequate centralised investment to avoid less cost-effective, more widely distributed, solutions, and to maintain a network structure for existing distributed facilities, e.g. for irradiation.

GSR 2 - Engineering support for detector R&D
In response to ever more integrated detector concepts, requiring holistic design approaches and large component counts, the R&D should be supported with adequate mechanical and electronics engineering resources, to bring in expertise in state-of-the-art microelectronics as well as advanced materials and manufacturing techniques, to tackle generic integration challenges, and to maintain scalability of production and quality control from the earliest stages.

GSR 3 - Specific software for instrumentation
Across DRDTs and through adequate capital investments, the availability to the community of state-of-the-art R&D-specific software packages must be maintained and continuously updated. The expert development of these packages - for core software frameworks, but also for commonly used simulation and reconstruction tools - should continue to be highly recognised and valued and the community effort to support these needs to be organised at a European level.

GSR 4 - International coordination and organisation of R&D activities
With a view to creating a vibrant ecosystem for R&D, connecting and involving all partners, there is a need to refresh the CERN RD programme structure and encourage new programmes for next generation detectors, where CERN and the other national laboratories can assist as major catalysers for these. It is also recommended to revisit and streamline the process of creating and reviewing these programmes, with an extended framework to help share the associated load and increase involvement, while enhancing the visibility of the detector R&D community and easing communication with neighbouring disciplines .

GSR 5 - Distributed R&D activities with centralised facilities
Establish in the relevant R&D areas a distributed yet connected and supportive tier-ed system for R&D efforts across Europe. Keeping in mind the growing complexity, the specialisation required, the learning curve and the increased cost, consider more focused investment for those themes where leverage can be reached through centralisation at large institutions, while addressing the challenge that distributed resources remain accessible to researchers across Europe and through them also be available to help provide enhanced training opportunities.

GSR 6 - Establish long-term strategic funding programmes
Establish, additional to short-term funding programmes for the early proof of principle phase of R&D, also long-term strategic funding programmes to sustain both research and development of the multi-decade DRDTs in order for the technology to mature and to be able to deliver the experimental requirements. Beyond capital investments of single funding agencies, international collaboration and support at the EU level should be established. In general, the cost for R&D has increased, which further strengthens the vital need to make concerted investments.

Detector R&D Roadmap: General Strategic Recommendations

GSR 7 - Blue-sky R&D
It is essential that adequate resources be provided to support more speculative R&D which can be riskier in terms of immediate benefits but can bring significant and potentially transformational returns if successful both to particle physics: unlocking new physics may only be possible by unlocking novel technologies in instrumentation, and to society. Innovative instrumentation research is one of the defining characteristics of the field of particle physics. Blue-sky developments in particle physics have often been of broader application and had immense societal benefit. Examples include: the development of the World Wide Web, Magnetic Resonance Imaging, Positron Emission Tomography and X-ray imaging for photon science.

GSR 8 - Attract, nurture, recognise and sustain the careers of R&D experts
Innovation in instrumentation is essential to make progress in particle physics, and R&D experts are essential for innovation. It is recommended that ECFA, with the involvement and support of its Detector R&D Panel, continues the study of recognition with a view to consolidate the route to an adequate number of positions with a sustained career in instrumentation R&D to realise the strategic aspirations expressed in the EPPSU. It is suggested that ECFA should explore mechanisms to develop concrete proposals in this area and to find mechanisms to follow up on these in terms of their implementation. Consideration needs to be given to creating sufficiently attractive remuneration packages to retain those with key skills which typically command much higher salaries outside academic research. It should be emphasised that, in parallel, society benefits from the training particle physics provides because the knowledge and skills acquired are in high demand by industries in high-technology economies.

GSR 9 - Industrial partnerships
It is recommended to identify promising areas for close collaboration between academic and industrial partners, to create international frameworks for exchange on academic and industrial trends, drivers and needs, and to establish strategic and resources-loaded cooperation schemes on a European scale to intensify the collaboration with industry, in particular for developments in solid state sensors and micro-electronics.

GSR 10 – Open Science
It is recommended that the concept of Open Science be explicitly supported in the context of instrumentation, taking account of the constraints of commercial confidentiality where these apply due to partnerships with industry. Specifically, for publicly-funded research the default, wherever possible, should be open access publication of results and it is proposed that the Sponsoring Consortium for Open Access Publishing in Particle Physics (SCOAP^3) should explore ensuring similar access is available to instrumentation journals (including for conference proceedings) as to other particle physics publications.

Update of the European Strategy for Particle Physics

5. Synergies with neighbouring fields

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

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

→ Joint ECFA-NuPECC-APPEC Activities (JENAA)

Joint ECFA-NuPECC-APPEC Activities (JENAA)

- Five Expressions of Interest for common activities endorsed:
  - *Dark Matter (iDMEu)*
  - *Machine-learning Optimized Design of Experiments (MODE)*
  - *Gravitational Waves for fundamental physics*
  - *Nuclear Physics at the LHC*
  - *Storage Rings for the Search of Charged-Particle Electric Dipole Moments*

- All these activities have held their first meetings to present and discuss their Expressions of Interest and to make first steps towards implementation of the common activities in autumn last year (more information is available here).

- Community-at-large has been informed (email sent on 27th April 2021)

- iDMEu: larger kick-off meeting took place 10 – 12 May 2021 https://indico.cern.ch/event/1016060/
  MODE: first meeting planned for 6 – 8 Sept 2021 in Louvain / Belgium
  https://mode-collaboration.github.io/workshop/index.html
  Gravitational waves: not as advanced yet, further meetings to be announced

  Charged Particle EDM: well organised from Nuclear Physics side; so far only few institutes from ECFA involved

Joint ECFA-NuPECC-APPEC Activities (JENAA) (cont.)

- A sixth **Expression of Interest** has been received recently
  (sent to the APPEC, ECFA, NuPECC Chairs)

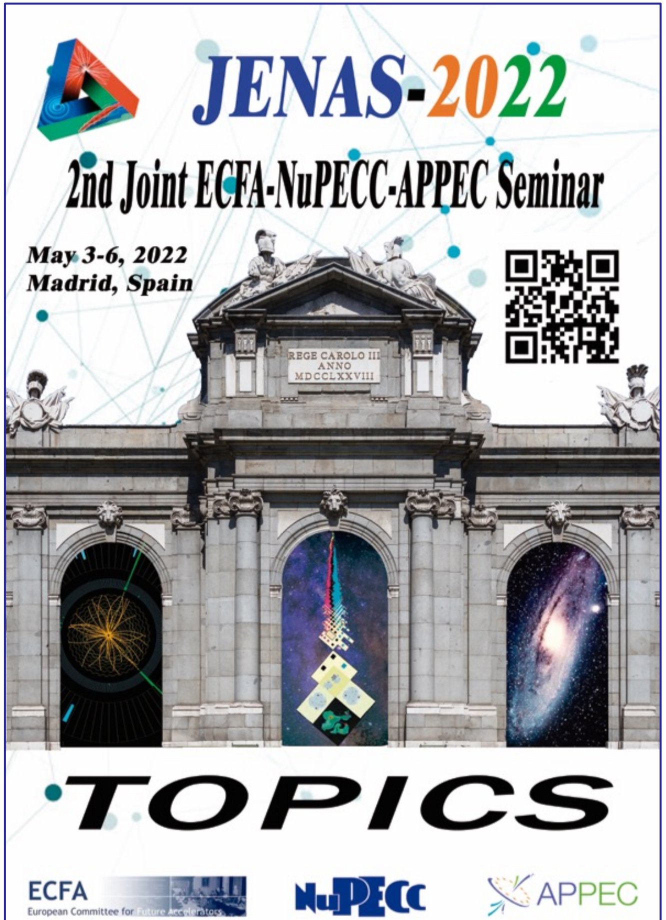
  “Synergies between the Electron-Ion Collider and the Large Hadron Collider experiments”

  Strong interest from Nuclear Physics (NuPECC)

- In addition we have received a first proposal for a coordinated effort to address the **flavour anomalies** (Experiment, theory, what can be done in other experiments?)

  Both proposals are under evaluation by APPEC, ECFA and NuPECC

Next JENA Seminar in Madrid 2022



2nd JENAS will take place in **Madrid** (3 – 6 May 2022);

- Several meetings between APPEC, NuPECC and ECFA Chairs and the local organisers took place
- Advanced version of the programme exists

Update of the European Strategy for Particle Physics

6. Organisational Issues

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.

Conclusions

- The Update of the European Strategy has put forward an ambitious plan for the next years

- e^+e^- Higgs factory is the highest-priority next collider

  - A timely realisation is essential for the field (overlap with LHC, or no large gap …)

- ***FCC Feasibility study has been set up by CERN management and approved by Council (June 2021)***

  - It must get the full support of CERN and the European (ECFA) countries
  - High-field SC magnet development is essential, should be followed up with high priority!

- ECFA and LDG on track to develop **roadmaps for detector and accelerator R&D**

  → Well advanced, will be released towards the end of 2021

- The full European Particle Physics Community must work coherently together to achieve the ambitious goals!

How can we maintain the future of our field?

- Accelerators are large, cost-expensive, funding situation becomes more difficult
- Young generation feels large uncertainty!!

  No concrete future project yet, beyond (HL)-LHC

- We must do all possible to decide soon (latest at the next strategy) on the next project to inject new energy (or keep the momentum) in our field

  → FCC feasibility study essential and must get full support of CERN + ECFA countries!

  Do we only consider an integrated FCC_ee + FCC_hh programme, or are we open as well for an ILC + FCC_hh solution?

  (Load on CERN would be reduced, better distributed world-wide, in Europe more resources could be focussed on key fcc_hh issues, i.e. high-field magnet development; will this be enough to develop magnets in a reasonable timescale?
  In addition, more time to accumulate funding for FCC?
  If ILC decision would be taken soon, e^+e^- machine could be realised earlier!!)

Backup Slides

Mandate WG 1

- **EFT** (global) interpretation of Higgs factory measurements, including EW, Z pole and top physics, and its impact on concrete new physics scenarios and models.
- **Extend the study of the impact also on specific models that cannot be matched onto EFT**.
- **Exploration of different flavour scenarios and interplay with flavour data**.
- Identification of measurements that **HL-LHC** can do in order to increase the physics potential of the future Higgs and top/EW Factory.
- **HL-LHC precision physics interplay** with the Higgs and top/EW factory potential, including the not-yet-complete assessment of the high-pT probes potential at the HL-LHC. Comparative attention should also be paid to the potential of other future colliders.
- Requirements for accuracy in **theoretical calculations** and **parametric uncertainties**, and perspectives to achieve it.
- Perspectives for **experimental uncertainties**.
- Broad exploration of the **new physics discovery potential** of the future Higgs and top/EW factory, including the search for Feebly Interacting Particles also in connection with “Physics Beyond Colliders” activities.
- Availability and development of **Monte Carlo generators** required to achieve the physics goals.

Mandate WG 2

- Monte Carlo generators for e+e- precision EW, Flavour, Higgs, and top physics
- Software framework
- Fast simulation and the limitations of such techniques
- Track and vertex reconstruction algorithms
- Jet algorithms / jet reconstruction
- Constrained kinematic fits
- Particle-flow reconstruction and global event description
- Requirements on particle identification
- Flavour tagging algorithms
- Importance of timing information
- Luminosity measurement

Until and between the ECFA Plenary Workshops

Plans of conveners, as presented on 18th June

Organize smaller events:
- Seminar series
- Topical workshops

Seminar series:
- ~monthly, mostly theory / physics topics

Topical workshops:
- Remote zoom: ½ day maximum
- Presence (+remote): 1+ day,
  in nice easy access places: Louvain, Madrid, Pavia, Padua, CERN, Orsay, DESY….
- Informal, intense discussions

Topics:
- Scope defined in mandates of the groups
- What is most urgent to discuss?
  => your input welcome!

Examples for topical workshops:
- Specific **reconstruction** topics: ACTS, kinematic fitting, PID, jet clustering, …
- Specific **experimental** topics: luminosity measurement, control of experimental systematics, standard candles for detector performance, …
- Specific **physics topics**: Higgs properties, M_W , A_{FB}, …
- Specific **theory** questions: precision calculations, event generators
- Global **interpretation**: EFT fitting, UV complete BSM models, …
- **Interplay with HL-LHC**
- How to **promote the need for a next collider** to other scientists / general public / politicians?

Examples for seminars:
- "BSM Higgs decays with colinear photons / leptons / quarks"
- "From top observables to top Yukawa coupling"