European Strategy on Particle Physics

2nd Joint ECFA-NuPECC-APPEC Seminar

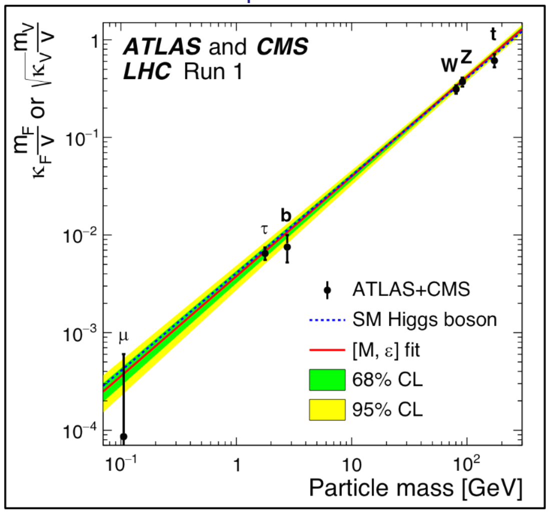
Madrid
3 – 6 May 2022

Karl Jakobs, ECFA Chair
University of Freiburg / Germany

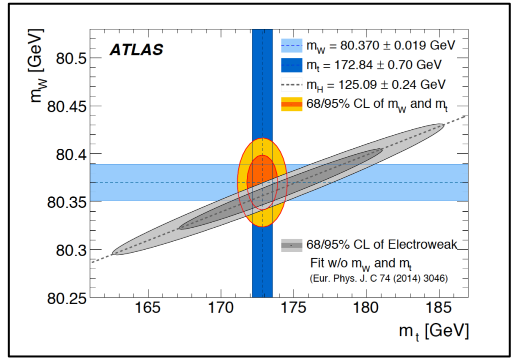
ECFA
European Committee for Future Accelerators

LHC: 10 Years at the Energy Frontier

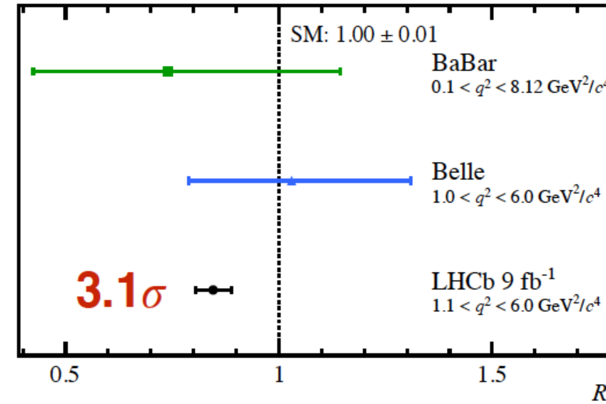
Discovery of the **Higgs boson** and precise measurement of its parameters



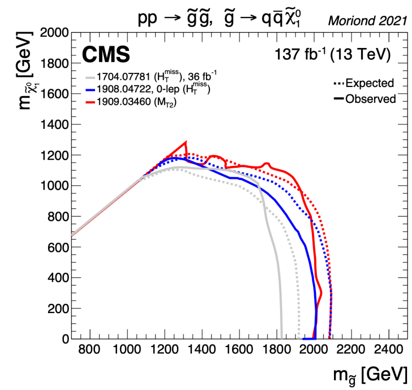
Precision tests of the Standard Model (SM)



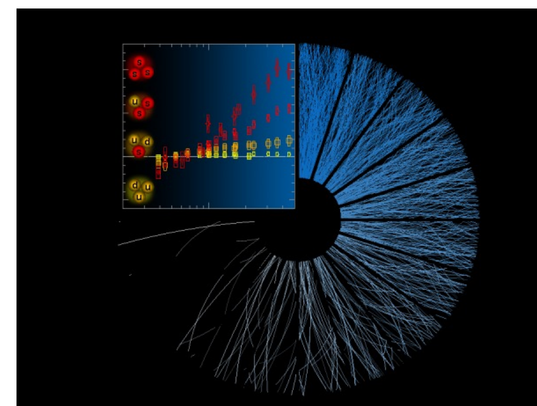
Challenging the SM in Flavour Physics



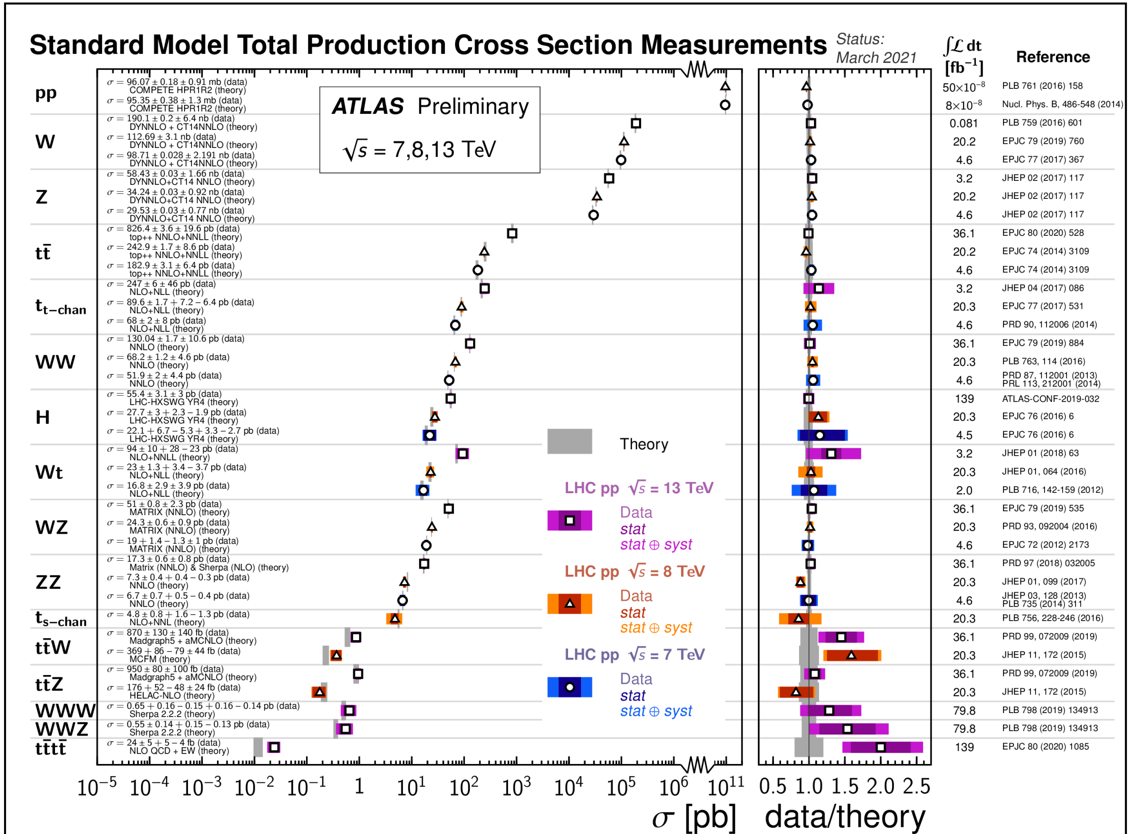
Constraints on **Physics Beyond SM**



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…

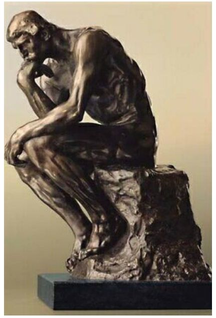
Open Questions

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

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).

→ Talk by Paris Sphicas

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:

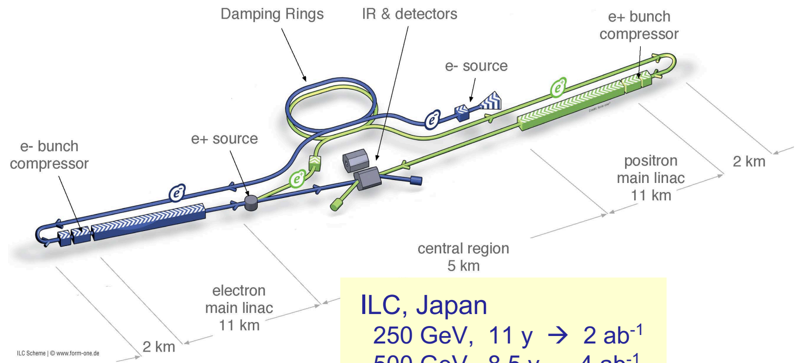
- *the particle physics community should ramp up its R&D effort focused on advanced accelerator technologies, in particular that for high-field superconducting magnets, including high-temperature superconductors;*

- *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.*

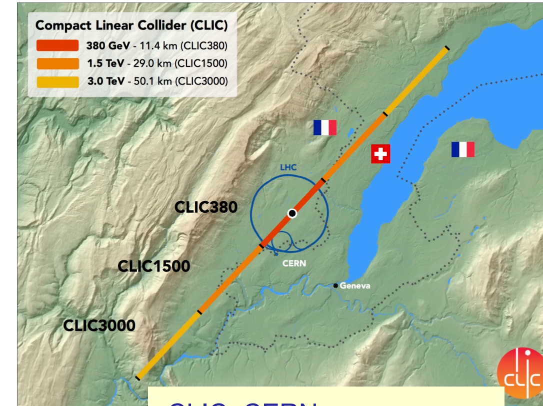
The timely realisation of the electron-positron International Linear Collider (ILC) in Japan would be compatible with this strategy and, in that case, the European particle physics community would wish to collaborate.

High-energy e+e- Collider Projects

Linear Colliders

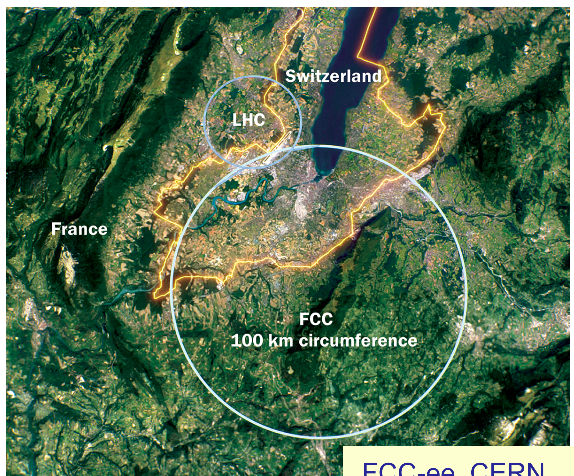


ILC, Japan
250 GeV, 11 y → 2 ab^{-1}
500 GeV, 8.5 y 4 ab^{-1}
1000 GeV, 8.5 y 8 ab^{-1}

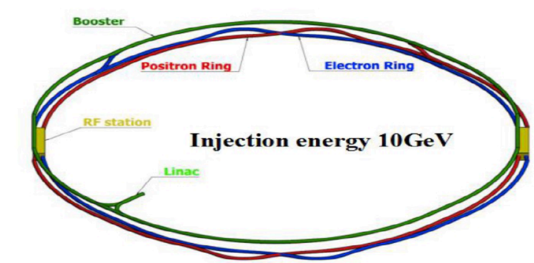


CLIC, CERN
380 GeV, 8 y → 1 ab^{-1}
1500 GeV, 7 y 2.5 ab^{-1}
3000 GeV, 8.5 y 5 ab^{-1}

Circular Colliders



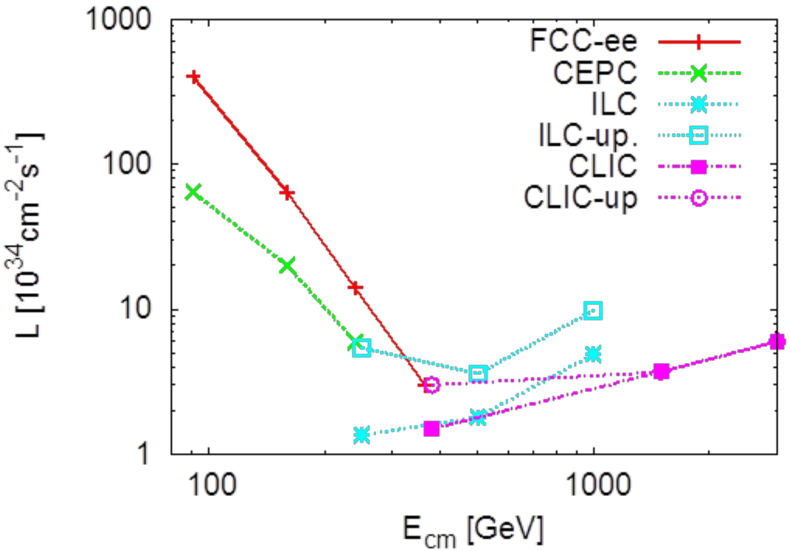
FCC-ee, CERN
m_Z, 4 y → 150 ab^{-1}
2 x m_W, 1-2 y → 10 ab^{-1}
240 GeV, 3 y → 5 ab^{-1}
2 x m_{top}, 5y → 1.5 ab^{-1}



CEPC, China
m_Z, 2 y → 16 ab^{-1}
2 x m_W, 1 y → 2.6 ab^{-1}
240 GeV, 7 y → 5.6 ab^{-1}

ECFA
European Committee for Future Accelerators

Achievable Luminosities



Circular Collider:

- Precision via high luminosity (el.weak factories)

per detector in e^+e^-	# Z	# B	# τ	# charm	# WW
LEP	4×10^6	1×10^6	3×10^5	1×10^6	2×10^4
SuperKEKB	-	10^{11}	10^{11}	10^{11}	-
FCC-ee	2.5×10^{12}	7.5×10^{11}	2×10^{11}	6×10^{11}	1.5×10^8

- Less luminosity at higher E_{CM} (synchrotron radiation)

- Huge potential in **integrated programmes with Hadron Collider option** (e.g. FCC-ee / FCC-hh / FCC-eh)

Linear Collider:

- Energy frontier machines

Precision in the Higgs sector

Complementarity between ee/eh/hh colliders

kappa-0-HL	HL+FCC-ee$_{240}$	HL+FCC-ee	HL+FCC-ee (4 IP)	HL+FCC-ee/hh	HL+FCC-eh/hh	HL+FCC-hh	HL+FCC-ee/eh/hh
κ_W [%]	0.86	0.38	0.23	0.27	0.17	0.39	0.14
κ_Z [%]	0.15	0.14	0.094	0.13	0.27	0.63	0.12
κ_g [%]	1.1	0.88	0.59	0.55	0.56	0.74	0.46
κ_γ [%]	1.3	1.2	1.1	0.29	0.32	0.56	0.28
$\kappa_{Z\gamma}$ [%]	10.	10.	10.	0.7	0.71	0.89	0.68
κ_c [%]	1.5	1.3	0.88	1.2	1.2	–	0.94
κ_t [%]	3.1	3.1	3.1	0.95	0.95	0.99	0.95
κ_b [%]	0.94	0.59	0.44	0.5	0.52	0.99	0.41
κ_μ [%]	4.	3.9	3.3	0.41	0.45	0.68	0.41
κ_τ [%]	0.9	0.61	0.39	0.49	0.63	0.9	0.42
Γ_H [%]	1.6	0.87	0.55	0.67	0.61	1.3	0.44

ALL COMBINED

only FCC-ee@240GeV

only FCC-hh

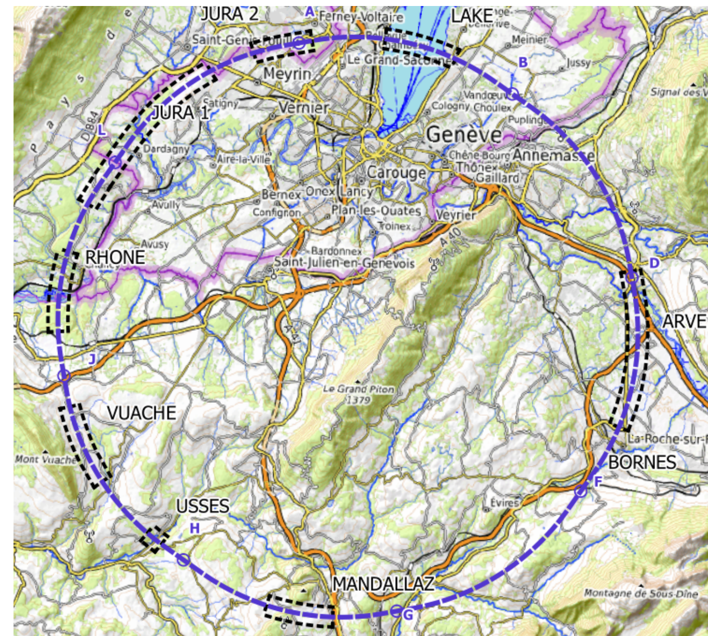
Precisison on Higgs coupling strength modifiers κ_i
(assuming no BSM particles in Higgs boson decays)

FCC Feasibility Study

"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."

- **Organisational Structure approved by the CERN Council in June 2021**

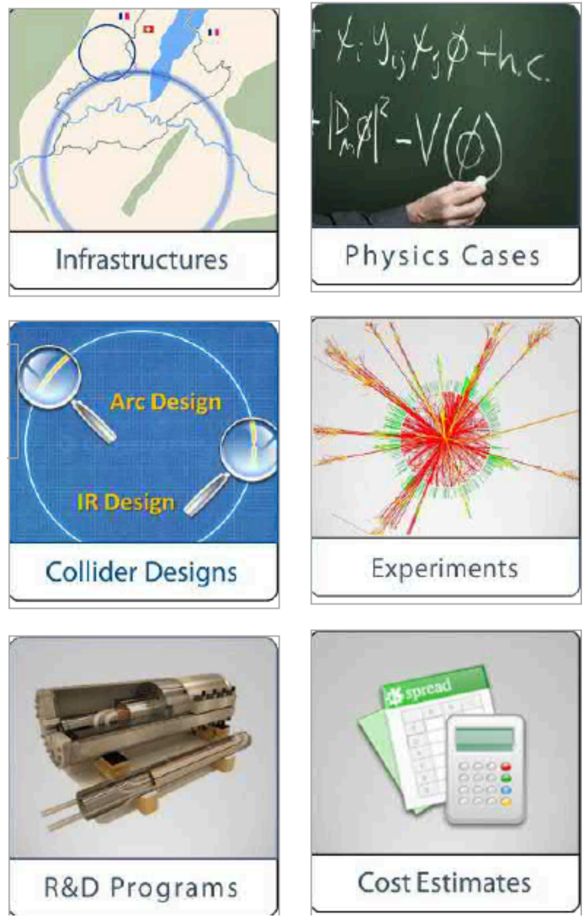
- **Main Deliverables & Milestones of the study have been defined**



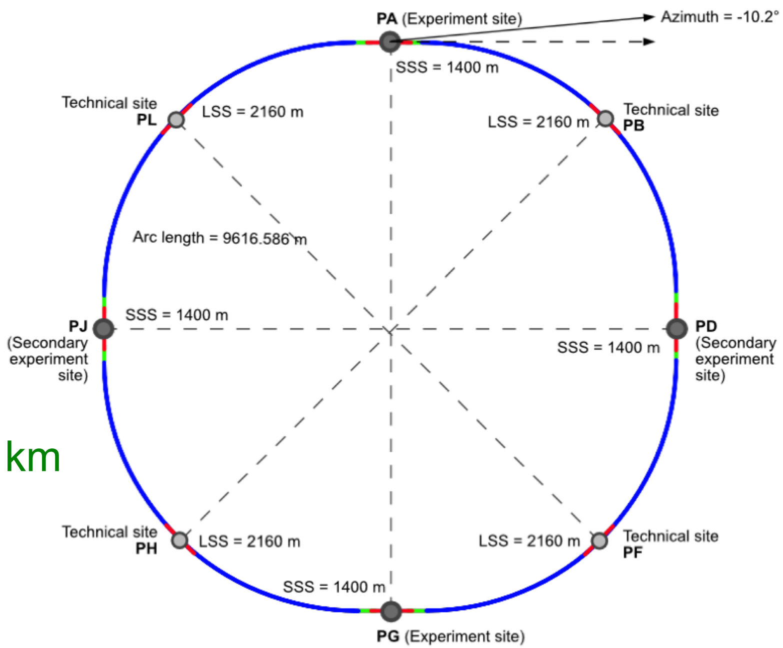
Major Goals of the FCC Feasibility Study

- 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.

Release Feasibility Study Report by end 2025



FCC Feasibility Study: “lowest risk” placement



C = 91 km

- 8 surface sites,
- 4-fold symmetry

- Allows for 4 interaction points (IP)

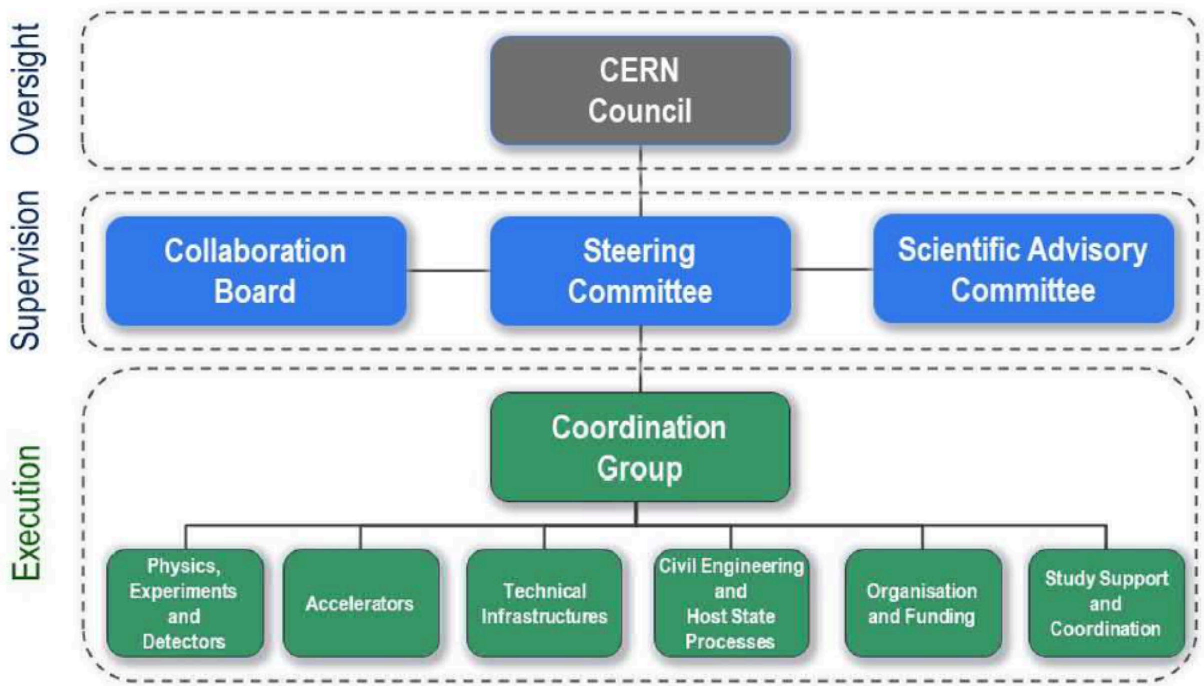
FCC-ee: 2 or 4 Ips

FCC-hh: 4 IPs

Studies related to the preferred implementation remain the focal point of the feasibility study with the goal to confirm this as new baseline by FCC Week 2022 (June)

Organisational Structure of the FCC Feasibility Study

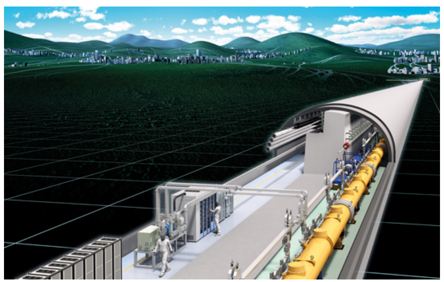
- Organisational Structure has been set up (very similar to the first phase of the FCC Study (2014 - 2020)



ECFA Workshops on e^+e^- physics

- *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



- Study has been launched, **Working Groups** have started their activities, important **Topical Meeting** have been held / are upcoming

WG 1: Physics Potential
WG 2: Physics Analysis Methods
WG 3: Detector R&D

2022 ECFA e^+e^- Workshop in Hamburg 5 – 7 October 2022

- Status of Working Group activities
- Discussion of future plans
- Interaction between theory and experiments
- …

Update of the European Strategy for Particle Physics

4. Other essential scientific activities for particle physics

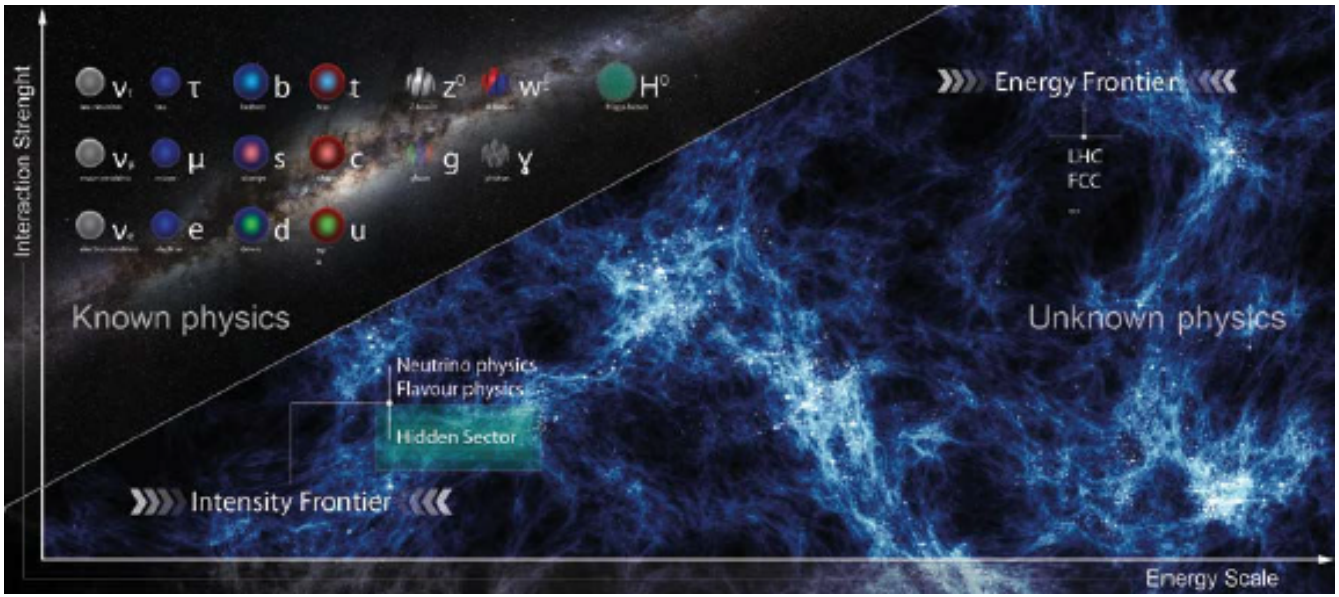
A. The quest for dark matter and the exploration of flavour and fundamental symmetries are crucial components of the search for new physics. This search can be done in many ways, for example through precision measurements of flavour physics and electric or magnetic dipole moments, and searches for axions, 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.

"Physics Beyond Colliders"   (at CERN and elsewhere, e.g. national labs)

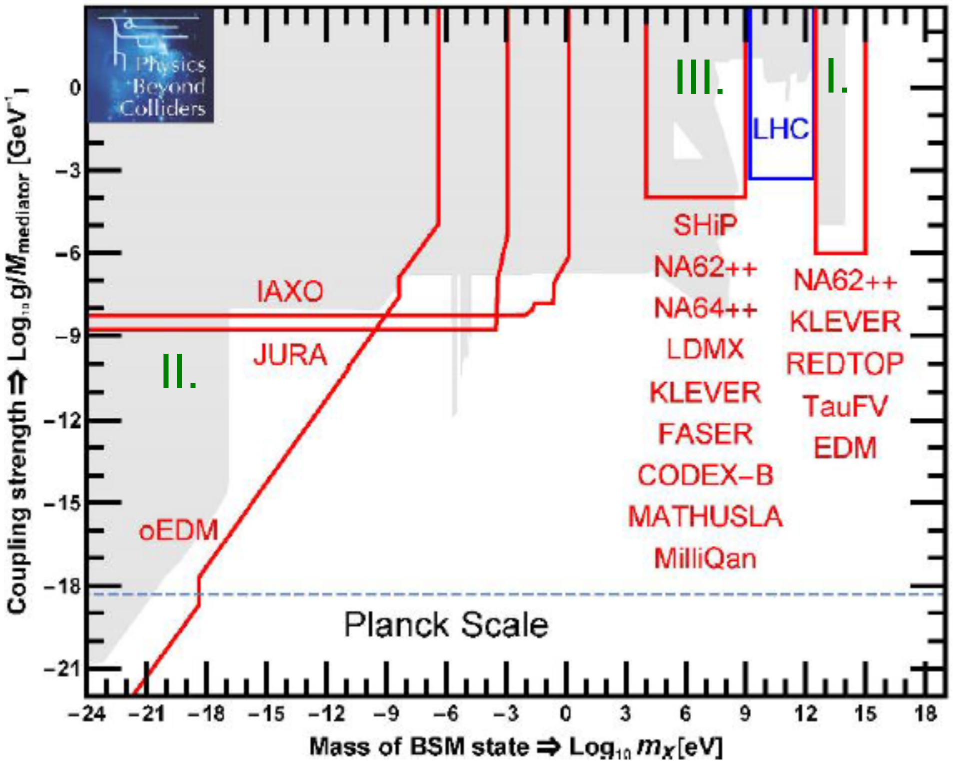
Paradigm Change in BSM Searches

In recent years, **interest in complementary methods to high-energy-frontier colliders** to explore BSM physics has grown.
Two ways to reconcile BSM physics with the non-observation in present experiments: **new particles** could be either **very massive** or **very weakly interacting** with SM particles



→ Many new ideas and experimental proposals emerged

Examples from CERN “Physics Beyond Colliders”

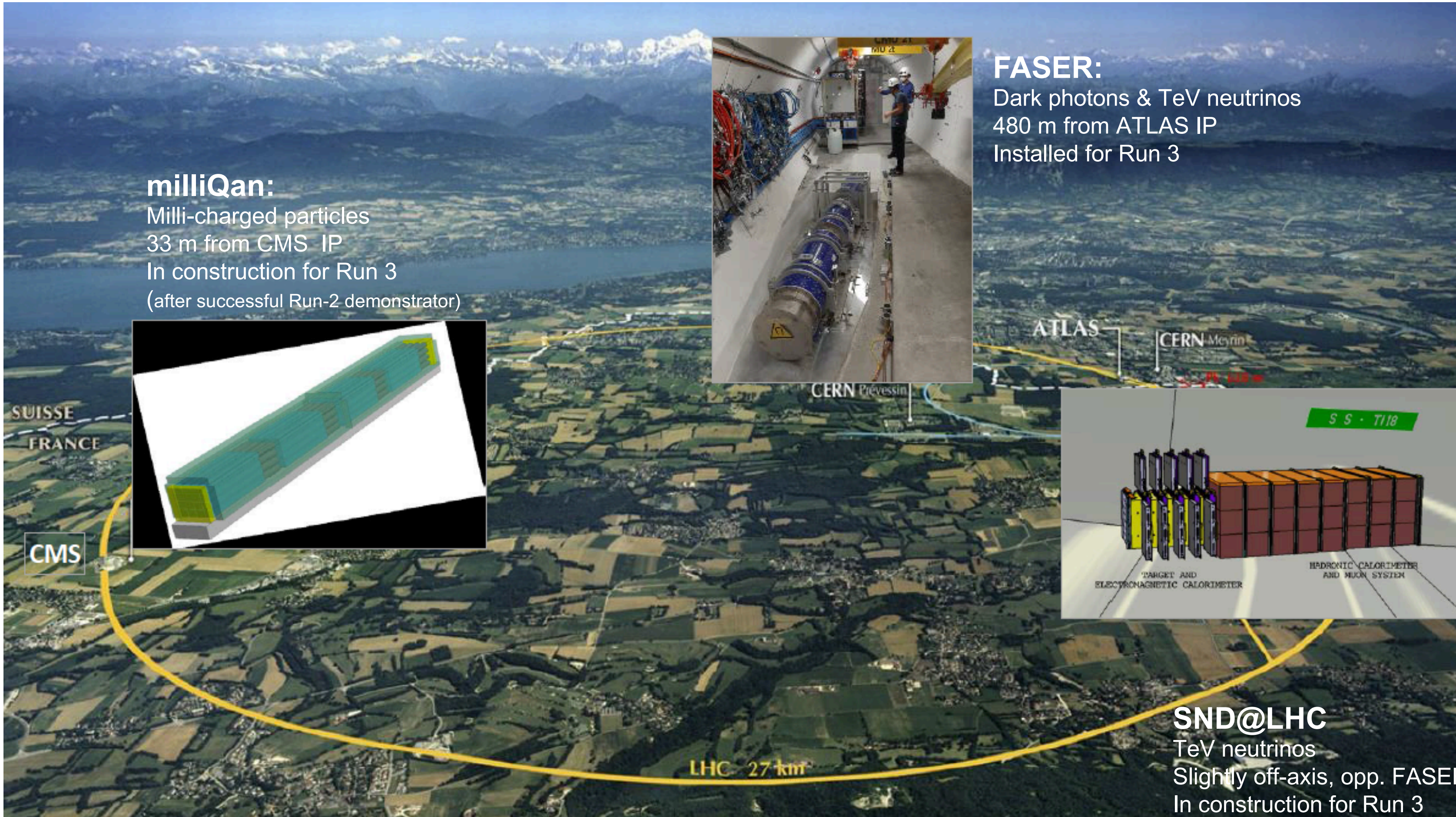


I. Precision experiments and searches for rare processes extend reach of high-E colliders

II. EDM & non-accelerator projects cover the very low-mass domain

III. SPS experiments (beam dump, searches for long-lived particles, …) probe MeV – GeV domain

New experiments at the LHC: Search for long-lived particles



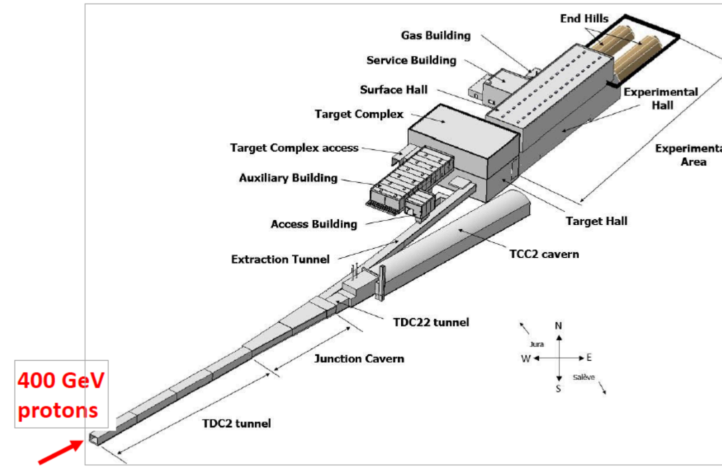
milliQan:
Milli-charged particles
33 m from CMS IP
In construction for Run 3
(after successful Run-2 demonstrator)

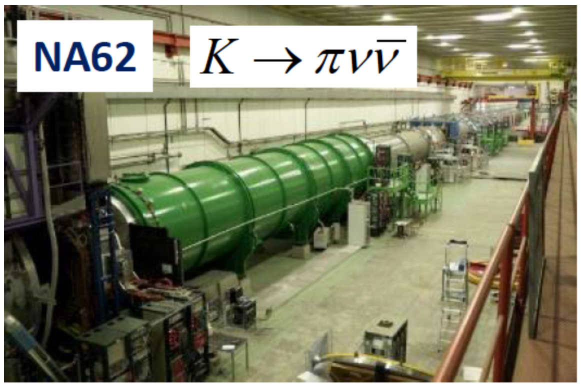
FASER:
Dark photons & TeV neutrinos
480 m from ATLAS IP
Installed for Run 3

SND@LHC
TeV neutrinos
Slightly off-axis, opp. FASER
In construction for Run 3

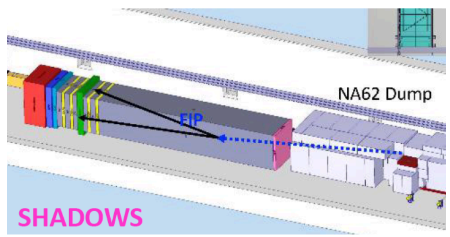
CERN Proton Beam Dump Facility

- Comprehensive Design Study of a new SPS facility done within PBC
- Promising option (lower cost) identified in existing ECN3 underground hall in CERN North Area (currently used by NA62)
- Under evaluation with respect to alternative NA62 extension + SHADOWS option (new idea to search off-axis for feebly interacting particles)

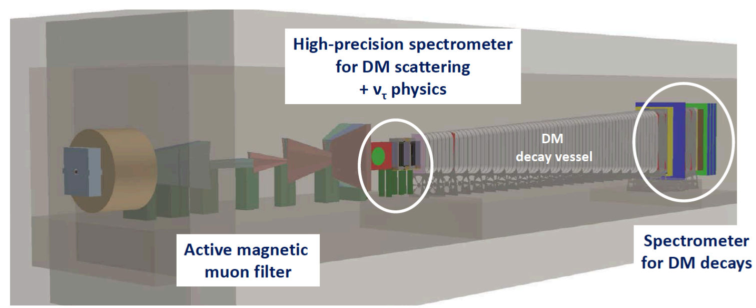




Instrumentation of NA62 decay vessel well adapted to searches in visible decay mode



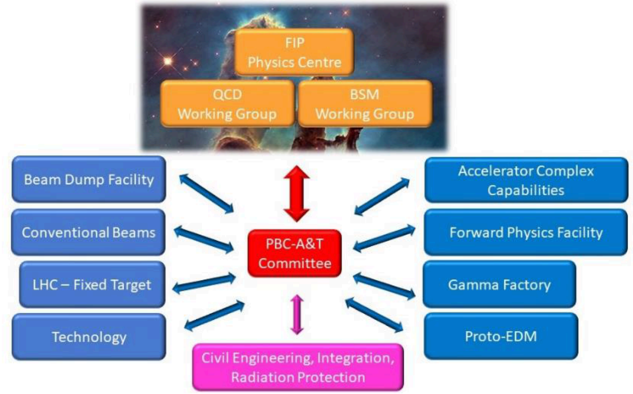
SHiP on the Beam Dump Facility



CERN Physics Beyond Colliders - Summary - (Claude Vallée)

- PBC study extended with a mandate updated to take into account EPPSU recommendations
- Several projects studied for EPPSU are now in implementation phase:
  - IAXO at DESY
  - QCD projects for Run 3 (MUonE, COMPASS (Rp), NA61 heavy flavours)
  - LHC small forward detectors (FASER, SND, ...)
- Main developments for other projects:
  - NA60++ (caloric curve of QCD phase transition)
  - AMBER long-term QCD facility
  - pEDM prototype ring study under the lead of Jülich (Joint Activity, EoI 4)
  - Gamma Factory Proof of Principle experiment preparation (talk by W. Krasny on Wednesday)
- Main new ideas:
  - Long term K^+ and K^0 rare decay physics ("HIKE") with higher intensity K beams in ECN3 (NA62++, KLEVER)
  - Completion of NA62 beam-dump mode with a small off-axis detector (SHADOWS) extending acceptance to higher-mass hidden particles
  - Possible relocation of BDF&SHiP in ECN3 to reduce the cost; Dedicated ECN3 Task Force set up to address the competition issue
  - Forward Physics Facility at LHC to extend the reach of forward physics in the HL-LHC era

PBC UPDATED ORGANISATION



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

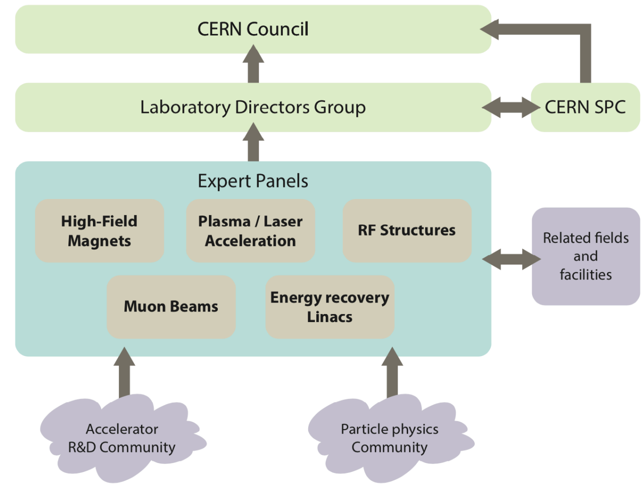
LDG: European "Lab Directors Group" (10 labs)
- CERN, CIEMAT, DESY, IRFU, IJCLAB, NIKHEF, LNF, LNGS, PSI, STFC-RAL
- lab-to-lab communications with a view to address together the ESPP
- current chairperson: Dave Newbold (STFC-RAL)

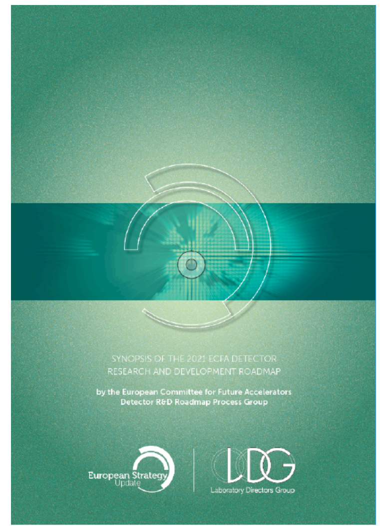
Roadmap for Accelerator R&D (cont.)

- **Intensive process during 2021**
  - Expert panels convened in January 2021
  - Intensive community consultation (accelerator R&D and particle physics communities)
  - Interim reports at EPS-HEP Conference in July 2021
  - Interactions with national communities (via ECFA delegates)
  - Reviews by SPC (CERN Scientific Policy Committee)
  - Closed process for prioritisation, planning and costing

- **Roadmap presented to CERN Council in Dec. 2021**

- **Content of the Roadmap:**
  - Broad and deep survey of each technology area
  - Identification of key R&D objectives for short term and long term
  - Definition of delivery plans for the next five to ten years
  - Outline estimates of resources needs and the necessary facilities
  - Overarching recommendations on the future R&D programme





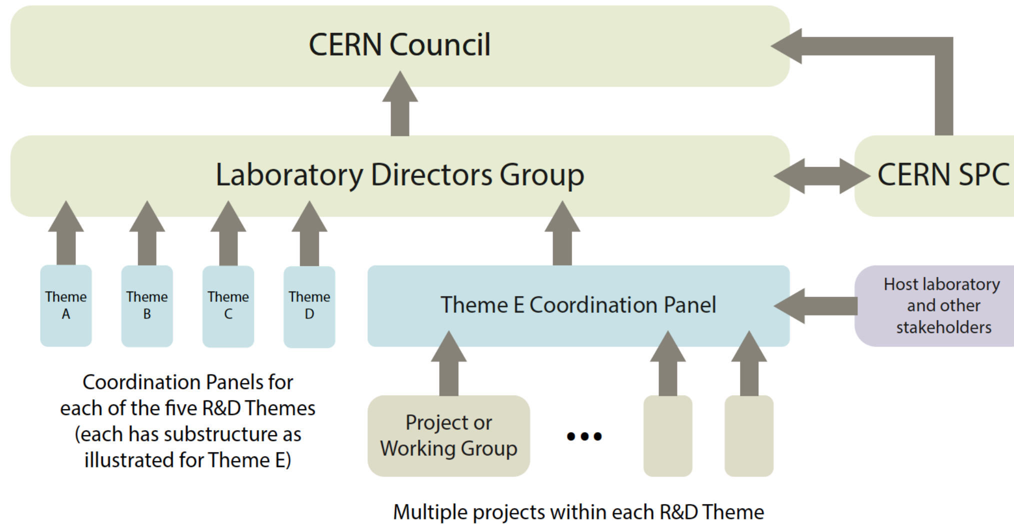
Roadmap for Accelerator R&D (cont.)

- Next step: LDG was mandated by Council in December 2021 to work out an implementation plan *(in close collaboration with the SPC, the funding agencies and the relevant research organisations in Europe and beyond)*

- Work ongoing

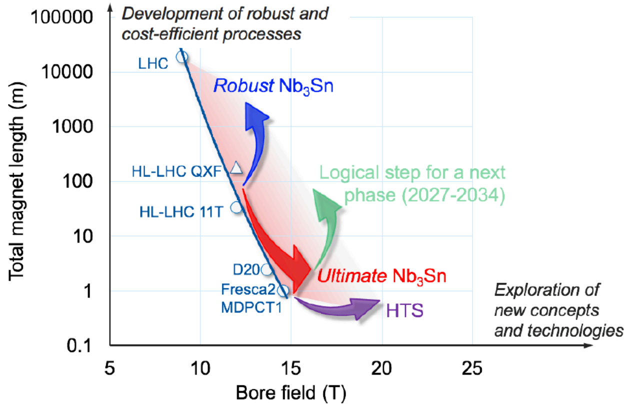
  - First Coordination Structure proposed

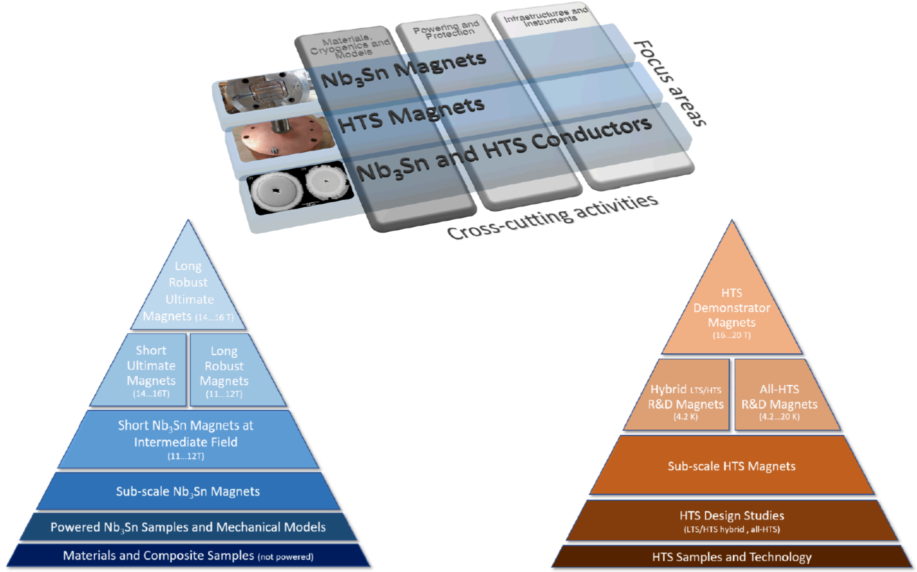
  - Discussions with CERN Council and Funding Agencies have started



Proposed coordination structure:
- Lightweight, causing minimal disruption / delay to existing projects
- Coordination panels introduced, oversight by LDG

Example: Objectives for High-Field Magnet Development





- Encompasses Ni3Sn and HTS (REBCO) developments
- 'Vertically integrated' approach to R&D
  - Development on all aspects from conductors to cables to magnets to systems
  - Emphases: full system optimisation; fast turnaround for R&D; modelling

For details, see presentation by Dave Newbold to Plenary ECFA (Nov 2021) https://indico.cern.ch/event/1085137/

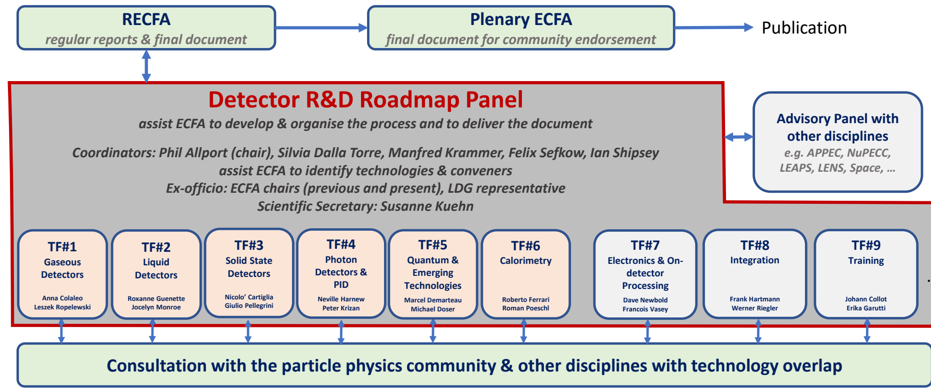
Update of the European Strategy for Particle Physics

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. …

Roadmap for Detector R&D (cont.)

- **Intensive process during 2021**
  - Detector R&D Roadmap Panel set up in 2020
    - * Coordination group
    - * Six technology Task Forces (TF)
    - * Transversal TF (electronics, integration, training)
  - Intensive community consultation
    (expert input sessions, open symposia for each TF)
  - Interim reports at EPS-HEP Conference in July 2021
  - Interactions with national communities (via ECFA delegates)
  - by SPC (CERN Scientific Policy Committee)



- **Roadmap presented to CERN Council in Dec. 2021, after endorsement by Plenary ECFA in Nov. 2021**

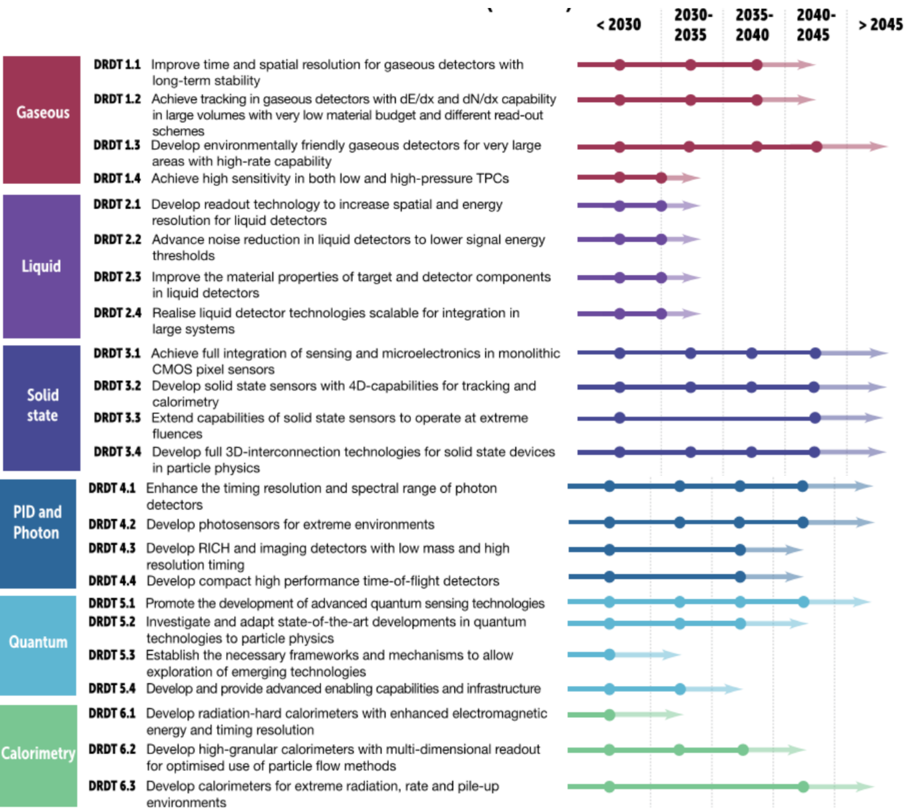
  Documents available: https://cds.cern.ch/record/2784893
  (incl. a short Synopsis Document)

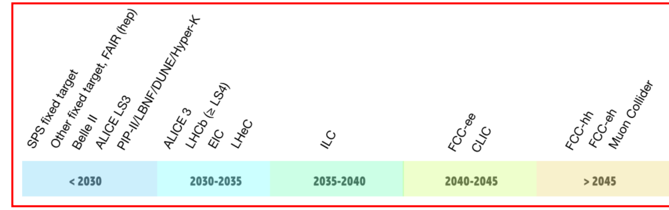
- **Content of the Roadmap:**

  1. Major Detector Research and Development Themes (DRDTs)

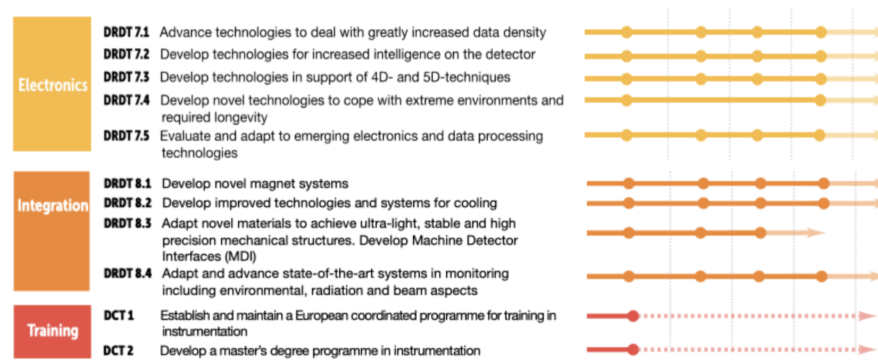
  2. General Strategic Recommendations

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





Priorities defined in Roadmap's DRDTs



For details, see presentation by Phil Allport to Plenary ECFA (Nov 2021)
https://indico.cern.ch/event/1085137/

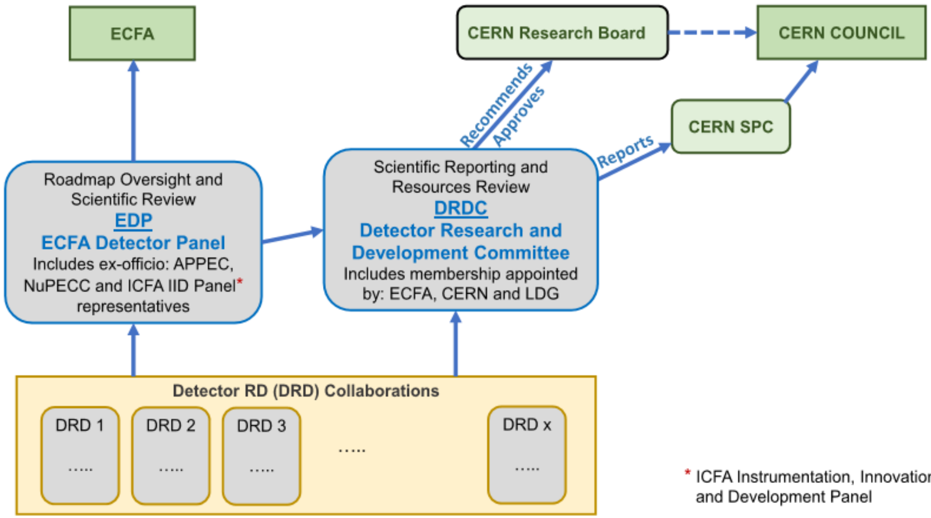
Roadmap for Accelerator R&D (cont.)

- Next step: ECFA was mandated by Council in December 2021 to work out an implementation plan *(in close collaboration with the SPC, the funding agencies and the relevant research organisations in Europe and beyond)*

- Work ongoing

  - First implementation plan proposed

  - Discussions with CERN Council and Funding Agencies have started



Proposed structure:
- Establish new Detector R&D Collaborations at CERN (one for each detector technology)
- Oversight and reviews by ECFA and CERN Committees

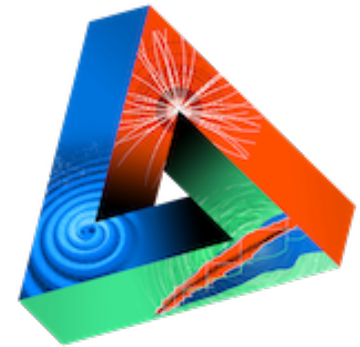
Update of the European Strategy for Particle Physics

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)
and Joint ECFA-NuPECC-APPEC Seminars



Conclusions

- The Update of the European Strategy has put forward an ambitious plan for the next years, with an e^+e^- Higgs factory as the highest-priority next collider
- FCC Feasibility study has been set up by CERN management and approved by Council (June 2021)
- Many interesting proposals on “Physics Beyond Colliders” emerging; Realisation to be addressed
- ECFA and LDG have successfully developed **Roadmaps for Detector and Accelerator R&D** and are working on the implementation plans at present

Good progress on addressing the main objectives of the European Strategy!

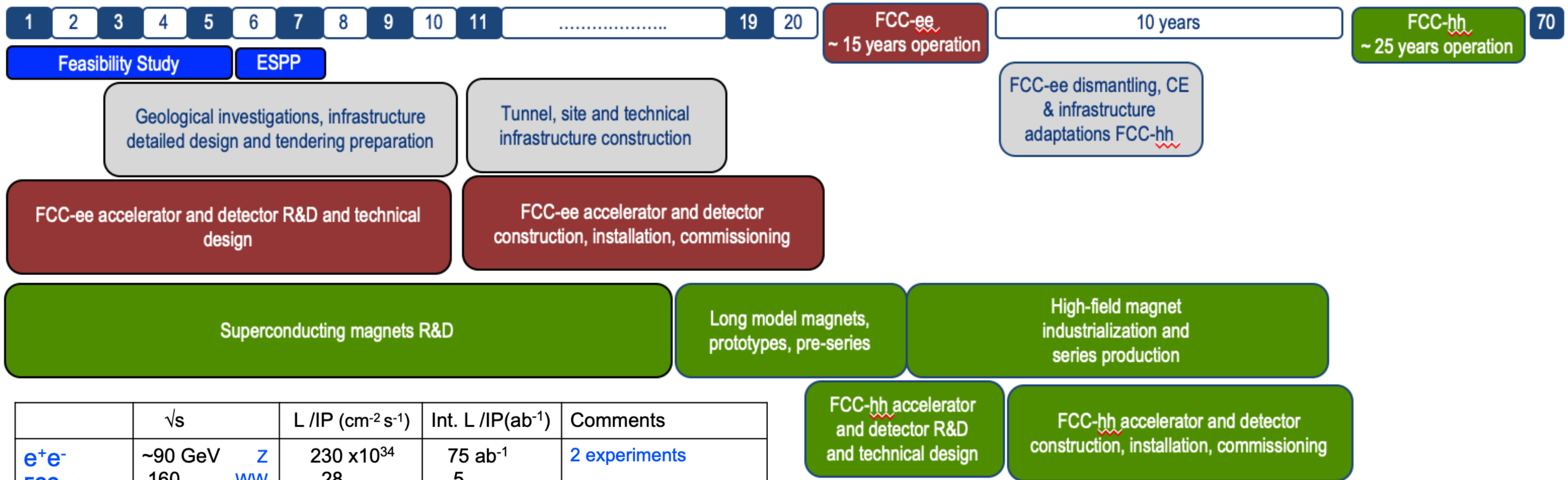
The full European Particle Physics Community must work coherently together to achieve the ambitious goals, to be ready for taking the decision on the next large collider project at the next Strategy Update

Backup Slides

FUTURE CIRCULAR COLLIDER

Timeline of the FCC integrated programme

Technical schedule

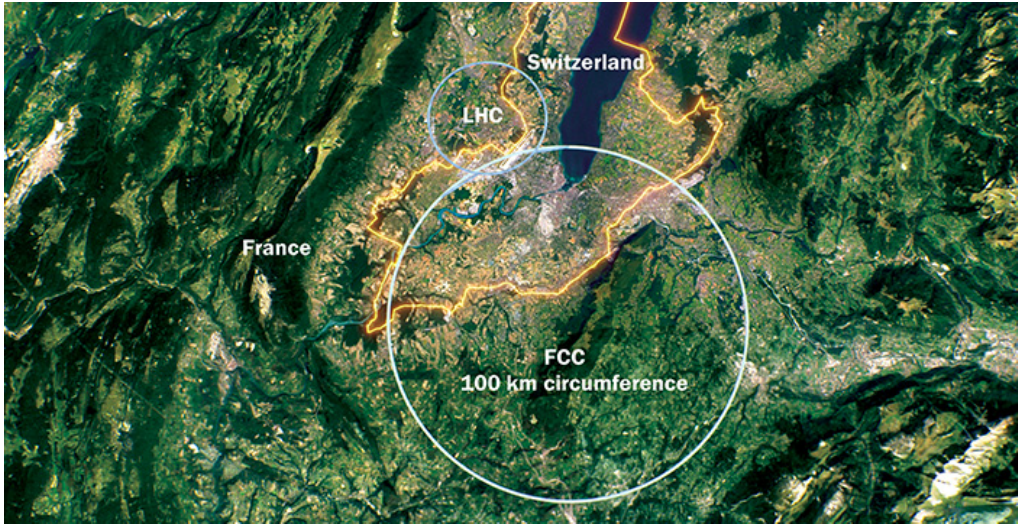


	√s	L /IP ($cm^{-2} s^{-1}$)	Int. L /IP(ab^{-1})	Comments
e^+e^- FCC-ee	~90 GeV Z 160 WW 240 H ~365 top	230 $\times 10^{34}$ 28 8.5 1.5	75 ab^{-1} 5 2.5 0.8	2 experiments 2-4 experiments operation
pp FCC-hh	100 TeV	5 $\times 10^{34}$ 30	20-30	2+2 experiments Total ~ 25 years of operation
PbPb FCC-hh	$\sqrt{s_{NN}}$ = 39TeV	3 x 10^{29}	100 nb^{-1}/run	1 run = 1 month operation
ep Fcc-eh	3.5 TeV	1.5 10^{34}	2 ab^{-1}	60 GeV e- from ERL Concurrent operation with pp for ~ 20 years
e-Pb Fcc-eh	$\sqrt{s_{eN}}$ = 2.2 TeV	0.5 10^{34}	1 fb^{-1}	60 GeV e- from ERL Concurrent operation with PbPb

- ❑ Feasibility Study: 2021-2025
- ❑ If project approved before end of decade → construction can start beginning 2030s
- ❑ FCC-ee operation ~2045-2060
- ❑ FCC-hh operation 2070-2090++

F. Gianotti

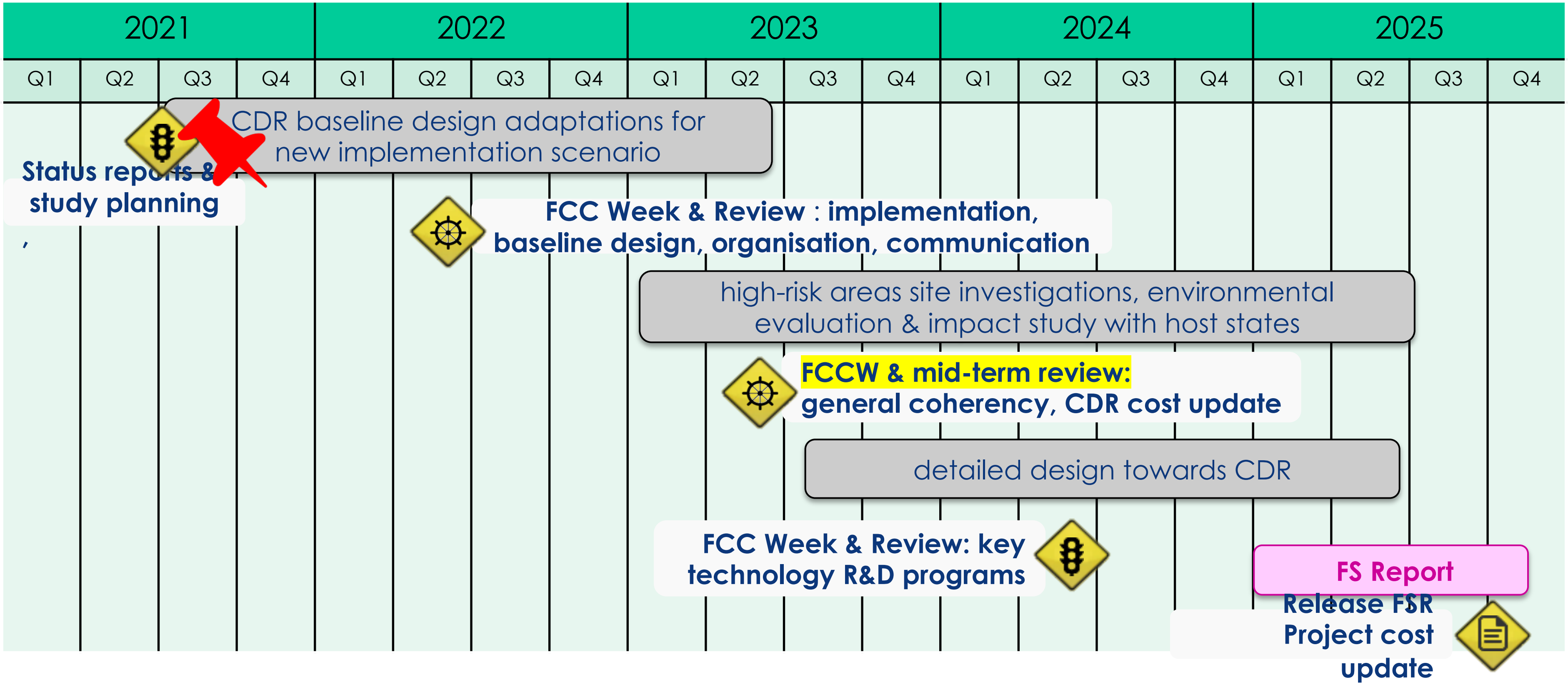
FCC Feasibility Study: Major Objectives



- 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

Feasibility Study Timeline



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.