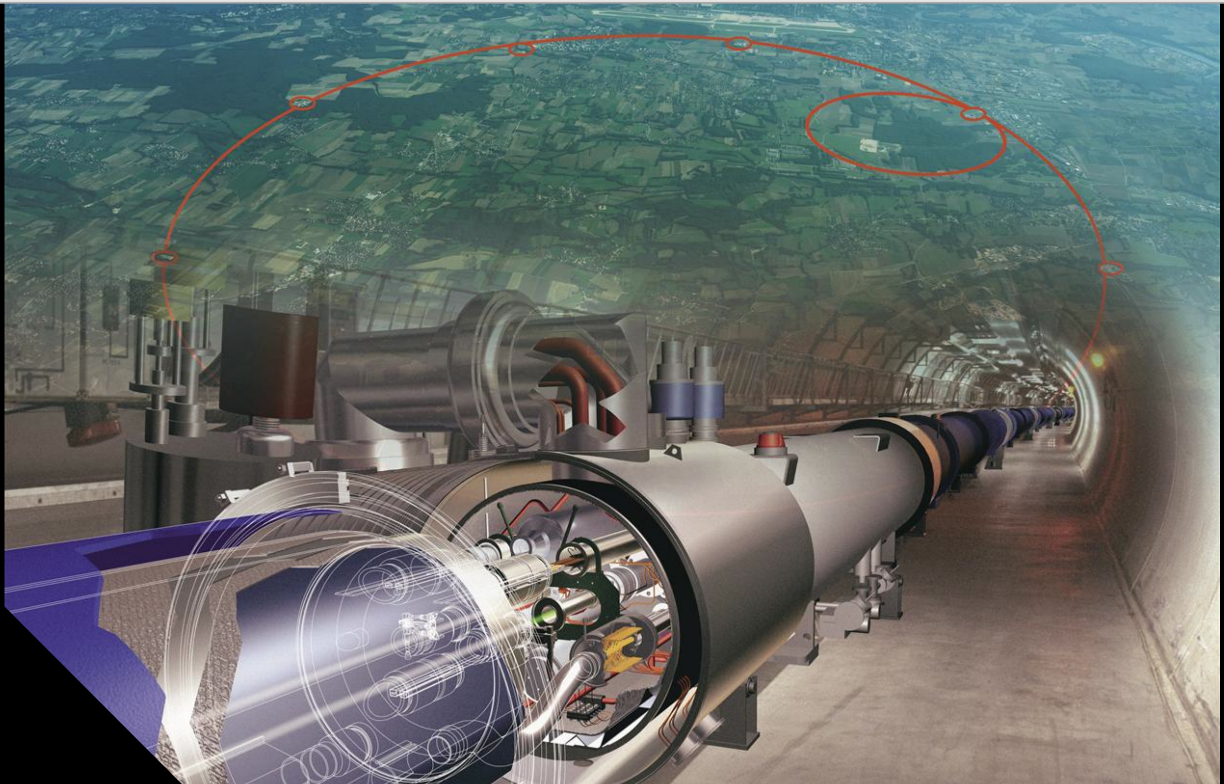
Road to an update of the European HEP Strategy

Jorgen D'Hondt
Vrije Universiteit Brussel
ECFA chairperson
(https://ecfa.web.cern.ch)

ICFA meeting
August 7, 2019
Toronto



HEP@VUB BRUSSELS

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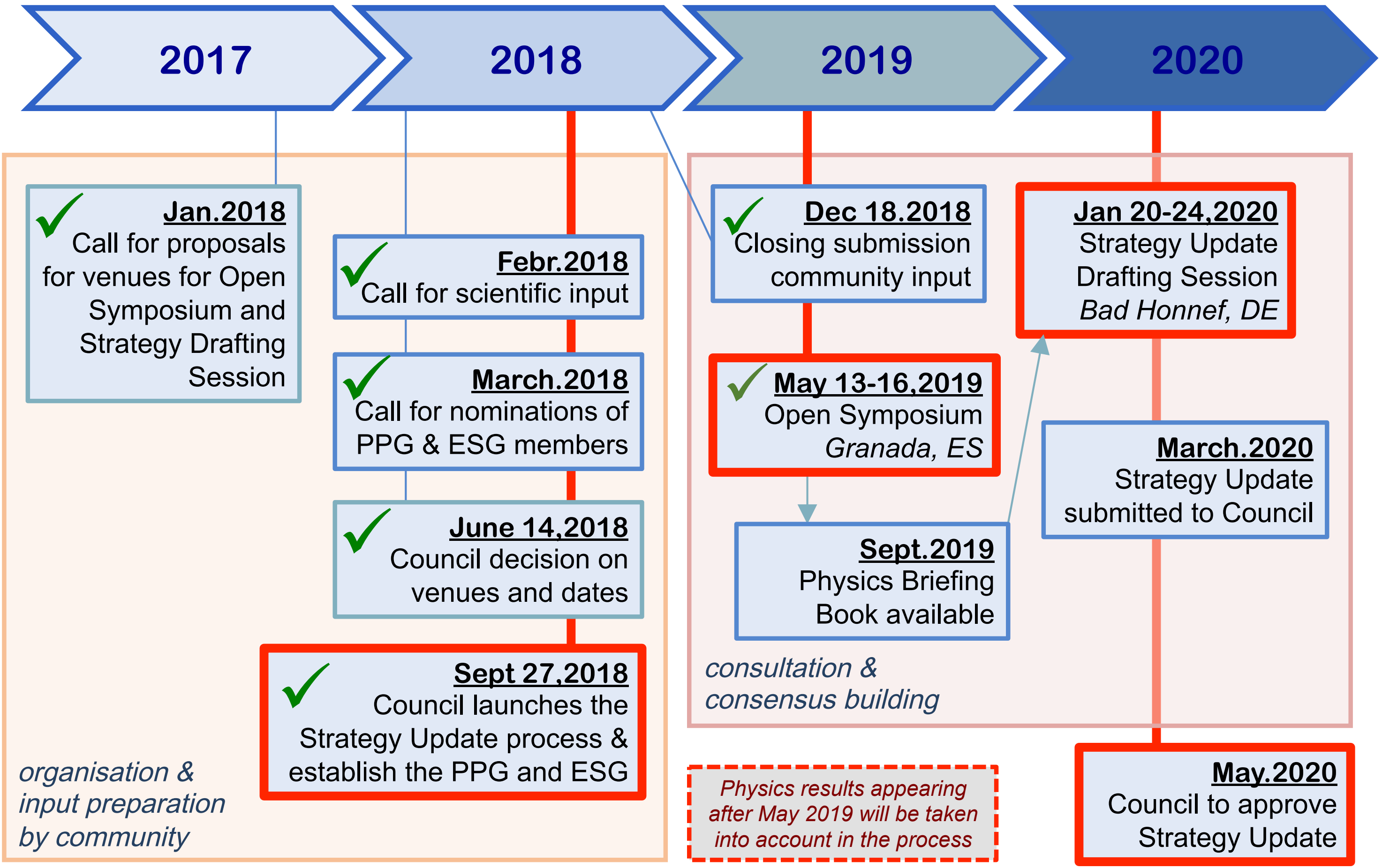

2017
2018
2019
2020
Jan.2018
Call for proposals for venues for Open Symposium and Strategy Drafting Session
Febr.2018
Call for scientific input
March.2018
Call for nominations of PPG & ESG members
June 14,2018
Council decision on venues and dates
Sept 27,2018
Council launches the Strategy Update process & establish the PPG and ESG
organisation & input preparation by community
Dec 18.2018
Closing submission community input
May 13-16,2019
Open Symposium
Granada, ES
Sept.2019
Physics Briefing Book available
Jan 20-24,2020
Strategy Update Drafting Session
Bad Honnef, DE
March.2020
Strategy Update submitted to Council
consultation & consensus building
Physics results appearing after May 2019 will be taken into account in the process
May.2020
Council to approve Strategy Update

Open Symposium
Towards updating the European Strategy for Particle Physics
May 13-16, 2019, Granada, Spain
https://cafpe.ugr.es/eppsu2019/
~600 participants
Information captured in 8 thematic summary talks

Long-term strategy for Particle Physics

Organization (2013 update):
http://europeanstrategygroup.web.cern.ch/europeanstrategygroup/

UPDATE of the European Particle Physics Strategy (2013)

TODAY

Higgs discovery (2012)

Start data taking at the LHC (2010)

European Particle Physics Strategy (2006)

Organization (2006):
http://council-strategygroup.web.cern.ch/council-strategygroup/

The European Particle Physics Strategy 2013

https://cds.cern.ch/record/1567258/files/esc-e-106.pdf - with the highest priority

① Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.

② CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.

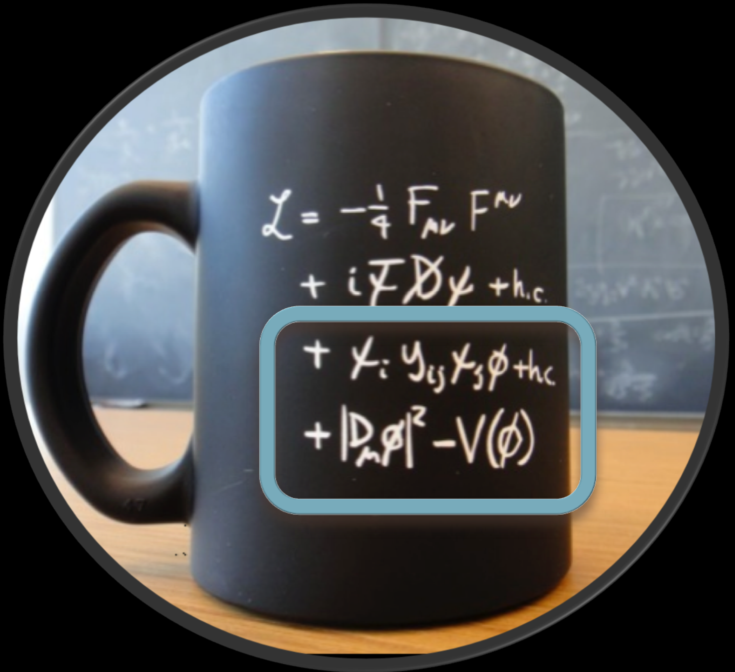
③ Europe looks forward to a [ILC] proposal from Japan to discuss a possible participation.

④ CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.

1st priority

LHC and HL-LHC

Initial legacy impact of the LHC



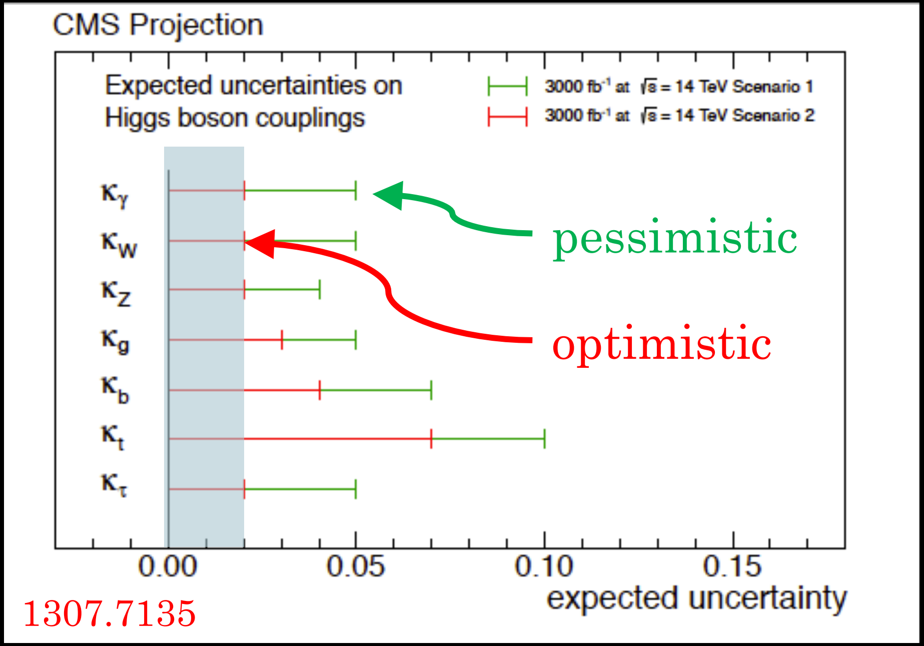
connection

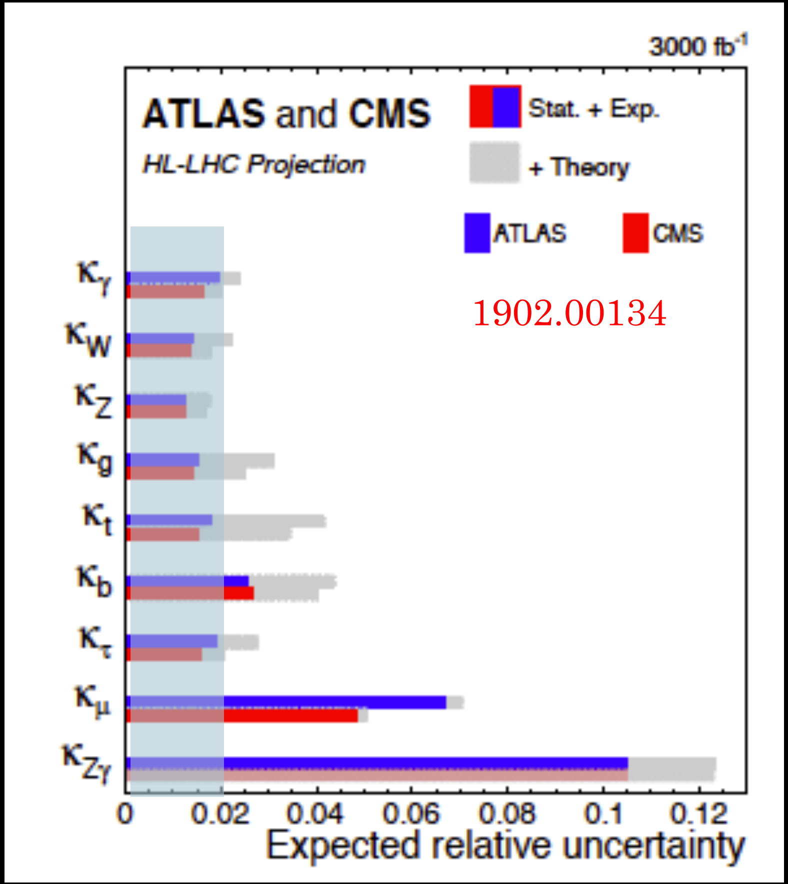
a MORE PRECISE and more COMPLETE description

new physics

ALICE – Upgrade LS2 – study Quark-Gluon Plasma formed in nuclear collisions
Monolythic-pixel Inner Tracking System
→ x3-5 better tracking precision
Pixel Muon Forward Tracker
→ non-prompt muons from B decays
GEM-based TPC readout
→ x100 readout rate in Pb-Pb
ΔV = 270 V
ΔV = 800 V
ΔV = 230 V
ΔV = 800 V
ΔV = 288 V
ΔV = 20 V
ΔV = 359 V
ΔV = 800 V
pad plane
• Low-pT heavy-flavour mesons/baryons:
• Low-pT charmonia: c-cbar melting and
• Low-mass di-electrons: QGP thermal r
LHCb – Upgrade LS2
Construction well advanced
Will collect 50 fb-1 at instantaneous lumi of 2x1033cm-2s-1
Full software trigger
New tracking detectors
New RICH photon detectors
New electronics read out at 40 MHz
Prototypes of DAQ board (PCIe40)
VELO RF-foil (250 um thick machined aluminum foil)
Machining and light scan of the scintillating fiber mats for the fibre tracker
Cherenkov ring from a full RICH MaPMT module
ream Tracker silicon or module under test
First scintillating fibre modules arriving at CERN
Calorimeter front-end board
Muon system readout ASIC
High-Luminosity LHC: 300/fb (by 2023) → 3000/fb (by 2037)
HiLumi HL-LHC PROJECT
CIVIL ENGINEERING
"CRAB" CAVITIES
LHC TUNNEL
CMS
ALICE
ATLAS
LHCb
FOCUSING MAGNETS
SUPERCONDUCTING LINKS
COLLIMATORS
BENDING MAGNETS
New IR-quads Nb3Sn (inner triplets)
New 11 T Nb3Sn (short) dipoles
Collimation upgrade
Cryogenics upgrade
Crab Cavities
Cold powering
Machine protection
Civil engineering
Formal approval by CERN Council (June 2016)
Cost to Completion : 950 MCHF (material)
Detector
plann
ATLAS – Upgrade Phase II (LS3)
NEW ALL-SILICON INNER TRACKER (ITK) WITH ETA COVERAGE UP TO 4
HIGH GRANULARITY TI IN FORWARD R
TDAQ OFF-DETECTOR ELECTRONICS:
• L0 HARDWARE TRIGGER:
• L0 CALORIMETER
• L0 TOPOLOGICAL
• L0 MUON
• L0 GLOBAL
• L1 HARDWARE TRIGGER (OPTION):
• L1 GLOBAL
• L1 TRACK TRIGGER
• READOUT SYSTEM
• HLT
44m
25m
Muon chambers
Toroid magnets
Solenoid magnet
Semiconductor tracker
Transition radiation tracker
Pixel detector
LAr electromagnetic calorimeters
Tile calorimeters
LAr hadronic end-cap and forward calorimeters
NEW MUON CHAMBERS IN THE INNER BARREL REGION
FORWARD MUON TAGGER (OPTION)
64
CMS – Upgrade Phase II (LS3)
Trigger/HLT/DAQ (interim TDR submitted)
• Track information in trigger at 40 MHz
• 12.5 μs latency
• HLT input/output 750/7.5 kHz
Barrel EM calorimeter
• New FE/BE electronics for full granularity readout at 40 MHz - with improved time resolution
• Lower operating temperature (8°)
Muon systems
• New DT & CSC FE/BE electronics
• New station to complete CSC at 1.6 < η < 2.4
• Extended coverage to η ≃ 3
New Endcap Calorimeters
• Rad. tolerant - High granularity transverse and longitudinal
• 4D shower measurement including precise timing capability
Beam radiation and luminosity
Common systems and infrastructure
New Tracker
• Rad. tolerant - increased granularity - lighter
• 40 MHz selective readout (strips) for Trigger
• Extended coverage to η ≃ 3.8
MIP precision Timing Detector
• Barrel layer: Crystal + SiPM
• Endcap layer: Low Gain Avalanche Diodes

Potential HL-LHC performance in Higgs couplings
anno 2013 versus anno 2019

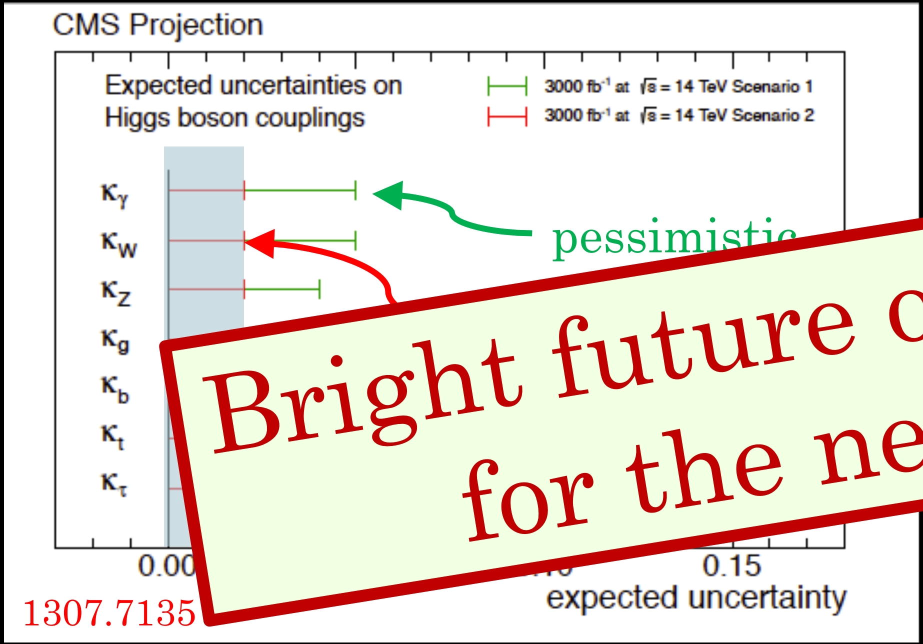


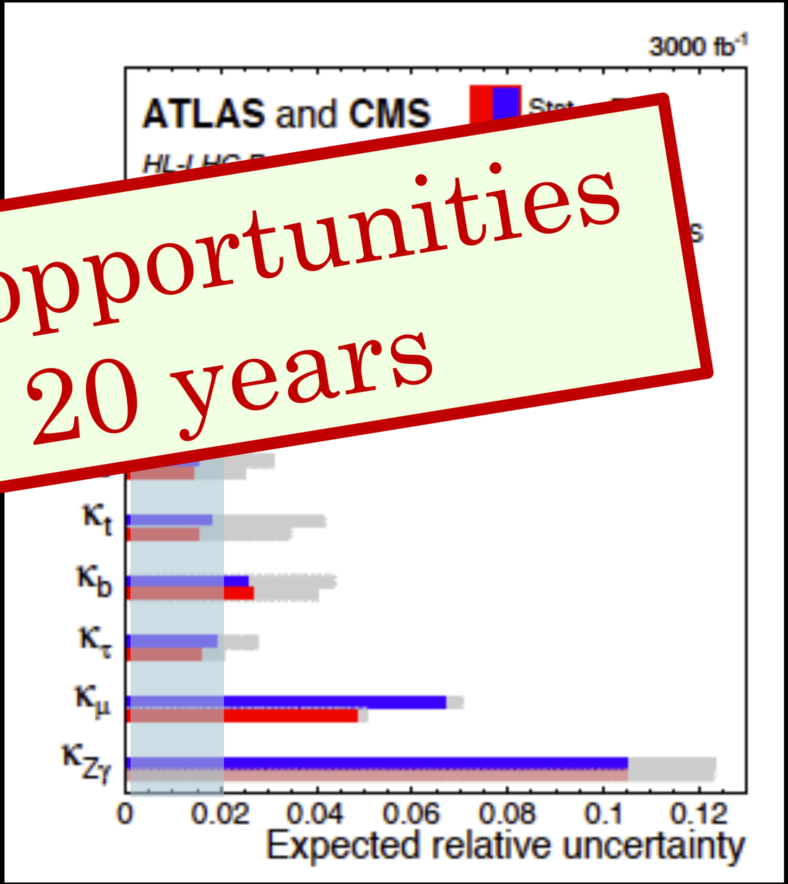


Taking into account innovative thoughts and research experience, what was optimistic in 2013 seems realistic in 2019.

Potential HL-LHC performance in Higgs couplings

anno 2013 versus anno 2019





Bright future of opportunities for the next 20 years

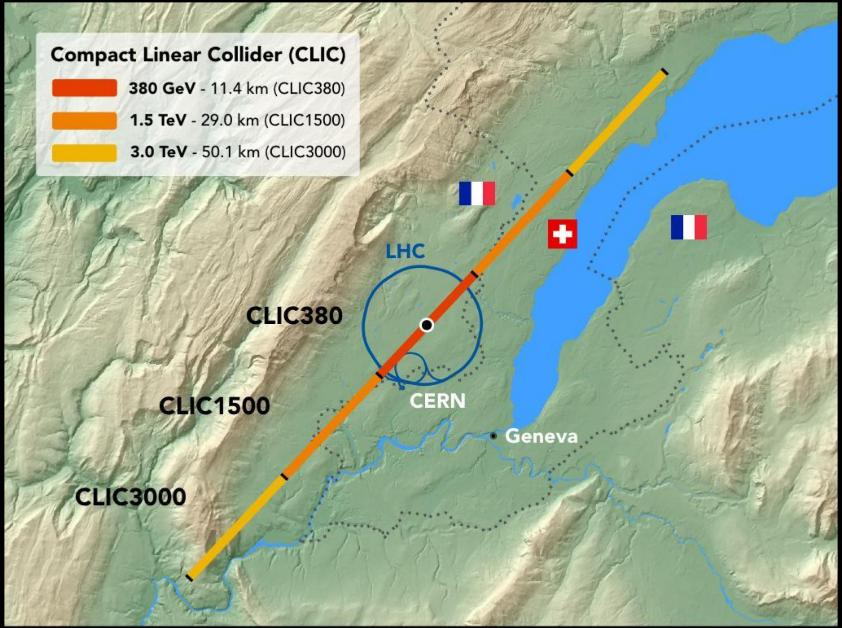
Taking into account innovative thoughts and research experience, what was optimistic in 2013 seems realistic in 2019.

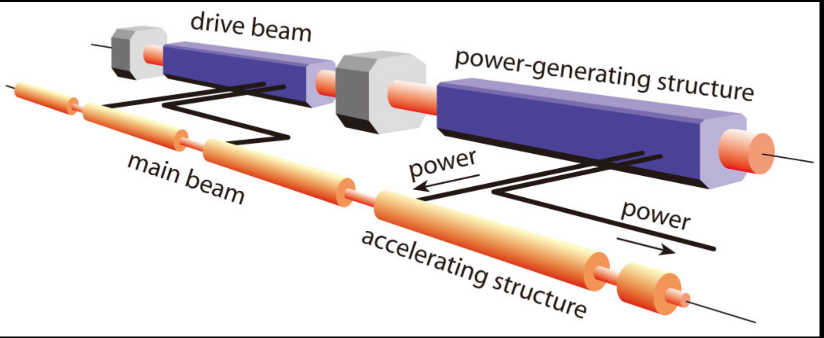
2nd priority

Future colliders at CERN

Concrete collider options studied at CERN

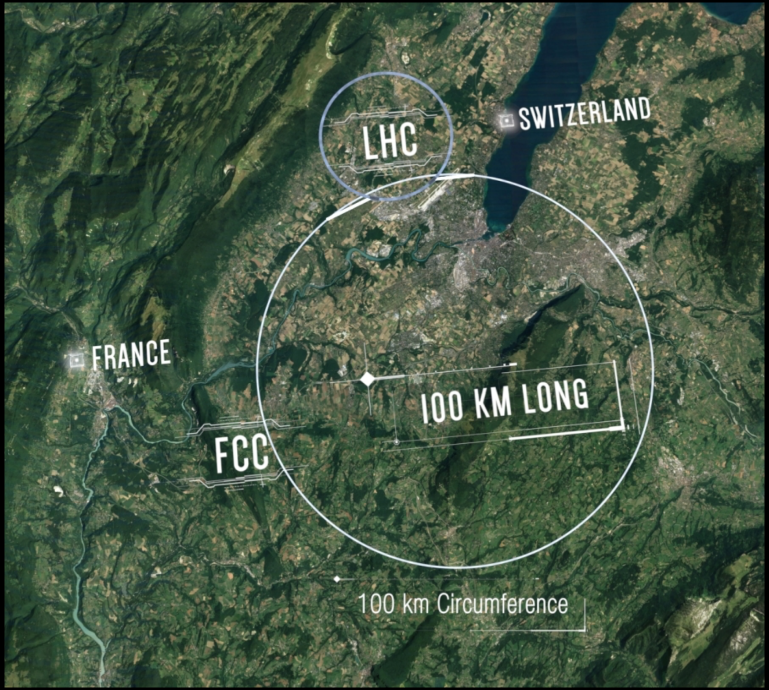
CLIC (ee), http://clic-study.web.cern.ch/





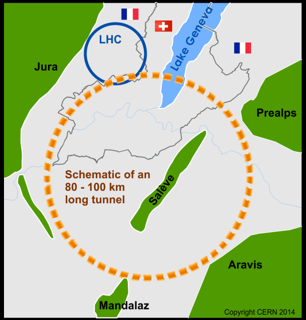
Concrete collider options studied at CERN

FCC (ee, ep, pp, pA, AA, eA), https://fcc-cdr.web.cern.ch/

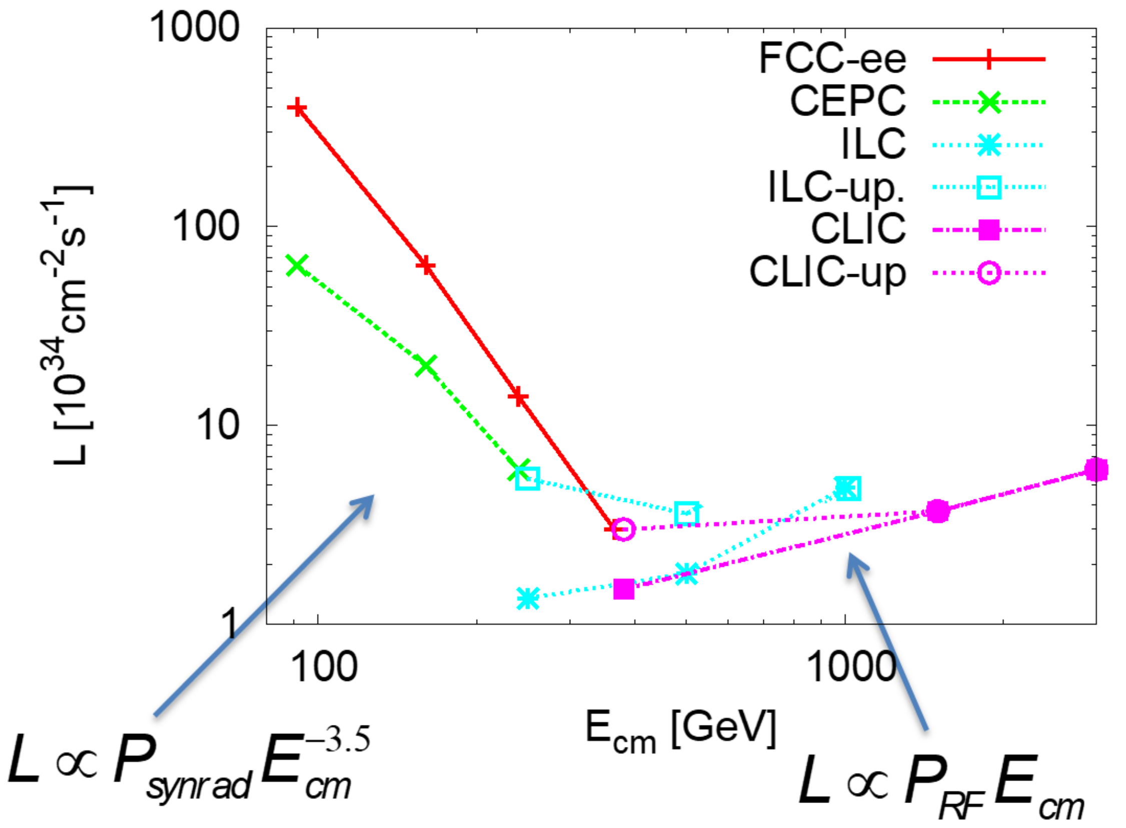


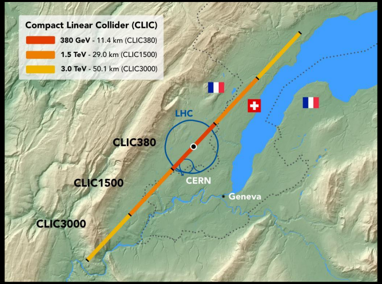
- **e^+e^- collider (*FCC-ee*) @ 90-365 GeV** as potential first step

  (ERL-technology, CLIC injector, …)
- ***pp*-collider (*FCC-hh*) @ 100 TeV**
- ***p-e* collider (*FCC-he*)**
- **HE-LHC** with *FCC-hh magnets*
- **$\mu\mu$ colider (*FCC-$\mu\mu$*)** option
- AA, Ap, Ae options

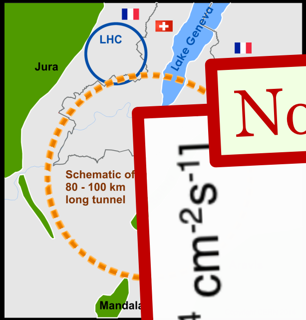


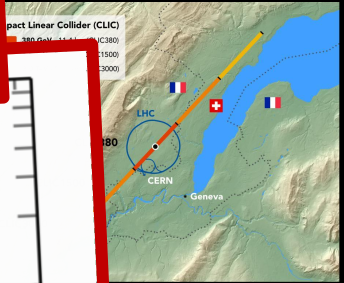
Luminosity per facility

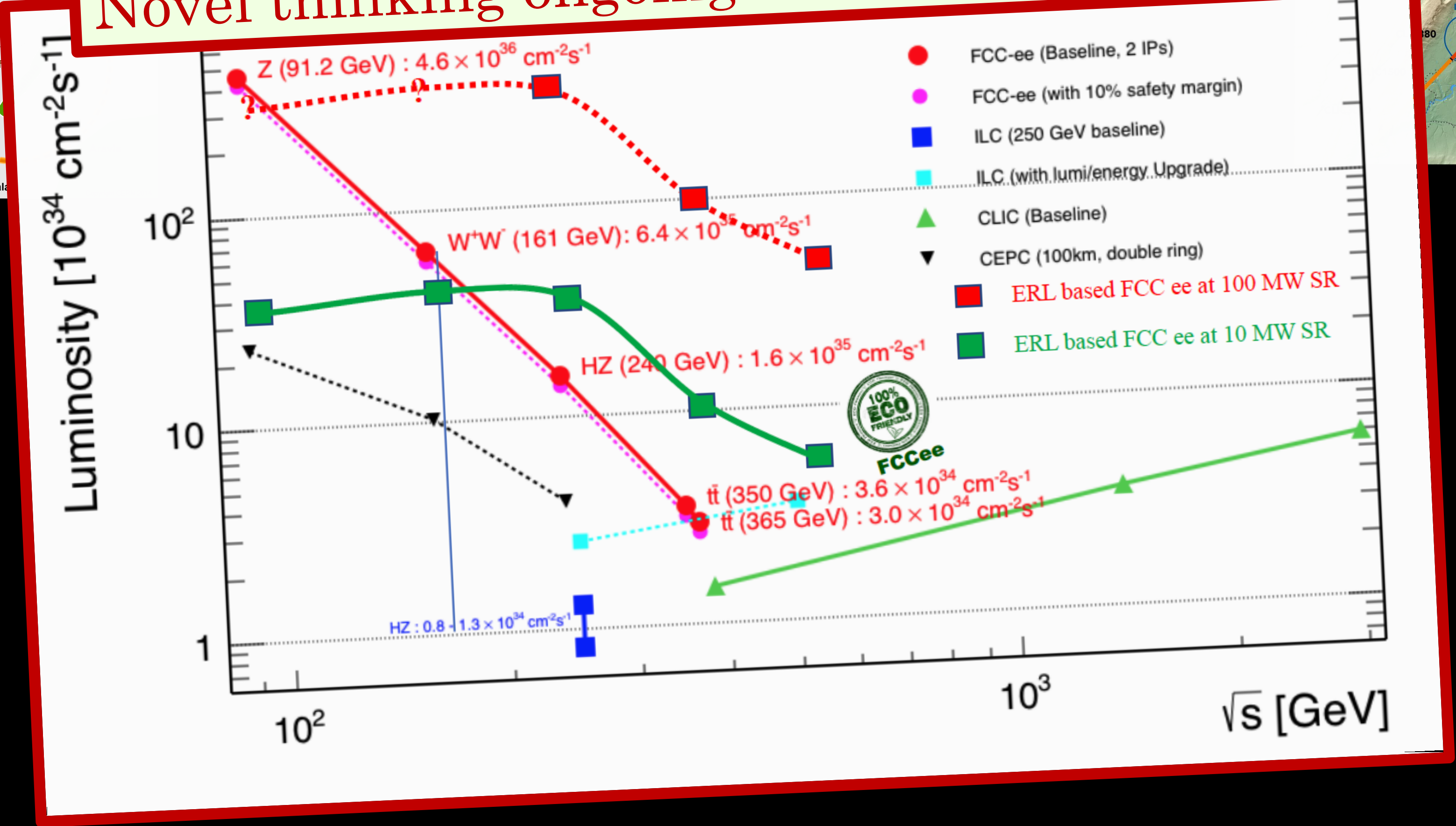




Novel thinking ongoing: ERL-based FCC-ee

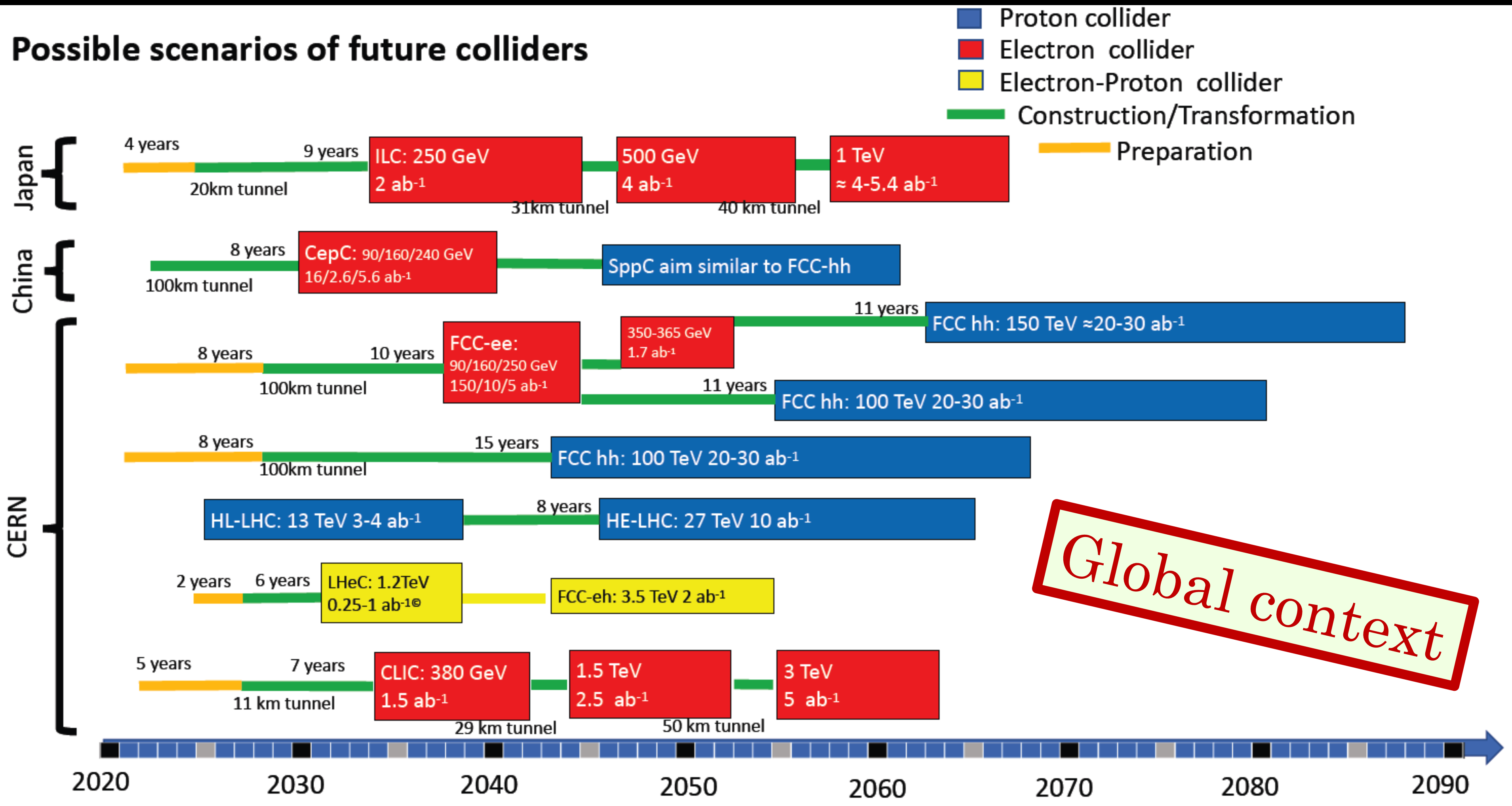






Maria Chamizo @ FCC week: https://indico.cern.ch/event/727555/contributions/3474689/

Possible scenarios of future colliders



Technology readiness

Akira Yamamoto
@ Granada

Personal View on Relative Timelines

Timeline	~ 5	~ 10	~ 15	~ 20	~ 25	~ 30	~ 35
Lepton Colliders							
SRF-LC/CC	Proto/pre-series	Construction		Operation		Upgrade	
NRF—LC	Proto/pre-series	Construction		Operation		Upgrade	
Hadron Collier (CC)							
8~(11)T NbTi /(Nb3Sn)	Proto/pre-series	Construction			Operation		Upgrade
12~14T Nb_3Sn	Short-model R&D		Proto/Pre-series		Construction	Operation	
14~16T Nb_3Sn		Short-model R&D		Prototype/Pre-series		Construction	

Technology readiness

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≲8T NbTi magnets for a "low-energy" 100km *pp* collider immediately following HL-LHC ?

Technology readiness

Akira Yamamoto
@ Granada

Personal View on Relative Timelines

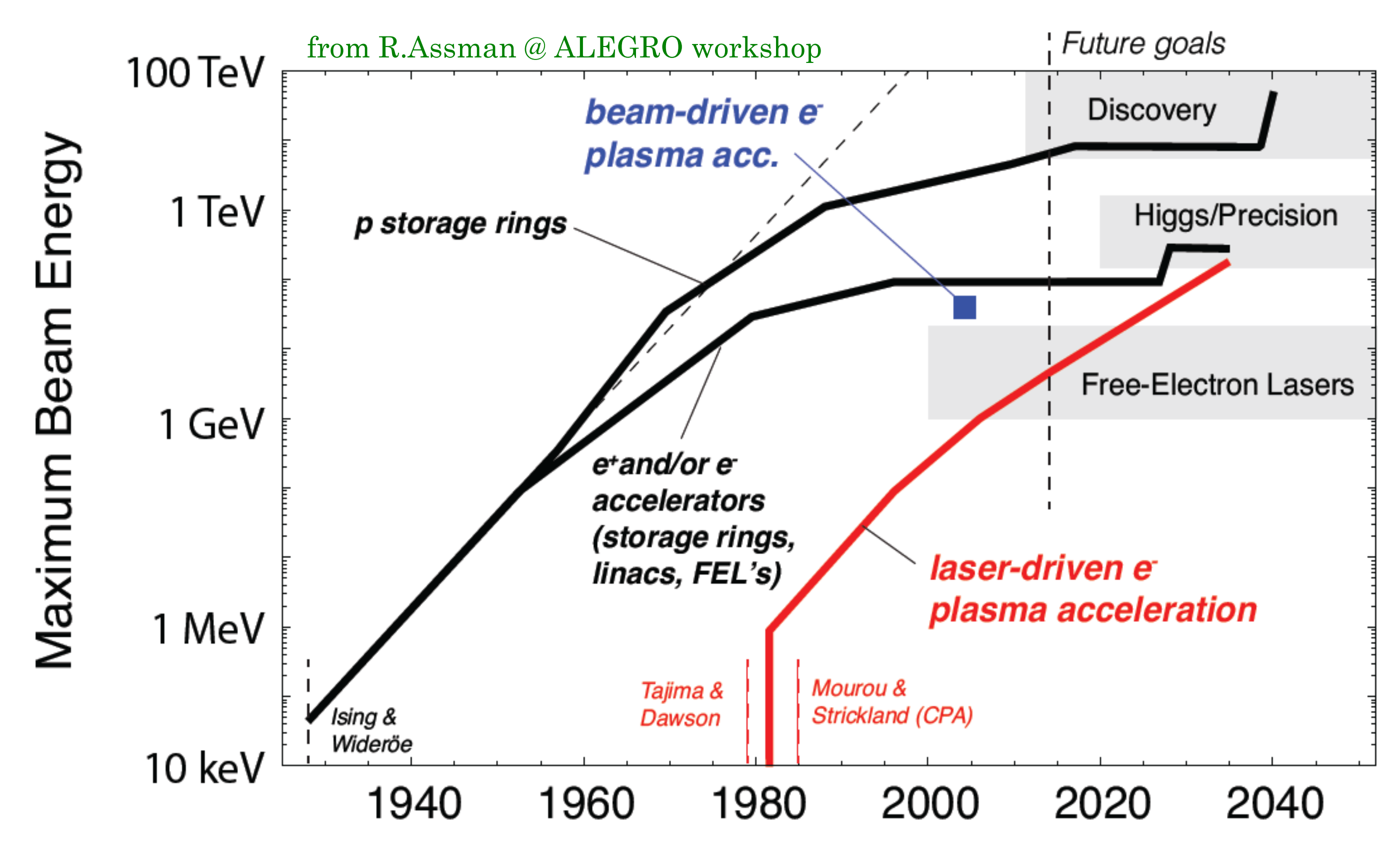
Timeline	~ 5	~ 10	~ 15	~ 20	~ 25	~ 30	~ 35
Lepton Colliders							
SRF-LC/CC	Proto/pre-series					Upgrade	
NRF—LC	Proto/pre					Upgrade	
Hadron Collier (CC)							
8~(11)T NbTi /(Nb3Sn)	Proto/pre-series	Construction		Operation			Upgrade
12~14T Nb_3Sn	Short-model R&D	Proto/Pre-series		Construction		Operation	
14~16T Nb_3Sn	Short-model R&D		Prototype/Pre-series			Construction	

<16T Nb_3Sn magnets ready for a "medium-energy" 100km *pp* collider immediately following HL-LHC ?

Accelerator R&D – Advanced Novel Accelerators (ICFA Panel)

ALEGRO (Advanced LinEar collider study GROup, for a multi-TeV Advanced Linear Collider)

ALEGRO delivered a document detailing the international roadmap and strategy of Advanced Novel Accelerators (ANAs).

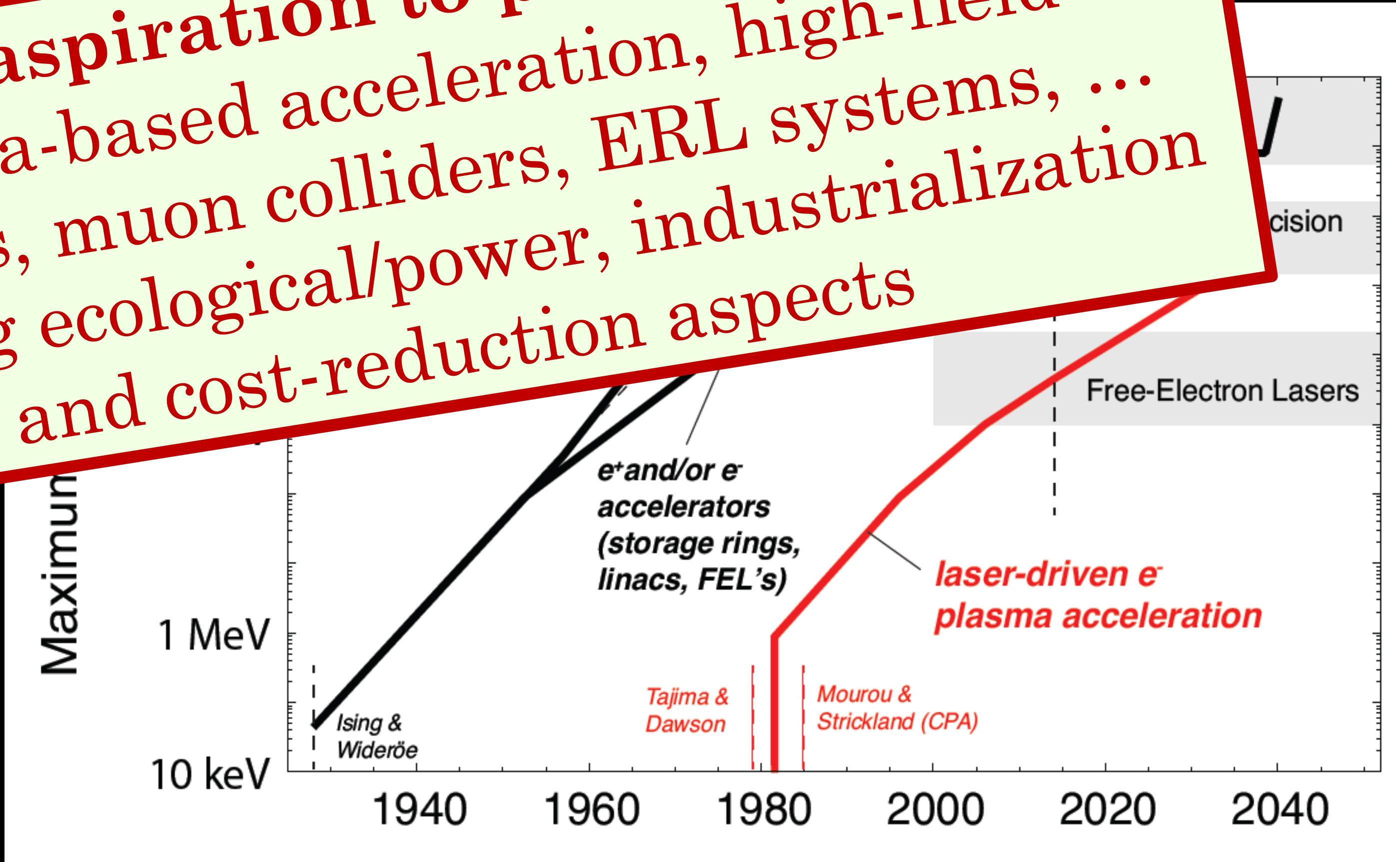


Accelerator R&D – Advanced Novel Accelerators (ICFA Panel)

ALEGRO (Advanced LinEar collider study GROup, fo… …r)

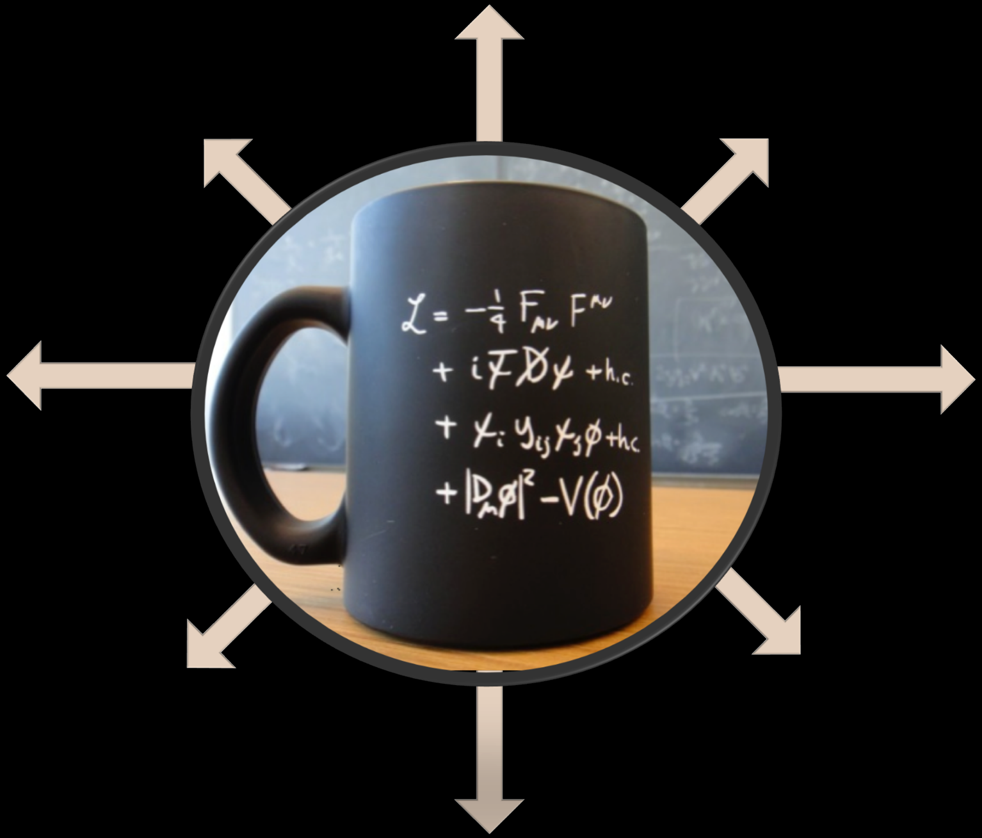
ALEG… docun… interna… and str… Novel A… (ANAs).…

Strong aspiration to pursue R&D for:
plasma-based acceleration, high-field magnets, muon colliders, ERL systems, …
including ecological/power, industrialization and cost-reduction aspects



higher energy interactions in the lab

earlier universe



rarer processes

higher energetic phenomena in the universe higher energy interactions in the lab

earlier uni

se

processes

Connection between particle physics
and astro(-particle) physics

e.g. jointly innovate technology
to make the invisible visible

higher energetic phenomena in the universe

Long-term strategy for Particle Physics

European Strategy Update

Organization (2013 update):
http://europeanstrategygroup.web.cern.ch/europeanstrategygroup/

Major facility after HL-LHC

Start data taking HL-LHC (2026)

UPDATE of the European Particle Physics Strategy (2013)

TODAY

Higgs discovery (2012)

UPDATE of the European Particle Physics Strategy (2020)

https://europeanstrategy.cern

Start data taking at the LHC (2010)

European Particle Physics Strategy (2006)

Organization (2006):
http://council-strategygroup.web.cern.ch/council-strategygroup/

Key open questions for particle physics?

Riccardo Rattazzi
@ Granada

Problems vs Mysteries

Problems

- Dark Matter
- Baryogenesis
- Strong CP
- Fermion mass spectrum & mixing

Plausible EFT solutions exist

Mysteries

- Cosmological Constant
- EW hierarchy
- Black Hole information paradox
- very Early Universe

Challenge or outside EFT paradigm

although there is no lack of novel theoretical ideas, there are no clear indications where new physics is hiding although there is no lack of novel theoretical ideas, there are no clear indications where new physics is hiding

an argument for a strong and diverse, yet coherent and concerted empirical exploration although there i

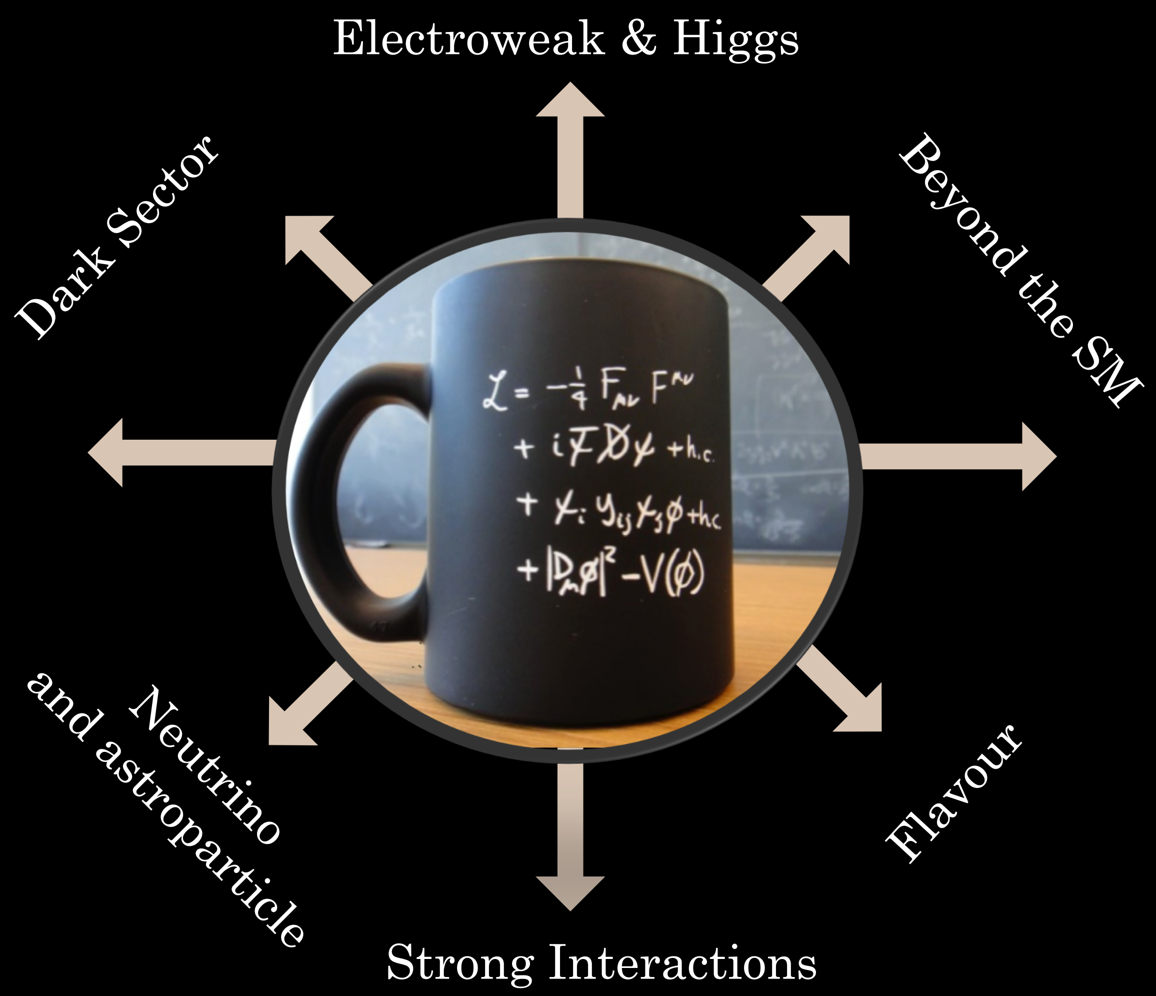
th

A strong research field needs a strong story

need for a strong and global scientific story how to make progress in unravelling the smallest and largest scales of Nature

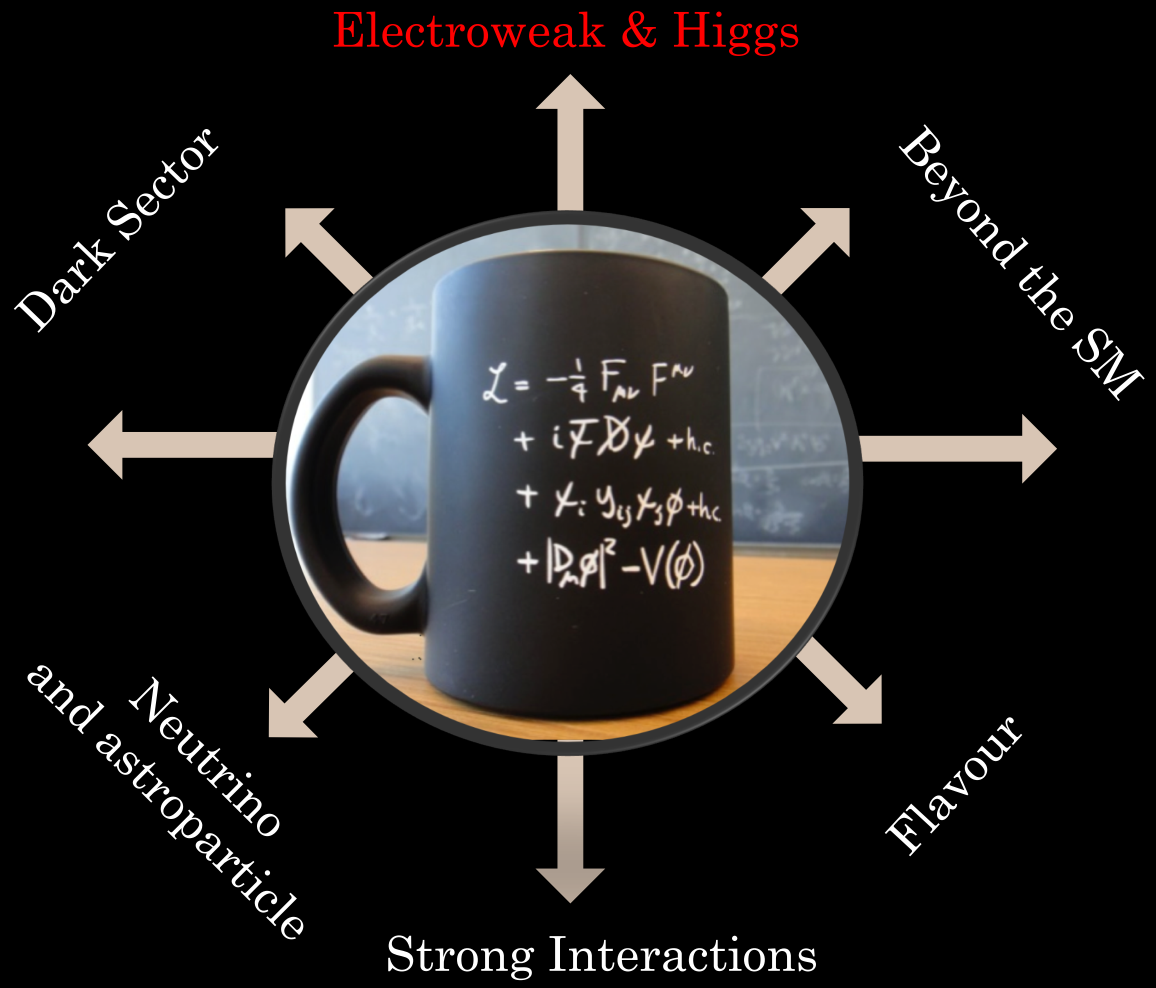
...ent for a strong and diverse, yet coherent and concerted empirical exploration

The Granada physics themes



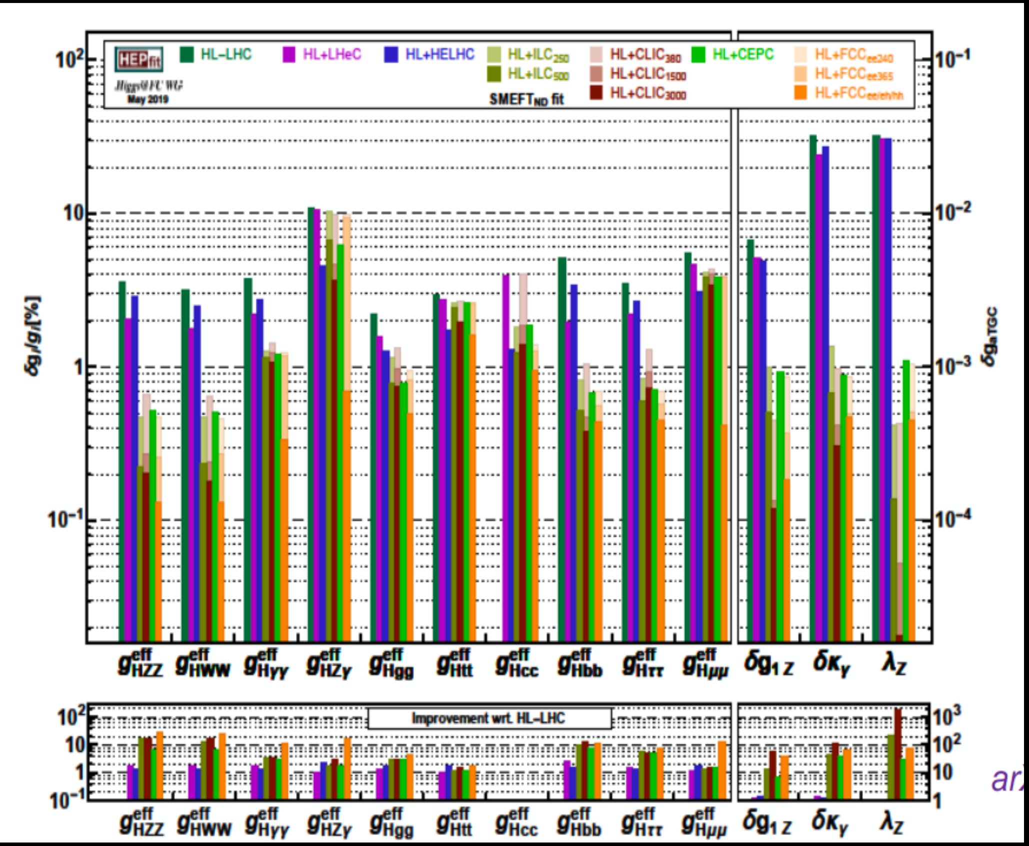
The Granada physics themes

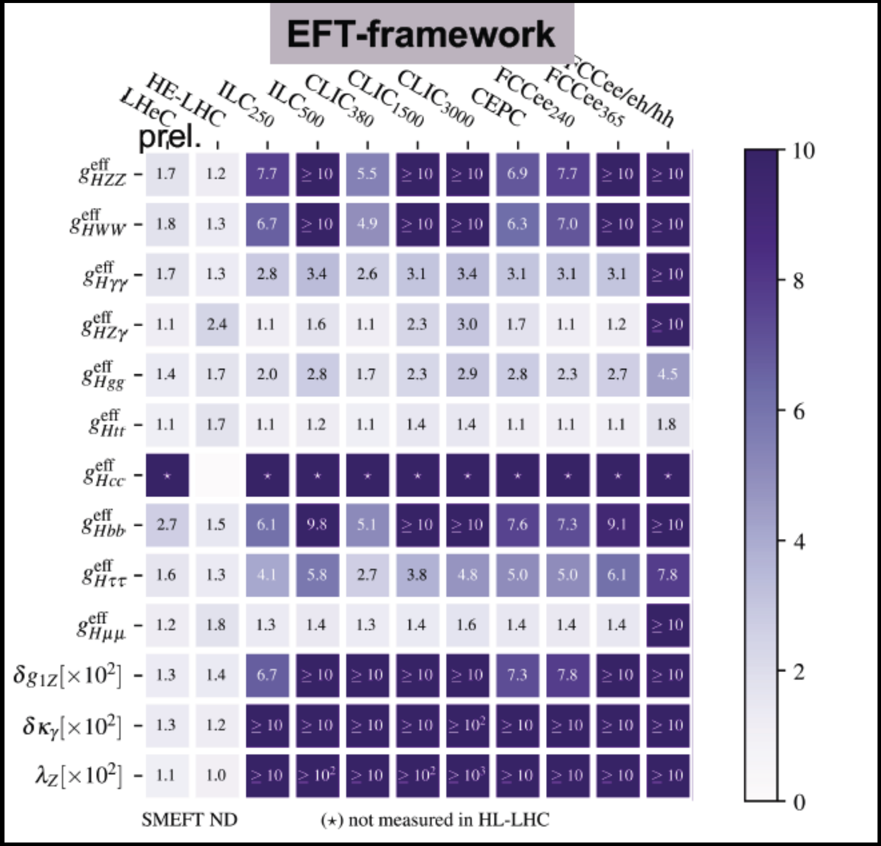
EW & Higgs



Potential to measure Higgs couplings

improvements wrt HL-LHC





Beate Heinemann @ Granada

arXiv:1905.03764 (ECFA/PPG working group: "*Higgs Boson Studies at Future Particle Colliders*")

of "largely" improved H couplings (EFT)

		Factor ≥2	Factor ≥5	Factor ≥10	Years from T_0
Initial run	CLIC380	9	6	4	7
	FCC-ee240	10	8	3	9
	CEPC	10	8	3	10
	ILC250	10	7	3	11
2nd/3rd Run ee	FCC-ee365	10	8	6	15
	CLIC1500	10	7	7	17
hh	HE-LHC	1	0	0	20
2nd/3rd Run ee	ILC500	10	8	6	22
	CLIC3000	11	7	7	28
ee,eh & hh	FCC-ee/eh/hh	12	11	10	>50

13 quantities in total

NB: number of seconds/year differs: ILC 1.6×10^7, FCC-ee & CLIC: 1.2×10^7, CEPC: 1.3×10^7

The Granada themes

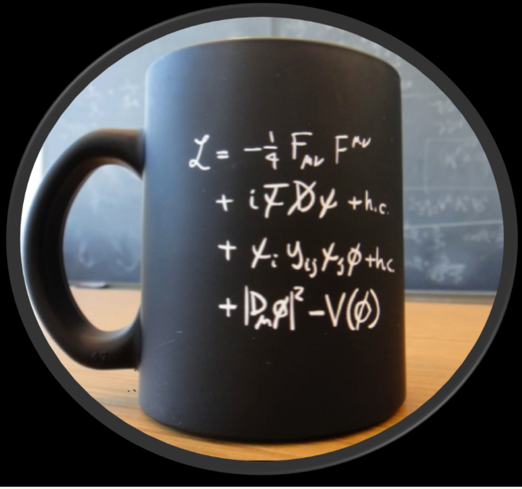
EW & Higgs

- Measuring Higgs couplings is perceived as one of the prime avenues in our search for new physics

1) With the HL-LHC one can probe many Higgs couplings to the few percent level
2) Additional to the HL-LHC sensitivity, all proposed first generation e^+e^- colliders can achieve major and comparable improvements
3) In a second stage, a higher energy e^+e^- collider or hadron collider are important to reach the ultimate sensitivity

There is new physics out there!

and it should be our main objective to discover it



The exploration of the scalar sector with colliders is only one avenue to search for new physics

some (personal) thoughts

Not written in stone, but on the collider front we might identify three eras

- the *immediate future* (2020-2040), e.g. the HL-LHC era
- the *mid-term future* (2040-2060), e.g. the Z/W/H/top-factory era
- the *long-term future* (2060-2080), e.g. the energy frontier era

	2020-2040 *HL-LHC era*	2040-2060 *Z/W/H/top-factory era*	2060-2080 *energy frontier era*
our technology	SCRF ~ 30 MV/m B ~ 11 T	SCRF ~ 50 MV/m B ~ 14 T plasma demo muon demo	SCRF ~ 70 MV/m B > 16 T (HTS?) plasma collider muon collider
other technology	AI for new physics quasi-online analysis digital imaging	quantum computing self-learning simulation	…
societal threats	eco friendly gases careers at mega-research facilities	energy consumption long-term engagement global vs sustained collaboration	human vs machine

Not writing in stone, but on the collider front we might identify three eras

- the *immediate future* (2020-2040), e.g. the HL-LHC era
- the *mid-term future* (2040-2060), e.g. the Z/W/H/top-factory era
- the *long-term future* (2060-2080), e.g. the energy frontier era

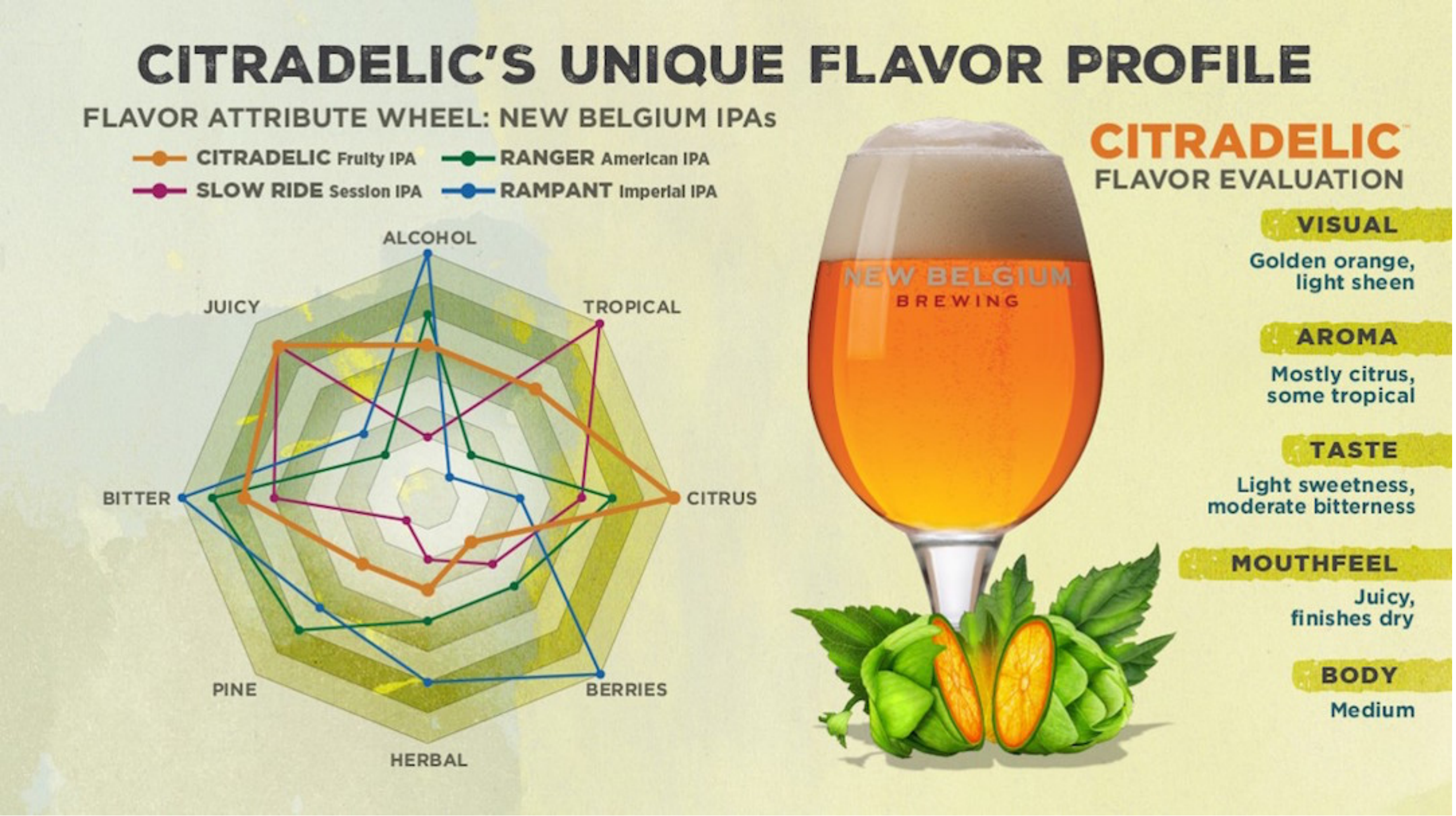
Several avenues towards the discovery of new physics

- *indirect exploration at the precision frontier*
- *breaking the Standard Model*
- *direct searches of hidden & visible sectors*
- …

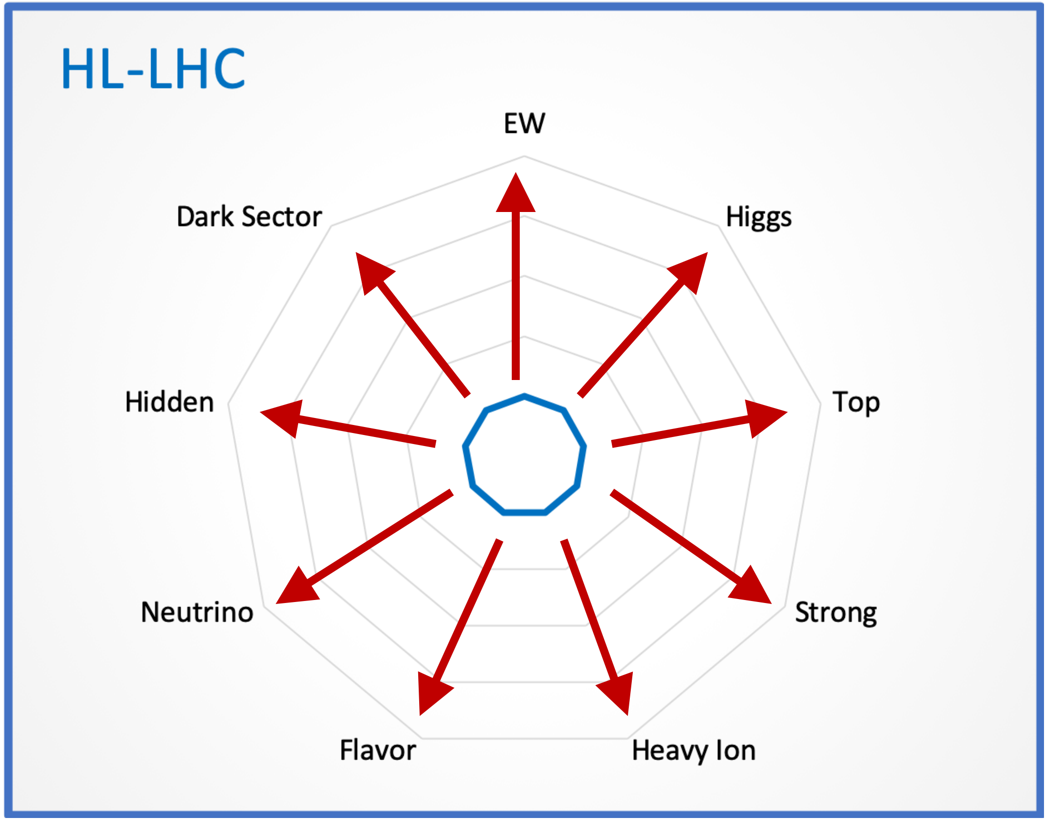
	2020-2040 *HL-LHC era*	2040-2060 *Z/W/H/top-factory era*	2060-2080 *energy frontier era*
precision frontier	H couplings to few % ν mass/mixing/nature QGP phase-transition b/c-physics	H couplings to % EW & QCD & top QGP vs Lattice QCD b/c/τ-physics	H couplings to ‰ H self-coupling to % proton structure di-boson processes
breaking the SM	next-gen K-beams proton precision e & n EDM lepton flavor (μ→e)	p EDM storage rings	rare top decays small-x physics
direct searches	SHiP / beam dump Long-Lived Signals DM vs neutrino floor axions/ALPs	eSPS for Light DM heavy neutral lepton	new high-mass part. next-gen hidden exp. low-mass DM

There is new physics to be discovered, but no guaranteed discovery path

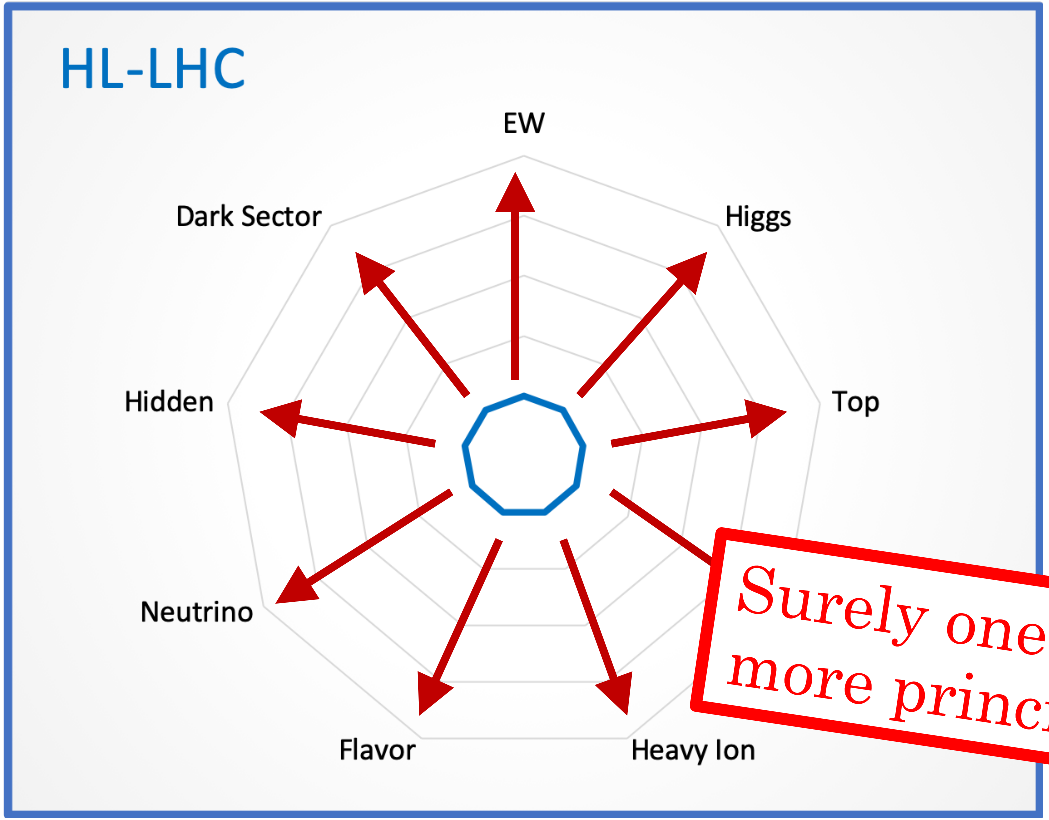
There is new physics to be discovered, but no guaranteed discovery path



If you want to discover a great taste, you will have to sample several

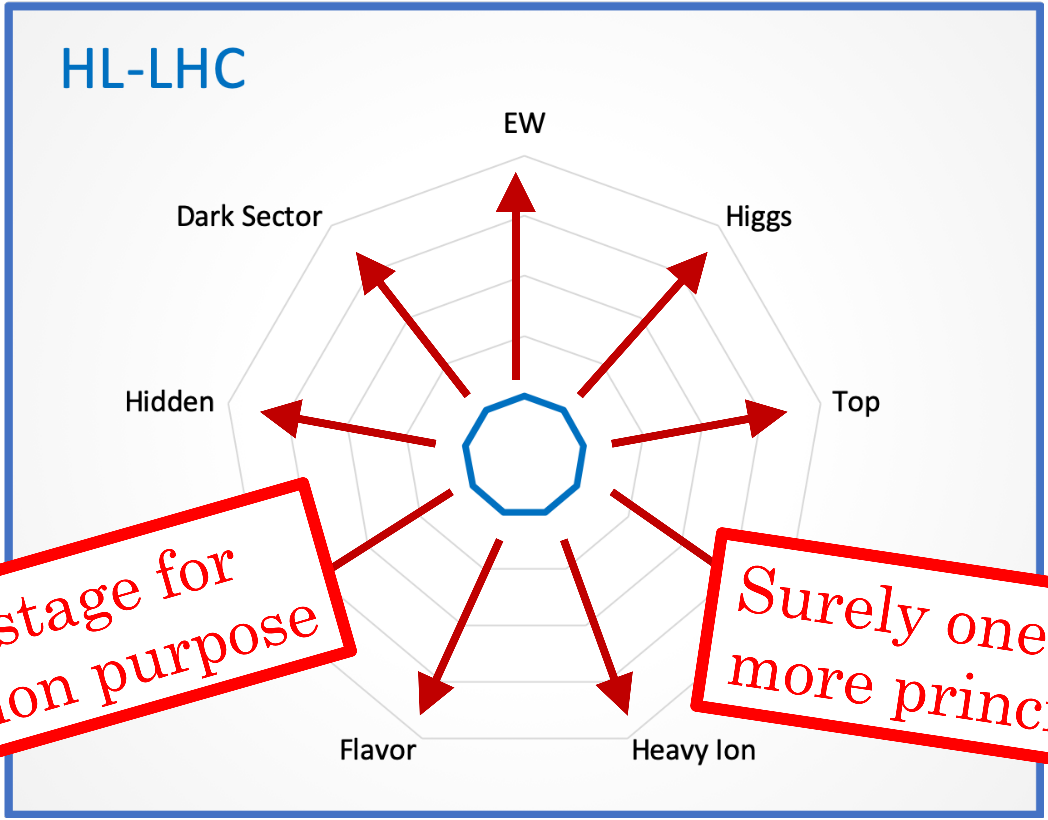


Progress relative to today’s knowledge and including the expected performance of the HL-LHC



Progress relative to today’s knowledge and including the expected performance of the HL-LHC

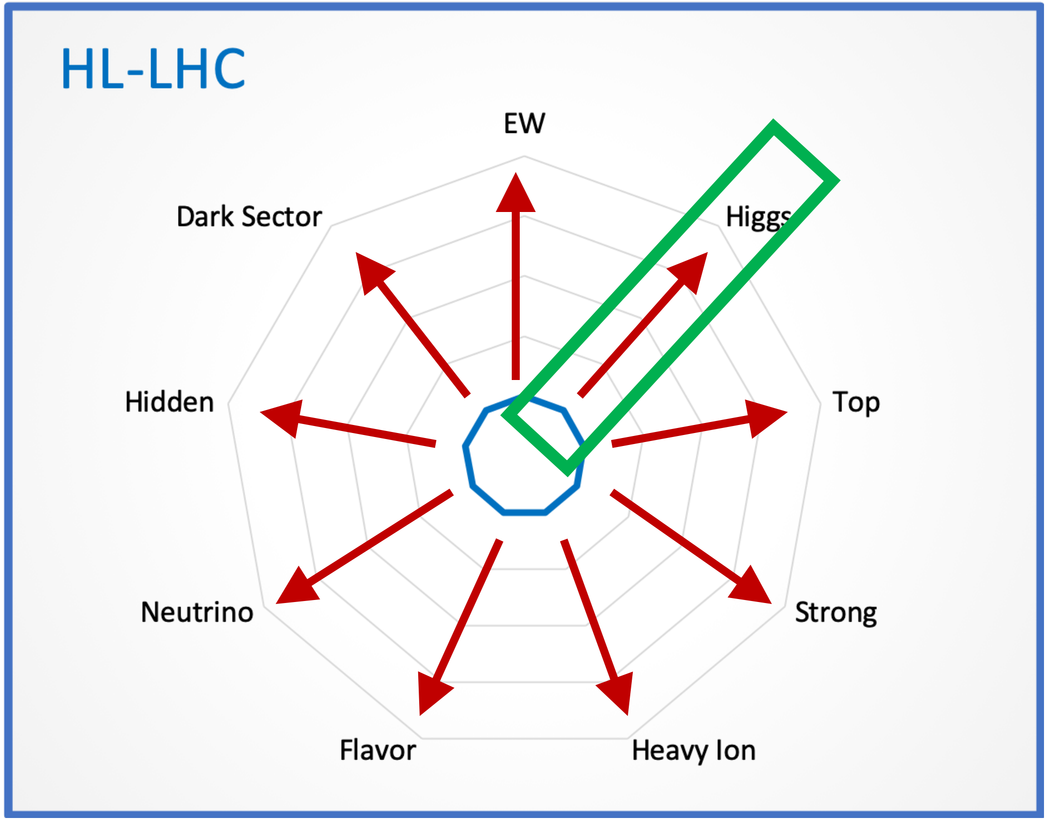
Surely one can think about more principle components



Progress relative to today's knowledge and including the expected performance of the HL-LHC

At this stage for illustration purpose

Surely one can think about more principle components



Progress relative to today's knowledge and including the expected performance of the HL-LHC

The Higgs-direction was explicitly quantified by the H@FC working group (arXiv:1905.03764)

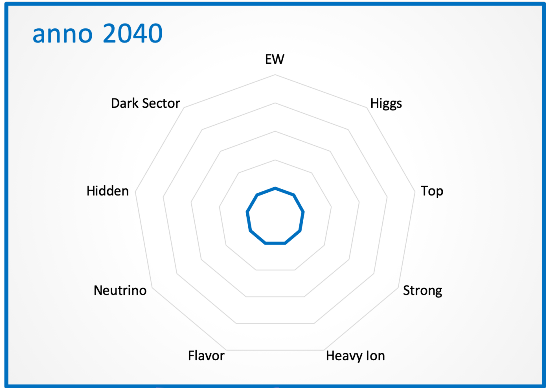
One can debate, but with a granularity of 20 years and in the absence of clear indications for new physics, the following general principle is probably wise:

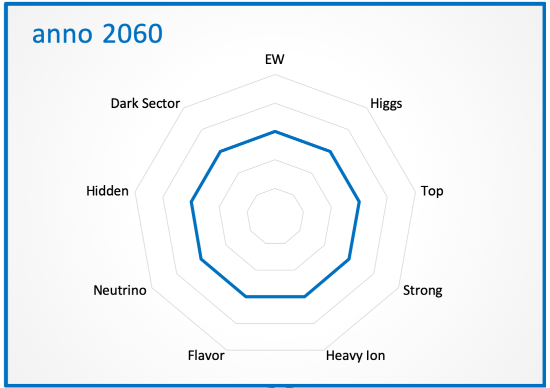
in each era you would want to take important steps forward for the largest variety of directions where new physics can be found

2020-2040
HL-LHC era

2040-2060
Z/W/H/top-factory era

2060-2080
energy frontier era





HL-LHC era

1st generation: at least include an exploration of the Higgs sector (very few major colliders)

2nd generation: the options might depend on choices made for the 1st generation (one major global collider)

Choices for 1st gen collider(s) beyond the HL-LHC have to be made without knowing the HL-LHC results & choices for the 2nd gen without knowing the results of the 1st gen experiments

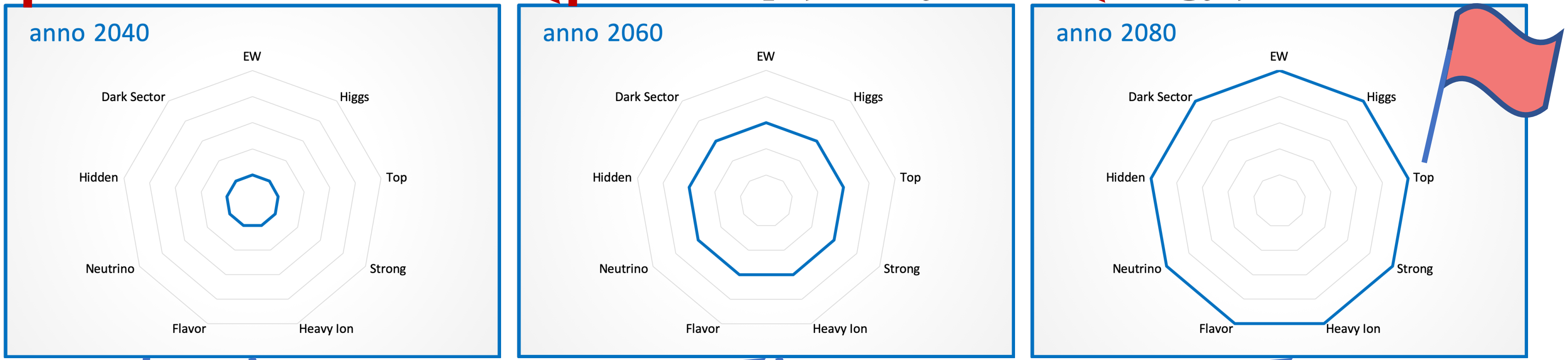
choice for 1st gen

choice for 2nd gen

2020-2040
HL-LHC era

2040-2060
Z/W/H/top-factory era

2060-2080
energy frontier era



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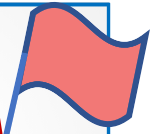
choice for 1st gen

choice f...

... era



With the input from the Physics Briefing Book, the next step is to define some overall long-term scenarios (incl options and with an eye on evolutions in the global landscape) and discuss within the European Strategy Group their coverage, feasibility and community support

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HL-LHC era

2nd generation: the options might depend on choices made for the 1st generation (one major global collider)

Some (Personal) Key Thoughts

- CERN: <u>CLIC vs FCC</u>, i.e. strategy to prepare the strongest and most concrete project proposal (administrative, technical, organizational) for a final decision by the next strategy update such that a project can be launched timely, i.e. the late 2020'ies
- Europe & CERN: verify the <u>status of ILC, CEPC, EIC, etc.</u> to include the information in the final decision potentially at the next strategy update
- Make strategic choices for the most competitive and complementary <u>non-collider programme</u> in Europe
- Strong supporting statements for <u>technology R&D</u> (e.g. towards demonstrator facilities for novel accelerator technologies in the "*energy frontier era*")
- *Confrontation between aspirations of scientists and constraints of funding bodies: challenge to entangle both in a bottom-up strategy process*