LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

[Prospects for the Future]

P. Conde Muíño

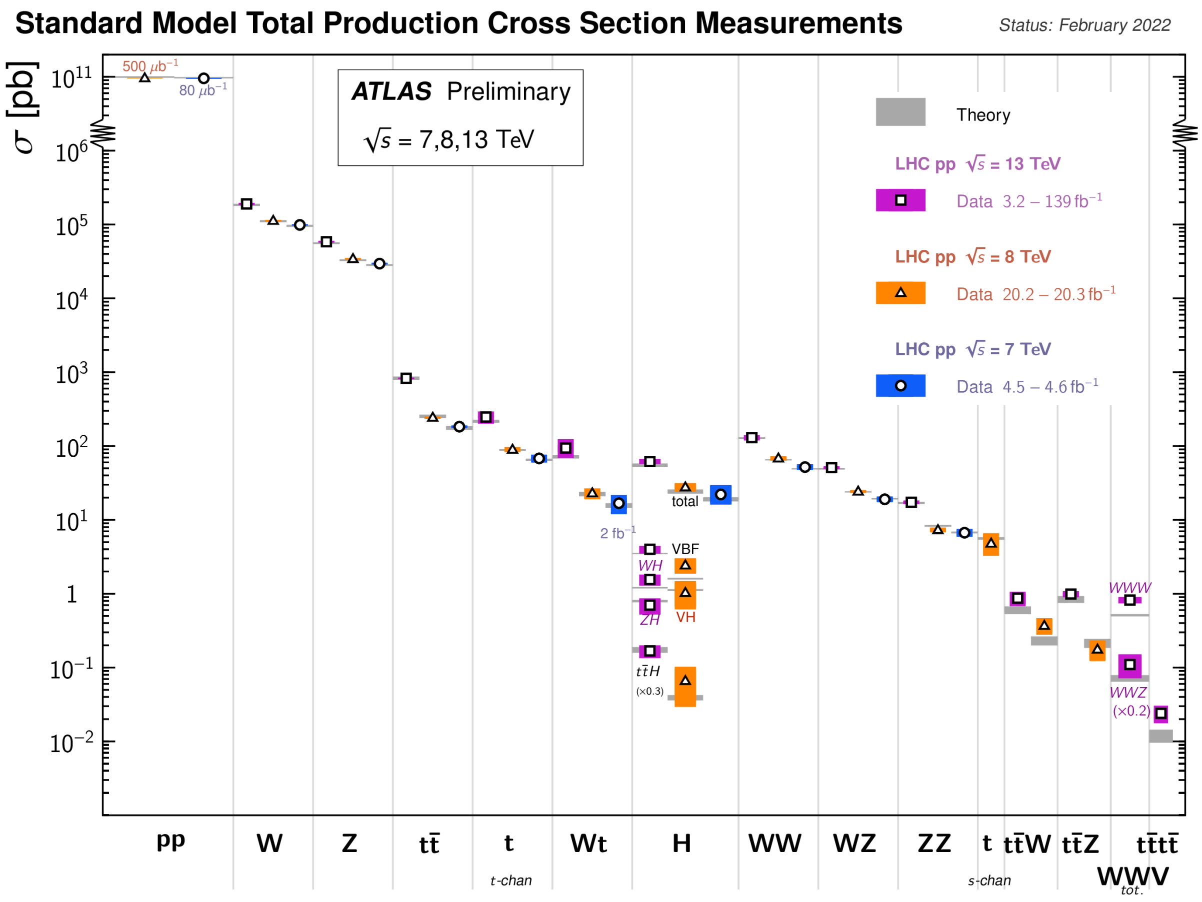
Outline

- Where do we stand?
- What are the main physics questions today?
- Future accelerators
- Update of the European Strategy for Particle Physics

Standard Model

Extensively probed

Remarkable agreement between measurements and experiment



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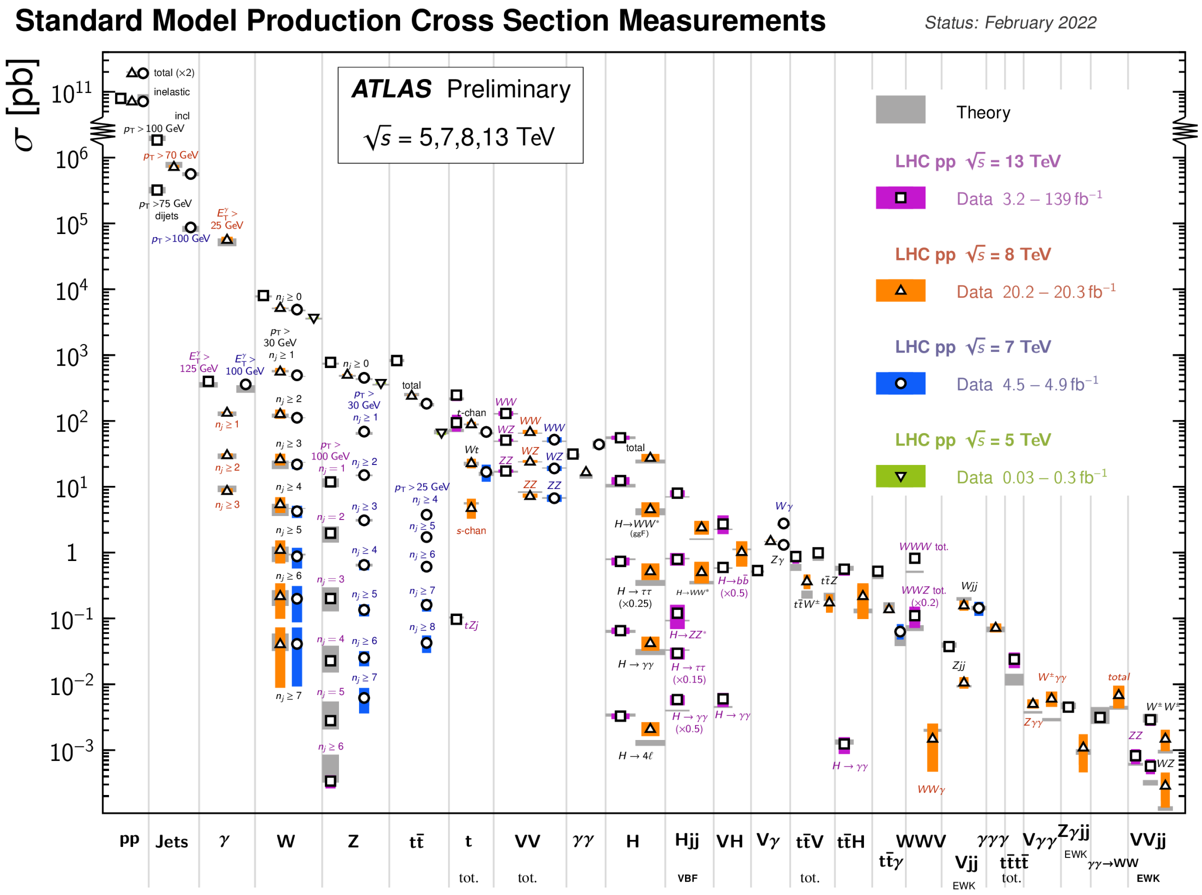
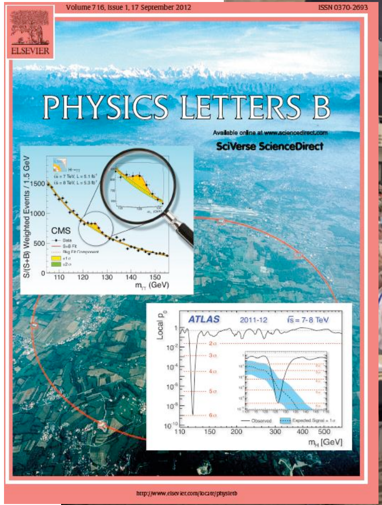


CERN | 10 years HIGGS boson discovery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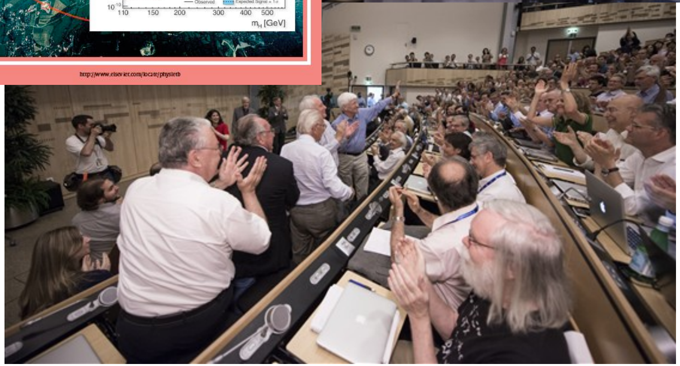
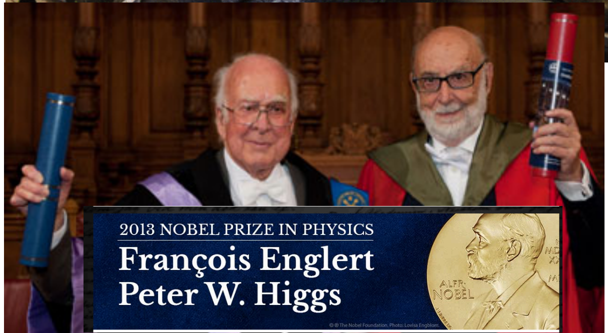
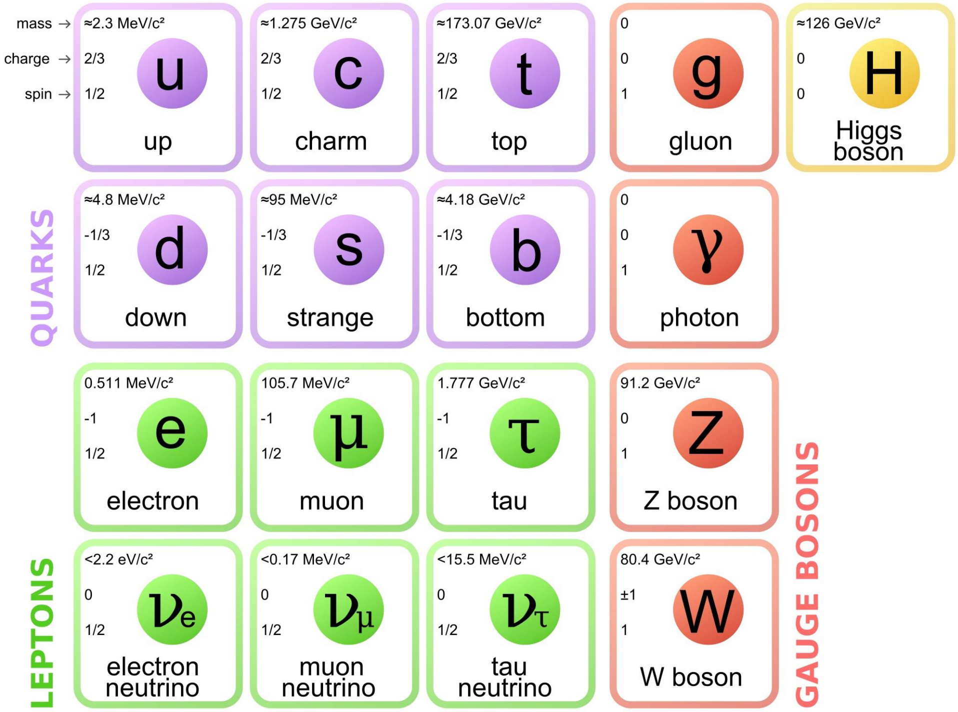




Last missing fundamental particle in the SM



Is this the last missing piece?

- Is this the Standard Model Higgs?

SM Higgs Lagrangian after symmetry breaking

$$\mathscr{L}_{SM} = D_\mu H^\dagger D_\mu H - (y_{ij} H \bar{\psi}_i \psi_j + h.c.) + \mu^2 H^\dagger H - \frac{\lambda}{2}(H^\dagger H)^2$$

Bosons

$$(m_W^2 W^{\mu +} W_\mu^- + \frac{1}{2} m_Z^2 Z^{\mu 0} Z_\mu^0)(1 + \frac{h}{v})^2$$

Fermions

$$-\sum_f m_f \bar{f} f (1 + \frac{h}{v})$$

Higgs potential

$$\frac{1}{2} m_h^2 h^2 + \lambda_3 v h^3 + \frac{1}{4} \lambda_4 h^4$$

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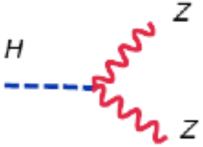
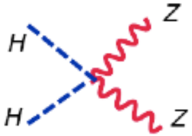
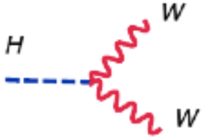


$$2i \frac{M_Z^2}{2v} g_{\mu\nu}$$



$$2i \frac{M_Z^2}{4v} g_{\mu\nu}$$



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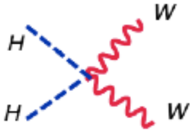

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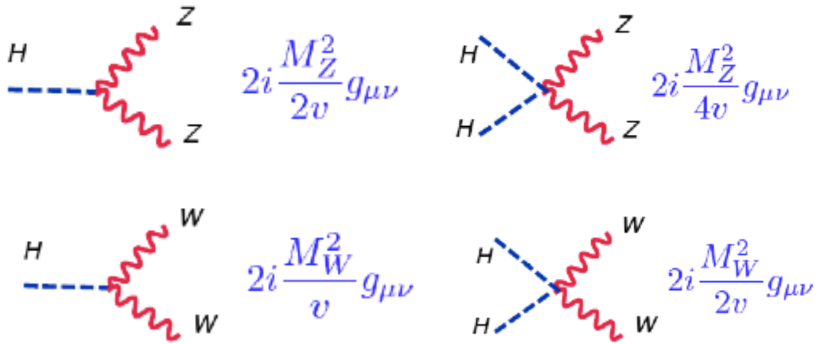

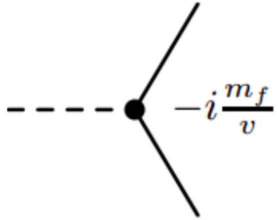

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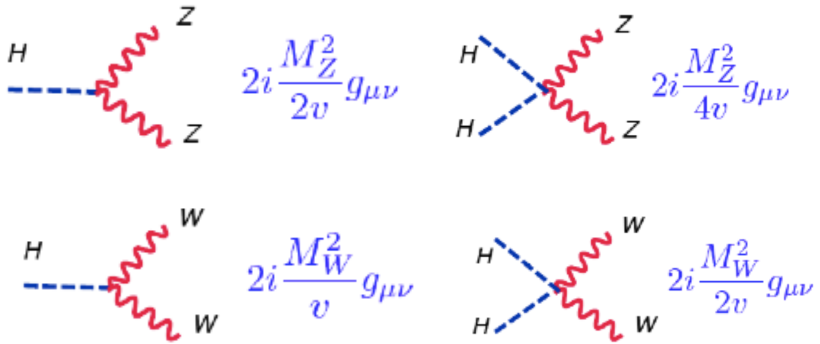

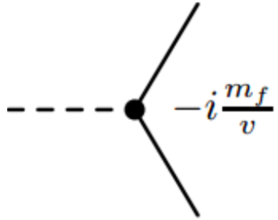

I	II	III
u	c	t
d	s	b
ν_e	ν_μ	ν_τ
e	μ	τ

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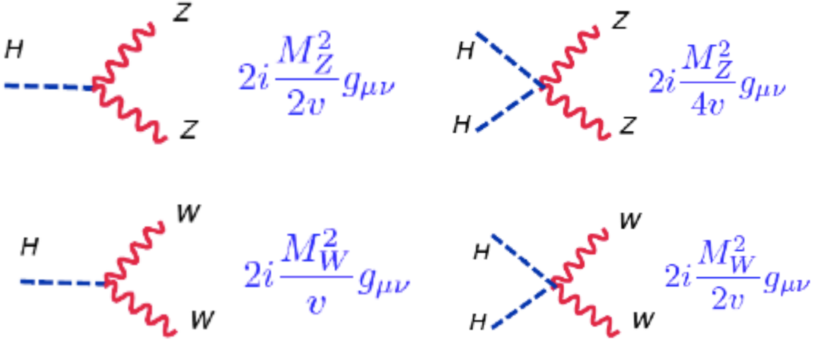

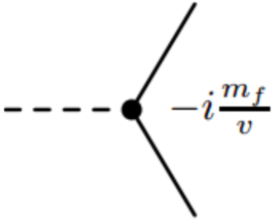

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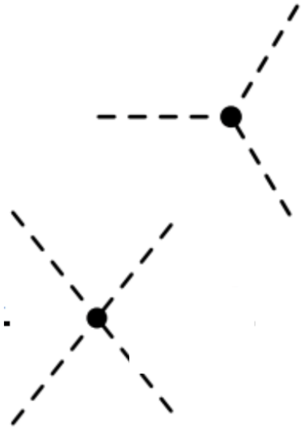

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Bosons	Fermions	Higgs potential
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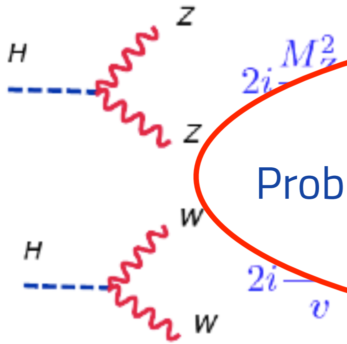
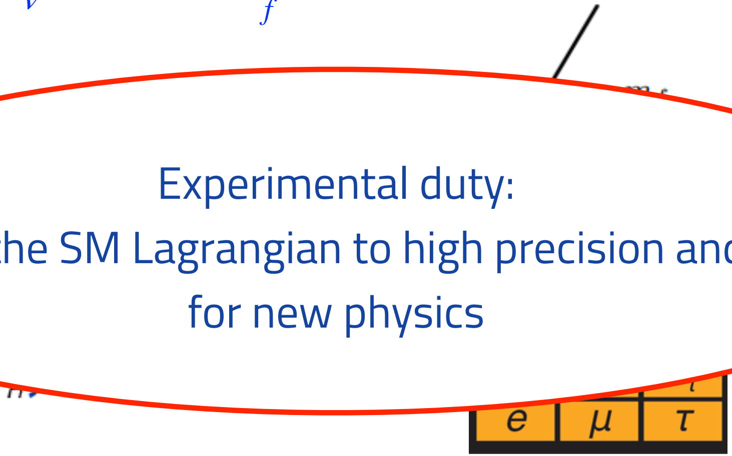
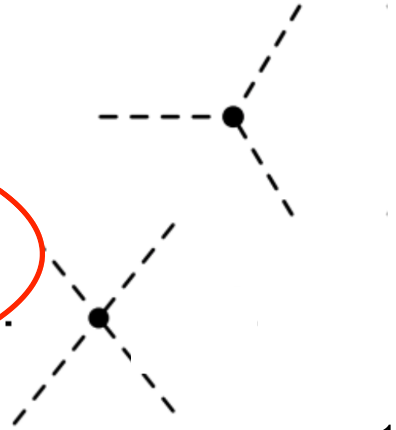






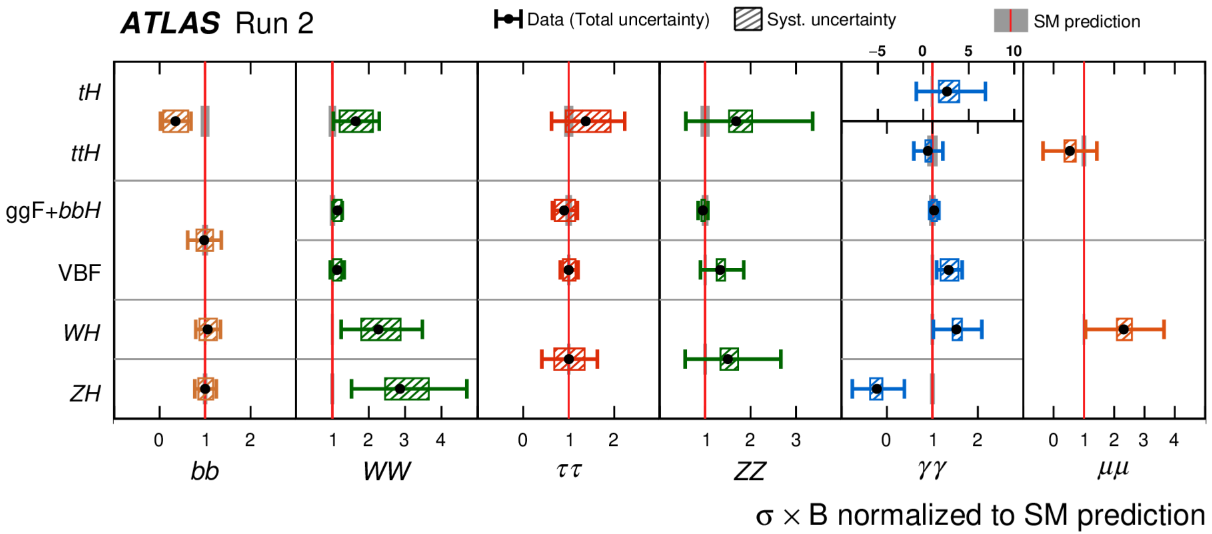
Experimental duty:
Probe the the SM Lagrangian to high precision and search for new physics

Higgs boson couplings to bosons & fermions

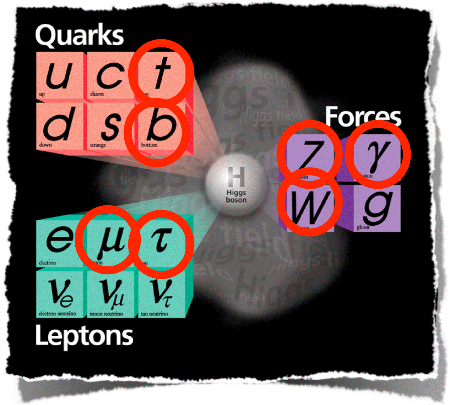
- Direct measurement of $\sigma \times BR$

Precision ATLAS & CMS

- ggF: better than 10%
- Other production modes: 10-20%
- BR~7-12%

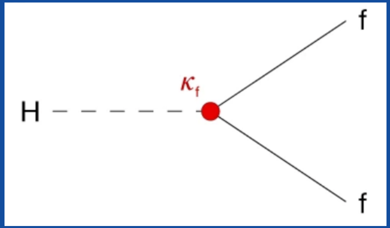


- ATLAS p-value: 72%
- Similar results for CMS

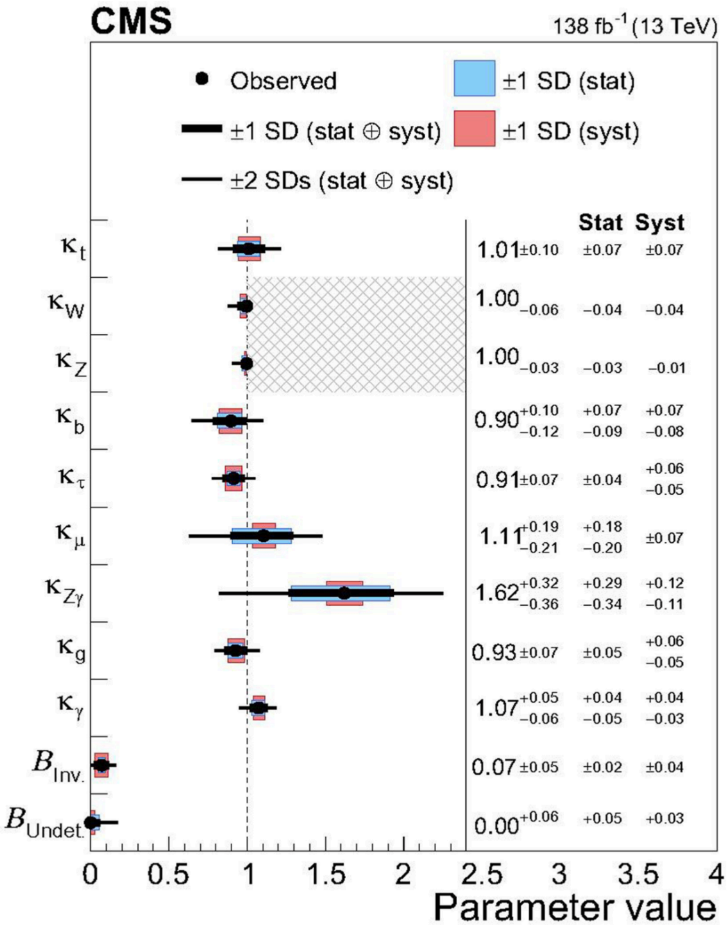


Coupling modifiers

For each interaction vertex introduce an effective vertex with a coupling modifier κ_i



Current precision~3-20%

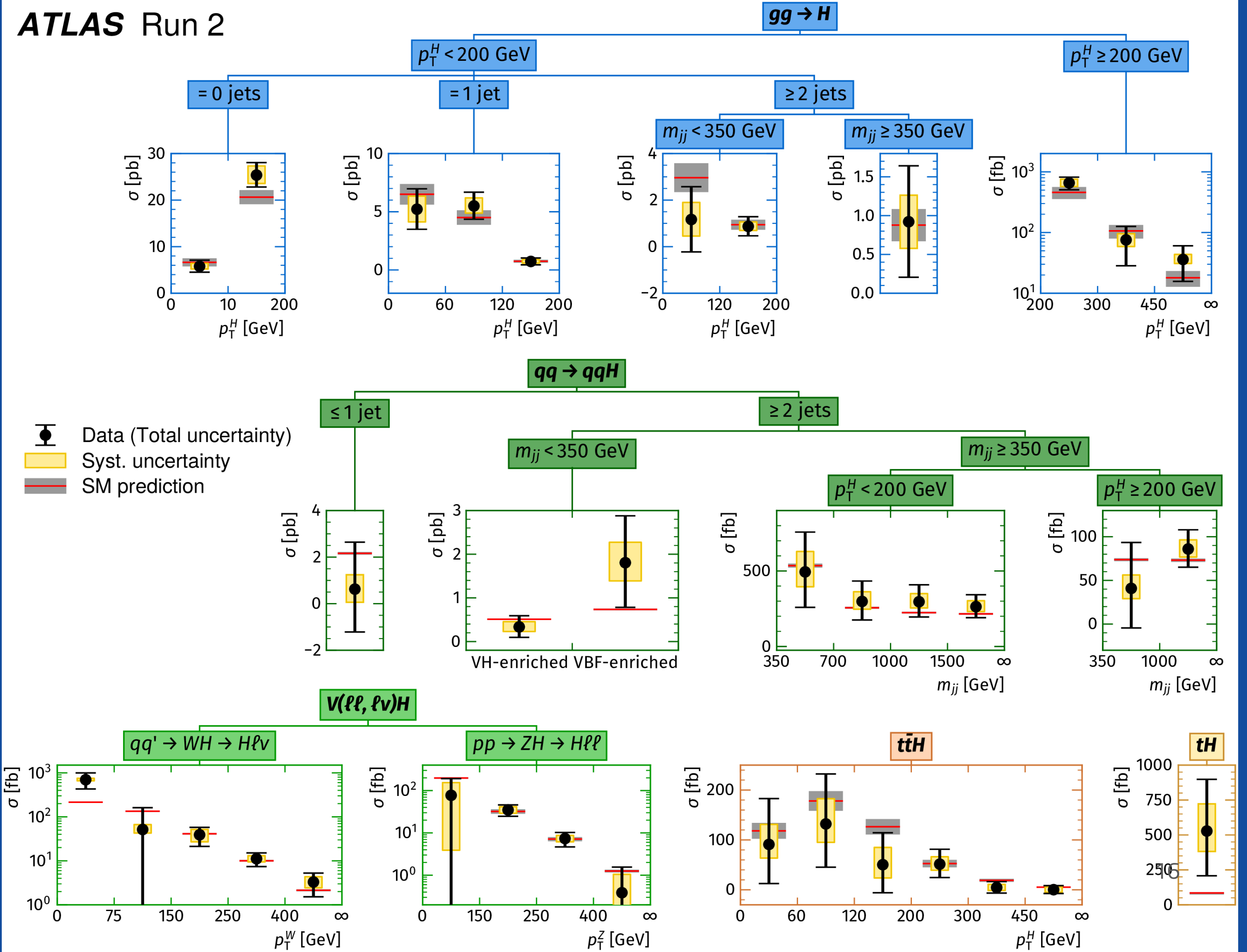


Higgs Cross section in different kinematic regions

Probing differential distributions

Combined p-value:

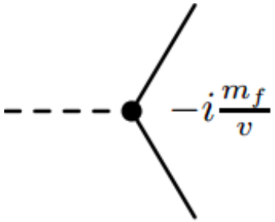
- 94%

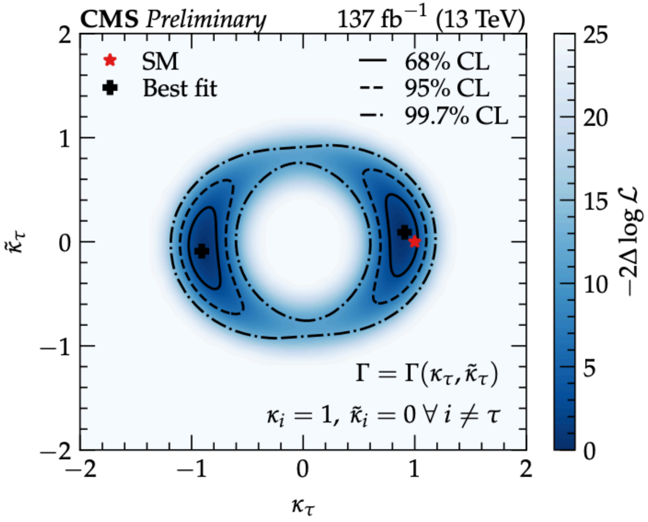


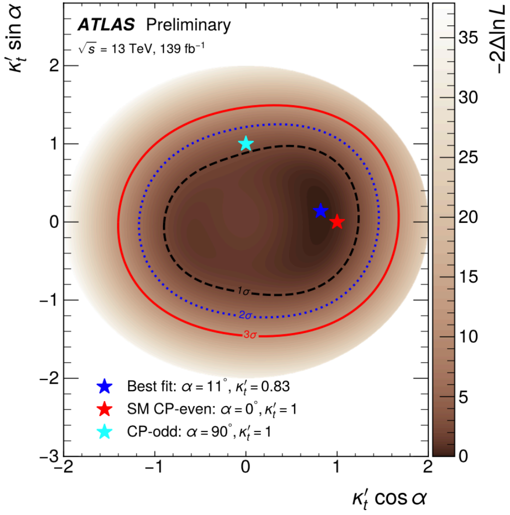
Probing the structure of coupling vertices

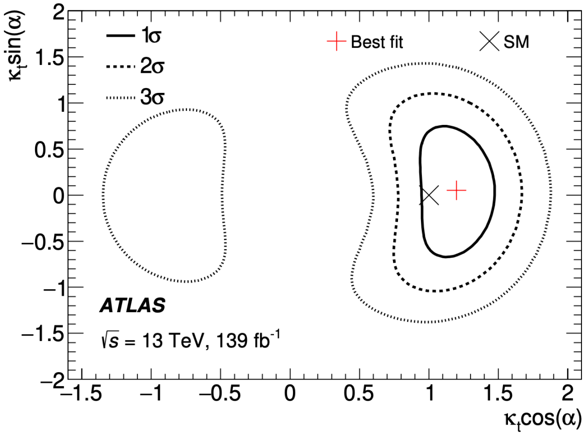
$$\mathcal{L} = -\frac{m_t}{v}\left\{\bar{\psi}_t \kappa_t \left[\cos(\alpha) + i\sin(\alpha)\gamma_5\right]\psi_t\right\} H$$

CP-even (SM) — CP-odd

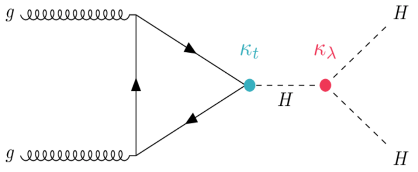


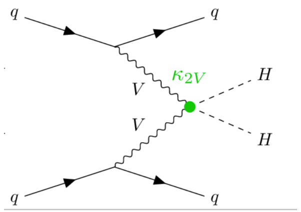






Higgs self coupling

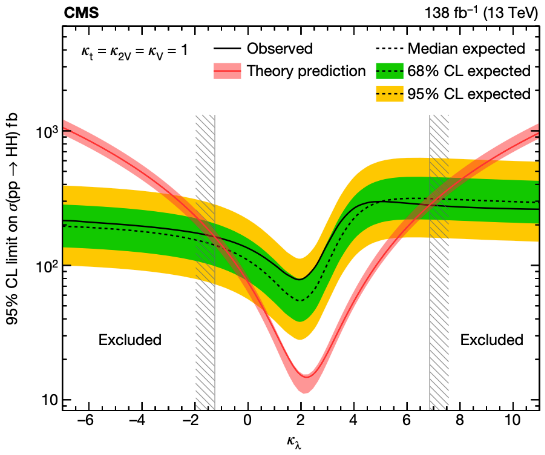


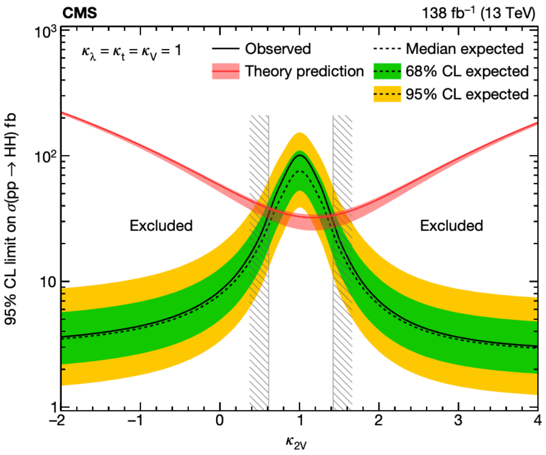


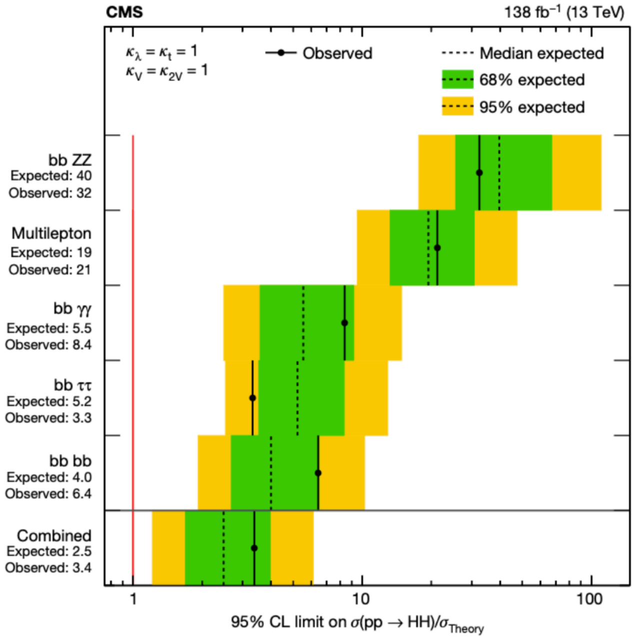
- Determine the shape of the Higgs potential

$$\frac{1}{2}m_h^2h^2 + \lambda_3 v h^3 + \frac{1}{4}\lambda_4 h^4$$

- Di-Higgs production

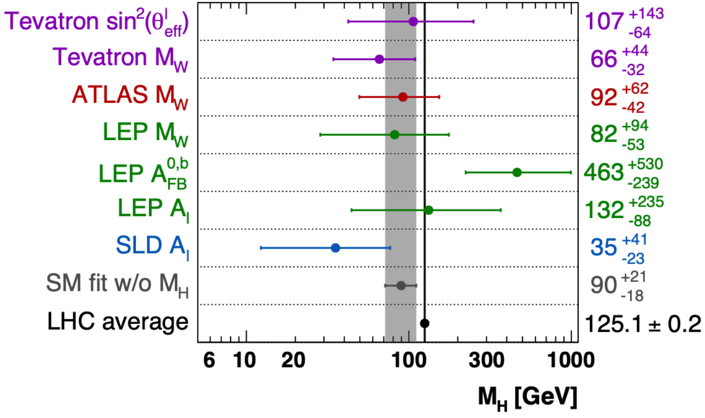


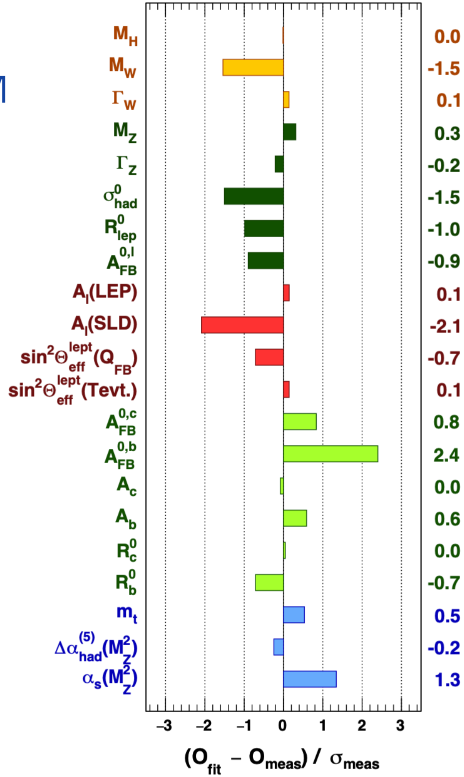


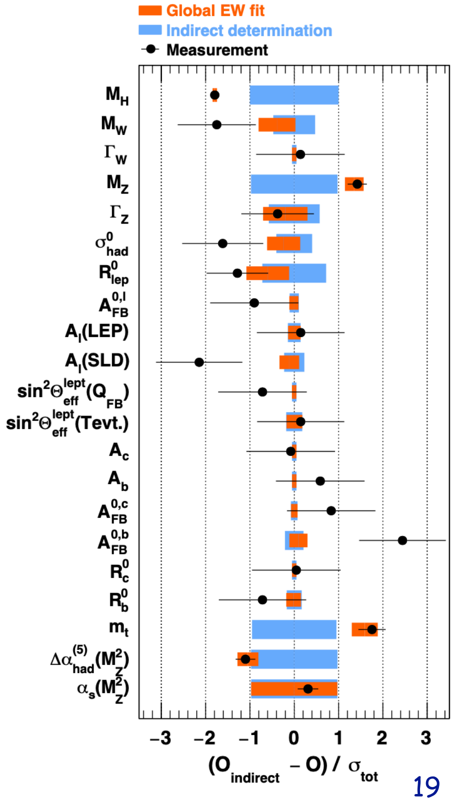


How does all fit together?

- Higher order corrections relate different SM observables
- Global fit
  - P-value of combined fit: 23%

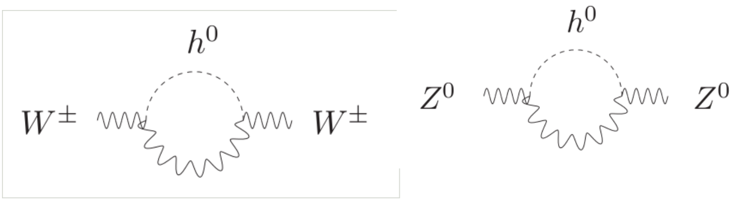






W, top and Higgs boson masses

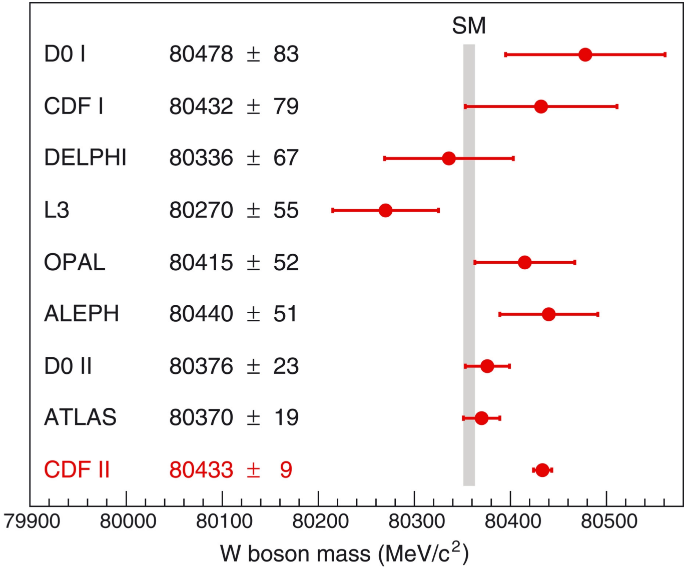
- M_{top}, M_W, M_H related through higher order electroweak corrections
    - Need very high precision —> extremely challenging
- Controversial experimental results on M_W

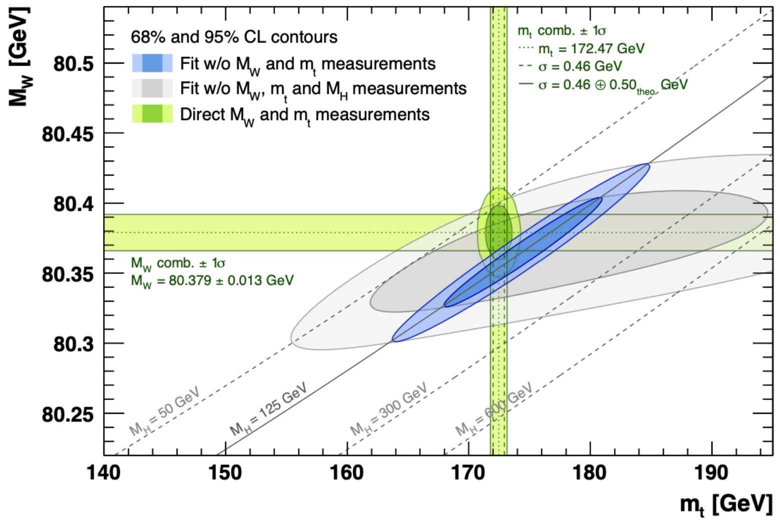


$$M_W^2 = \rho\, M_Z^2 \cos^2\theta_W$$

$$(\rho-1) \sim M_{top}^2$$

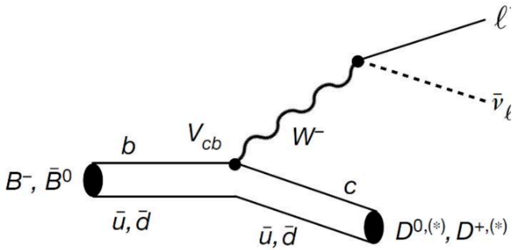
$$(\rho-1) \sim \ln M_H$$

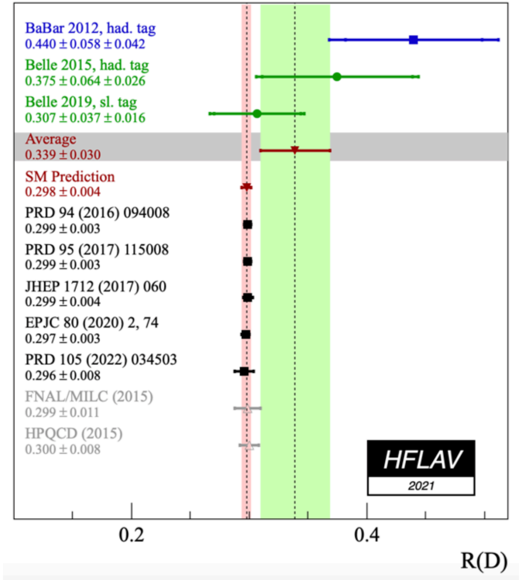


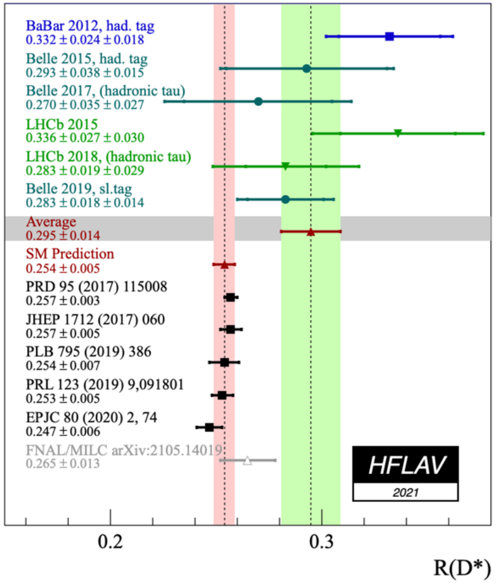


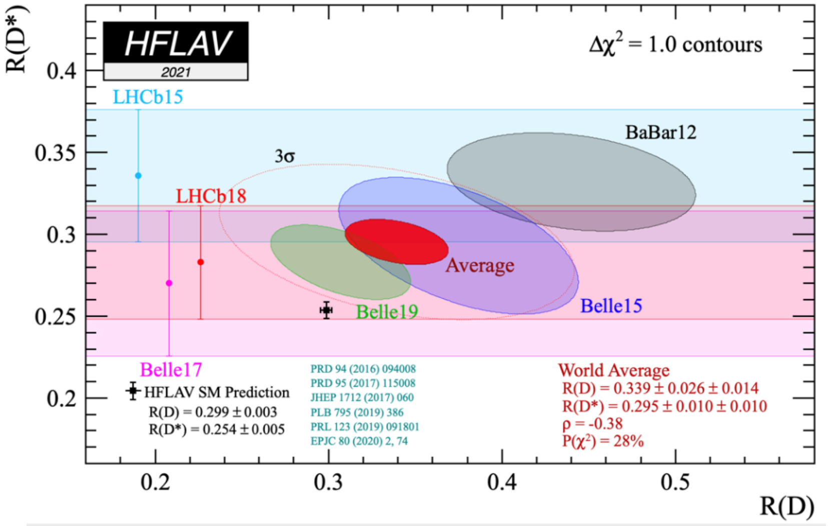
Flavour anomalies

$$R(D^{(*)}) = \frac{BF(\bar{B} \to D^{(*)}\tau^- \upsilon_\tau)}{BF(\bar{B} \to D^{(*)}\mu^- \upsilon_\mu)}$$









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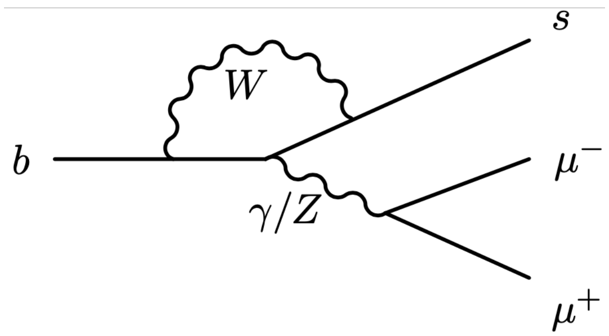
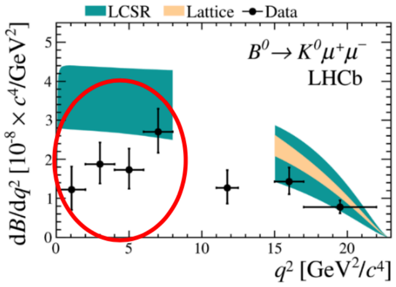
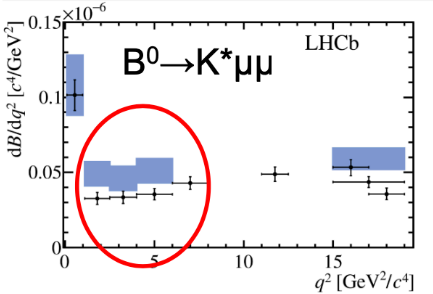


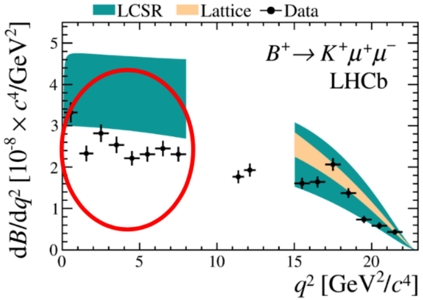
- Differential branching fraction systematically low at high q^2

[JHEP 06 (2014) 133]



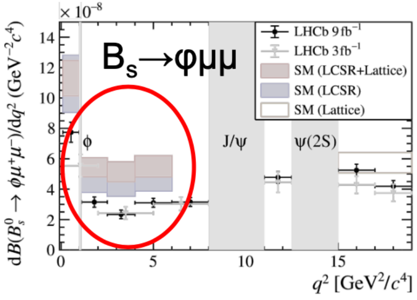


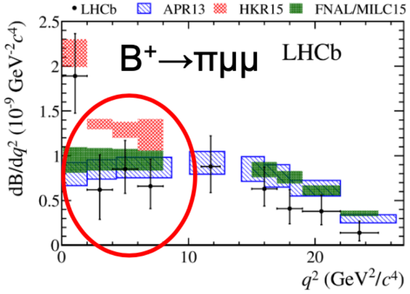
[JHEP 04 (2017) 142]



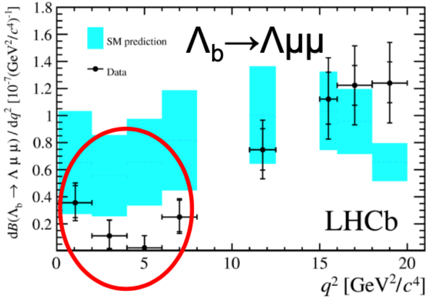
[JHEP 06 (2014) 133]

[PRL 127 (2021) 151801]



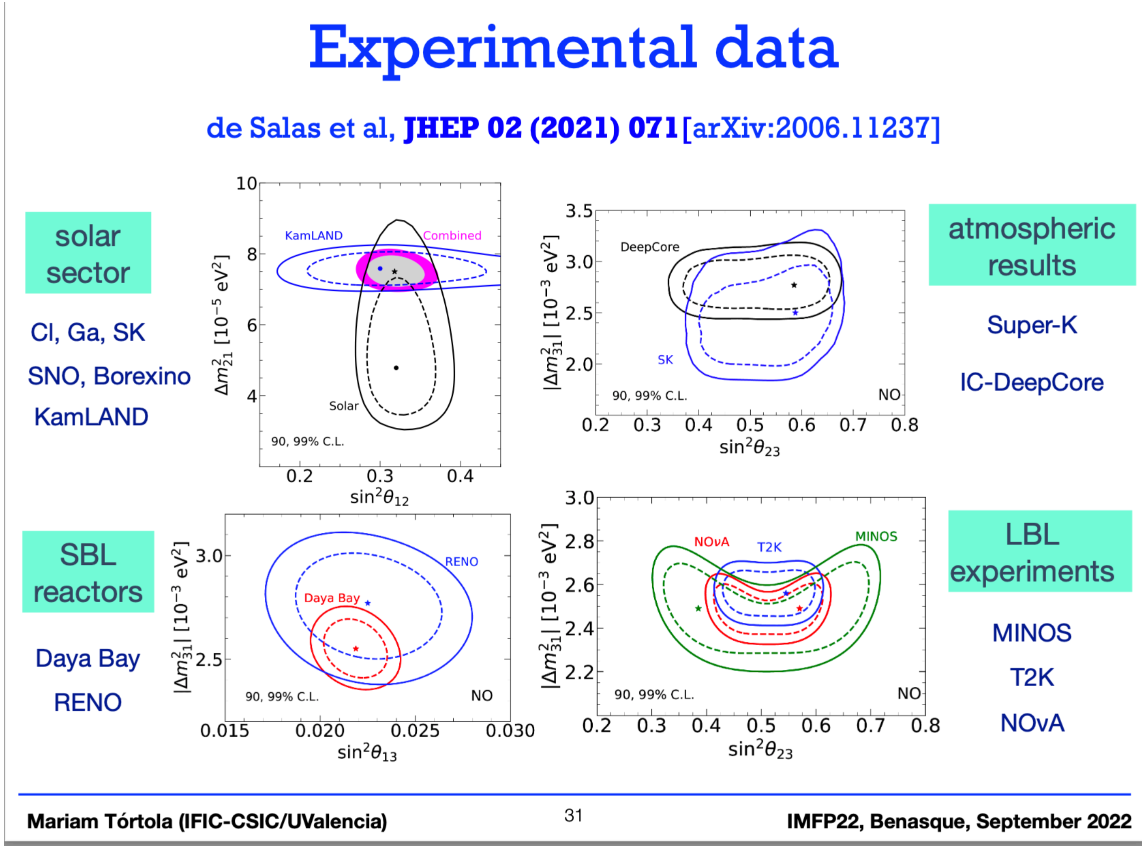


[JHEP 10 (2015) 034]



[JHEP 06 (2015) 009]

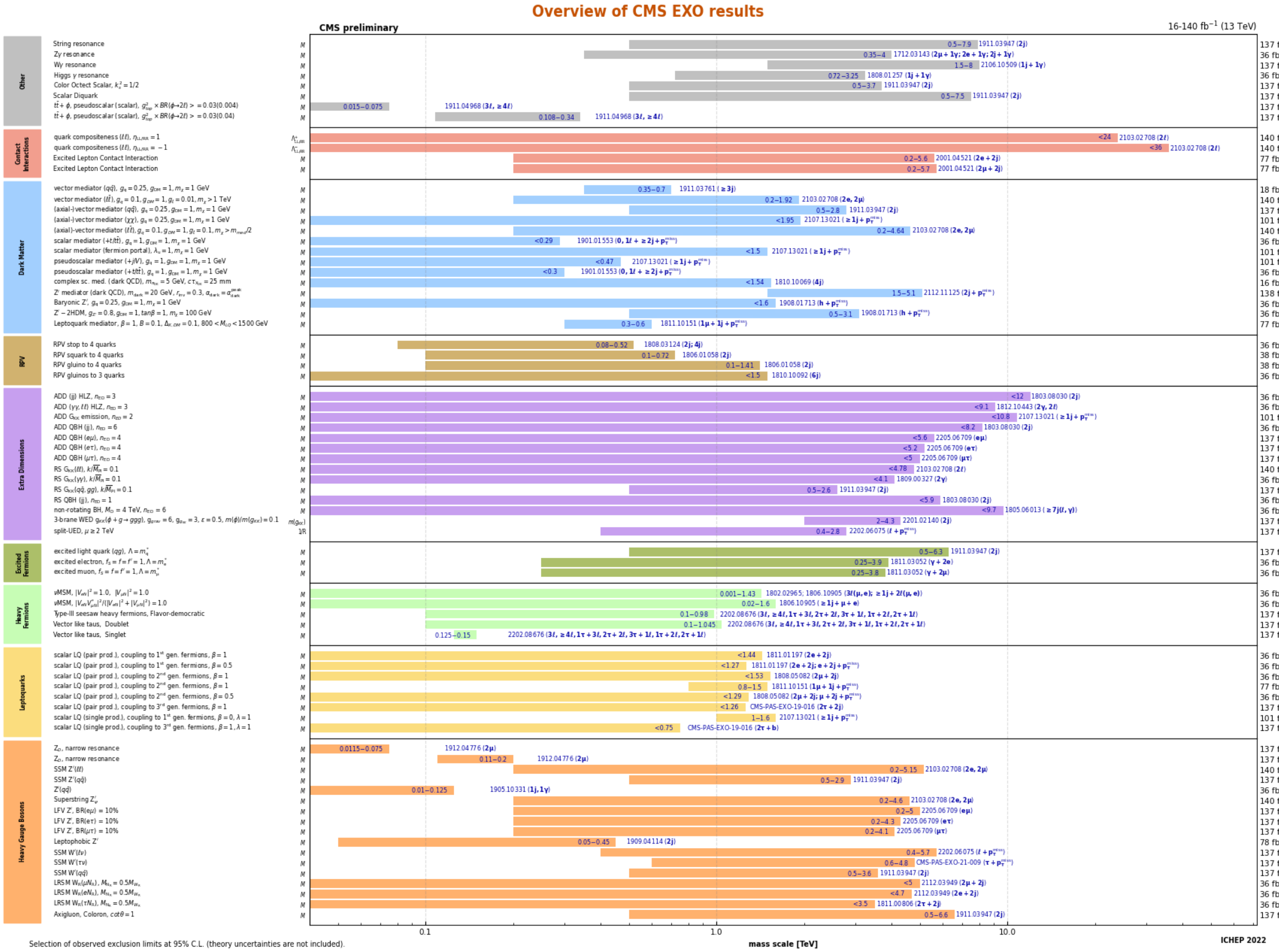
Neutrino masses



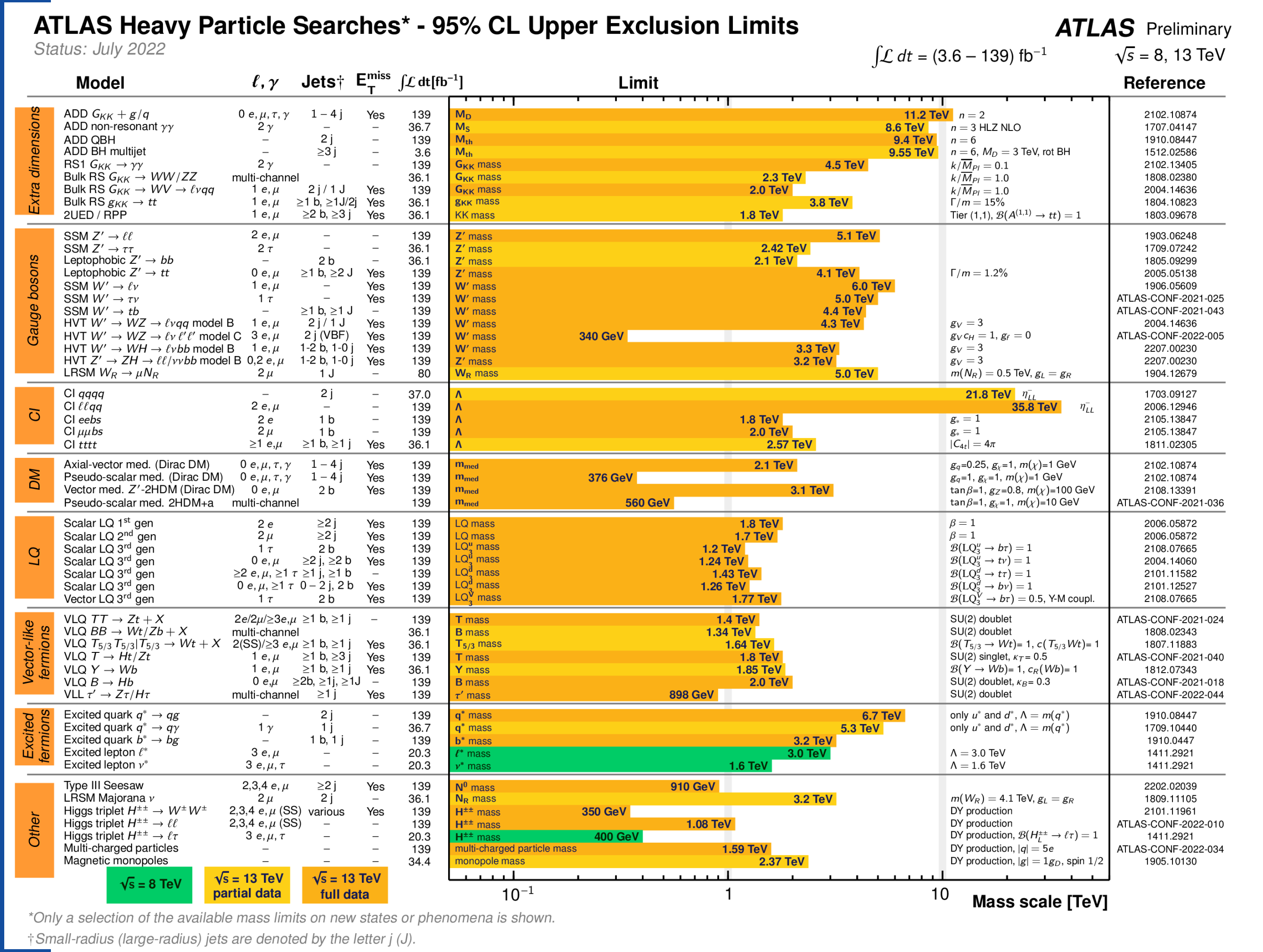
Many answered questions remain…

- Why is there a matter-antimatter asymmetry in the Universe?
- What are dark matter and dark energy?
- Why is gravity so weak?
- Why is the Higgs boson so light (naturalness/hierarchy problem)?
- Why three fermion families?
- Why do neutral leptons, charged leptons and quarks behave differently?
- What is the origin of neutrino masses and oscillations?
- …

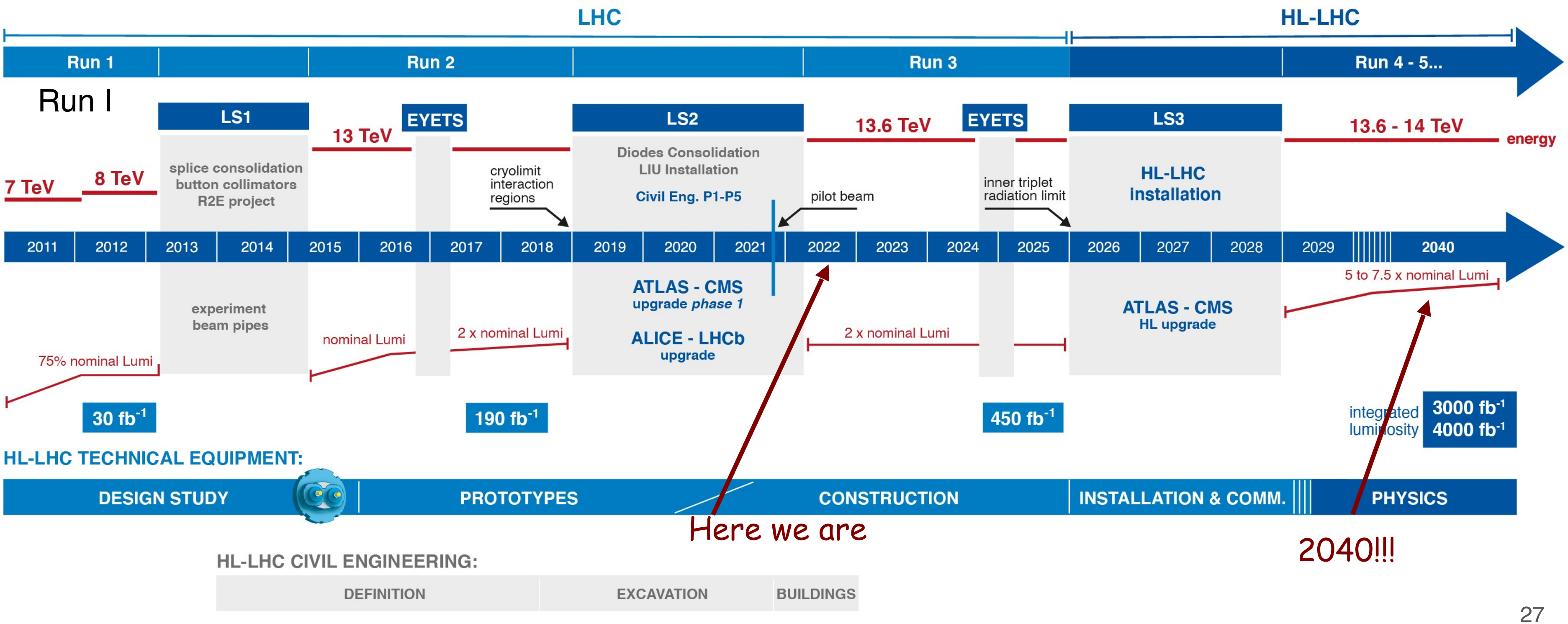
Searches for new exotic particles at the LHC



Searches for long lived massive particles

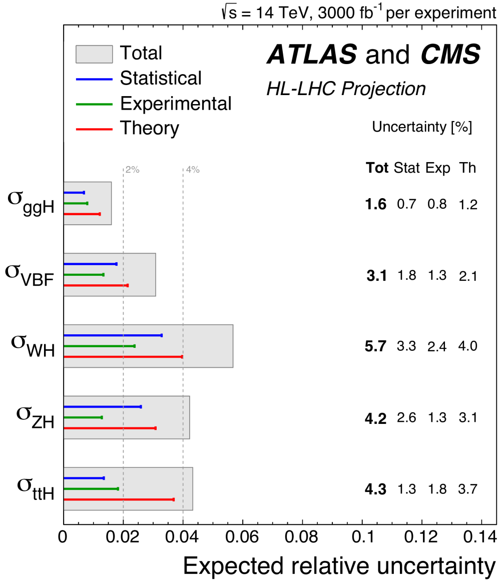


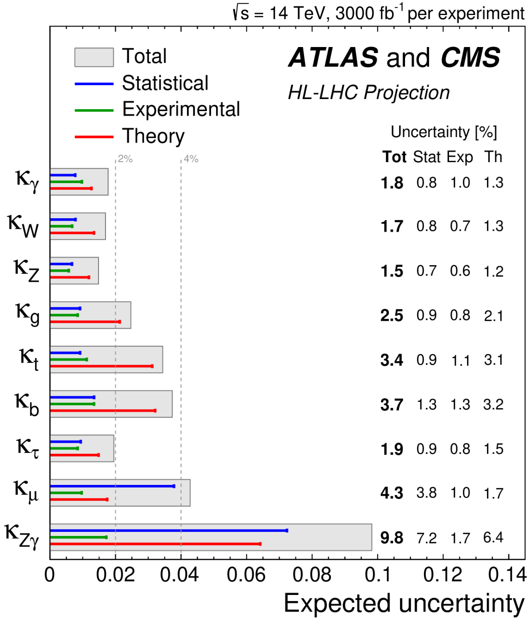
LHC / HL-LHC Plan

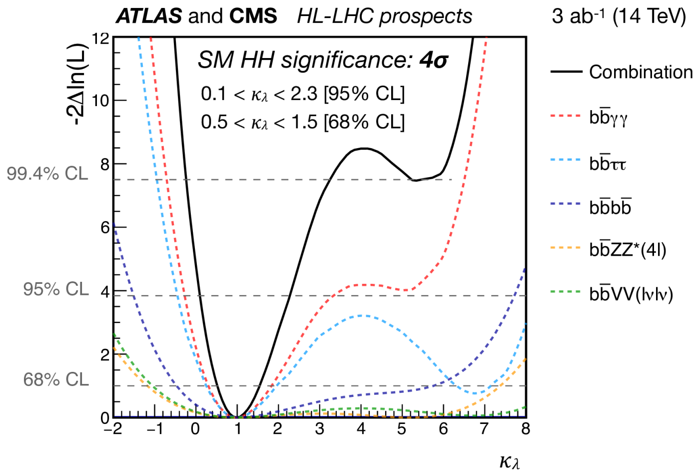


ATL-PHYS-PUB-2022-018
CMS PAS FTR-22-001

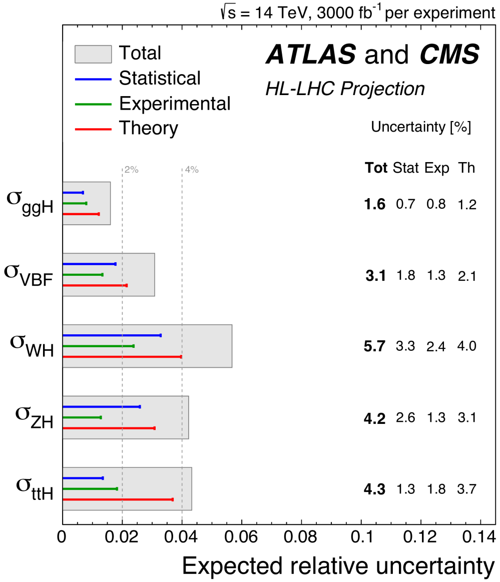
High Luminosity LHC expectations

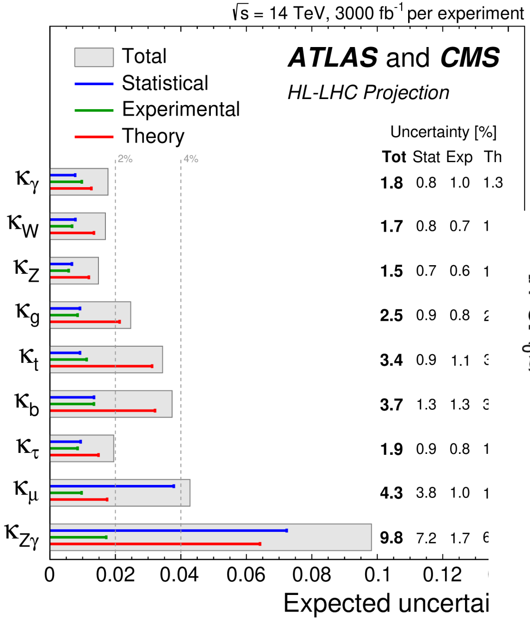


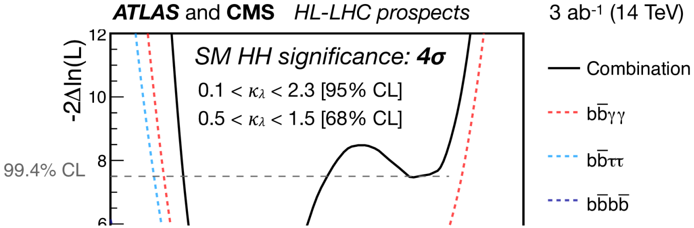


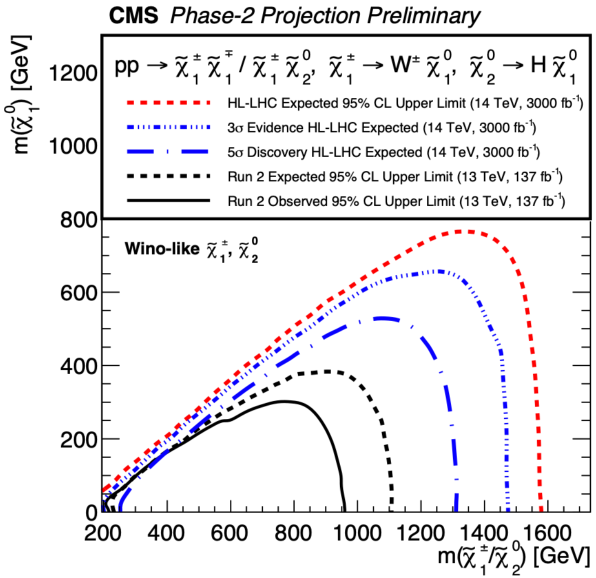


High Luminosity LHC expectations









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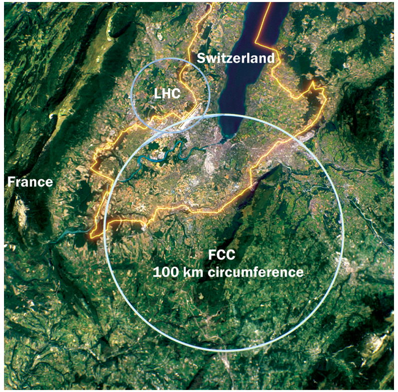
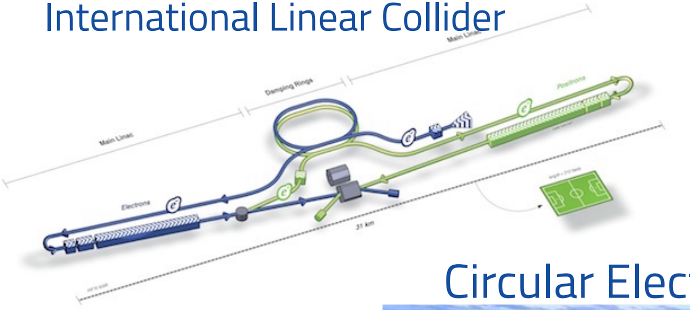
What's next?

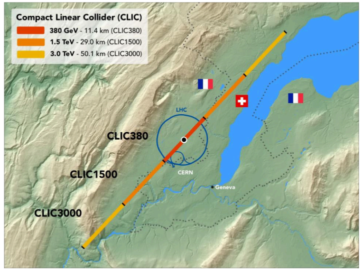


Future Circular Collider

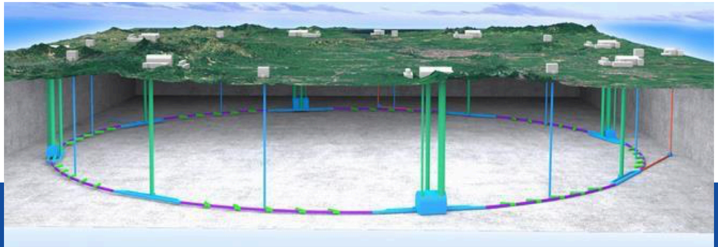
International Linear Collider



Compact Linear Collider



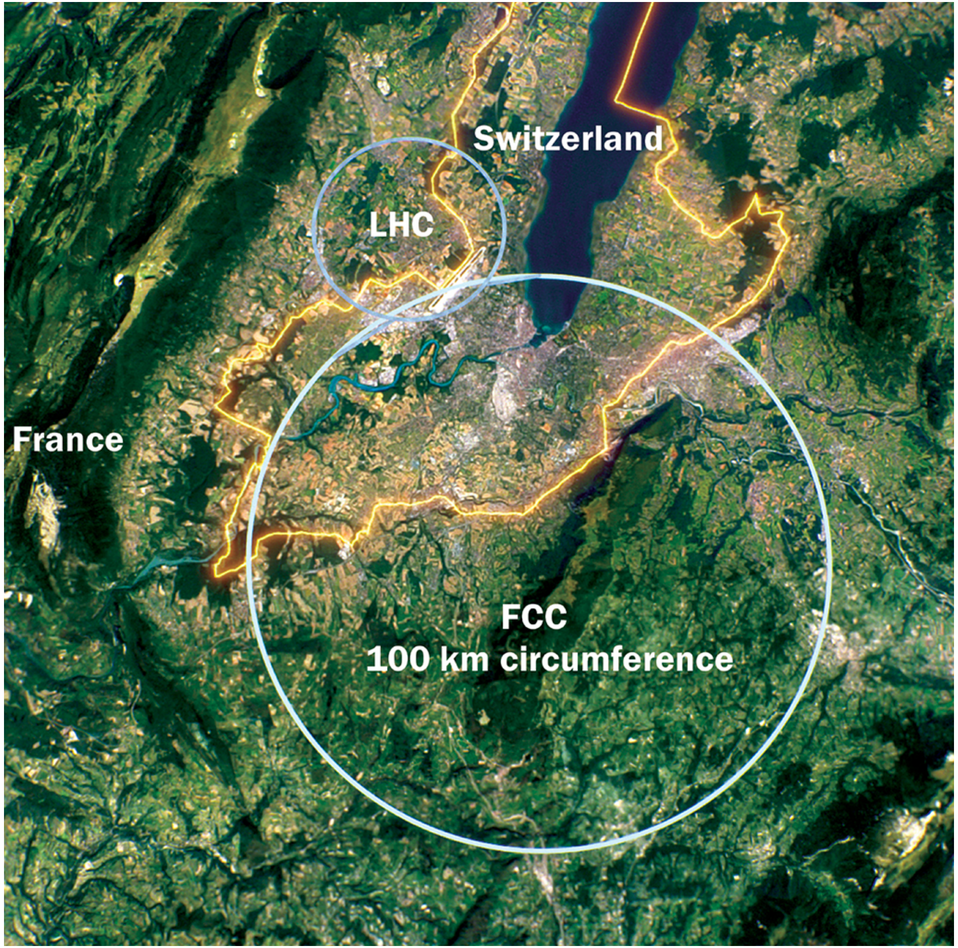
Circular Electron Positron Collider



Future Colliders

Future Circular Collider

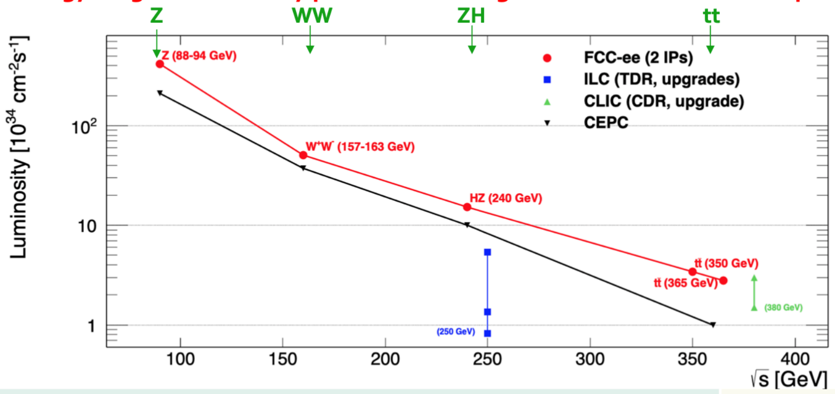
- 100 km circular collider
- FCC-ee: e^+e^- collider
  - $\sqrt{s} = 91 - 350 \text{ GeV}$
  - Precision physics
- FCC-hh: pp collider
  - 100 TeV
  - Enlarge discovery potential



Future Circular Collider

- 100 km circular collider
- FCC-ee: e^+e^- collider
  - $\sqrt{s} = 91 - 350 GeV$
  - Precision physics
- FCC-hh: pp collider
  - Discovery machine
  - 100 TeV

Great energy range for SM heavy particles AND highest luminosities AND √s precision



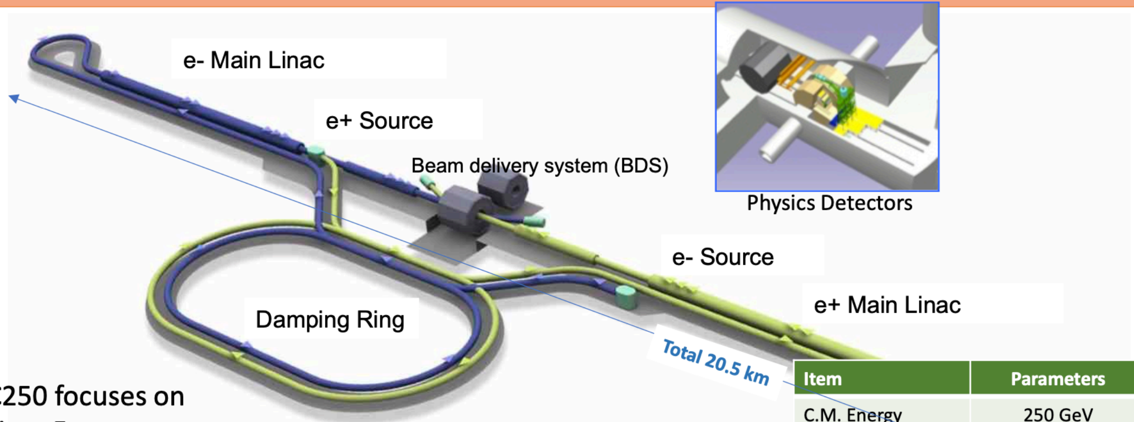
						√s errors
ZH maximum	√s ~ 240 GeV	3 years	10^6	$e^+e^- \to ZH$	Never done	2 MeV
$\bar{t}t$ threshold	√s ~ 350 GeV	5 years	10^6	$e^+e^- \to t\bar{t}$	Never done	5 MeV
Z peak	√s ~ 91 GeV	4 years	5×10^{12}	$e^+e^- \to Z$	LEP x 10^5	< 100 keV
WW threshold+	√s ≥ 161 GeV	2 years	$> 10^8$	$e^+e^- \to W^+W^-$	LEP x 10^3	< 300 keV
s-channel H	√s = 125 GeV	? Years	~5000	$e^+e^- \to H$	Never done	< 200 keV

Slide by P. Janot

ILC

- e^+e^- linear collider
- Center of mass energy:
  - 250, 500, 1000 GeV

[1] Design outline: ILC250 accelerator facility

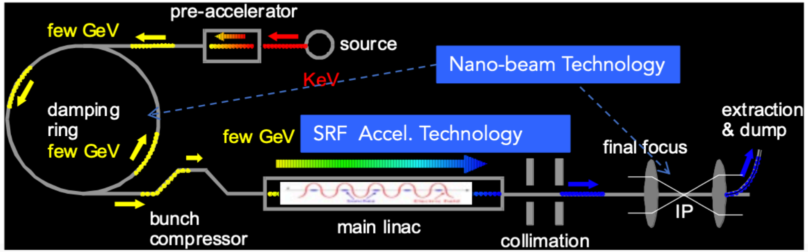


ILC250 focuses on Higgs Factory;
Length becomes 20km

Total Cost of Acc. is ~6BSF including human & Civil
Tunnel cost ~ 1.1BSF

Item	Parameters
C.M. Energy	250 GeV
Length	20km
Luminosity	1.35 x10^{34} $cm^{-2}s^{-1}$
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA (in pulse)
Beam size (y) at FF	7.7 nm@250GeV
SRF Cavity G. Q_0	31.5 MV/m (35 MV/m) Q_0 = 1x10 ^{10}

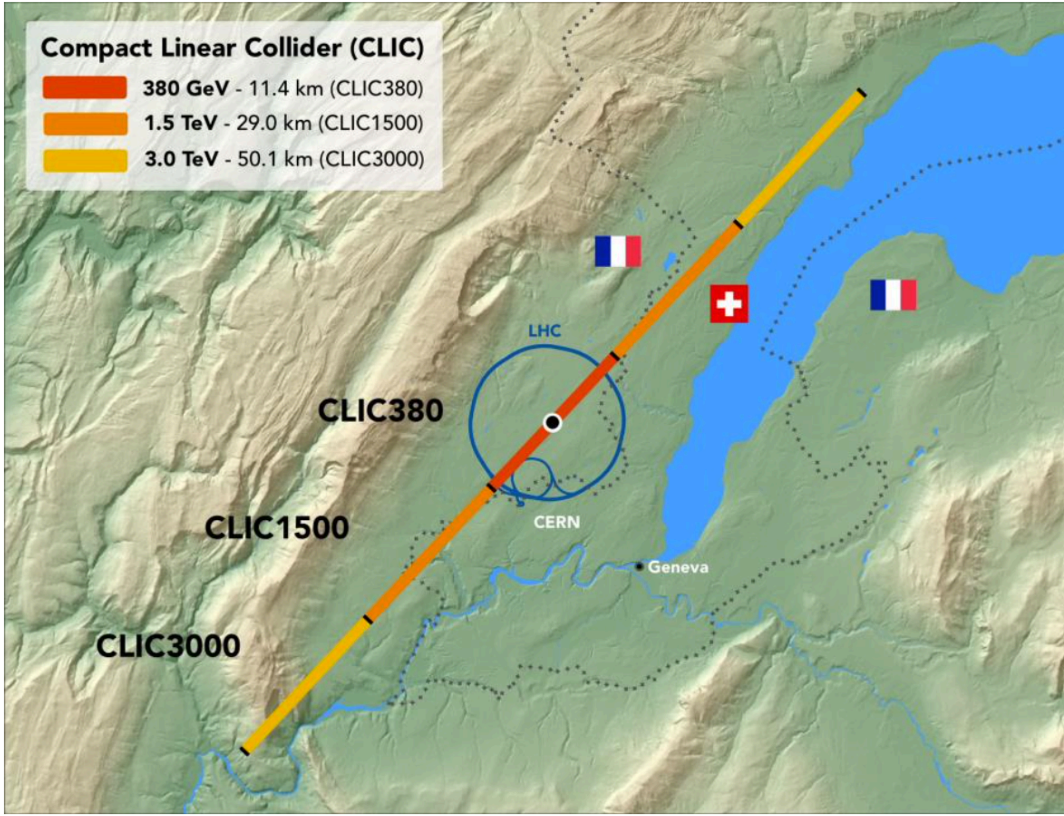
Key Technologies



Slide by S. Asai

CLIC

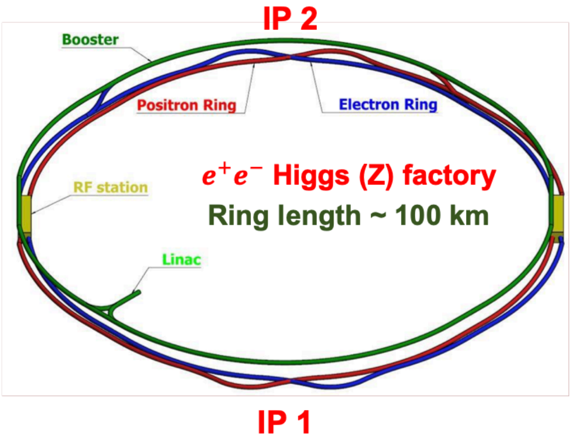
- Linear e^+e^- collider
- $\sqrt{s} = 380 - 3000\ \mathrm{GeV}$

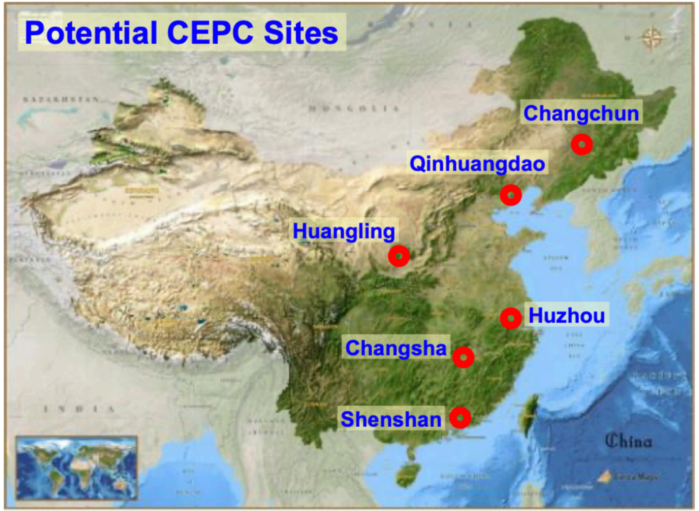


CEPC

The Circular Electron Positron Collider

- The CEPC aims to start operation in 2030's, as a Higgs (Z / W) factory in China.
- To run at $\sqrt{s}$ ~ 240 GeV, above the **ZH** production threshold for ~1 M Higgs; at the **Z** pole for ~Tera Z; at the **W^+W^-** pair and possible $t\bar{t}$ pair production thresholds.
- Higgs, EW, flavor physics & QCD, probes of physics BSM.
- Possible *pp* collider (SppC) of $\sqrt{s}$ ~ 50–100 TeV in the future.

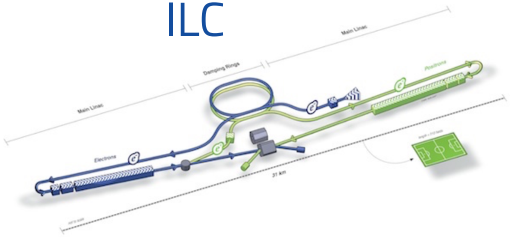




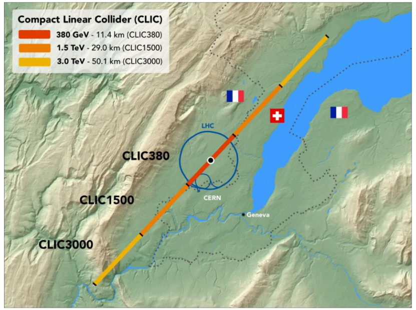
Slide by J. Wang

e^+e^- colliders — operation goals

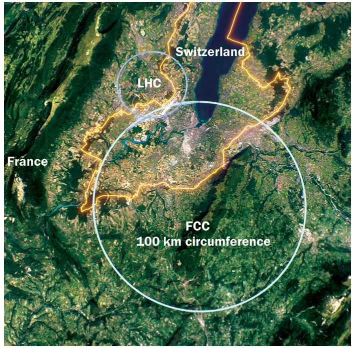
ILC



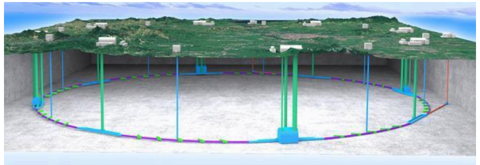
CLIC



FCC



CEPC



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}

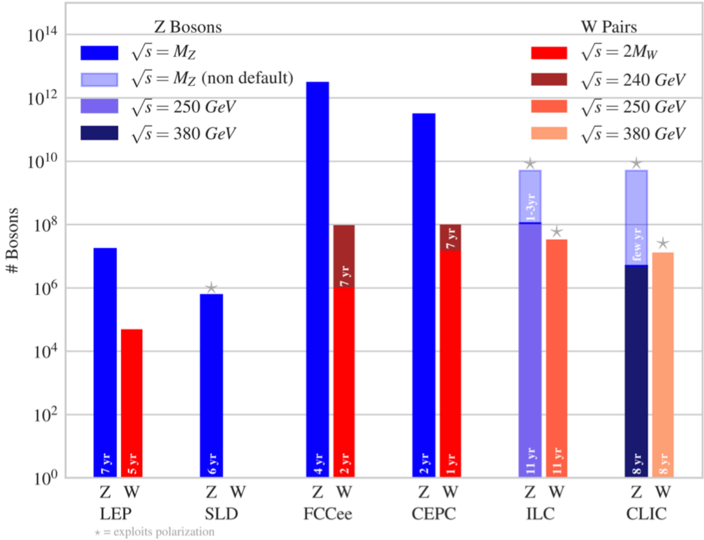
FCC-ee, CERN

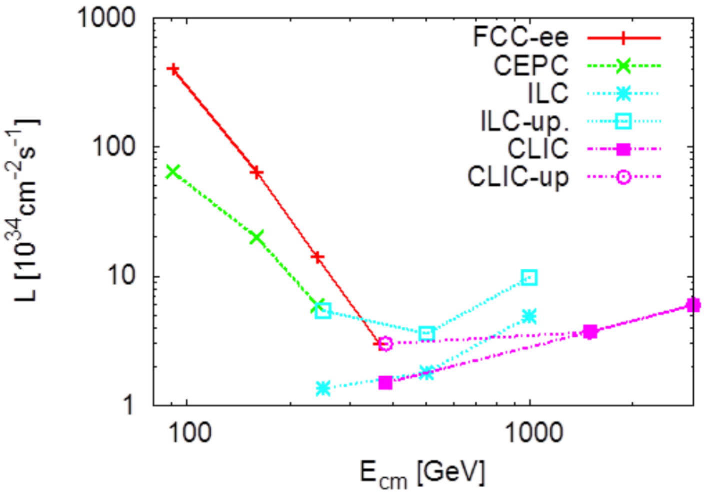
m_Z,	4 y	→	150 ab^{-1}
2 x m_W,	1-2 y	→	10 ab^{-1}
240 GeV,	3 y	→	5 ab^{-1}
2 x m_{top},	5y	→	1.5 ab^{-1}

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}

e^+e^- colliders — energies and luminosities





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

Precision physics

- Complementarity 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

only FCC-ee@240GeV

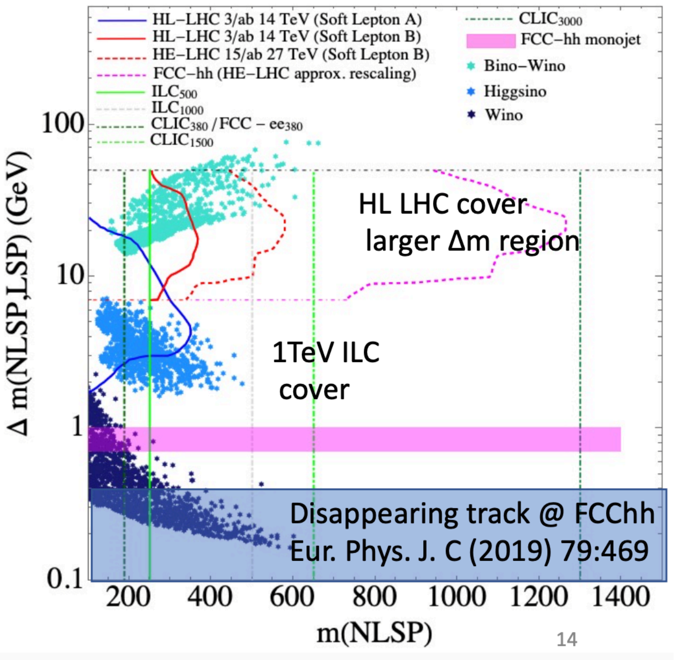
only FCC-hh

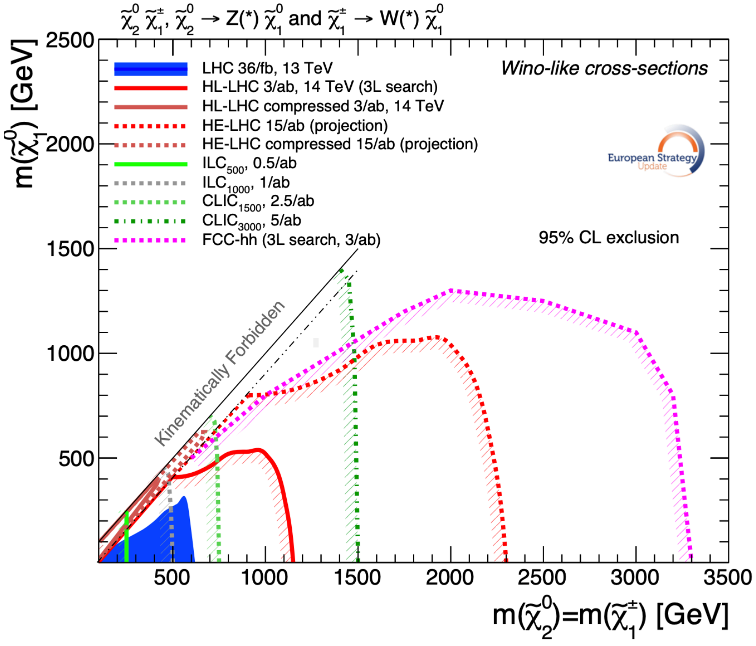
ALL COMBINED

New physics searches

- Examples of sensitivity to new physics for different future colliders

arXiv:2103.13403



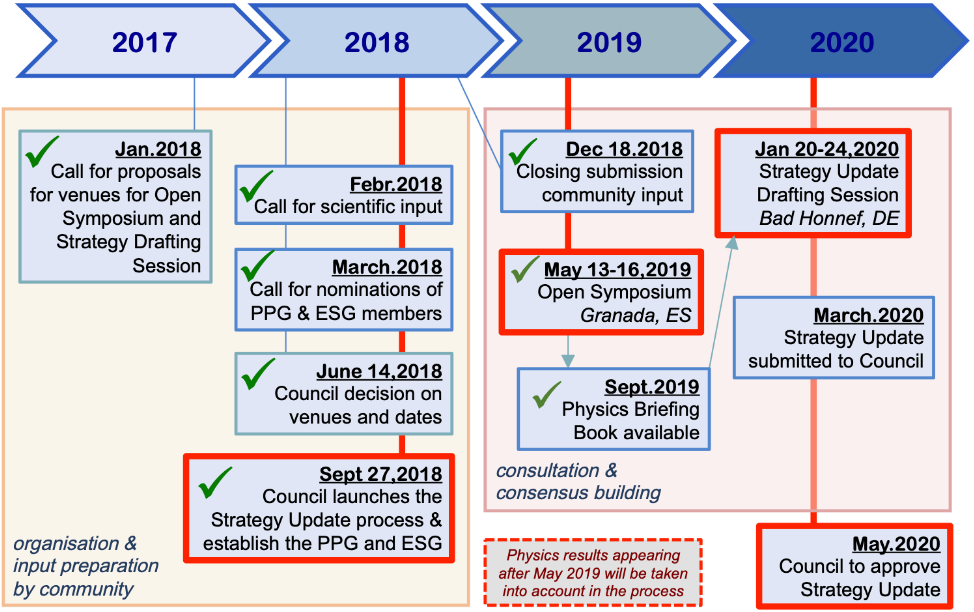


The road towards the future colliders

Update of the European Strategy for Particle Physics

Provides a clear prioritisation of European ambitions in advancing the science of particle physics

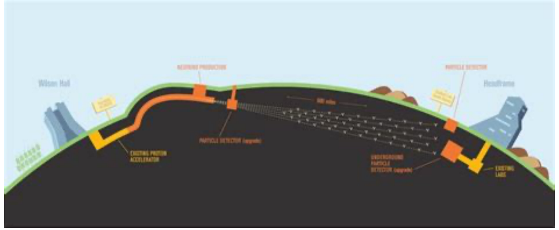
- takes into account the worldwide particle physics landscape and developments in related fields



1 Major developments from the 2013 Strategy

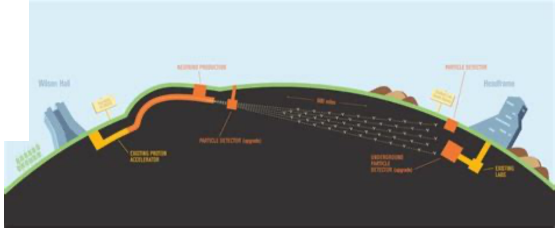
A. Since the recommendation in the 2013 Strategy to proceed with the programme of upgrading the luminosity of the LHC, the HL-LHC project, was approved by the CERN Council in June 2016 and is proceeding according to plan. In parallel, the LHC has reached a centre-of-mass energy of 13 TeV, exceeded the design luminosity, and produced a wealth of remarkable physics results. Based on this performance, coupled with the innovative experimental techniques developed at the LHC experiments and their planned detector upgrades, a significantly enhanced physics potential is expected with the HL-LHC. The required high-field superconducting Nb_3Sn magnets have been developed. ***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.***

HiLumi
HL-LHC PROJECT



1 Major developments from the 2013 Strategy

B. The existence of non-zero neutrino masses is a compelling sign of new physics. The worldwide neutrino physics programme explores the full scope of the rich neutrino sector and commands strong support in Europe. Within that programme, the Neutrino Platform was established by CERN in response to the recommendation in the 2013 Strategy and has successfully acted as a hub for European neutrino research at accelerator-based projects outside Europe. ***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).***



2 General considerations for the 2020 update

A. 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.***

B. The European organisational model centred on close collaboration between CERN and the national institutes, laboratories and universities in its Member and Associate Member States is essential to the enduring success of the field. This has proven highly effective in harnessing the collective resources and expertise of the particle, astroparticle and nuclear physics communities, and of many interdisciplinary research fields. Another manifestation of the success of this model is the collaboration with non-Member States and their substantial contribution. ***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.***

2 General considerations for the 2020 update

C. The broad range of fundamental questions in particle physics and the complexity of the diverse facilities required to address them, together with the need for an efficient use of resources, have resulted in the establishment of a global particle physics community with common interests and goals. This Strategy takes into account the rich and complementary physics programmes being undertaken by Europe's partners across the globe and of scientific and technological developments in neighbouring fields. ***The implementation of the Strategy should proceed in strong collaboration with global partners and neighbouring fields.***

3 | High-priority future initiatives

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.

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.***

B. Theoretical physics is an essential driver of particle physics that opens new, daring lines of research, motivates experimental searches and provides the tools needed to fully exploit experimental results. It also plays an important role in capturing

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.***

Accelerators R&D Roadmap

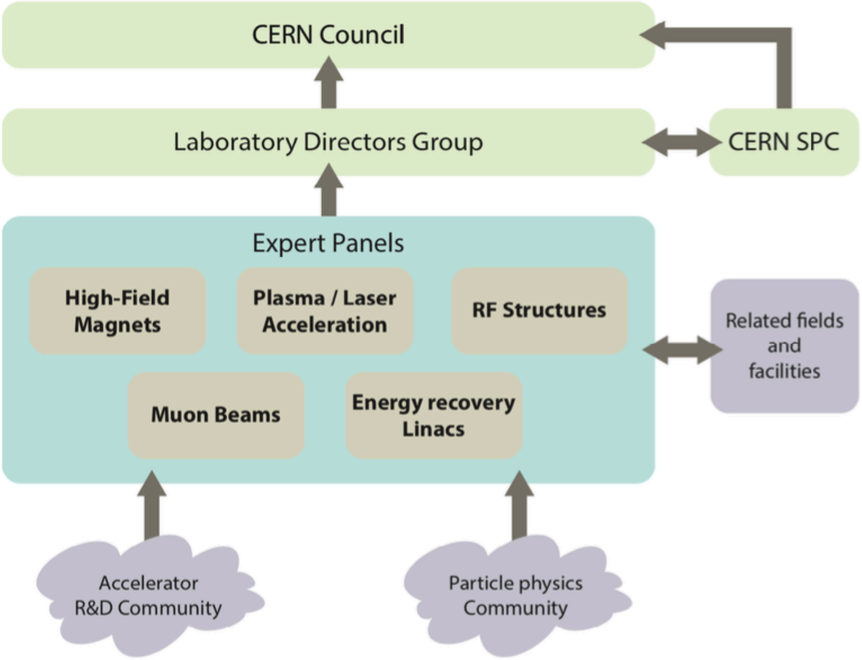
B. Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders. It is also a powerful driver for many accelerator-based fields of science and industry. The technologies under consideration include high-field magnets, high-temperature superconductors, plasma 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) mandated to develop the Accelerators R&D 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)

Accelerators R&D Roadmap development

- Intensive process during 2021
  - Expert panels convened in January 2021
  - Intensive community consultation
  - 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

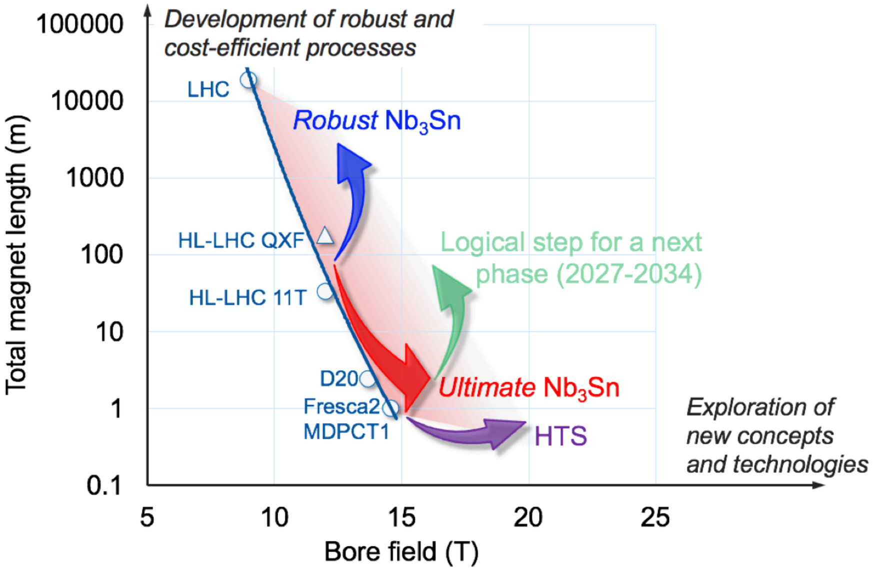


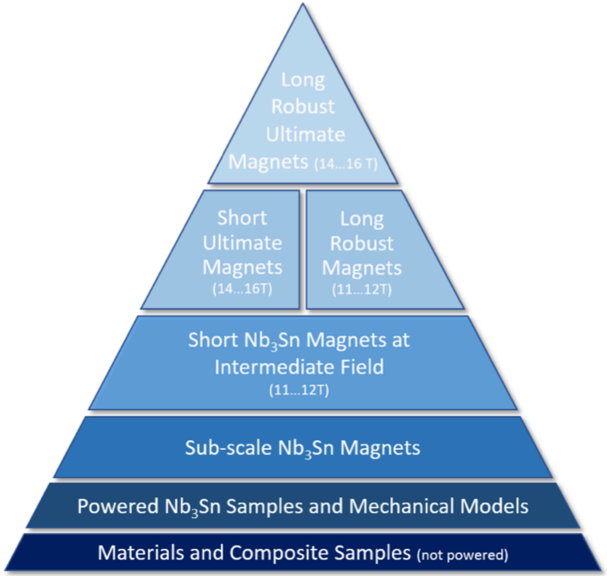
Accelerators R&D Roadmap

- Roadmap presented to CERN Council in Dec. 2021
  - 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

Accelerators R&D Roadmap

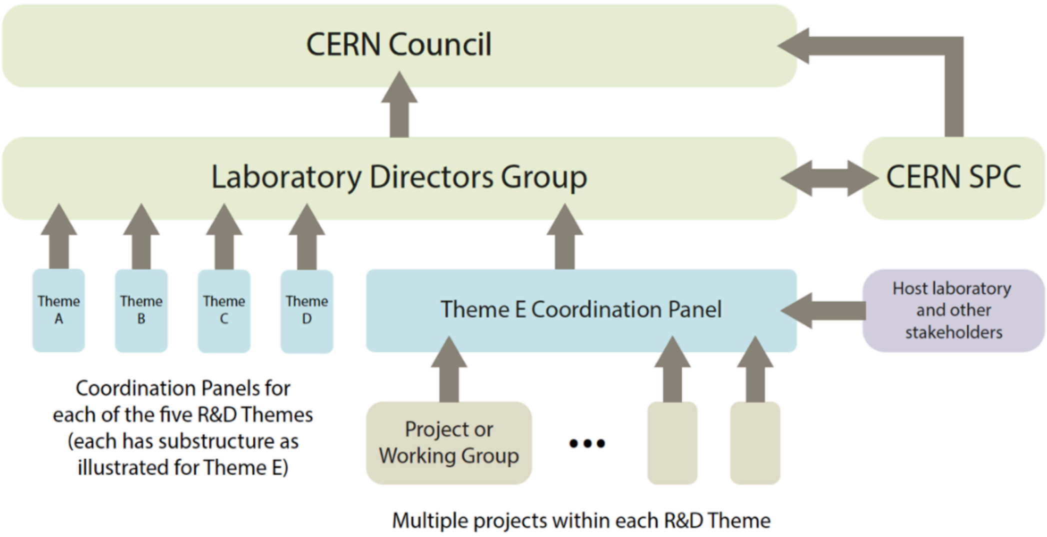
- Example: high field magnet development





Accelerators R&D Roadmap implementation

- LDG was mandated by Council in December 2021 to work out an implementation plan
- First Coordination Structure proposed
  - Lightweight, causing minimal disruption / delay to existing projects
  - Discussions with CERN Council and Funding Agencies have started

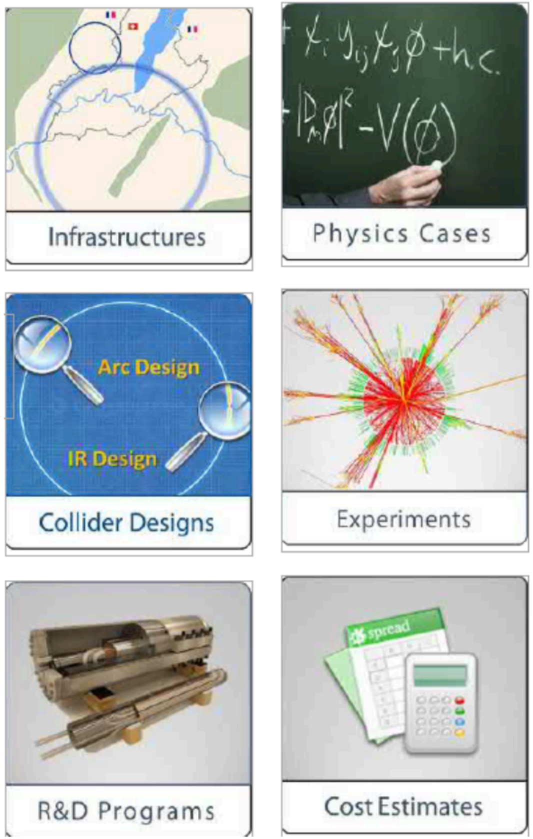


FCC Feasibility Study

• *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.*

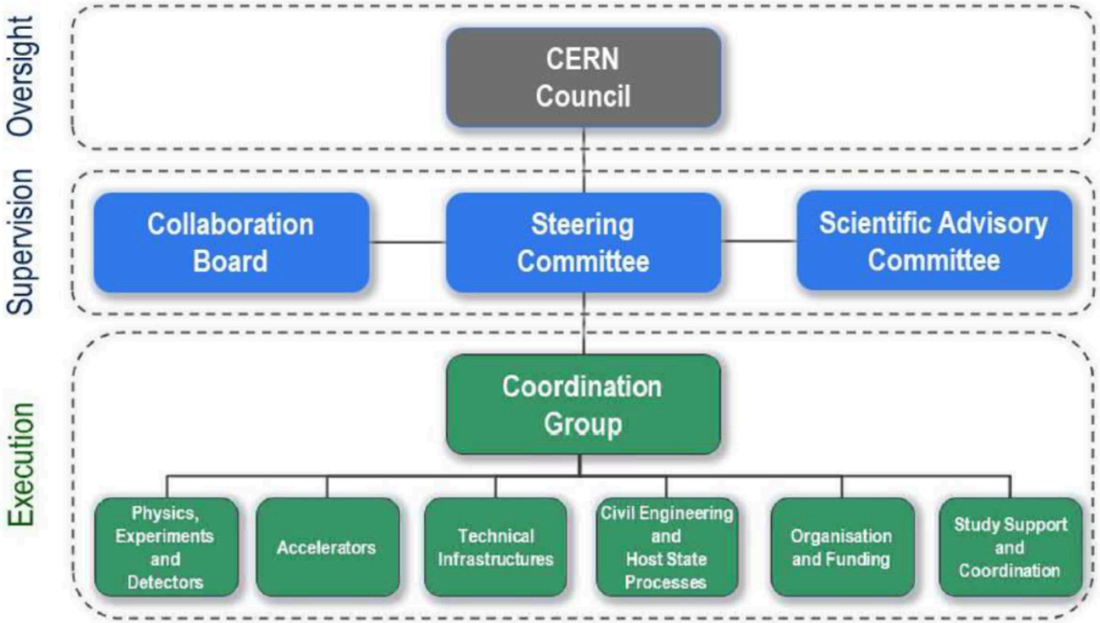
FCC Feasibility Study

- Release Feasibility Study Report by end 2025
- Optimisation of placement and layout of the ring and demonstration of the geological, technical, environmental and administrative feasibility of the tunnel and surface areas
- Pursue, 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



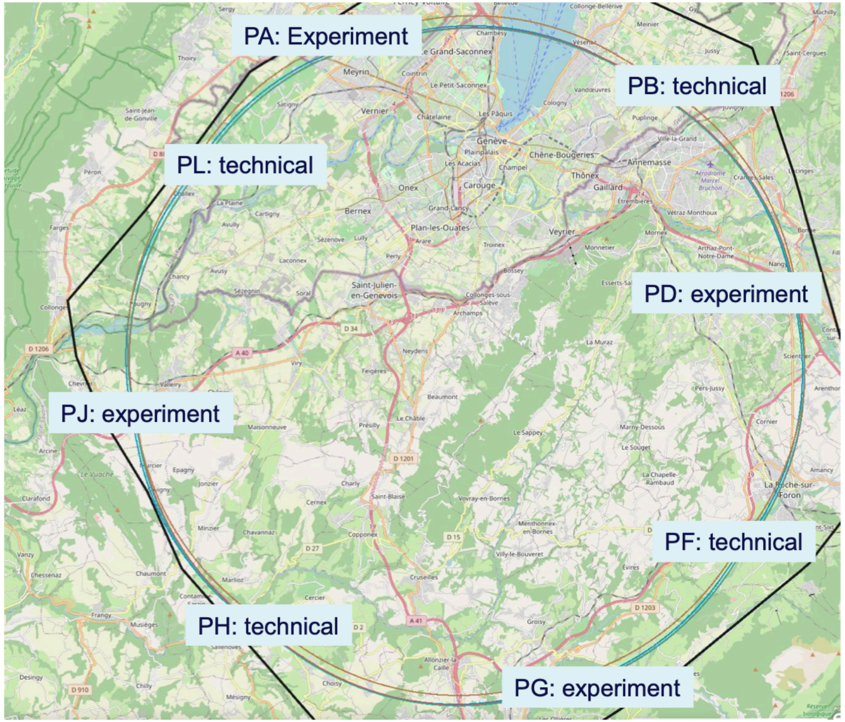
Future Circular Collider Feasibility Study

- Classical structure common to CERN projects



FCC Feasibility Study

- New lowest risk placement identified
  - 8 surface sites
  - C = 91.2 km
  - 4-fold symmetry and 4-fold superperiodicity
  - FCC-ee 2 or 4 IPs
  - FCC-hh 4 IPs
- Present implementation variant was established considering:
  - Geological 3D model and tunnelling risks
  - 95% in molasse geology for minimising tunnel construction risks



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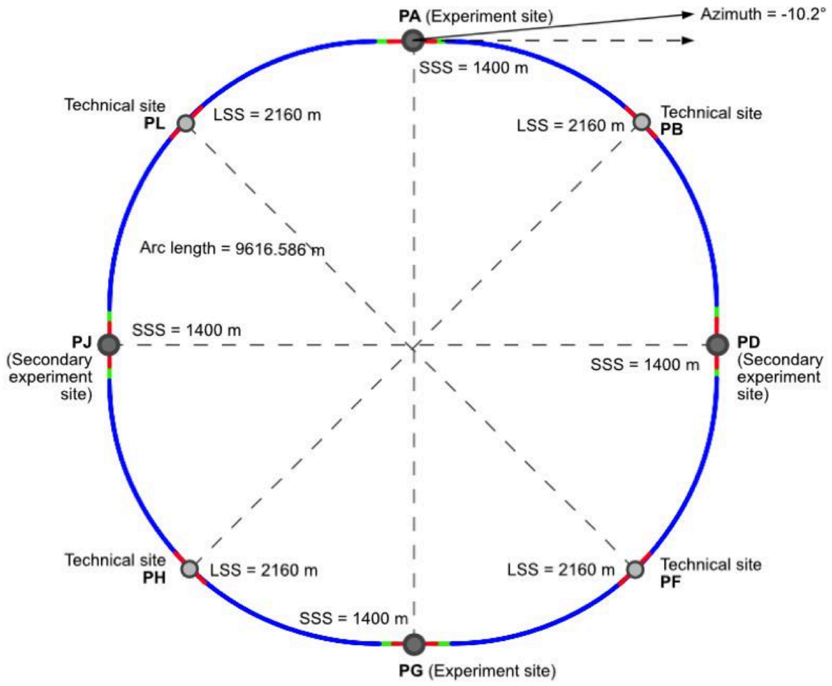
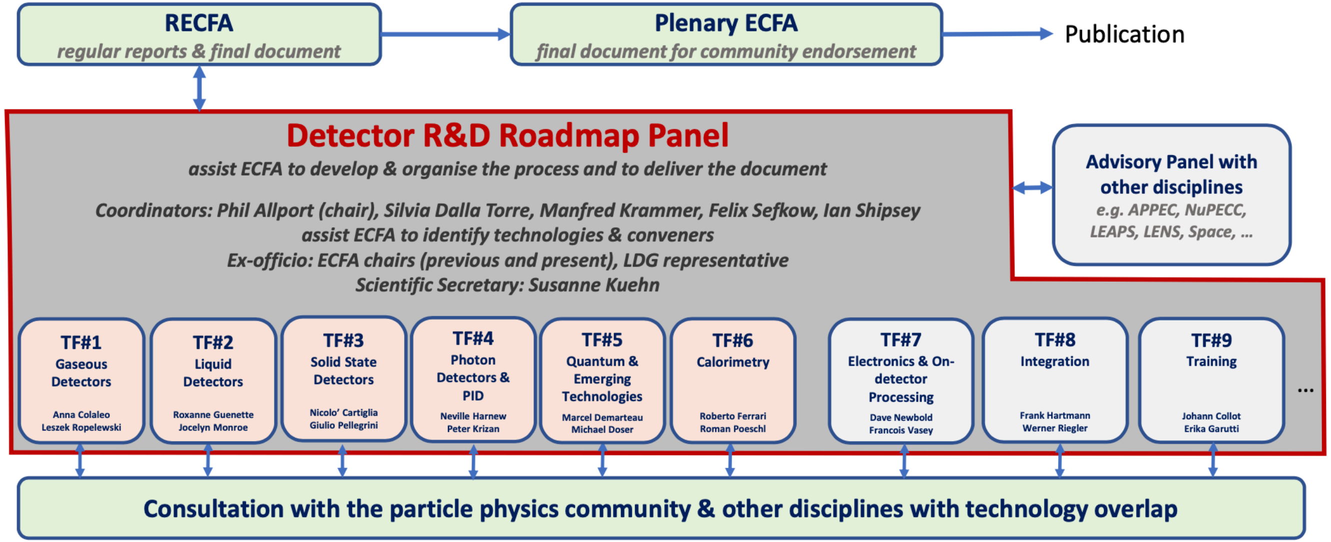


Detectors R&D Roadmap

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.***

Detectors R&D Roadmap

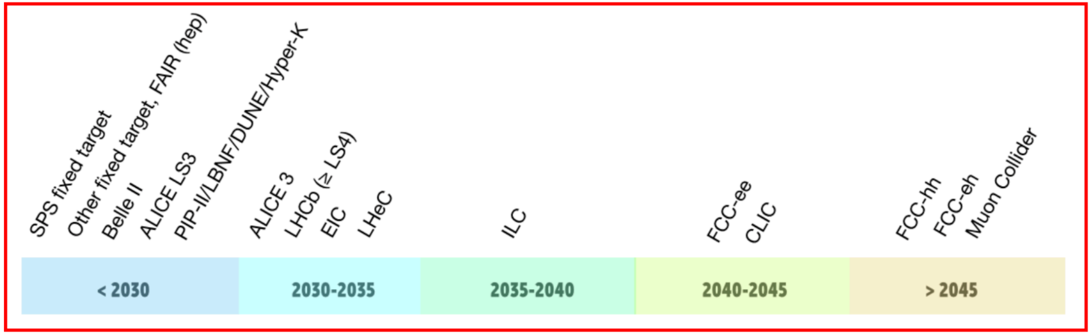
- Intensive process during 2021
  - Community consultation
  - Interim reports at EPS-HEP Conference in July 2021



- Interactions with national communities (via ECFA delegates)
- SPC (CERN Scientific Policy Committee)
- Roadmap presented to CERN Council in Dec. 2021, after endorsement by Plenary ECFA in Nov. 2021

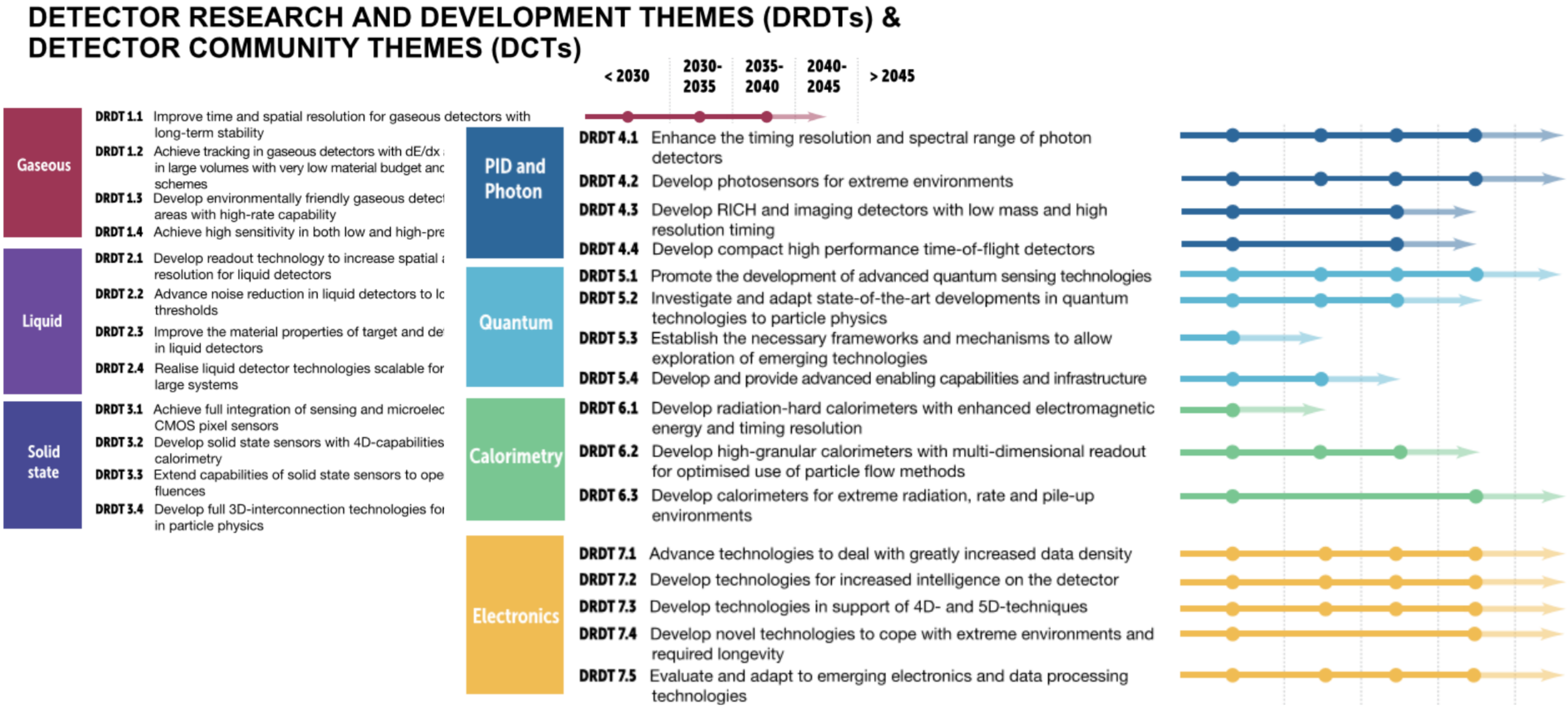
Detectors R&D Roadmap Document

- Identified R&D objectives to ensure that detectors R&D is not the limiting factor at the earliest feasible start dates of a proposed facility
- Defined Detector Research and Development Themes (DRDTs) and objectives

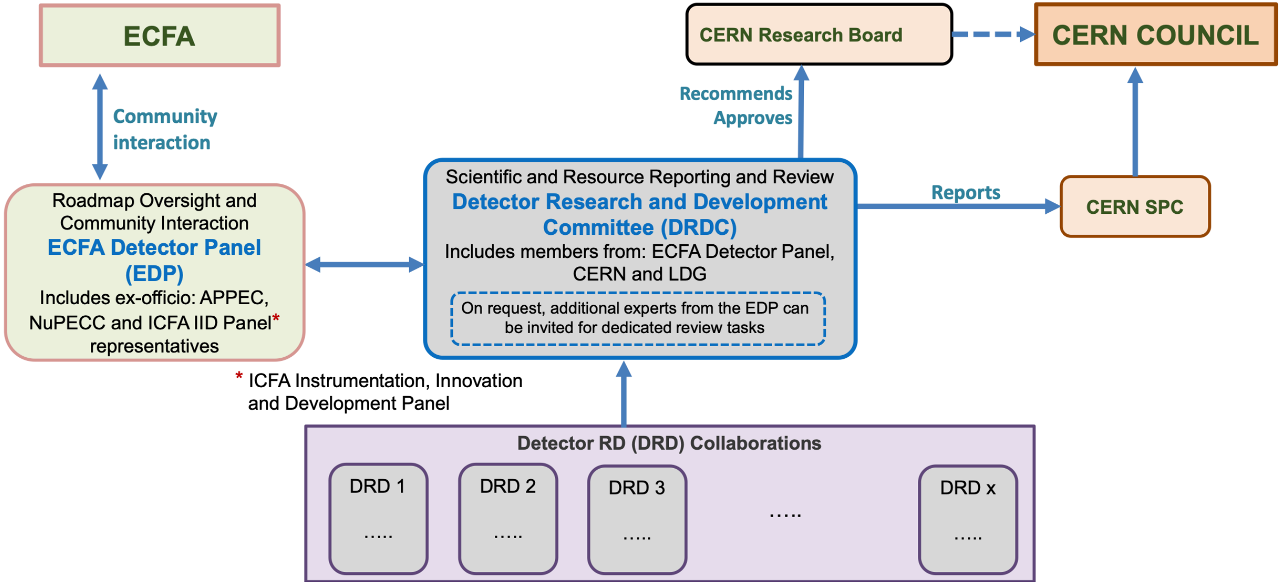


Detectors R&D Roadmap

See presentation by S. Kuehn



Detectors R&D Roadmap Implementation



- 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
- First implementation plan proposed

ECFA studies towards e^+e^- top/EW/Higgs Factory

- ECFA statement (endorsed by Plenary ECFA, July 2020):
  - 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
    - 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
- 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 studies towards e^+e^- top/EW/Higgs Factory

- Kick-off workshop in June 2021 with 422 registrants
- Central information web page: indico. Agendas for meetings and workshops: indico
- Structure of the study:
  - Activities organised via three Working Groups
  - Community gathers for two major workshops, 2022 and 2023
  - Will provide a report as input to next European Strategy Update
- Focus on e+e- potential
  - Includes electroweak and top factory
    - 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 (software, simulation, fast simulation, …), common analysis methods
  - Exploit synergies, discuss challenges, do not restrict to common items
  - Need for theoretical accuracy and MC generator improvements

Working groups

Conveners: J. Alcaraz (CIEMAT), J. De Blas (Granada), J. List (DESY), F. Maltoni (UC Louvain / Bologna)

- WG 1: Physics Potential
  - Collect, compare and harmonise the work of the different project-specific efforts
  - Interplay between (HL)-LHC and a future Higgs factory
    - e.g. include LHC potential on high-pT measurements and EFT interpretations
  - Identify specific topics where concrete work should be organised
  - Requirements on accuracy in theoretical calculations and parametric uncertainties, …
  - 5 physics teams initiated:
    - WG1-GLOB: global interpretations
    - WG1-PREC: theoretical and experimental precision
    - WG1-HTE: specific Higgs/Top/EW studies (+ connection with LHC)
    - WG1-HF: Heavy Flavour
    - WG1-SRCH: Direct searches (weakly-interacting, directly accessible particles)

Working groups

- WG 2: Physics analysis methods

  Conveners: P. Azzi (INFN-Padova / CERN), F. Piccinini (INFN Pavia) and D. Zerwas (IJCLab/DMLab)

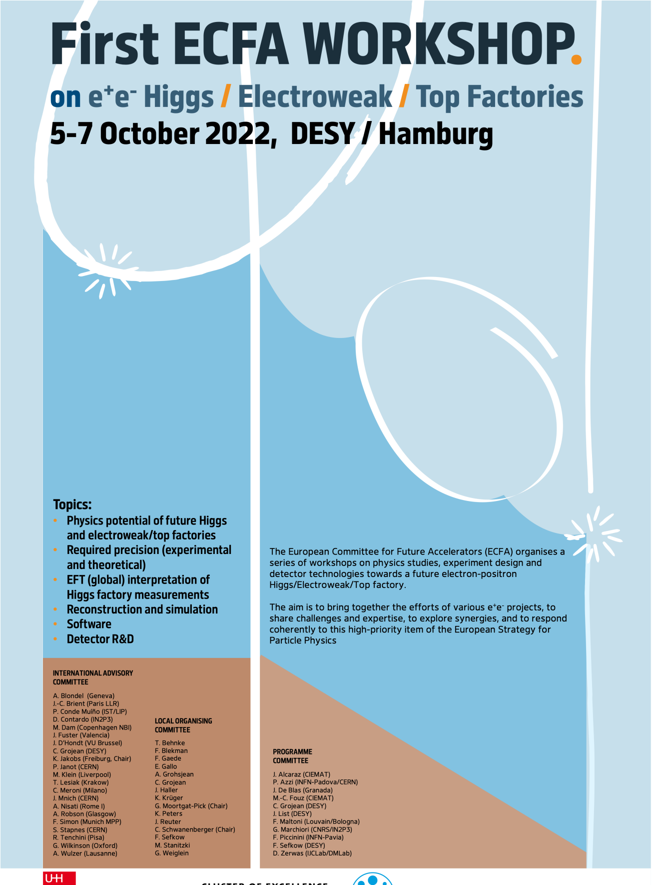
  - Monte Carlo generators for e+e- precision EW/top Higgs factory
  - Software framework
  - Fast simulation (and its limitations)
  - Particle flow
  - Luminosity measurement
  - Workshops already held on topics of generators, simulation, reconstruction
- WG3: Detector technologies

  Conveners: M. C. Fouz (CIEMAT), G. Marchiori (APC Paris), F. Sefkow (DESY Hamburg)

  - Activities launching imminently, in light of ECFA Detector R&D roadmap
  - Bridge between detector technology activities and detector concepts

First ECFA Workshop towards e^+e^- top/EW/Higgs Factory

- Plenary and parallel sessions
  - Discussions related to working group activities
  - Parallel sessions: mix of invited and submitted contributions



- Registration Open!! @Link

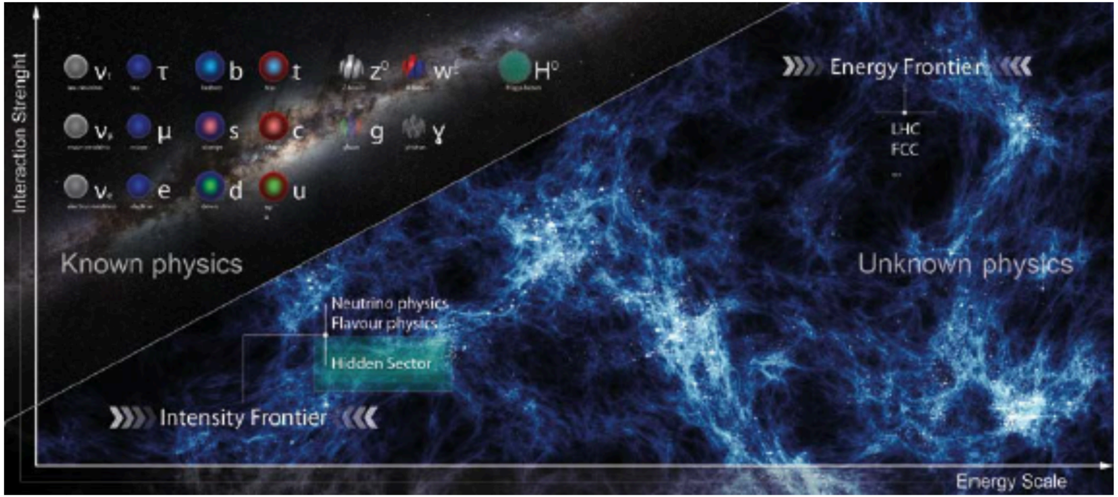
First ECFA Workshop towards top/EW/Higgs Factory

- Public event targeting the wider scientific community
  - DESY auditorium, webcast via DESY Youtube channel
- Focus:
  - big open questions in fundamental science why a future machine is needed
  - competition and synergy with other big-science projects
    how science fits in society; derived applications; environment

- Speaker: H. Murayama
- Panel:
  - F. Gianotti, B. Heinemann, K. Jakobs,
  - 'mid-career' experimentalist and theorist
  - potentially one 'outsider'

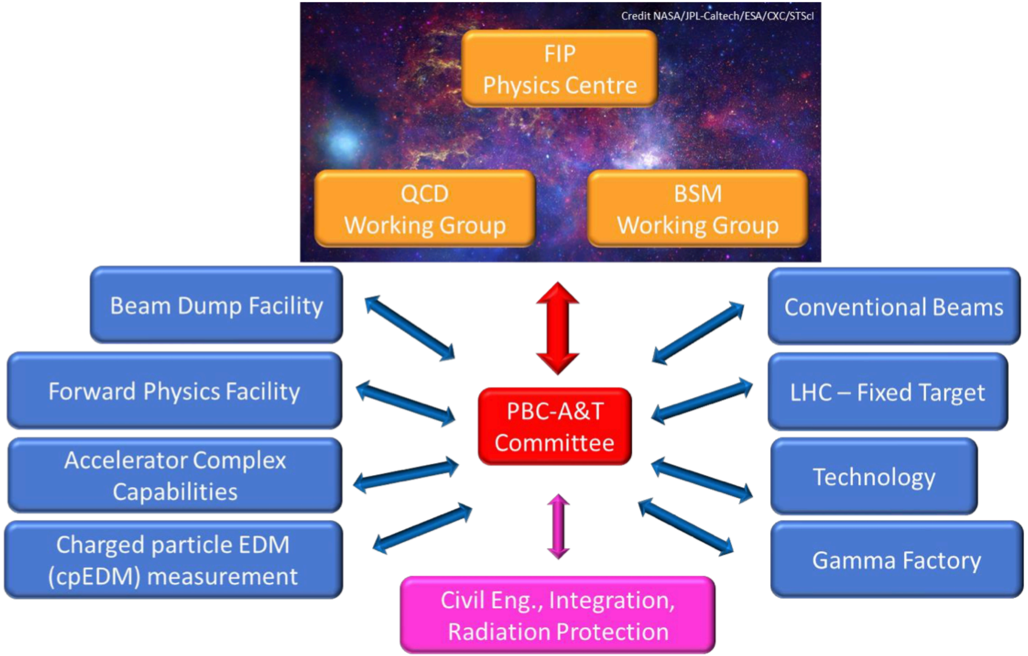
Physics Beyond Colliders

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*** .



Physics Beyond Colliders

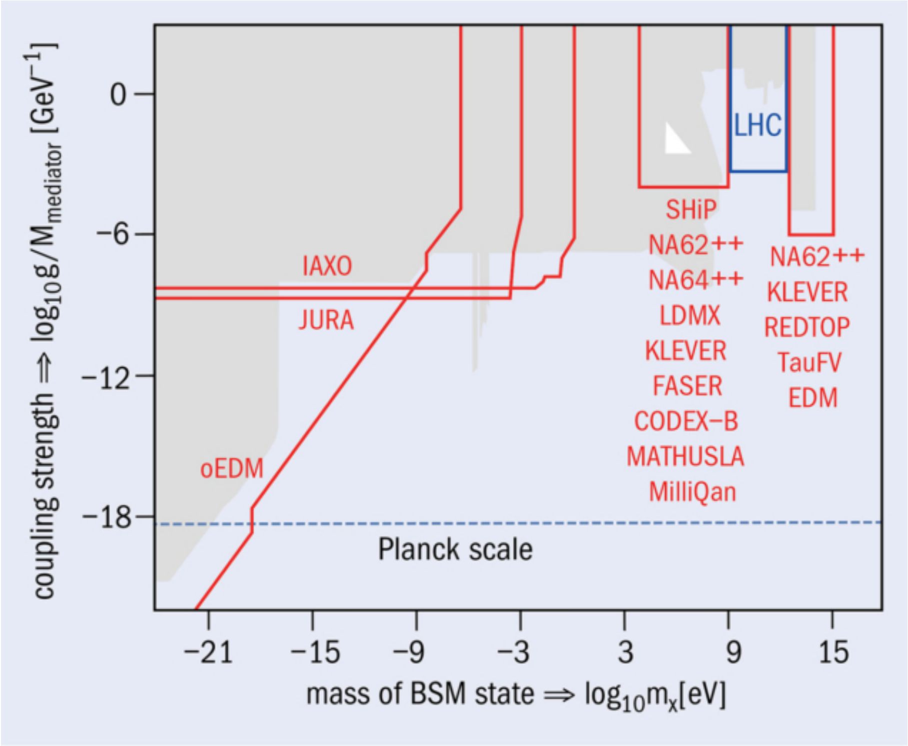
- Complementary methods to high energy frontier
- To reconcile BSM physics with the non-observation in present experiments, new particles could be
  - very massive
  - very weakly interacting with SM particles



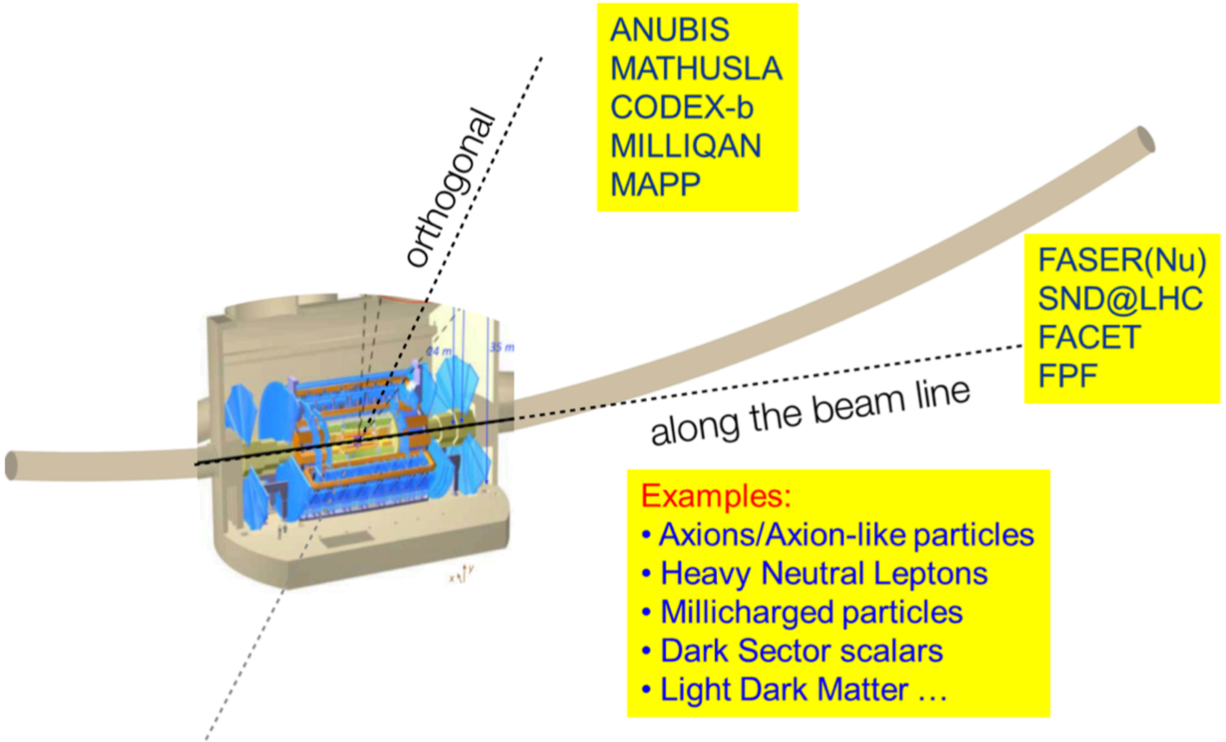
Coordinators: G. Arduini (CERN), J. Jaeckel (Heidelberg), C. Vallée (CPPM, Marseille)

Complementarity of the physics programme

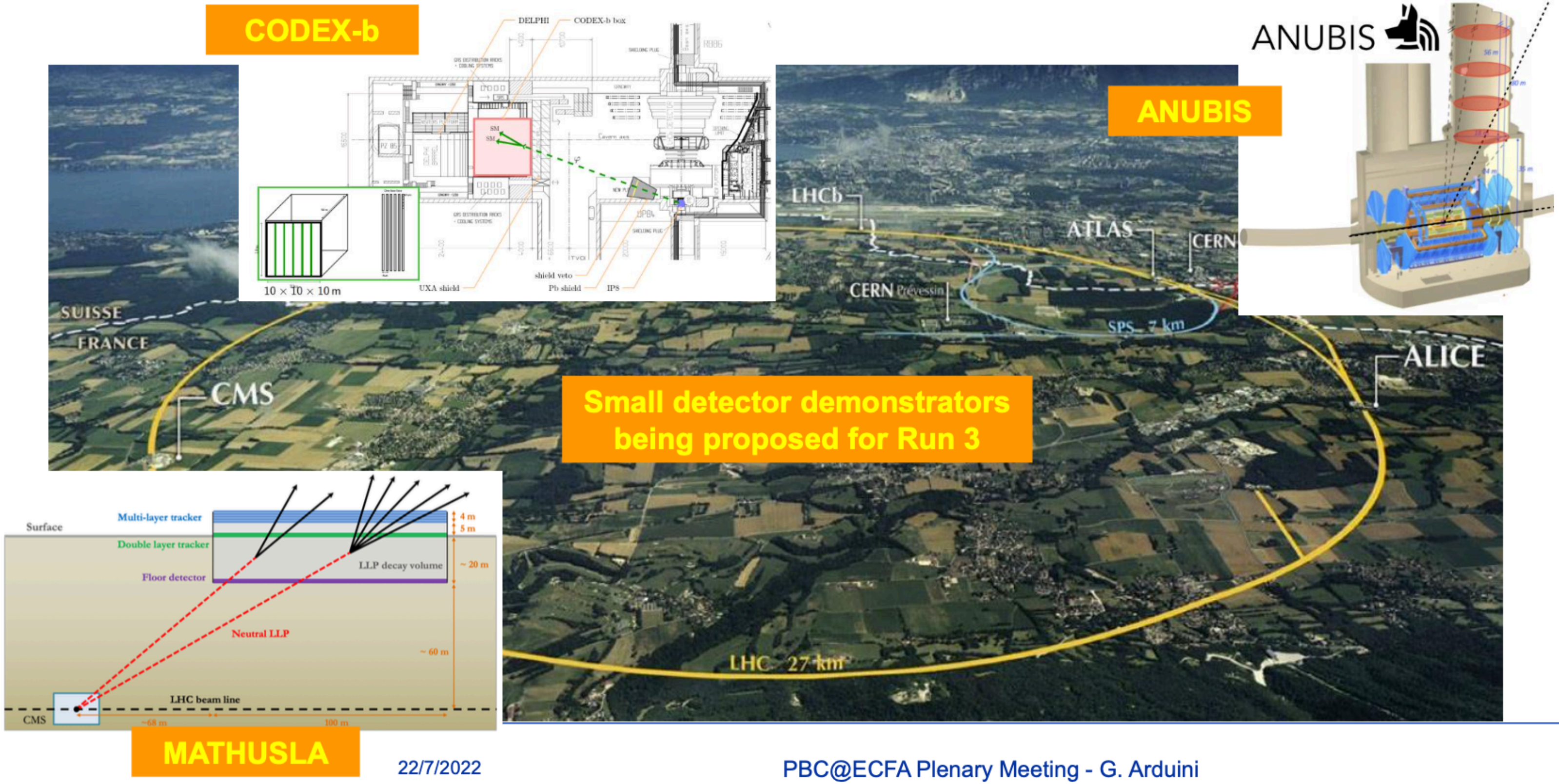
- Extend the reach of high-E colliders through precision experiments and searches for rare processes
- EDM & non-accelerator projects cover the very low-mass domain
- SPS experiments (beam dump, searches for long-lived particles, …) probe MeV – GeV domain



Search for long lived particles



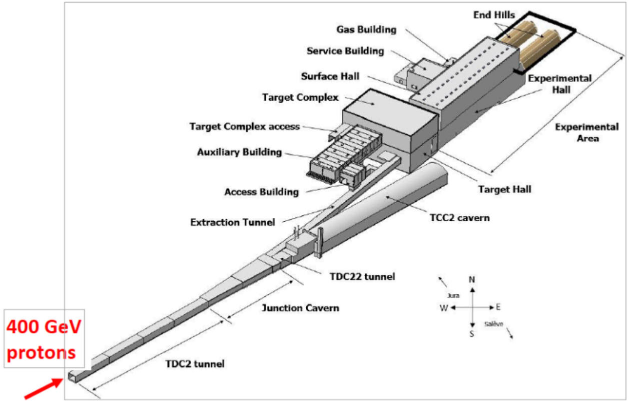
Search for long lived particles

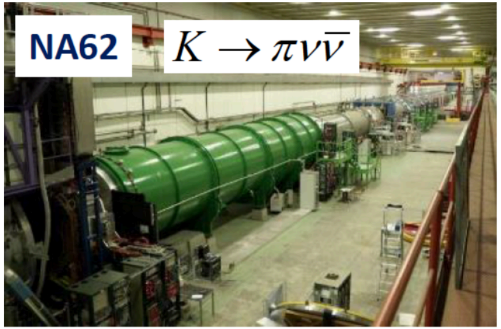


Proton Beam Dump Facility

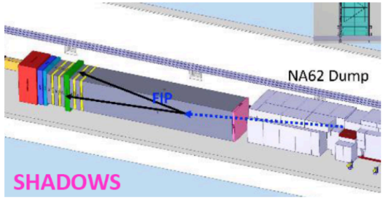
Slide by K. Jakobs

- 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)

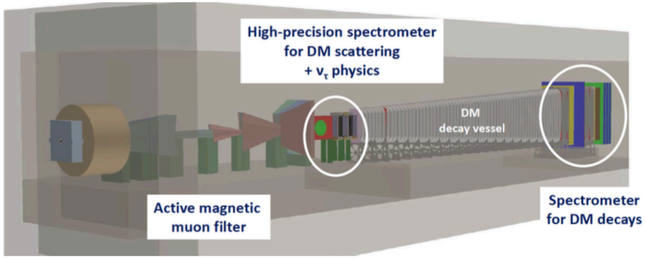




Instrumentation of NA62 decay vessel well adapted to searches in visible decay mode



SHiP on the Beam Dump Facility



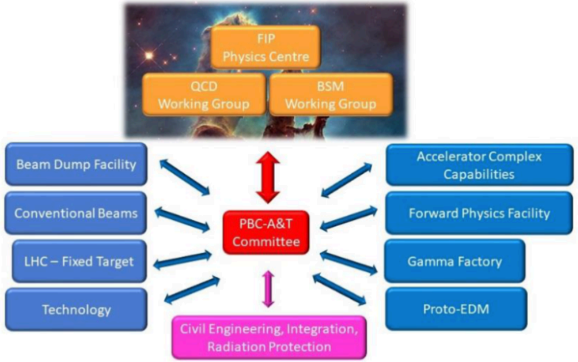
CERN Physics Beyond Colliders - Summary - (Claude Vallée)

- 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)

PBC UPDATED ORGANISATION



- 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

Conclusions

- Many open questions in particle physics today
  - Long way ahead of us
- Update of the European Strategy for Particle Physics
  - Highest priority future collider: e^+e^- Higgs factory
  - Ambitious plan for the next years in order to achieve that
    - Accelerators R&D Roadmap
    - Detectors R&D Roadmap
    - FCC Feasibility Study
    - Physics Beyond Colliders programme
    - ECFA studies/workshops towards top/EW/Higgs Factory

Thanks!

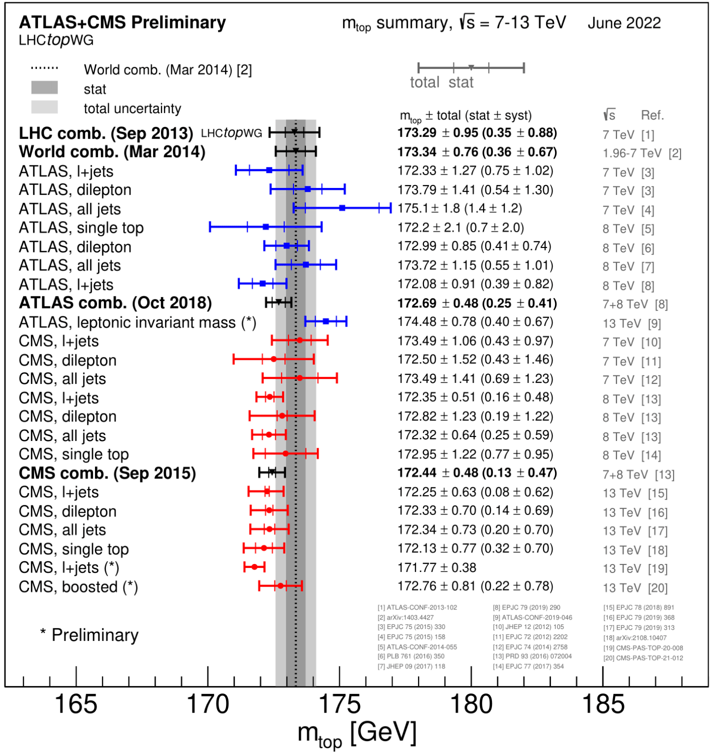
Acknowledgments

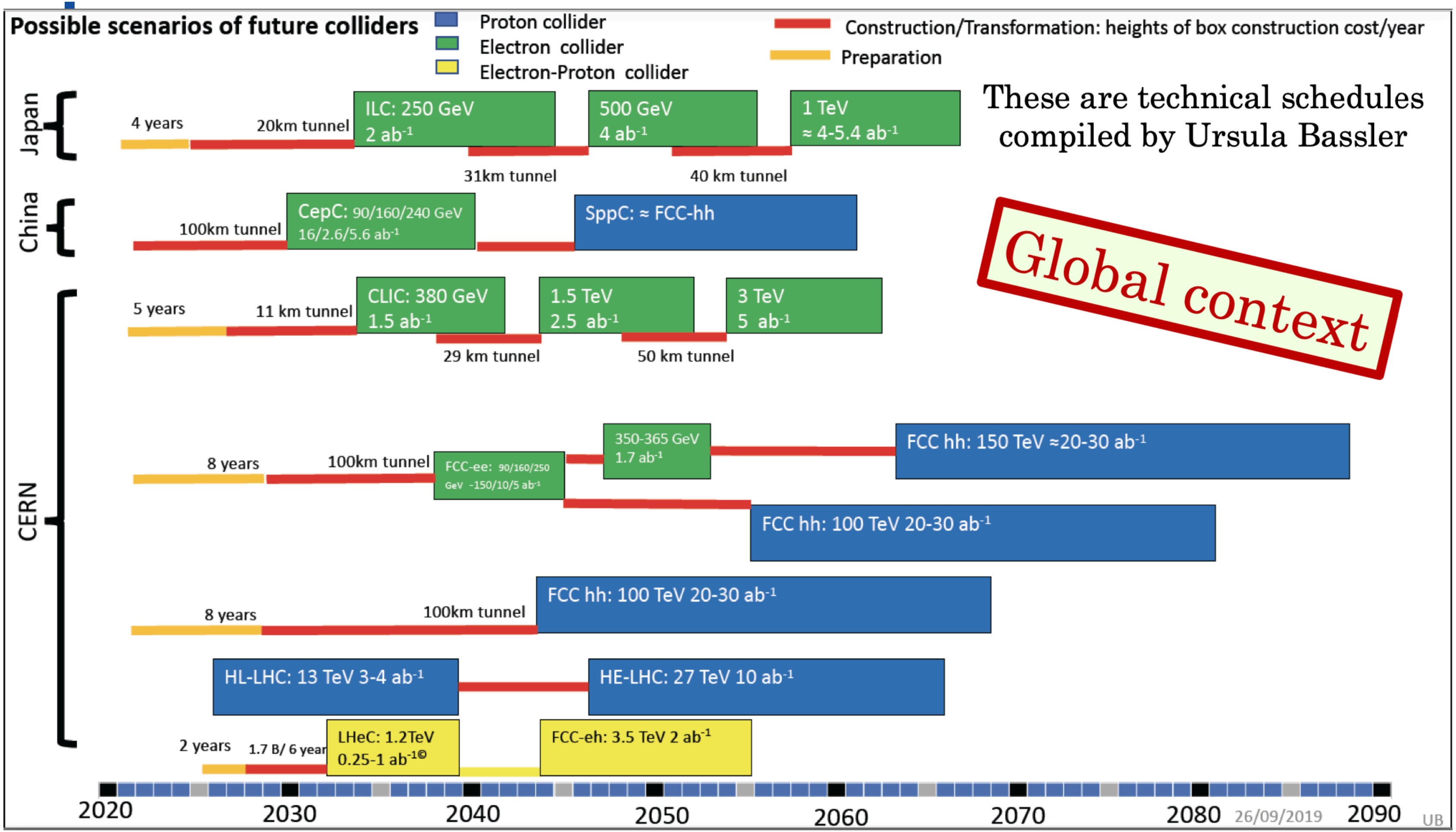
REPÚBLICA PORTUGUESA

FCT Fundação para a Ciência e a Tecnologia

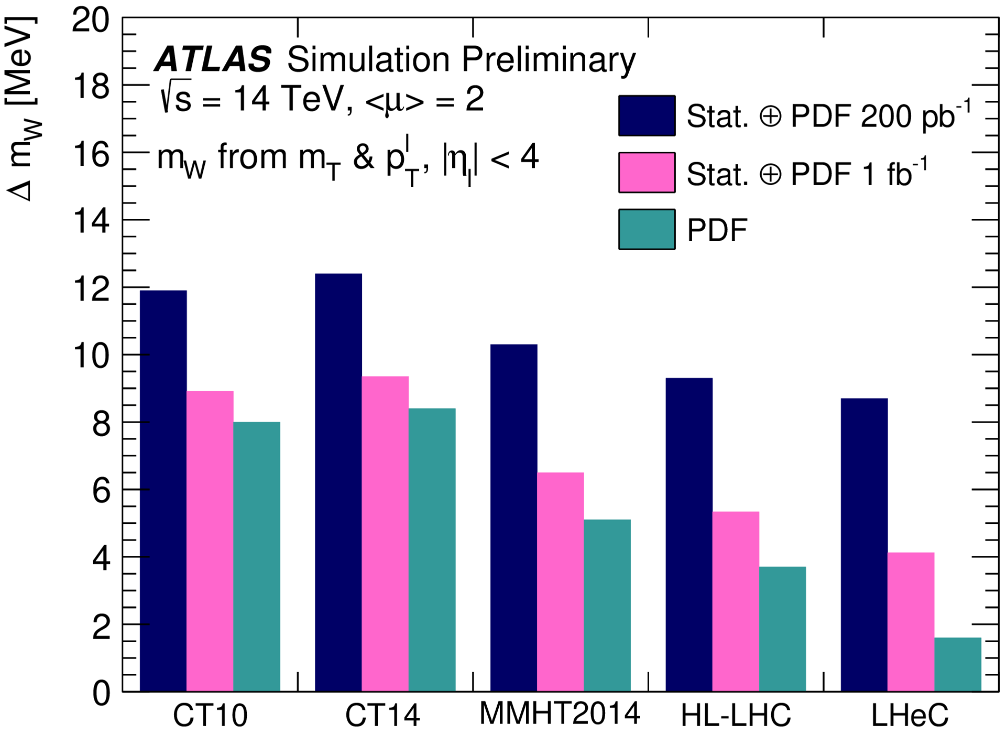
Backup

Top quark mass measurement





Possible scenarios of future colliders
Proton collider
Electron collider
Electron-Proton collider
Construction/Transformation: heights of box construction cost/year
Preparation
Japan
4 years
20km tunnel
ILC: 250 GeV 2 ab-1
500 GeV 4 ab-1
1 TeV ≈ 4-5.4 ab-1
31km tunnel
40 km tunnel
China
100km tunnel
CepC: 90/160/240 GeV 16/2.6/5.6 ab-1
SppC: ≈ FCC-hh
CERN
5 years
11 km tunnel
CLIC: 380 GeV 1.5 ab-1
1.5 TeV 2.5 ab-1
3 TeV 5 ab-1
29 km tunnel
50 km tunnel
8 years
100km tunnel
FCC-ee: 90/160/250 GeV -150/10/5 ab-1
350-365 GeV 1.7 ab-1
FCC hh: 150 TeV ≈20-30 ab-1
FCC hh: 100 TeV 20-30 ab-1
8 years
100km tunnel
FCC hh: 100 TeV 20-30 ab-1
HL-LHC: 13 TeV 3-4 ab-1
HE-LHC: 27 TeV 10 ab-1
2 years
1.7 B/ 6 year
LHeC: 1.2TeV 0.25-1 ab-1©
FCC-eh: 3.5 TeV 2 ab-1
2020
2030
2040
2050
2060
2070
2080
26/09/2019
2090
UB
These are technical schedules compiled by Ursula Bassler
Global context



ATLAS Simulation Preliminary
$\sqrt{s}$ = 14 TeV, <μ> = 2
m_W from m_T & p_T^l, $|\eta_l| < 4$
Stat. ⊕ PDF 200 pb^{-1}
Stat. ⊕ PDF 1 fb^{-1}
PDF
Δm_W [MeV]
0
2
4
6
8
10
12
14
16
18
20
CT10
CT14
MMHT2014
HL-LHC
LHeC