Round-table discussion on Spanish contributions to the next collider – accelerator and detector technology, theory & analysis

Marcel Vos,

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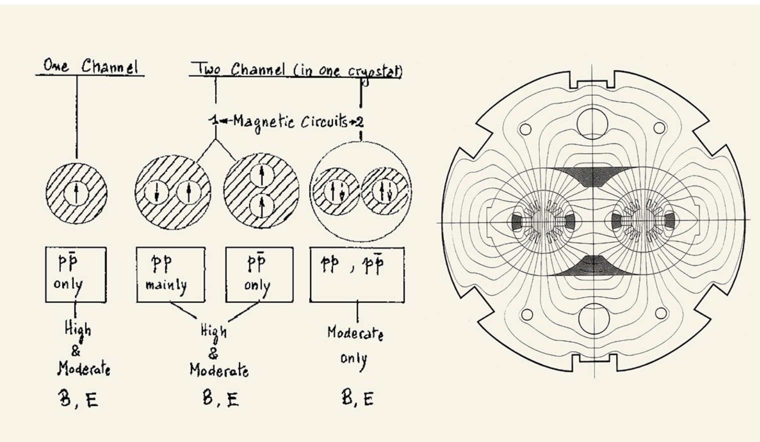
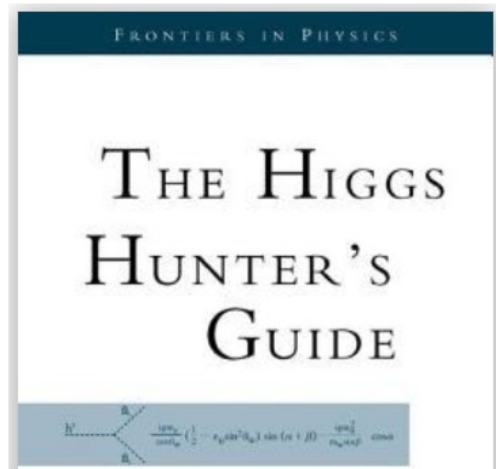
Jornadas CPAN & Winter meeting

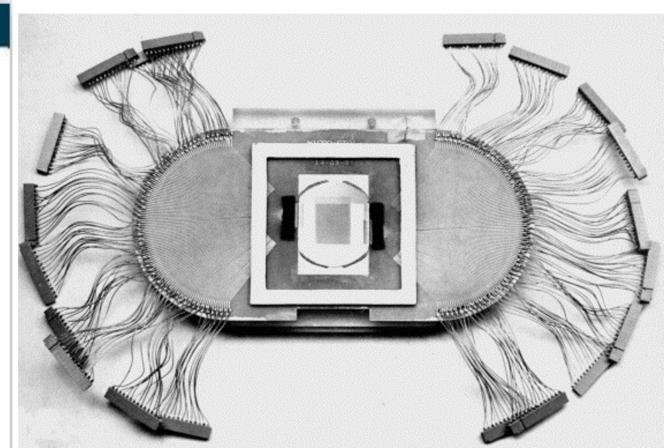
Santander, October 2023

The long game

All those results at the LHC shown at this winter meeting/CPAN are possible thanks to people in the '80s…







…doodling magnet designs, dreaming up the physics case, tinkering with new detectors

Also: solving the dark matter puzzle (from 1933) with quantum sensors (from the future)

Sustainable exploration of the fundamental laws of nature needs a long-term view and requires long-term investments

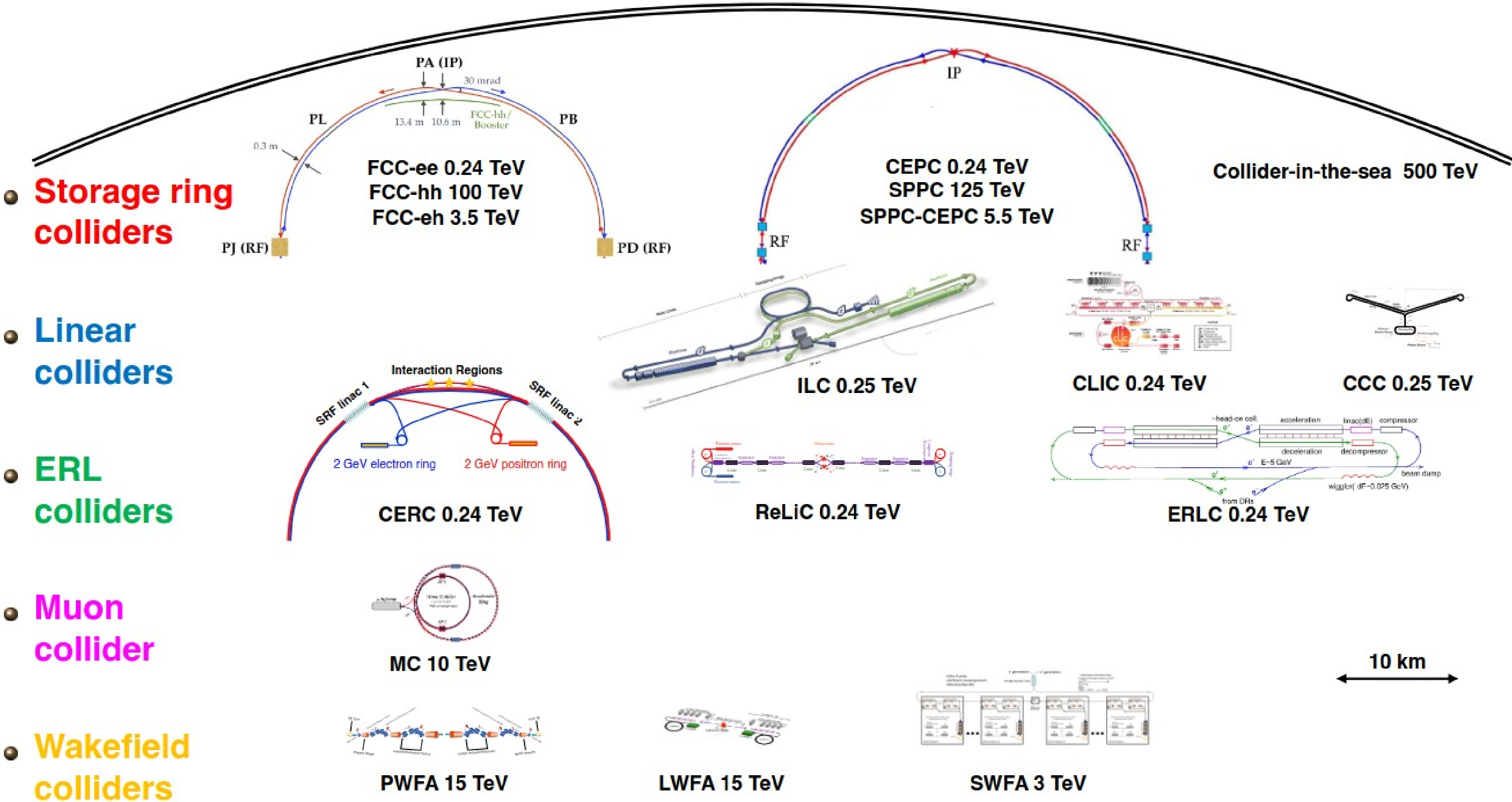
LHC for a while

Fortunately, the LHC will continue to deliver for another decade+

The HL-LHC is no longer a future collider; in our long game it's practically the present

Today's collider landscape… see Karl Jakob's talk

Future collider proposals: 0.125 – 500 TeV; e+e-, hh, eh, μμ, γγ, …



More options than Spanish FTE devoted to future colliders?

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The collider landscape – with a broad brush

European, American and Asian strategies agree on big picture

— e+e- Higgs factory first:

large circular colliders: FCC-ee (CERN) and CEPC (China)
linear colliders: ILC (Japan?), CLIC (CERN), CCC (US)

— exploration of the energy frontier next:

large pp collider: FCC-hh (CERN), SPPC (China)
muon collider: μ-collaboration (CERN+US)
plasma: accelerator R&D (EUPRAXIA, AWAKE), collider studies (i.e. ALEGRO)

Snowmass report

The proposed plans in five-year periods starting in 2025 are given below.

For the five-year period starting in 2025:

1. Prioritize the HL-LHC physics program, including auxiliary experiments,
2. Establish a targeted e^+e^- Higgs Factory Detector R&D program,
3. Develop an initial design for a first-stage TeV-scale Muon Collider in the U.S.,
4. Support critical Detector R&D towards EF multi-TeV colliders.

For the five-year period starting in 2030:

1. Continue strong support for the HL-LHC physics program,
2. Support the construction of an e^+e^- Higgs Factory,
3. Demonstrate principal risk mitigation for a first-stage TeV-scale Muon Collider.

Plan after 2035:

1. Continuing support of the HL-LHC physics program to the conclusion of archival measurements,
2. Support completing construction and establishing the physics program of the Higgs factory,
3. Demonstrate readiness to construct a first-stage TeV-scale Muon Collider,
4. Ramp up funding support for Detector R&D for energy frontier multi-TeV colliders.

European strategy update

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:

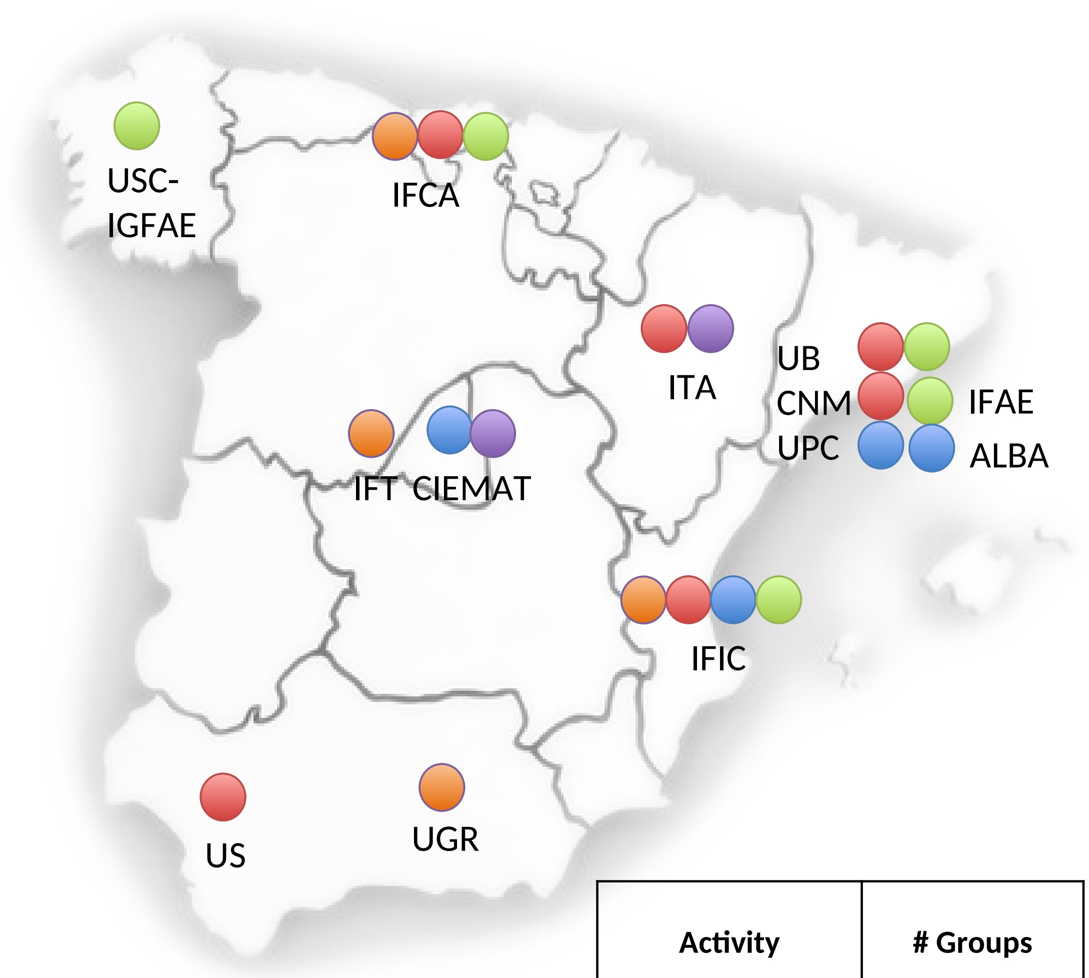
Spanish contributions

Future colliders is “mostly detector R&D…”

We need excellent contributions to the experiments and it’s great to see the initiative on detector R&D

All of us – from theorist to technician - should worry about the future of high energy physics

The main driver of progress in HEP is accelerator technology



Activity	# Groups
Accelerator	6
Si/Tracking	6
Si/Pixel	5
Calorimetry	3
Phenomenology	4

Spain is a big country, with a very sizable contribution to CERN: we need to be ambitious about our contribution

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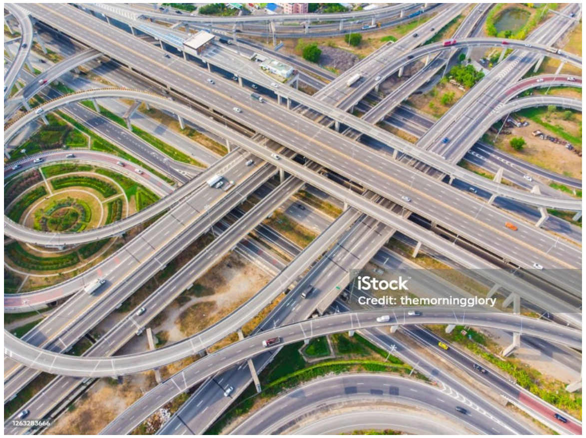
Funding for future colliders

Funding for blue-sky R&D and not-yet-approved collider projects is scarce
Long-term investments are not popular, in Spain and elsewhere

Identify existing strengths and build on those: clear synergies with existing projects such as the HL-LHC upgrades (possibly also nuclear physics, medical imaging…)
A challenge: avoid “solution in search of a problem”

Find intermediate “stepping stones” in other applications and experiments:
i.e. medical applications for accelerators and detectors
i.e. Belle 2 & Luxe detectors (possibly also CMS HGCAL, electron-ion collider)
A challenge: feed results back into long-term future collider goal



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Presenting the expert panel

— Theory & analysis:

Developing the physics case for the next collider

ECFA Higgs/top/EW factory study, Sven Heinemeyer, MCruz Fouz, J. de Blas, A. Irles

— Detector technology:

Addressing the challenges of the precision physics programme

R&D embedded in DRD structure & networks & AIDAinnova, Giulio Pellegrini

Detector design: ILD as a generic e+e- detector concept, MaryCruz Fouz, Alberto Ruiz

— Accelerator technology:

The key to any future collider project

Groups at CIEMAT, ALBA, ESS, IFIC, Luis Garcia-Tabares, Juan Fuster

Funding often tied to applications beyond HEP; EU projects linked to projects

— Spanish science industry:

Any discussion of Spanish in-kind contributions must involve Spanish companies

Especially in contributions to the accelerator, Erik Fernandez

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Scope

Recent strategy discussion in Europe, the Americas and Asia identify a high-energy electron-positron collider as the highest-priority future facility in high-energy physics. Under the umbrella of the European Committee for Future Accelerators studies, the European HEP community pursues studies of the scientific potential of this Higgs/top/EW factory, as well as an extensive R&D programme to develop the necessary accelerator and detector technology.

This round table discussion aims to identify strategic areas of this programme, where Spanish particle physics institutes, technological centres and industry can make leading contributions.

Questions…

----- Which are the strengths of Spain - in accelerator and detector technology, as well as in analysis and theory - that are most relevant for the next large-scale facility in HEP?

----- And which strategic areas that are likely very important in the future are we not covering adequately today?

Questions…

----- How can we achieve an adequate funding to make progress in R&D and design studies during the period before approval of the Higgs/top/EW factory?

----- Which funding schemes are there beyond the national programme?

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Questions…

----- How do we involve specialized technological centres and the science industry (even more) in HEP?

----- How do we make sure society benefits from developments in our field?

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Backup slides

Which future collider?

https://cerncourier.com/a/we-cant-wait-for-a-future-collider/

Many ideas and projects (good!), but unclear time lines, opaque strategies, unclear financial and political international situation (not so good!)

The future of the field can be a frustrating area for impatient young particle physicists

We can't wait. Don't wait! Get involved. We'll need to make this happen together!

Which project? Picking the winning horse:

Gambling.com: Learning how to pick a winning horse is a skill honed over a lifetime

Quora: can't you just bet on all horses in a race?
A: technically you can, but you won't make any money.

Good solutions tend to work irrespective of the final choice of technology/location

Most relevant new developments

Technology progress:
– High-efficiency klystrons (good for all projects): CERN-IHEP project pushes 80%
– High-gradient SCRF cavities: FNAL&IHEP push the envelope > 40 GV/m

Design studies:
– Energy-recovery LINACs, boost luminosity of e+e- colliders, https://arxiv.org/abs/1909.04437 + first conceptual designs for real machines
– Cool Copper Collider, shrink Higgs factory to 8 km facility, https://arxiv.org/abs/2203.07646
– Hybrid, asymmetric wakefield & RF collider, shrink Higgs factory to 3.3 km facility, https://arxiv.org/abs/2303.10150
– Muon collider (the μC is back!), energy-efficient multi-TeV lepton collisions https://arxiv.org/abs/2209.01318

Global R&D progress is pushing accelerator technology; several new collider concepts have been launched in recent years

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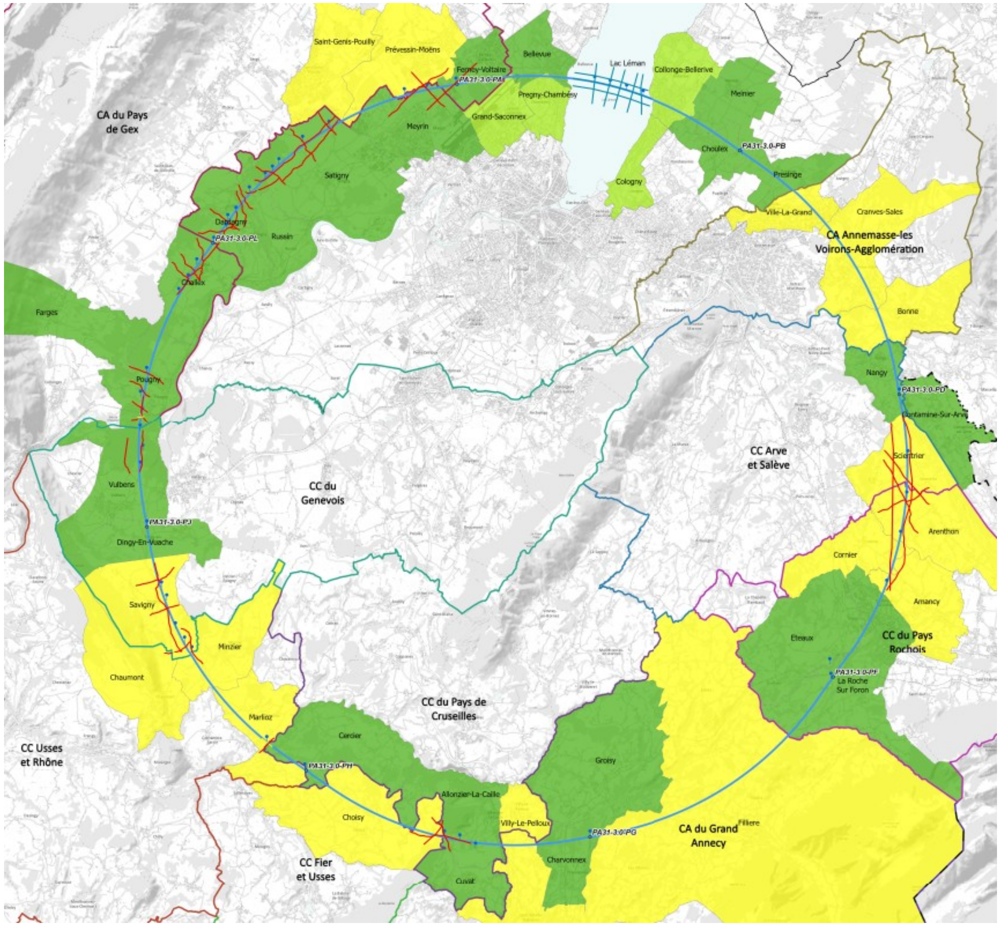
Higgs/top/EW factory project progress

Detailed FCC design based on geology and accelerator studies, but also road access, power supply, etc.

Parameter	unit	2018 CDR [1]	2023 Optimised
Total circumference	km	97.75	90.657
Total arc length	km	83.75	76.93
Arc bending radius	km	13.33	12.24
Arc lengths (and number)	km	8.869 (8), 3.2 (4)	9.617 (8)
Number of surface sites	—	12	8
Number of straights	—	8	8
Length (and number) of straights	km	1.4 (6), 2.8 (2)	1.4 (4), 2.031 (4)
superperiodicity	—	2	4



FCC mid-term review end of 2023, CERN council statement Feb. ‘24

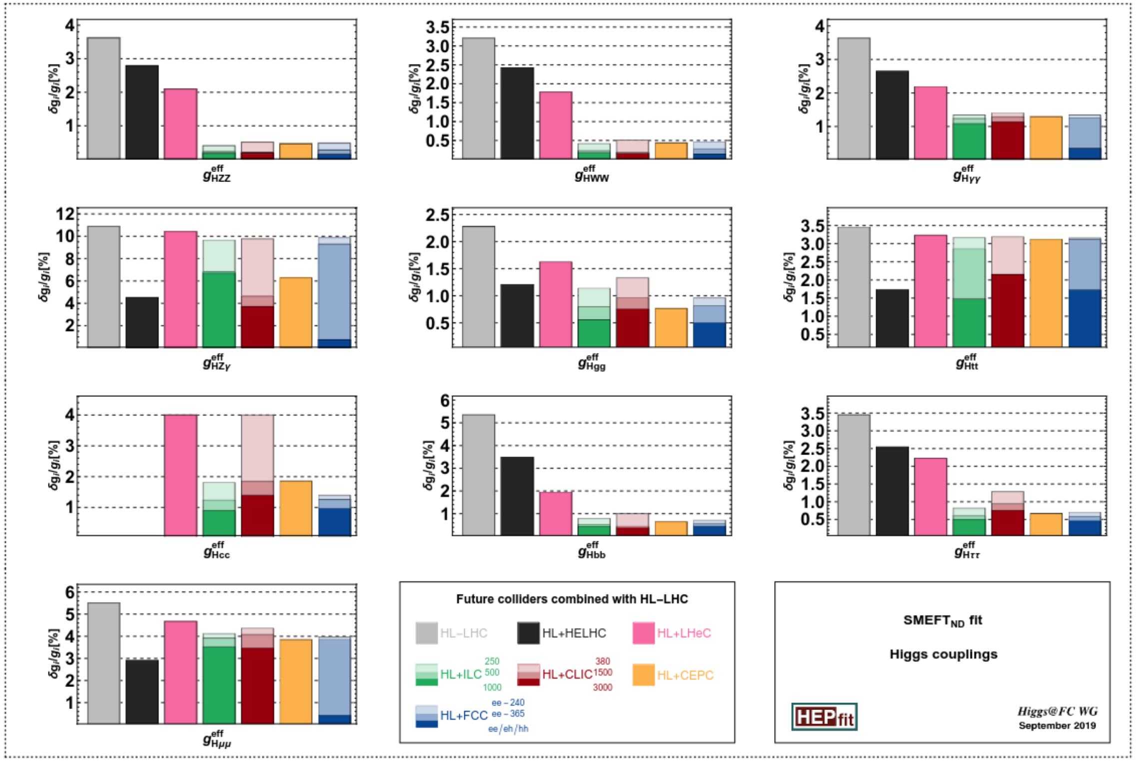
US P5 panel to provide recommendations this year

ILC: signs CERN-KEK agreement for common R&D programme on the accelerator

CEPC: Chinese Academy of Sciences pre-selects CEPC

Circular or linear?

- Circular machines provide superior luminosity at LEP energies (i.e. TeraZ Z-pole run)
- All machines can do excellent Higgs physics and can reach the $t\bar{t}$ threshold
- Upgraded linear colliders access di-Higgs, ttH, and “energy-growth” in new physics



European strategy physics briefing book, https://arxiv.org/pdf/1910.11775.pdf

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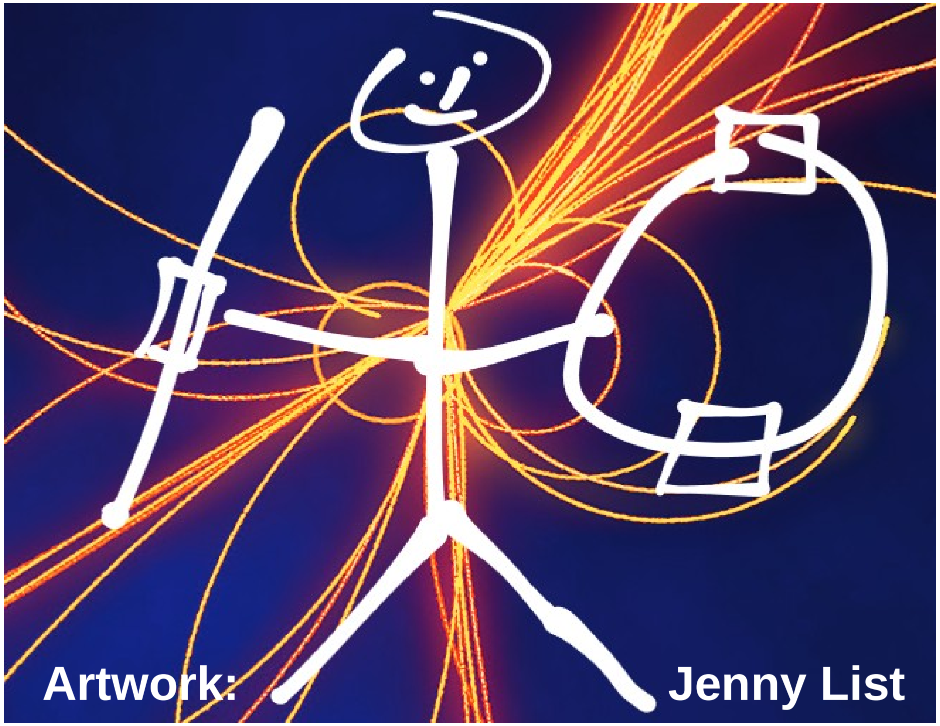


The scientific choice is essentially Z-pole vs. energy upgrade, the rest is “just” politics

Politics: comparison of main figures of merit
(according to Snowmass Collider Implementation Task Force)

1) for two experiments, 2) accurate beam energy 3) polarized beams enhance cross sections

	Proposal Name	CM energy nom. (range) [TeV]	Lum./IP @ nom. CME [10^{34} cm^{-2}s^{-1}]	Years of pre-project R&D	Years to first physics	Construction cost range [2021 B$]	Est. operating electric power [MW]
Higgs factory	FCC-ee[1,2]	0.24 (0.09-0.37)	7.7 (28.9)	0-2	13-18	12-18	290
Higgs factory	CEPC[1,2]	0.24 (0.09-0.37)	8.3 (16.6)	0-2	13-18	12-18	340
Higgs factory	ILC[3] - Higgs factory	0.25 (0.09-1)	2.7	0-2	<12	7-12	140
Higgs factory	CLIC[3] - Higgs factory	0.38 (0.09-1)	2.3	0-2	13-18	7-12	110
Higgs factory	CCC[3] (Cool Copper Collider)	0.25 (0.25-0.55)	1.3	3-5	13-18	7-12	150
+ERL	CERC[3] (Circular ERL Collider)	0.24 (0.09-0.6)	78	5-10	19-24	12-30	90
+ERL	ReLiC[1,3] (Recycling Linear Collider)	0.24 (0.25-1)	165 (330)	5-10	>25	7-18	315
+ERL	ERLC[3] (ERL linear collider)	0.24 (0.25-0.5)	90	5-10	>25	12-18	250
Exotic HF	XCC (FEL-based $\gamma\gamma$ collider)	0.125 (0.125-0.14)	0.1	5-10	19-24	4-7	90
Exotic HF	Muon Collider Higgs Factory[3]	0.13	0.01	>10	19-24	4-7	200

More complete report

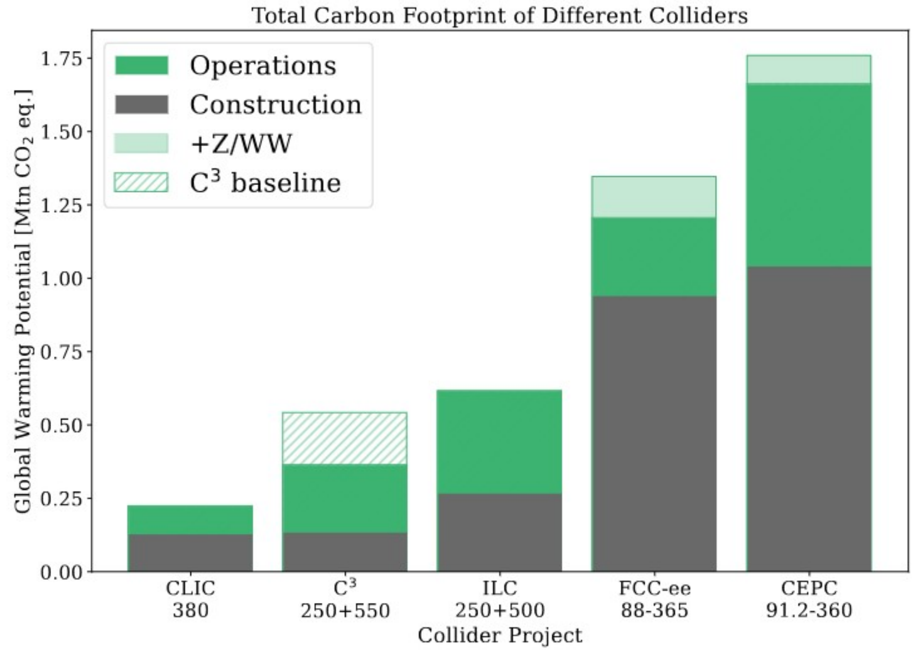
More figures of merit

Carbon footprint of colliders
https://arxiv.org/pdf/2307.04084.pdf

A Sustainability Roadmap for C[3]

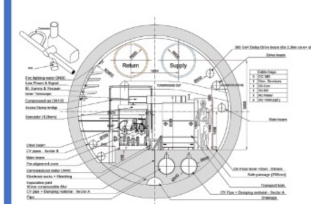
Martin Breidenbach, Brendon Bullard, Emilio Alessandro Nanni, Dimitrios Ntounis[†], Caterina Vernieri
SLAC National Accelerator Laboratory [†] & Stanford University

Complete ISO life-cycle assessment ongoing for several projects

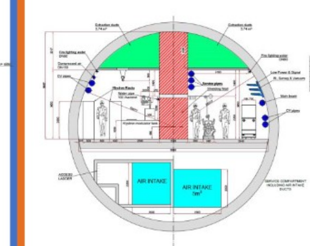


Lessons: construction of the facility (boring, concrete+steel for tunnel) has a large impact, exceeding that of energy consumption during operation for most projects.

Optimize design to minimize impact (i.e. CLIC drive beam vs. Klystrons)



CLIC Drive beam, 5.6m dia.



CLIC Klystron, 10m dia.