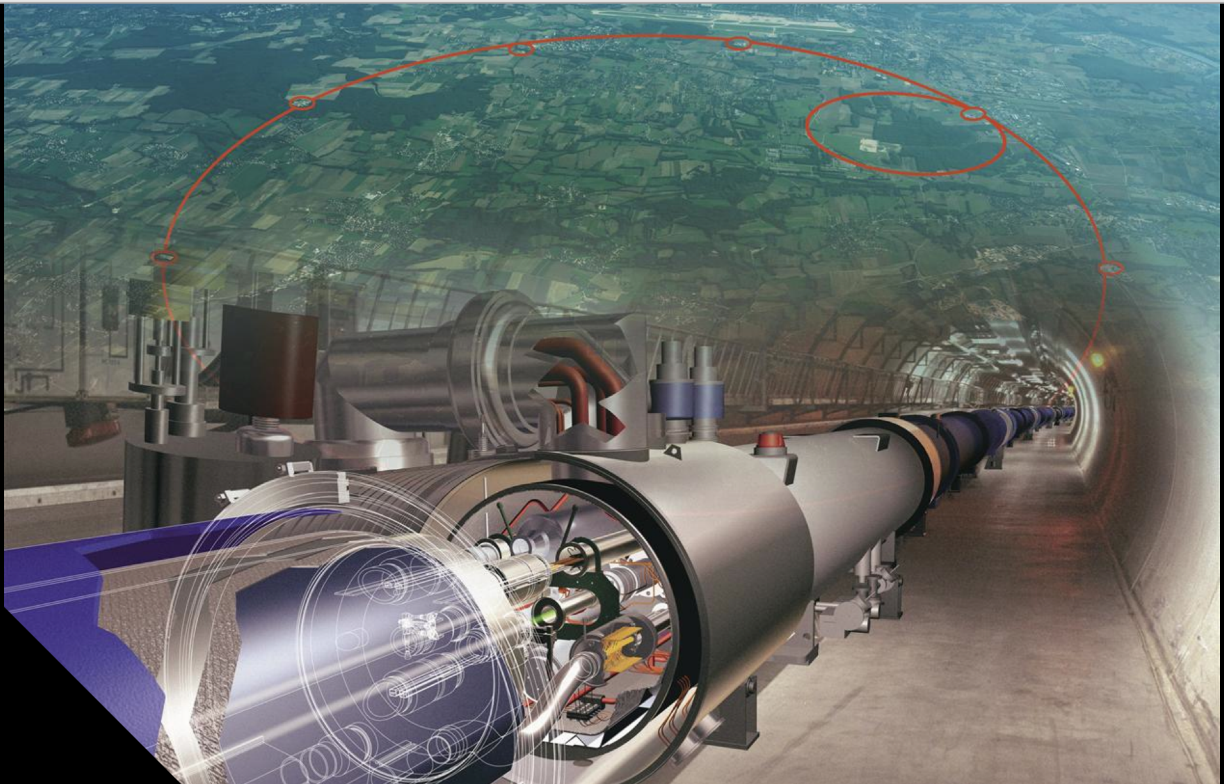
Road to an update of the European HEP Strategy

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

Gordon Research Conference
June 30 – July 5, 2019
Hong Kong

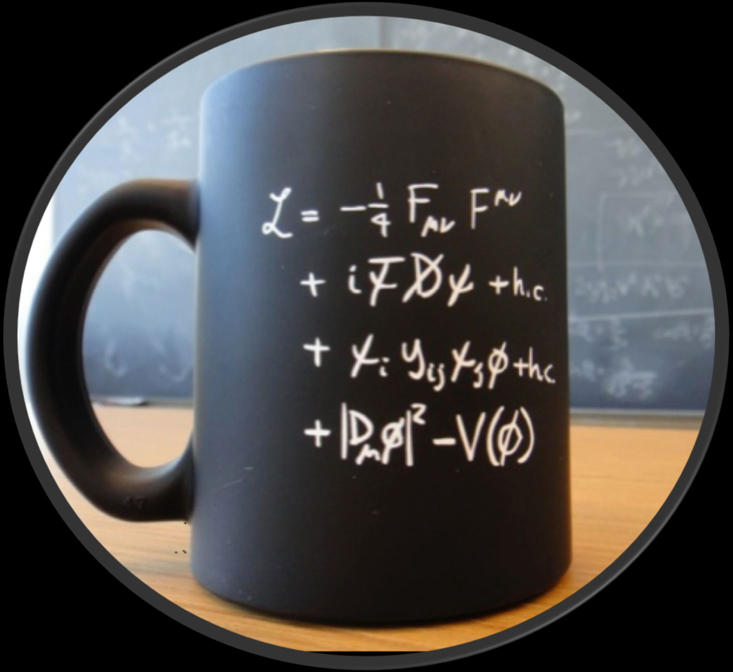


HEP@VUB BRUSSELS

VUB iihe BRUXELLES BRUSSEL

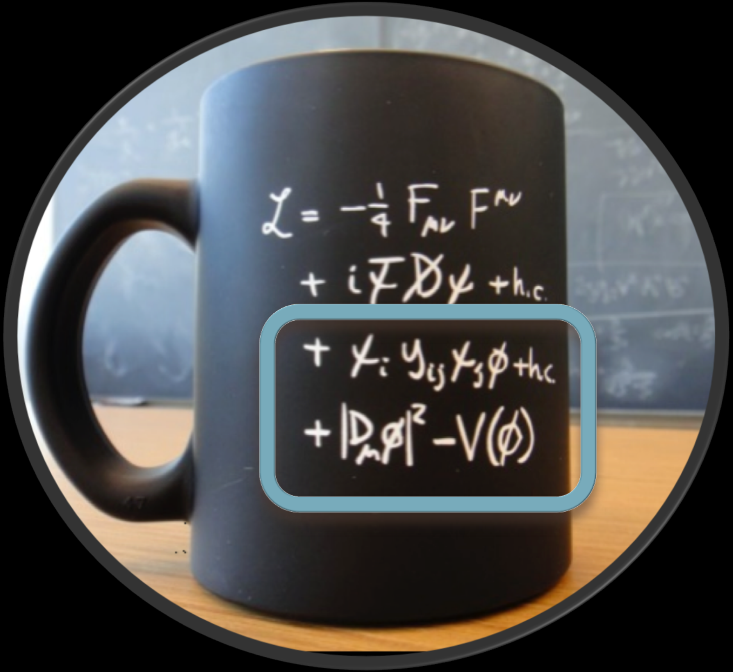
understand nature at the
largest and the smallest scales

Particle Physics today



enormous success in describing matter at the smallest scales

Particle Physics today



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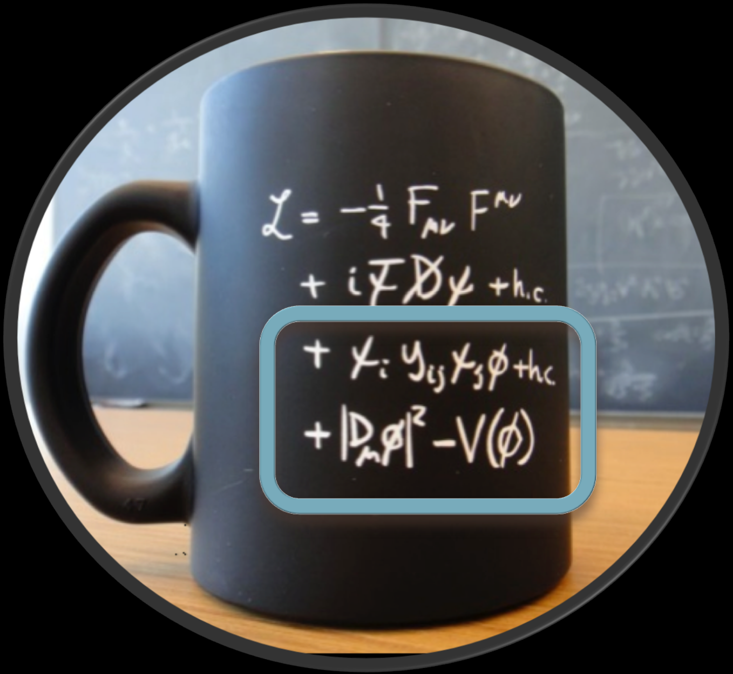
Particle Physics today



enormous success in describing matter at the smallest scales

describing $\neq$ understanding

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

Need to agree on a long-term strategy for Particle Physics

UPDATE of the European Particle Physics Strategy (2013)

TODAY

Higgs discovery (2012)

Start data taking at the LHC (2010)

European Particle Physics Strategy (2006)

Need to agree on a long-term strategy for Particle Physics

European Strategy Update

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

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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.

The European Particle Physics Strategy 2013

Other scientific activities essential to the particle physics programme

① Europe should support a diverse, vibrant theoretical physics programme, ranging from abstract to applied topics, in close collaboration with experiments and extending to neighbouring fields such as astroparticle physics and cosmology. Such support should extend also to high-performance computing and software development.

② Experiments in Europe with unique reach should be supported, as well as participation in experiments in other regions of the world. Examples: quark flavour physics, dipole moments, charged-lepton flavour violation, etc.

③ Detector R&D programmes should be supported strongly at CERN, national institutes, laboratories and universities. Infrastructure and engineering capabilities for the R&D programme and construction of large detectors, as well as infrastructures for data analysis, data preservation and distributed data-intensive computing should be maintained and further developed.

④ In the coming years, CERN should seek a closer collaboration with ApPEC on detector R&D with a view to maintaining the community's capability for unique projects in this field.

⑤ The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.

Need to agree on a long-term strategy for Particle Physics

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Start data taking HL-LHC (2026)

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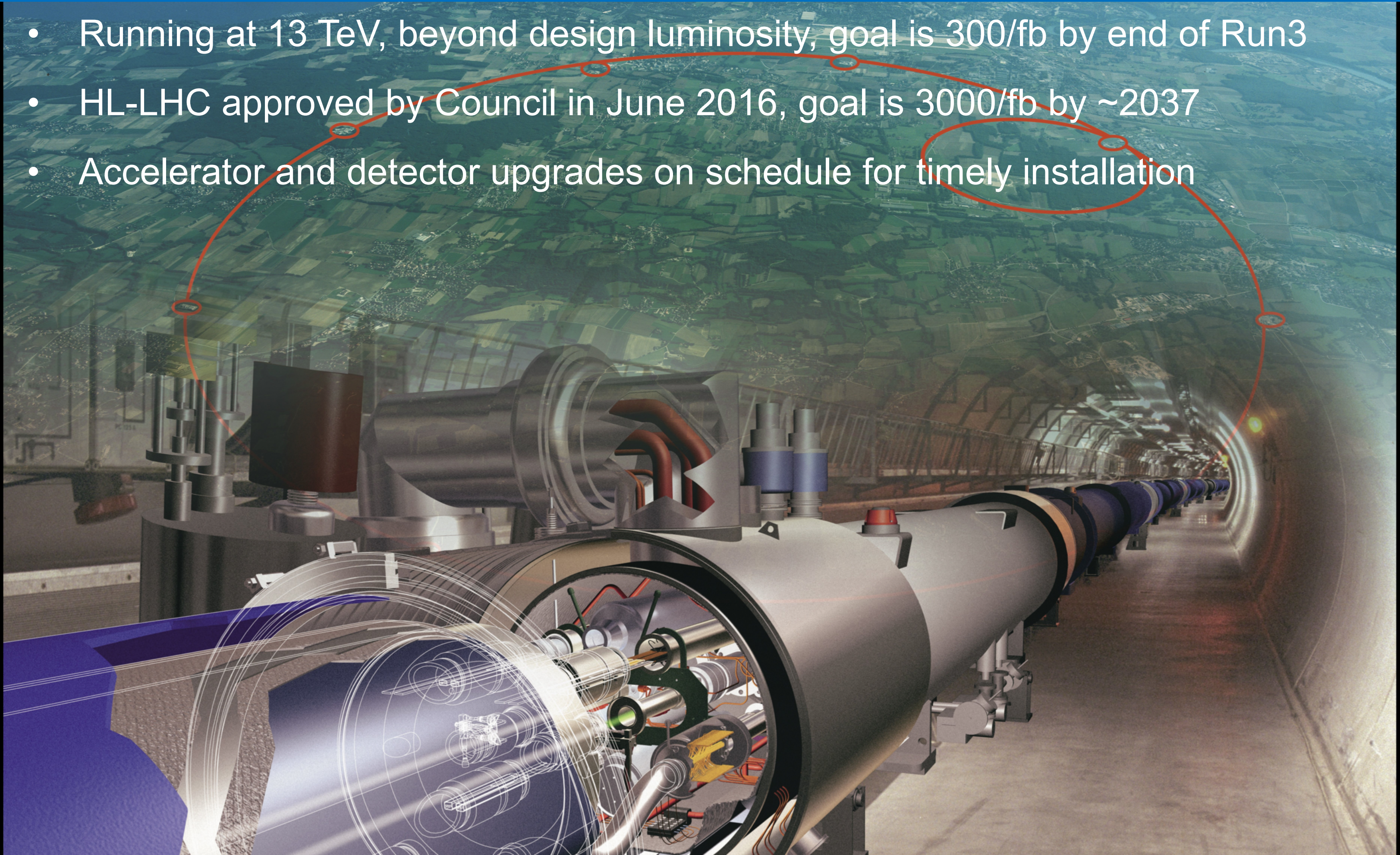
1st priority

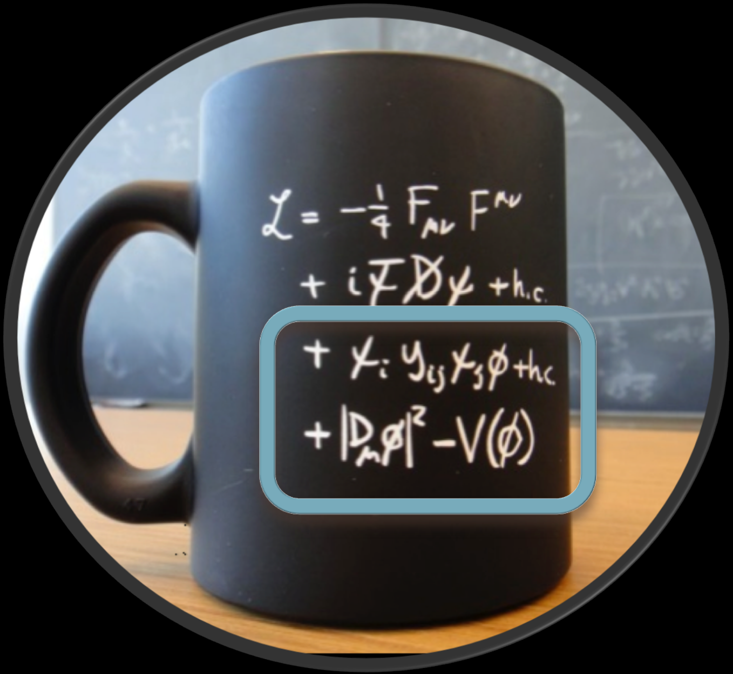
LHC and HL-LHC

The (HL-)LHC at the frontline – colliding protons & ions

- Running at 13 TeV, beyond design luminosity, goal is 300/fb by end of Run3
- HL-LHC approved by Council in June 2016, goal is 3000/fb by ~2037
- Accelerator and detector upgrades on schedule for timely installation



The impact of the LHC



connection

a MORE PRECISE and more COMPLETE description

new physics

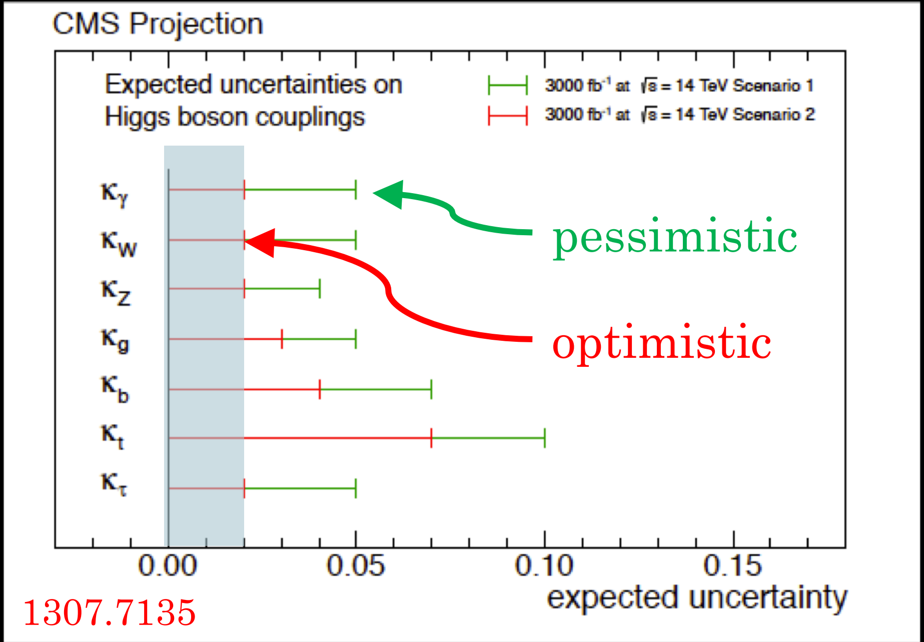
more data is needed

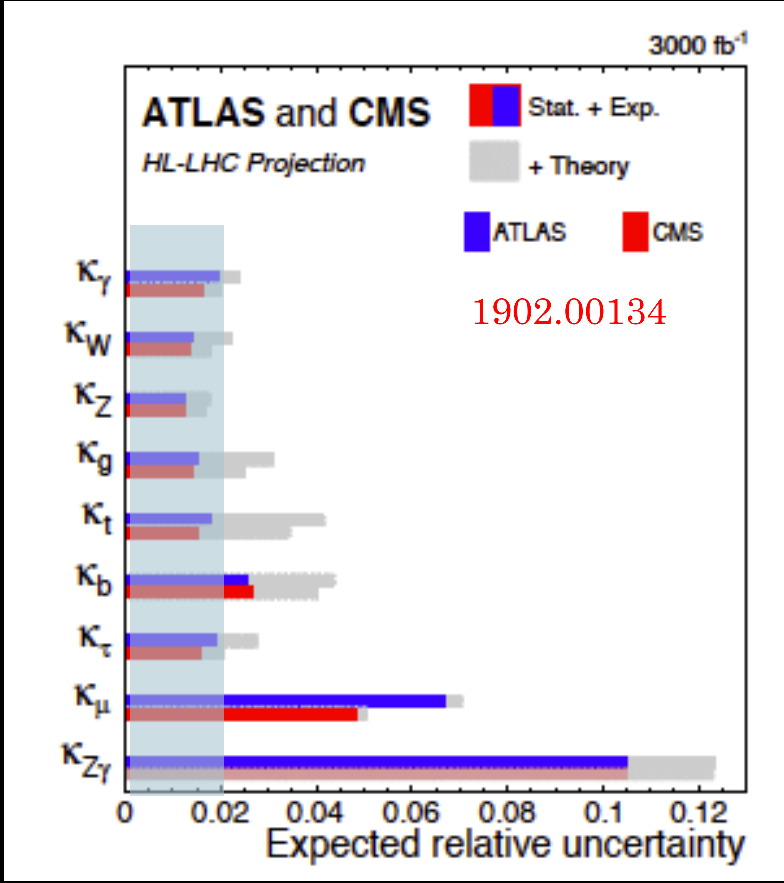
and due to our innovations in technology

more data is coming

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 Nb_3Sn (inner triplets)
New 11 T Nb_3Sn (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
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
Low-p_T heavy-flavour mesons/baryons:
Low-p_T 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 $2x10^{33}cm^{-2}s^{-1}$
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
First scintillating fibre modules arriving at CERN
Calorimeter front-end board
Muon system readout ASIC
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
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





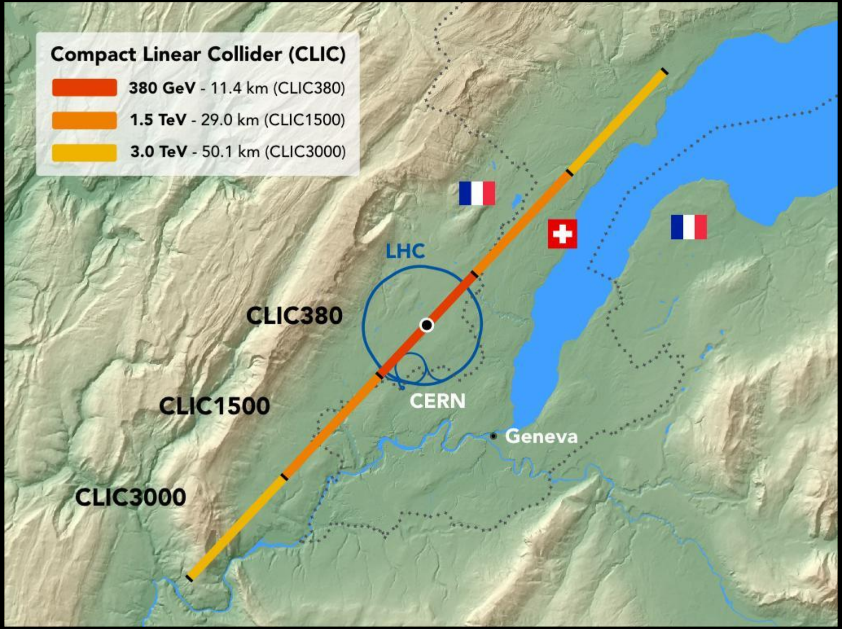
Taking into account innovative thoughts and research experience, what was optimistic in 2013 seems realistic in 2019.

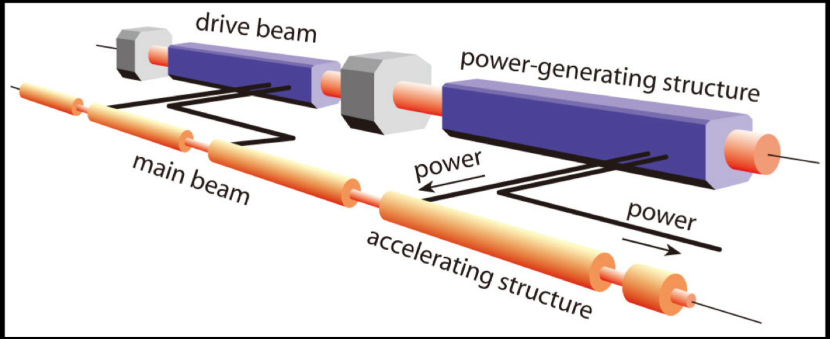
2nd priority

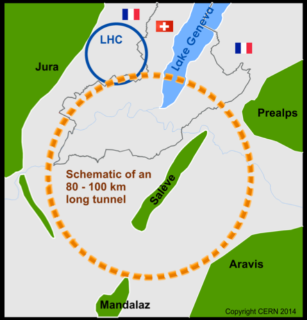
Future colliders at CERN

Concrete collider options studied at CERN

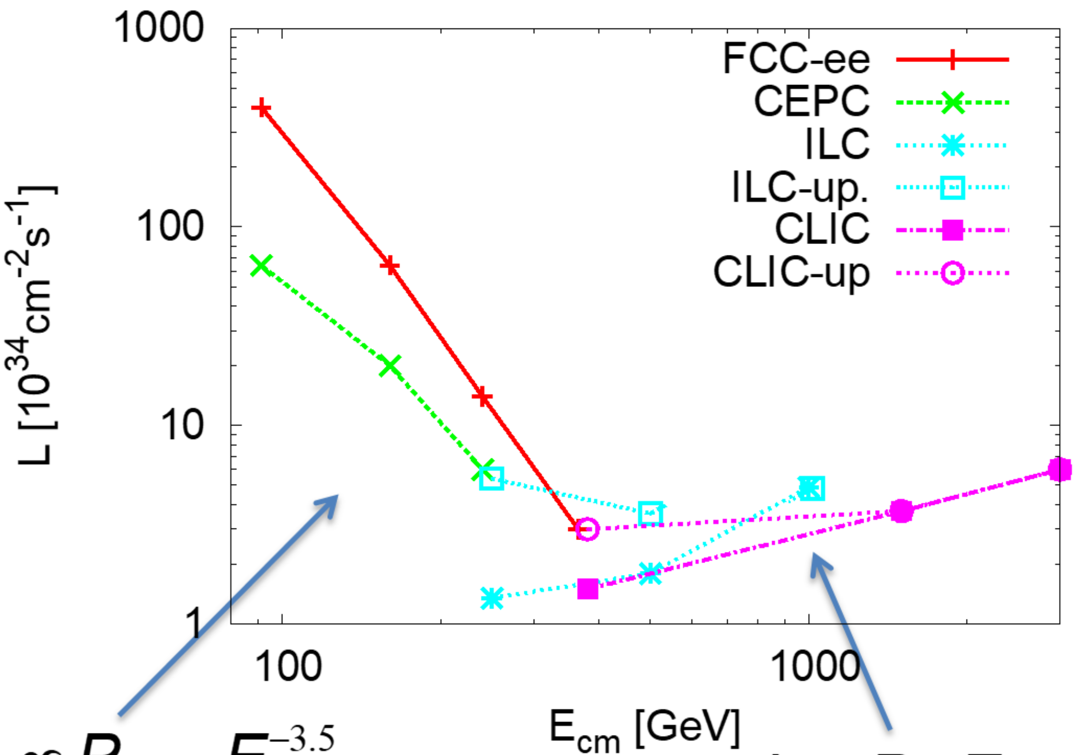
CLIC (ee), http://clic-study.web.cern.ch/





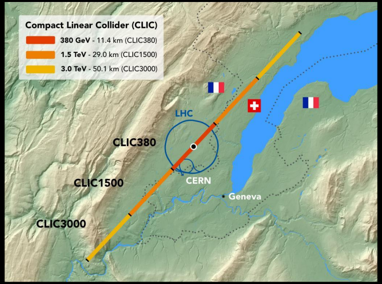


Luminosity per facility



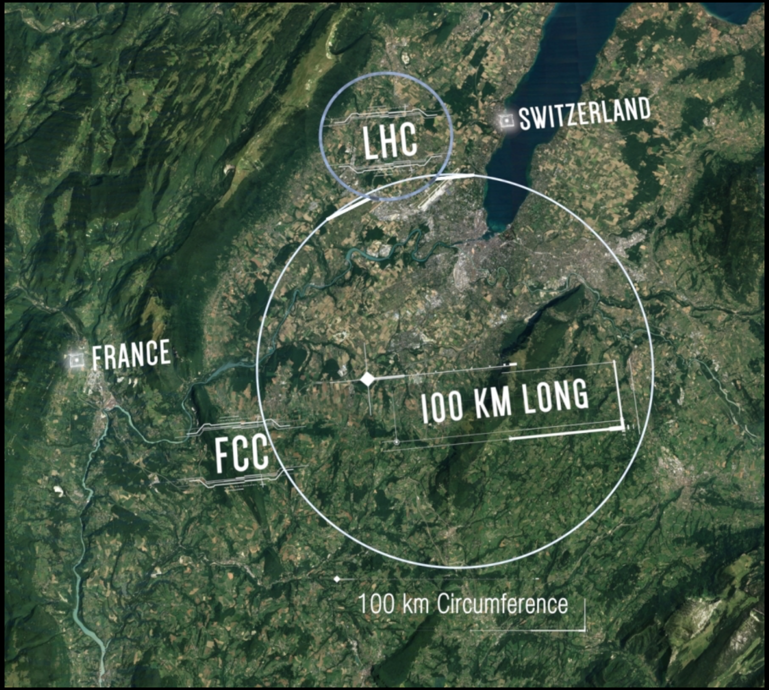
$$L \propto P_{synrad} E_{cm}^{-3.5}$$

$$L \propto P_{RF} E_{cm}$$



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
- ***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

SC Magnet R&D – *16 T magnets would allow to reach much higher pp collision energies*

FRESCA2 @ CERN

EuCARD²

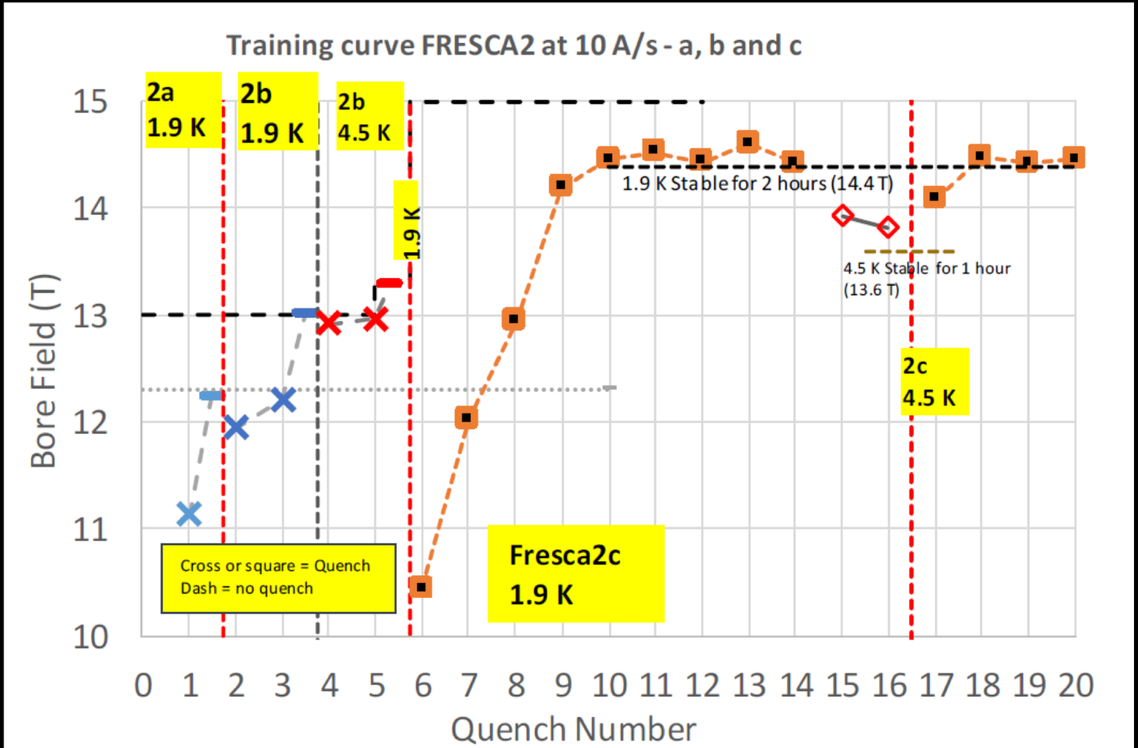
Test new superconductive cables (Nb_3Sn)

Dipole magnet
1.5 m long, 1 m diameter, 10 cm aperture

Nominal 13 T design, with an ultimate goal of 15 T, and reached 14.6 T (April 2018), a record for a magnet with a “free” aperture, and with only few quenches

SC Magnet R&D – *16 T magnets would allow to reach much higher pp collision energies*

FRESCA2 @ CERN



F. Toral @ Plenary ECFA meeting Nov 2018

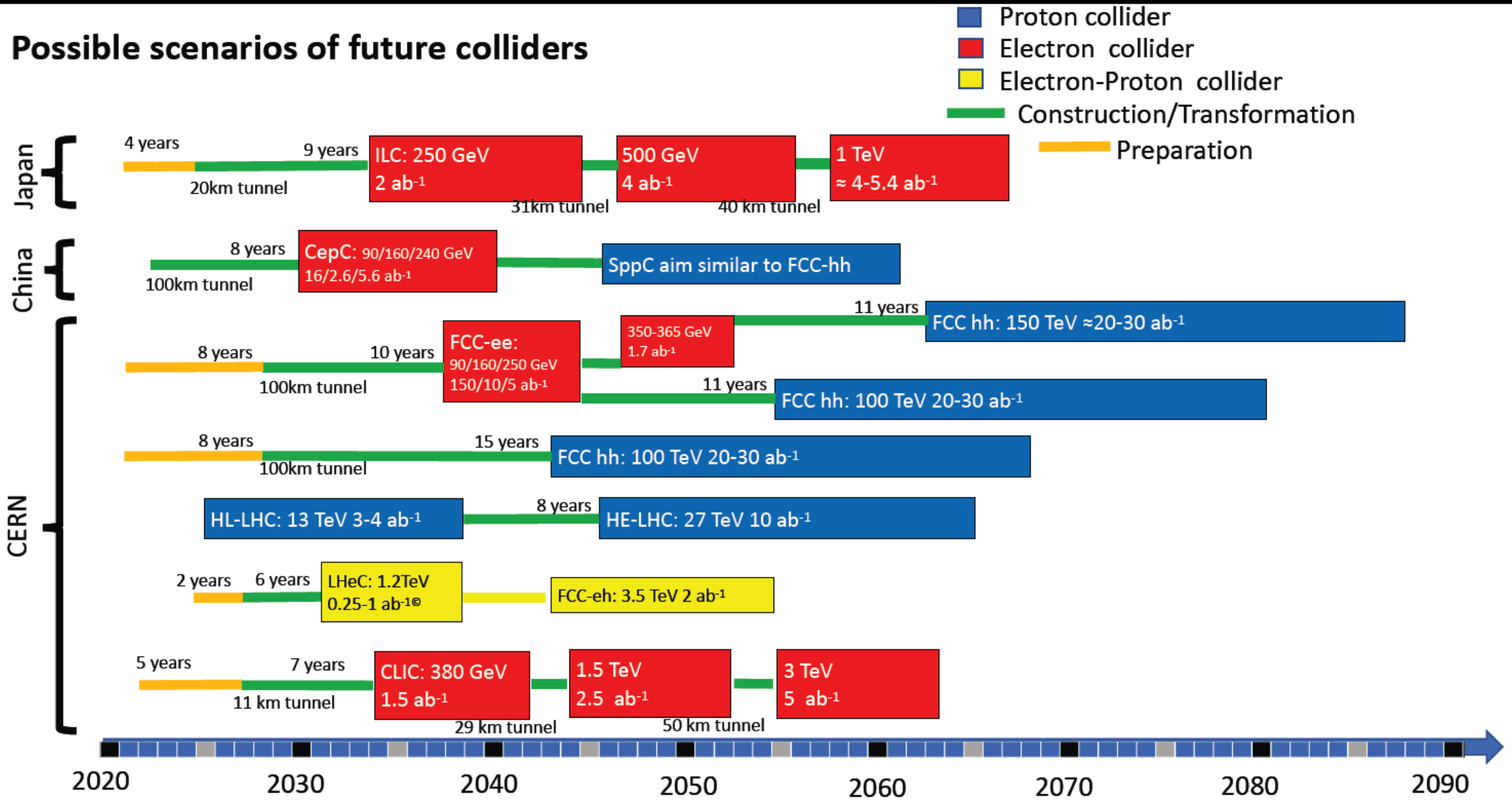
Timelines

Akira Yamamoto
@ Granada

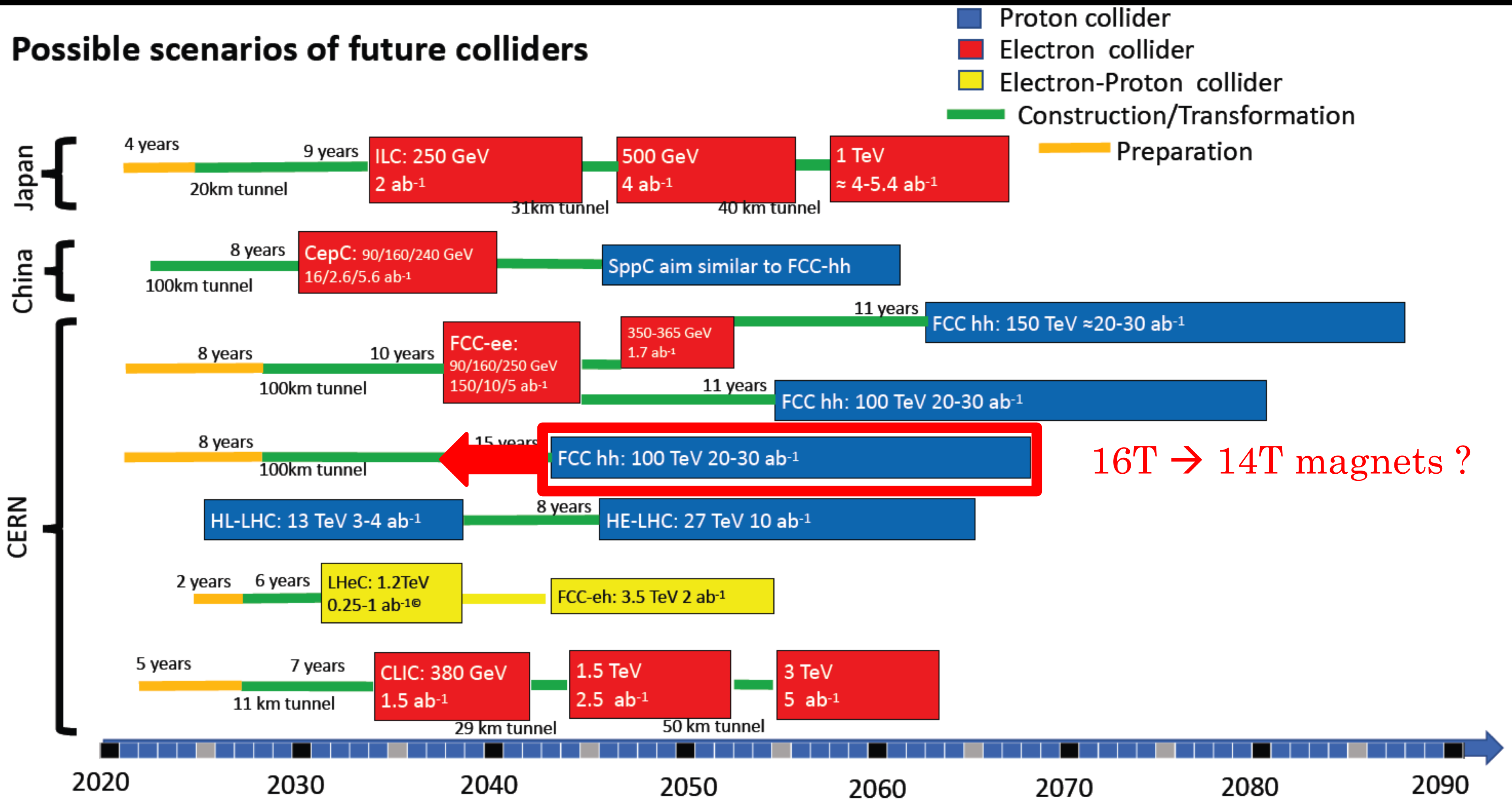
Personal View on Relative Timelines

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	

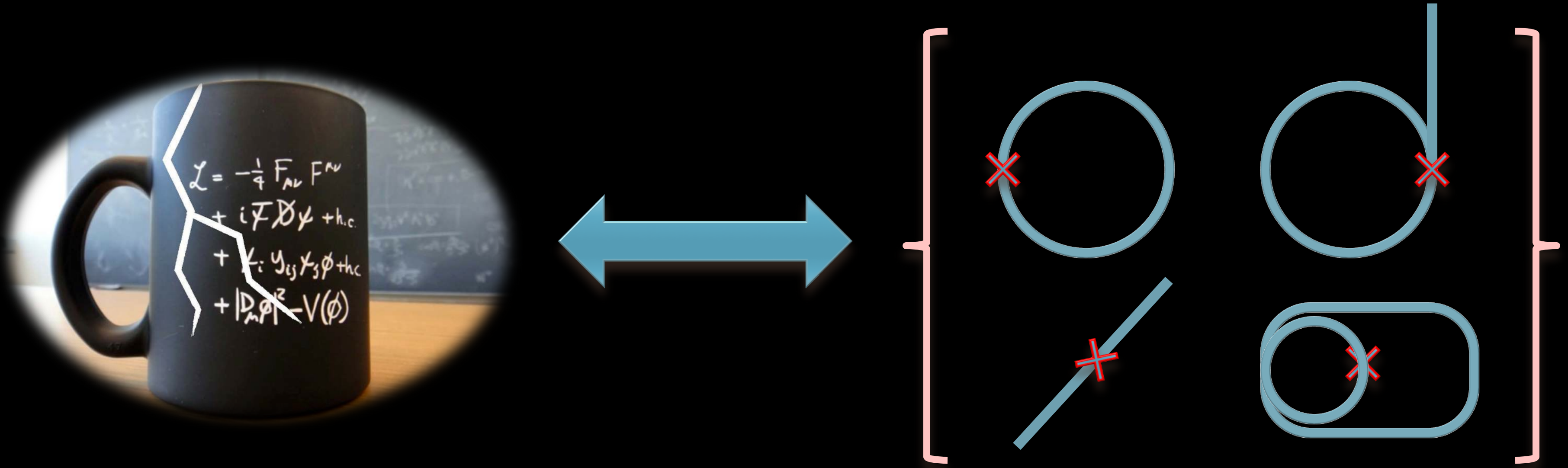
Possible scenarios of future colliders



Possible scenarios of future colliders



If non-collider experiments would provide hints where to look for new physics, it would be interesting if we can address these with current and future colliders



<u>In general</u>: explore the synergies of the physics potential of non-collider and collider experiments

Need to agree on a long-term strategy for Particle Physics

European Strategy Update

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

UPDATE of the European Particle Physics Strategy (2013)

Future

Start data taking HL-LHC (2026)

TODAY

Higgs discovery (2012)

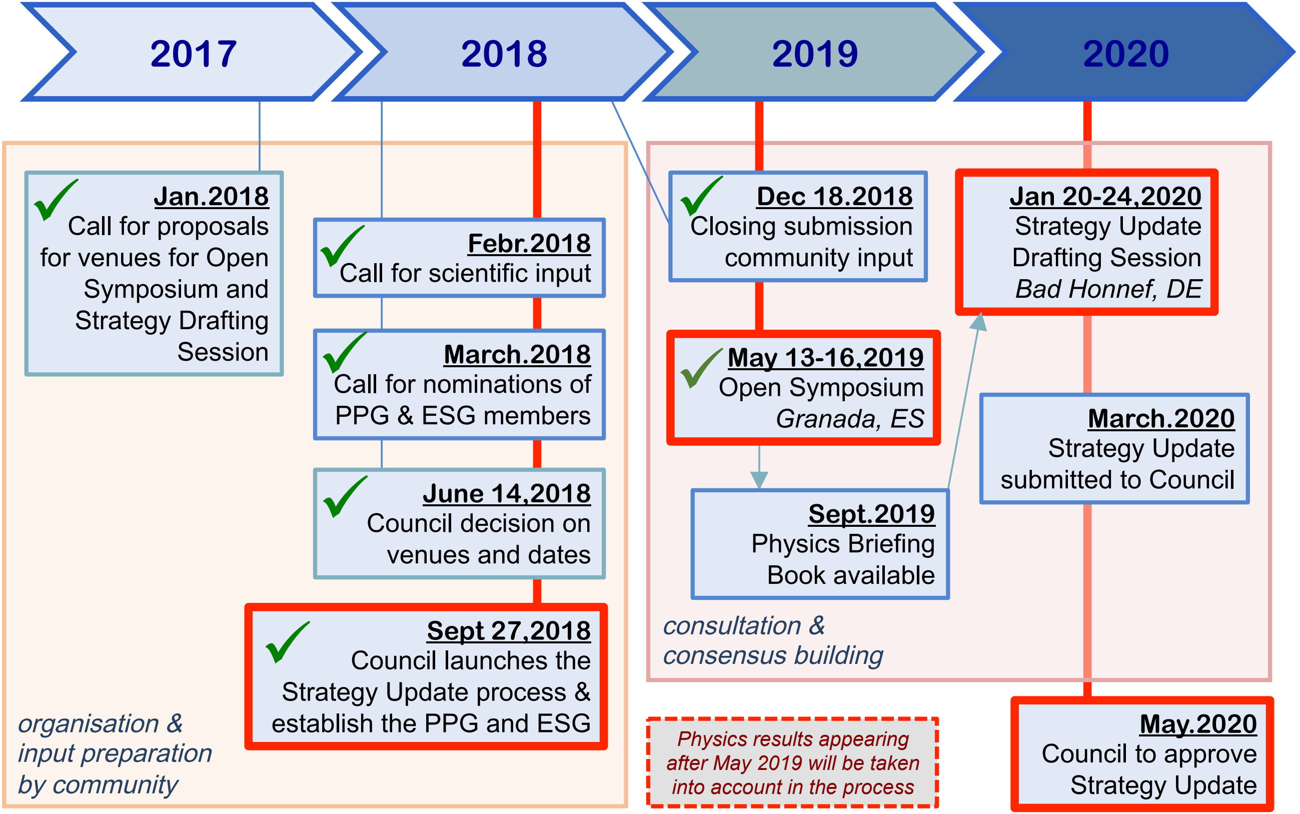
Start data taking at the LHC (2010)

UPDATE of the European Particle Physics Strategy (2020)
https://europeanstrategy.cern

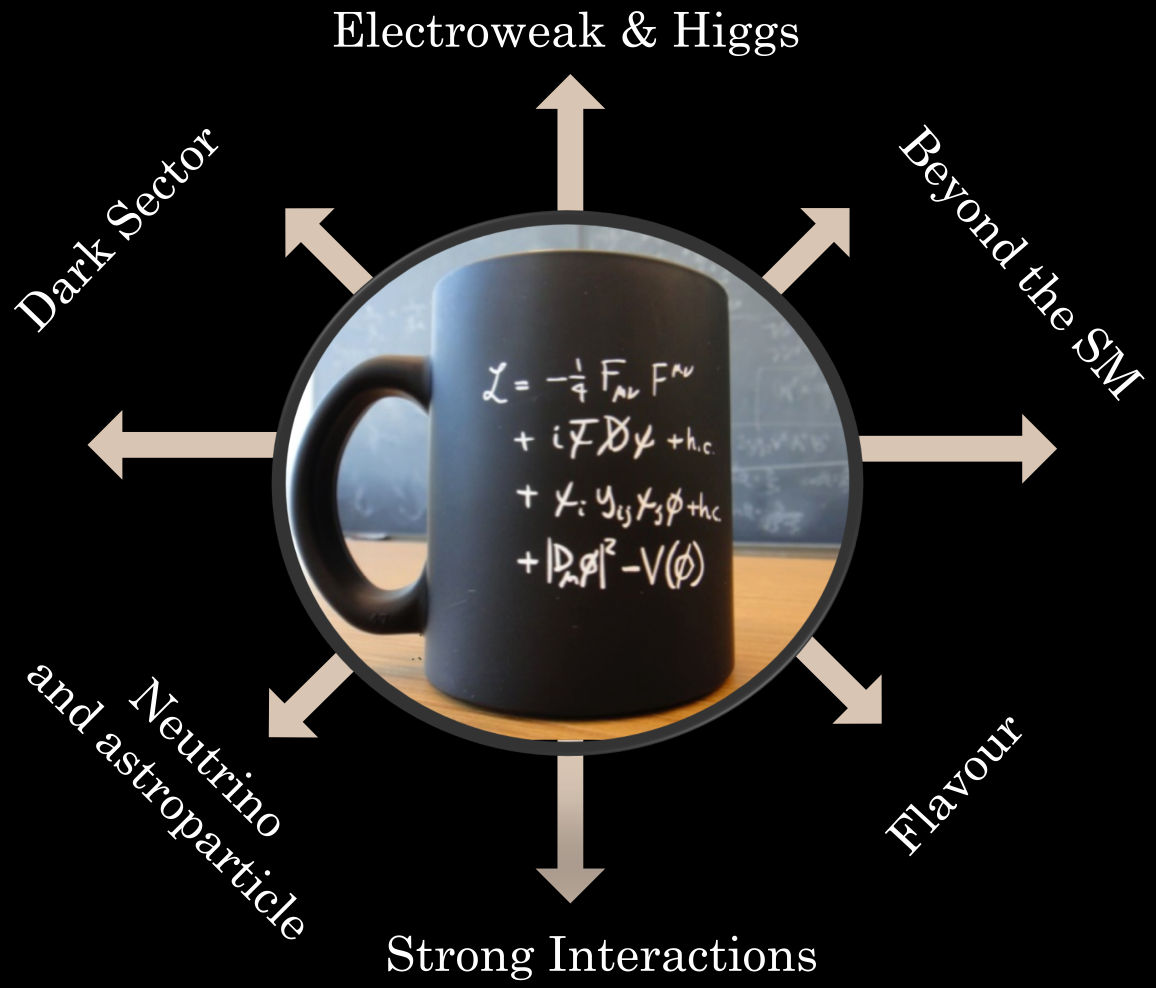
European Particle Physics Strategy (2006)

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

Open Symposium
Towards updating the European Strategy for Particle Physics
May 13-16, 2019, Granada, Spain
https://cafpe.ugr.es/eppsu2019/

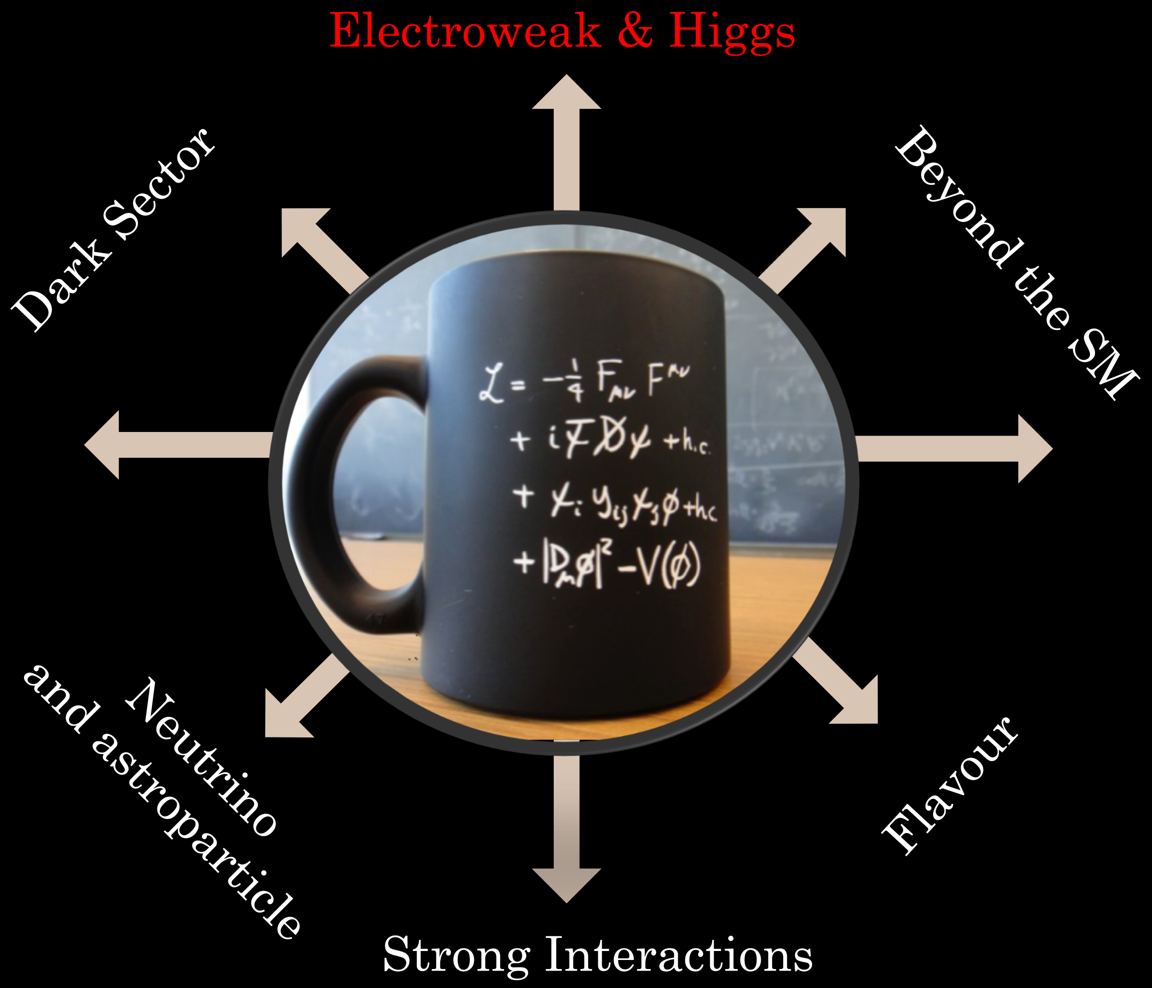

2017
2018
2019
2020
Jan.2018
Call for proposals for venues for Open Symposium and Strategy Drafting Session
Febr.2018
Call for scientific input
March.2018
Call for nominations of PPG & ESG members
June 14,2018
Council decision on venues and dates
Sept 27,2018
Council launches the Strategy Update process & 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
consultation & consensus building
Physics results appearing after May 2019 will be taken into account in the process
Jan 20-24,2020
Strategy Update Drafting Session
Bad Honnef, DE
March.2020
Strategy Update submitted to Council
May.2020
Council to approve Strategy Update

The Granada themes



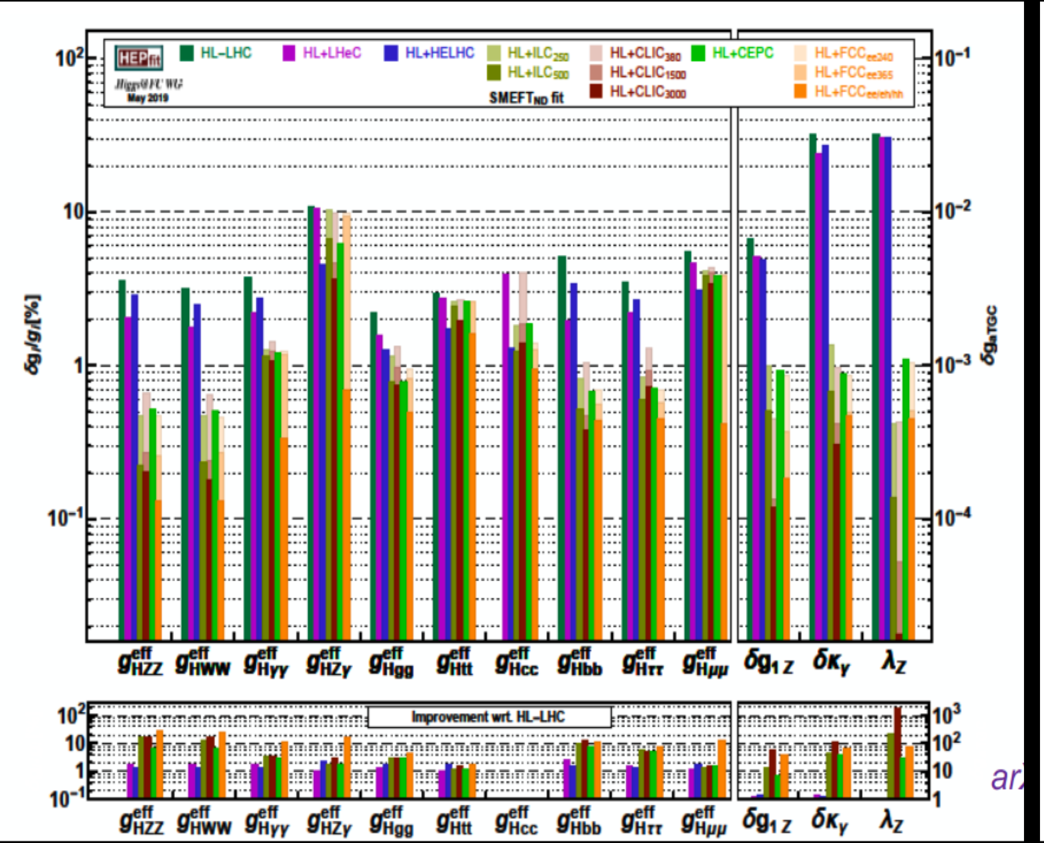
The Granada themes

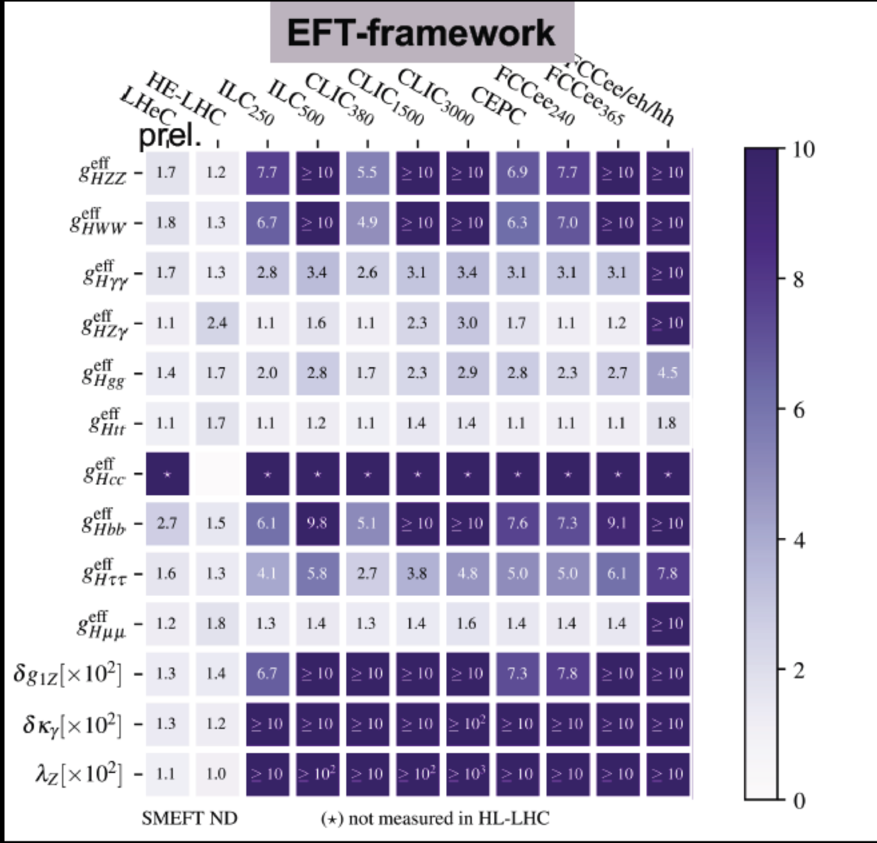
EW & Higgs



Potential to measure Higgs couplings

improvements wrt HL-LHC





arXiv:1905.03764

of "largely" improved H couplings (EFT)

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

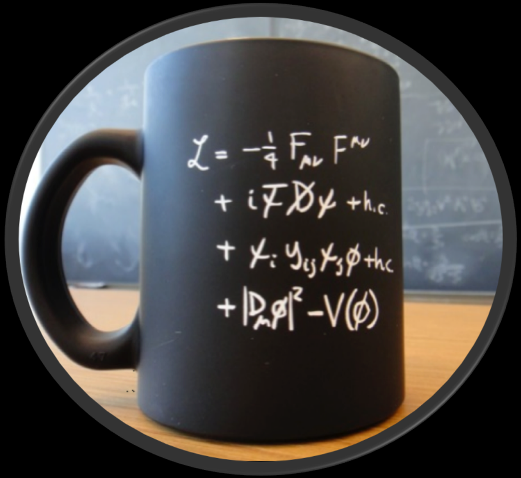
The Granada themes

EW & Higgs

- Measuring Higgs couplings is perceived as one of the prime avenues in our search for new physics
- With the HL-LHC one can probe many Higgs couplings to the few percent level
- Additional to the HL-LHC sensitivity, all proposed first generation e^+e^- colliders can achieve major and comparable improvements
- 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
is only one avenue to search for it

some personal thoughts

Open for discussion, 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

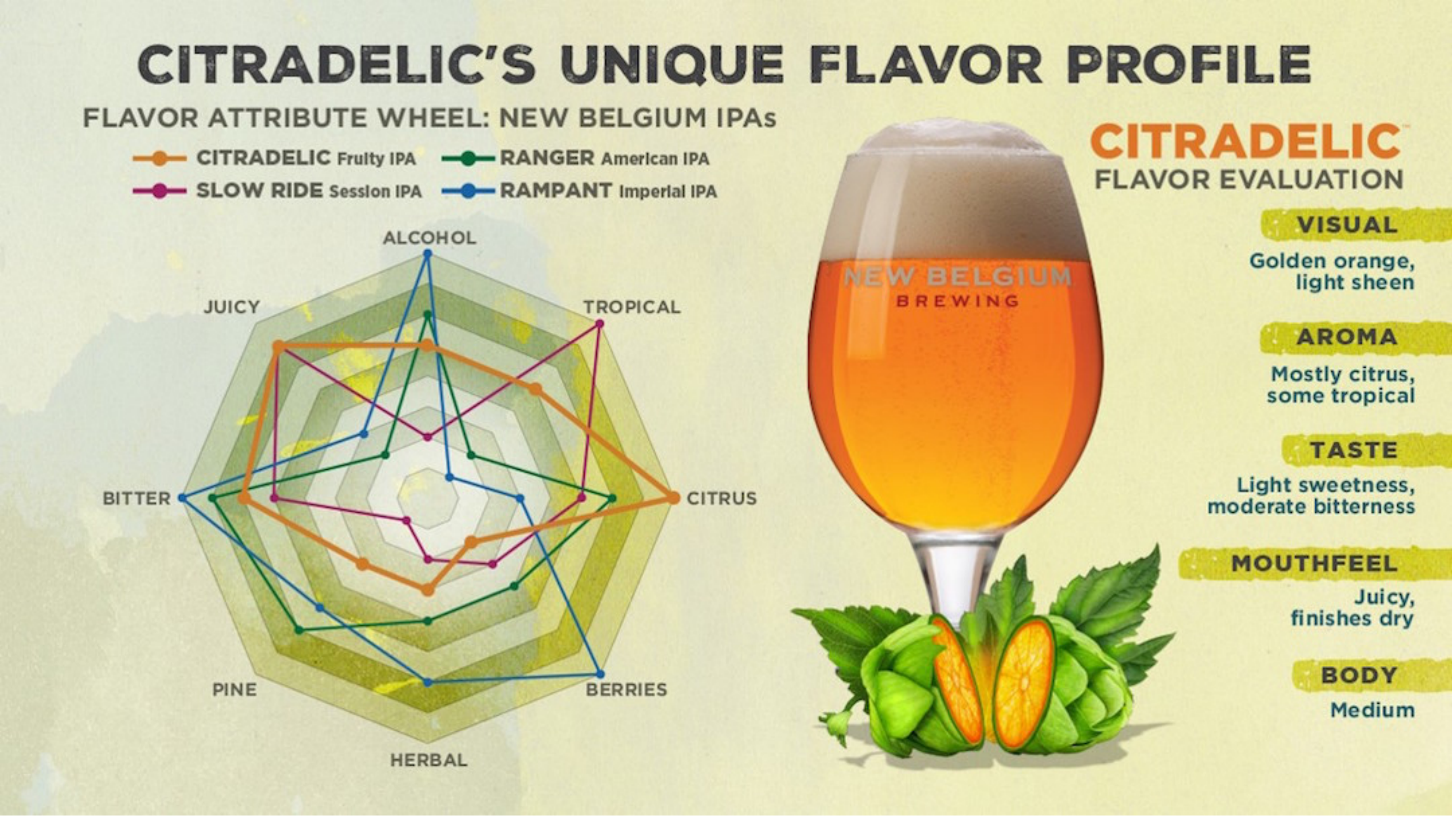
Several avenues towards the discovery of new physics

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

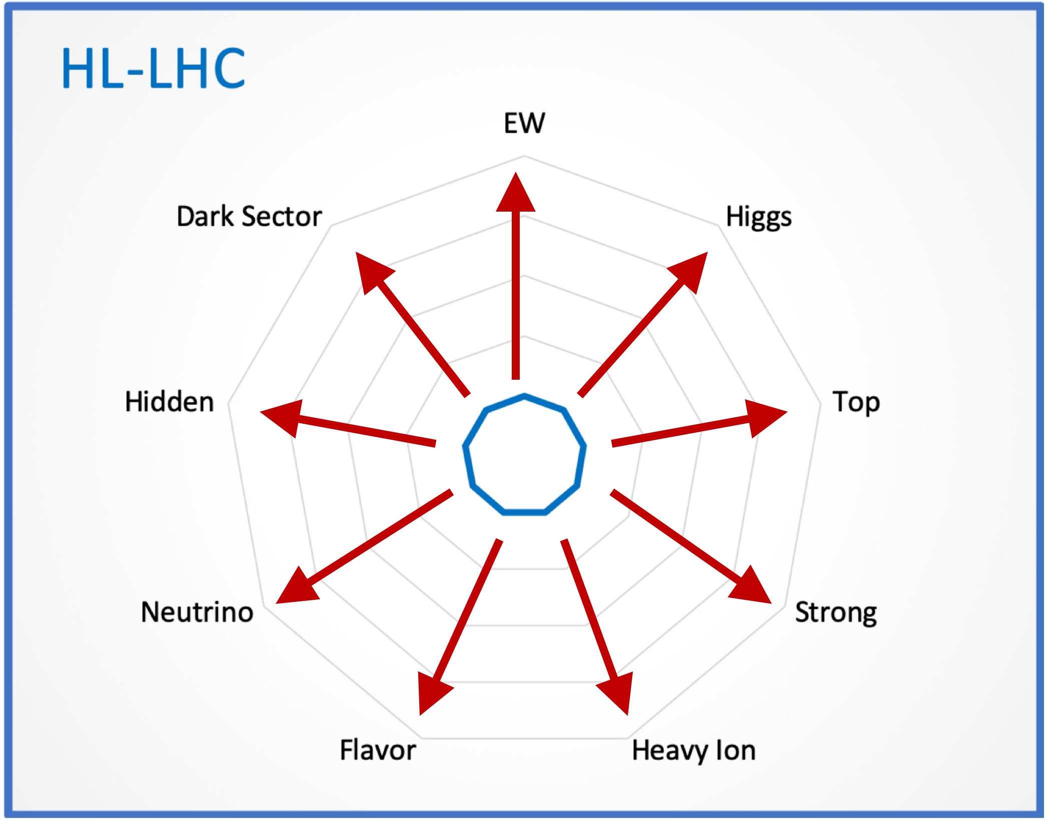
	2020-2040 *HL-LHC era*	2040-2060 *Z/W/H/top-factory era*	2060-2080 *energy frontier era*
precision frontier	H couplings to few % ν mass/mixing/nature QGP phase-transition b/c-physics	H couplings to % EW & QCD & top QGP vs Lattice QCD b/c/τ-physics	H couplings to ‰ H self-coupling to % proton structure 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

but there is no guaranteed discovery path

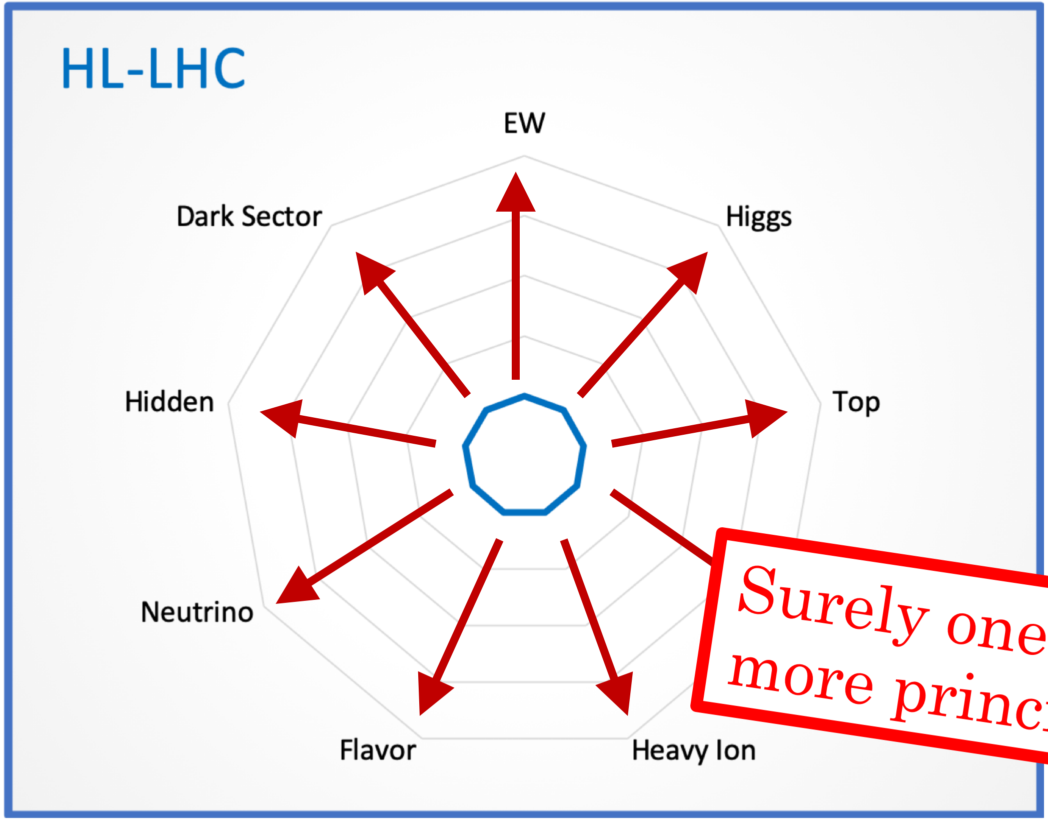
There is new physics to be discovered, but no guaranteed discovery path



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

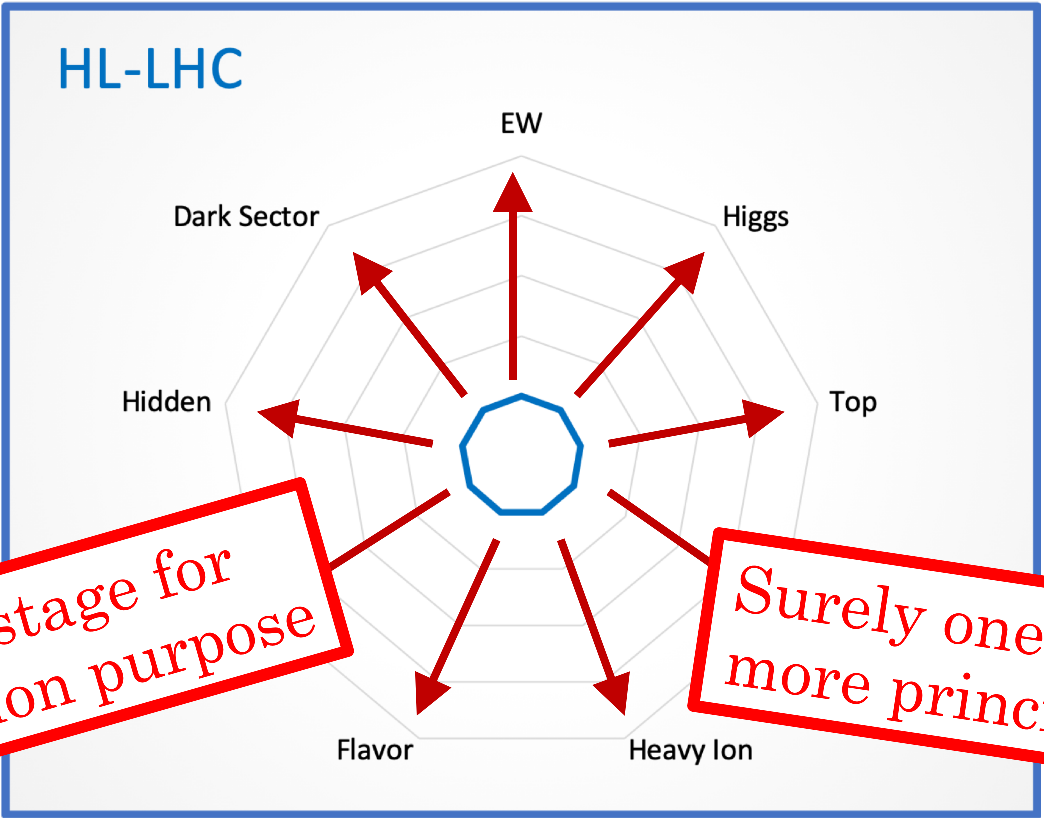


Progress relative to today’s knowledge and including the expected performance of the HL-LHC



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

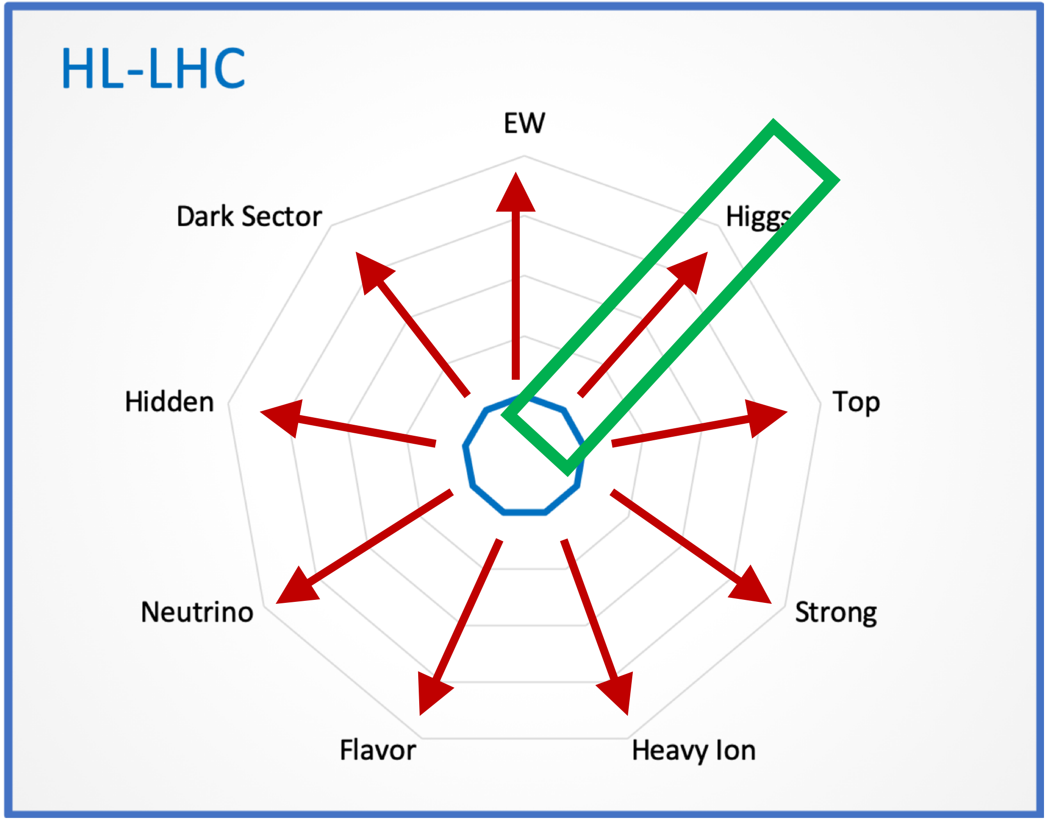
Surely one can think about more principle components



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*

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

"*Don't leave flavor physics to only flavor physicists*"

Riccardo Rattazzi
Kandersteg, July 2, 2019

2020-2040

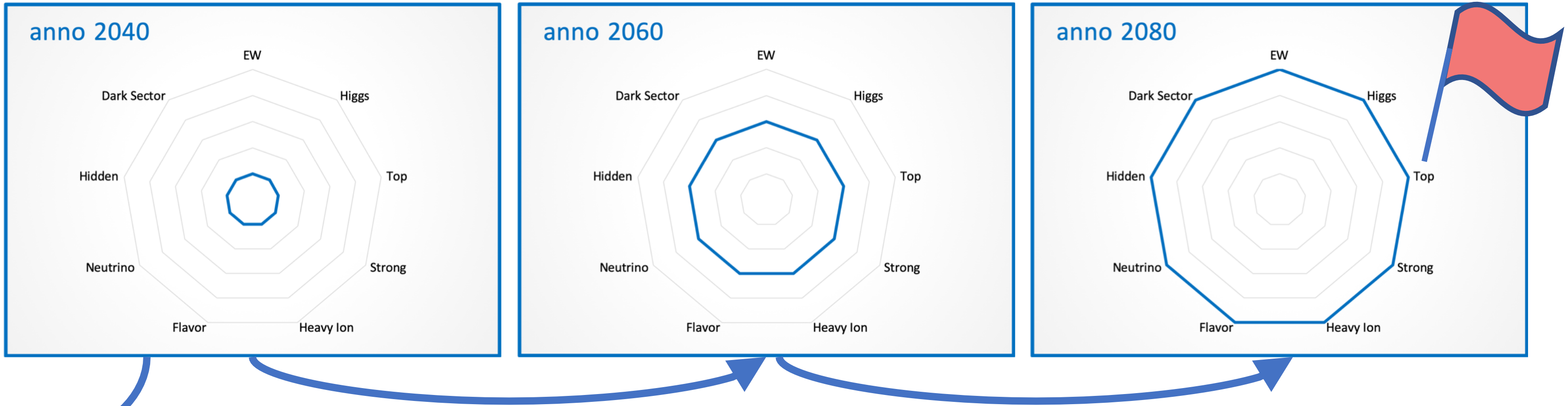
HL-LHC era

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

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)

Next steps in the process

define and investigate concrete scenarios taking into account all aspects, e.g. scientific, technological, global, financial, societal, …

The ESG (European Strategy Group) created working groups to reflect on the following topics:

- social and career aspects for the next generation,
- organizational structure for European participation in global projects,
- relations with external bodies and fields of physics,
- knowledge and technology transfer,
- outreach, education and communication,
- sustainability and environmental impact

Thank you for your attention

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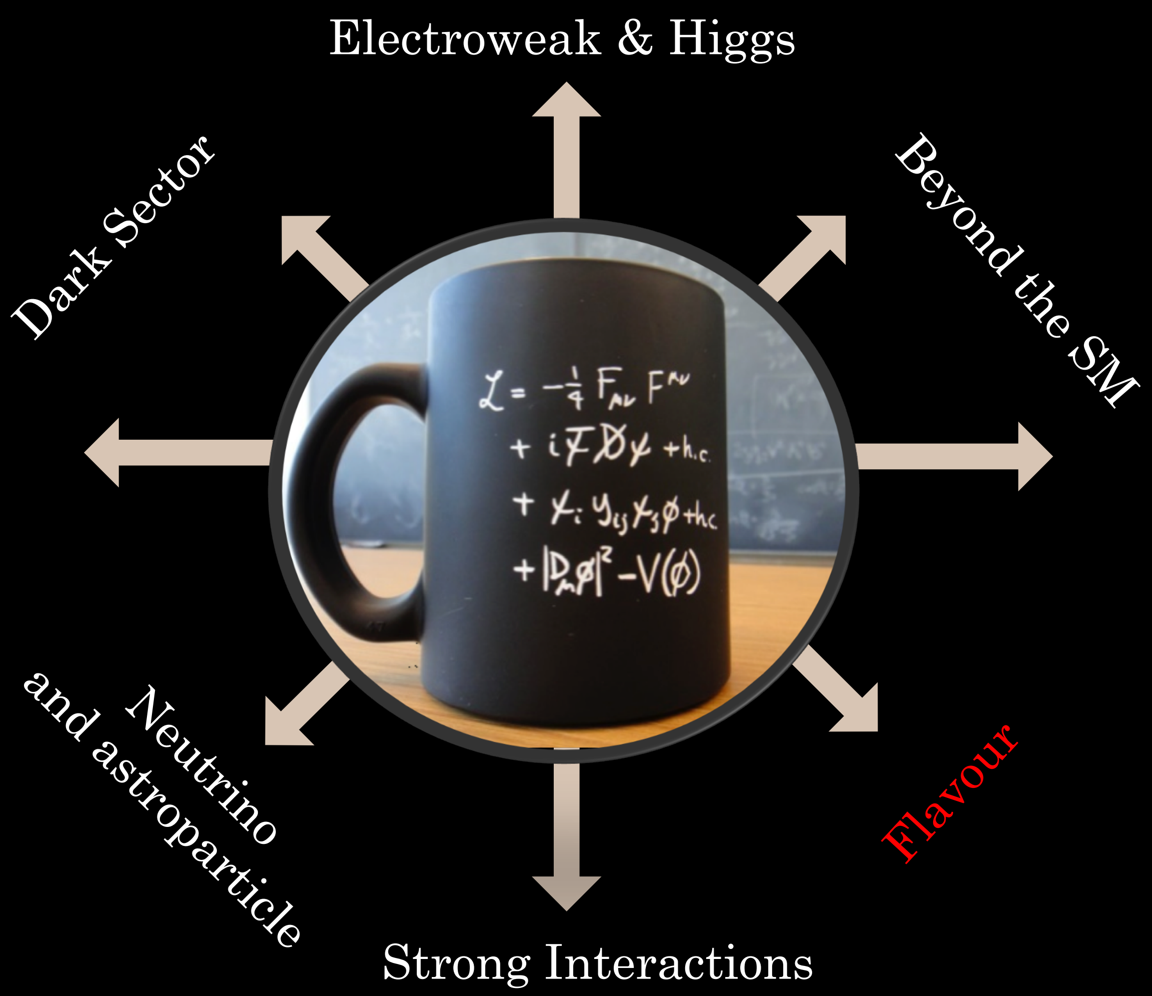
The ESG (European Strategy Group) created working groups to reflect on the following topics:

- social and career aspects for the next generation,
- organizational structure for European participation in global projects,
- relations with external bodies and fields of physics,
- knowledge and technology transfer,
- outreach, education and communication,
- sustainability and environmental impact

The Granada themes

Flavor & CP



The light sector (u,d,s + e,μ)

Three “clear” cases calling for diversity in the short/mid-term:

1. EDMs [d_e, d_n, d_N,.]	Strong CP EW CP	new: Storage rings
2. μ→e processes	1 → 2 Gen Lep. Mix.	Intense μ beams
3. Rare K decays	1 → 2 Gen. Quark Mix.	Intense K beams

$\Lambda > 10^3$ TeV for O(1) couplings
Storage ring JEDI/CPEDM start construction in 2027

Antonio Zoccoli @ Granada

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Sensitivity improvement x10000

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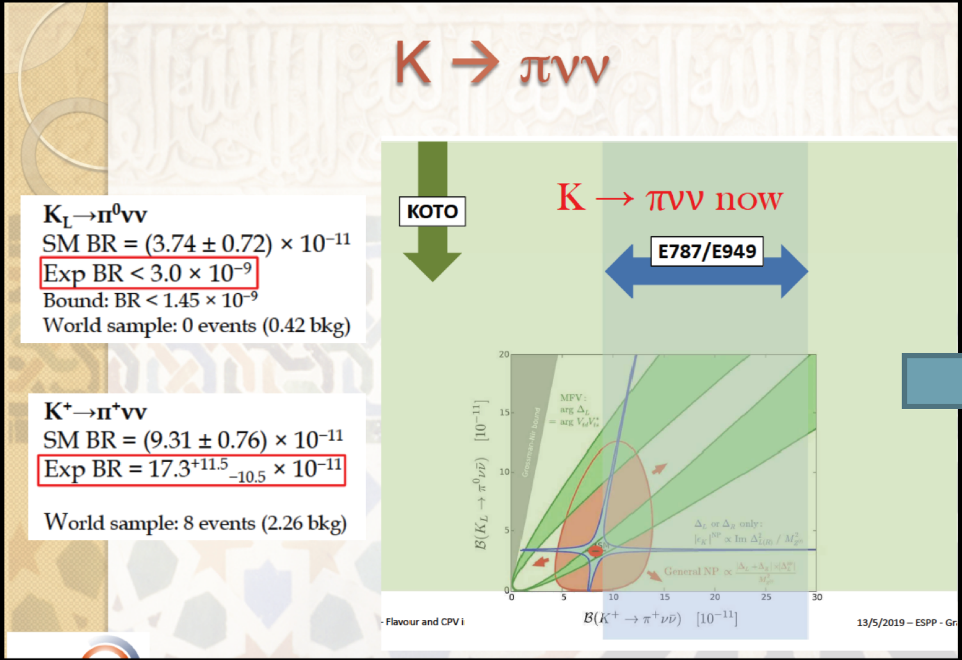
Sensitivity improvement x10000

Great potential
Difficult experiments

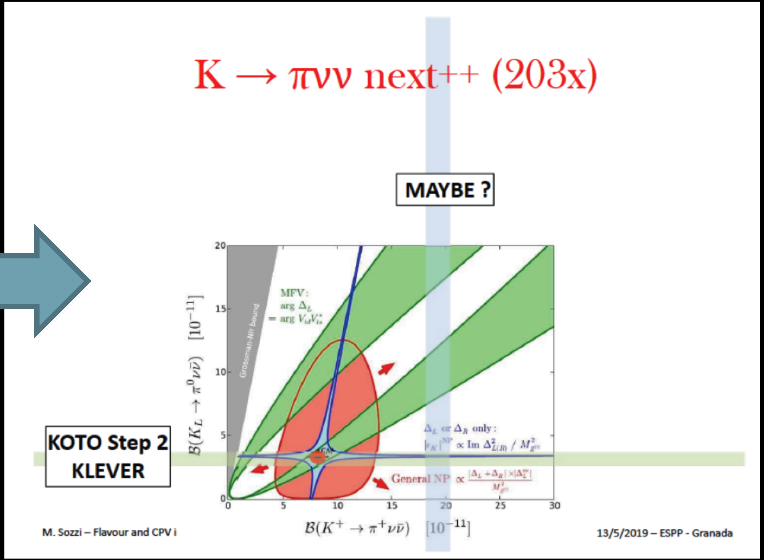
Antonio Zoccoli @ Granada

The light sector (u,d,s + e,μ): rare K decay evolution

NA62@SPS & KOTO@J-PARC



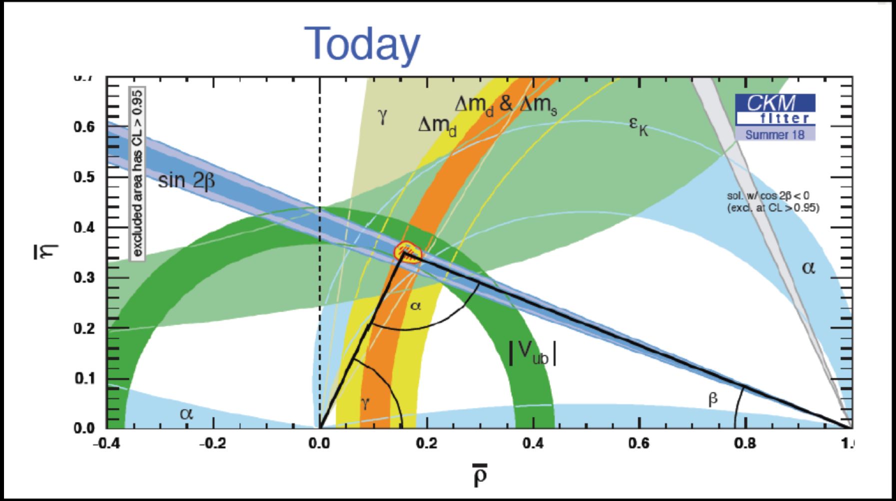
KOTO-Step2 & KLEVER@CERN

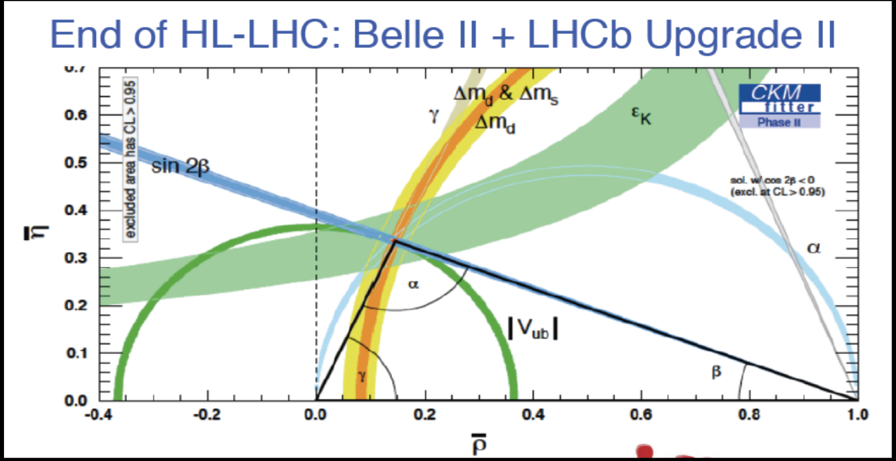


Antonio Zoccoli @ Granada

The heavy sector (b,c,t + τ + h)

Antonio Zoccoli @ Granada





Belle II+1= Belle III

Just started within Belle II

Goal: x5 increase in peak luminosity

- ❑ Doable from a machine perspective ?
- ❑ Detectors issues running at 4 10^{36} cm^{-2} s^{-1}
- ❑ Physics case

Under study, more before the end of 2019

Z^0 factories

Goal: $10^{11} – 10^{12}$ Z^0 (CEPC)
5. 10^{12} Z^0 (FCCee)
$BR(Z^0 \to b\bar{b}) = 15\%$

ILD-like detector + charged hadron PID.

FCC-pp a dedicated experiment (à la LHCb)

e^+e^- Super Charm-Tau Factories:
SCT (BINP, Novosibirsk) and STCF/HIEPA (China)
E: 2 to 6 GeV
Peak Luminosity (> 4 GeV) 10^{35} cm^{-2} s^{-1}

“Flavor is the usual graveyard for BSM electroweak theories”

Antonio Zoccoli

The Granada themes

Flavor & CP

- Challenging experiments, but a must-have in our experimental portfolio
- Outstanding BSM scale reach: $\Lambda > 10^2$-10^5 TeV
- Particle-ID detectors should be part of any future collider program at high energies
- Different environments (ee and pp) are complementary
- A Z^0-factory is a fantastic tool for flavor physics

The Granada themes

Beyond the SM

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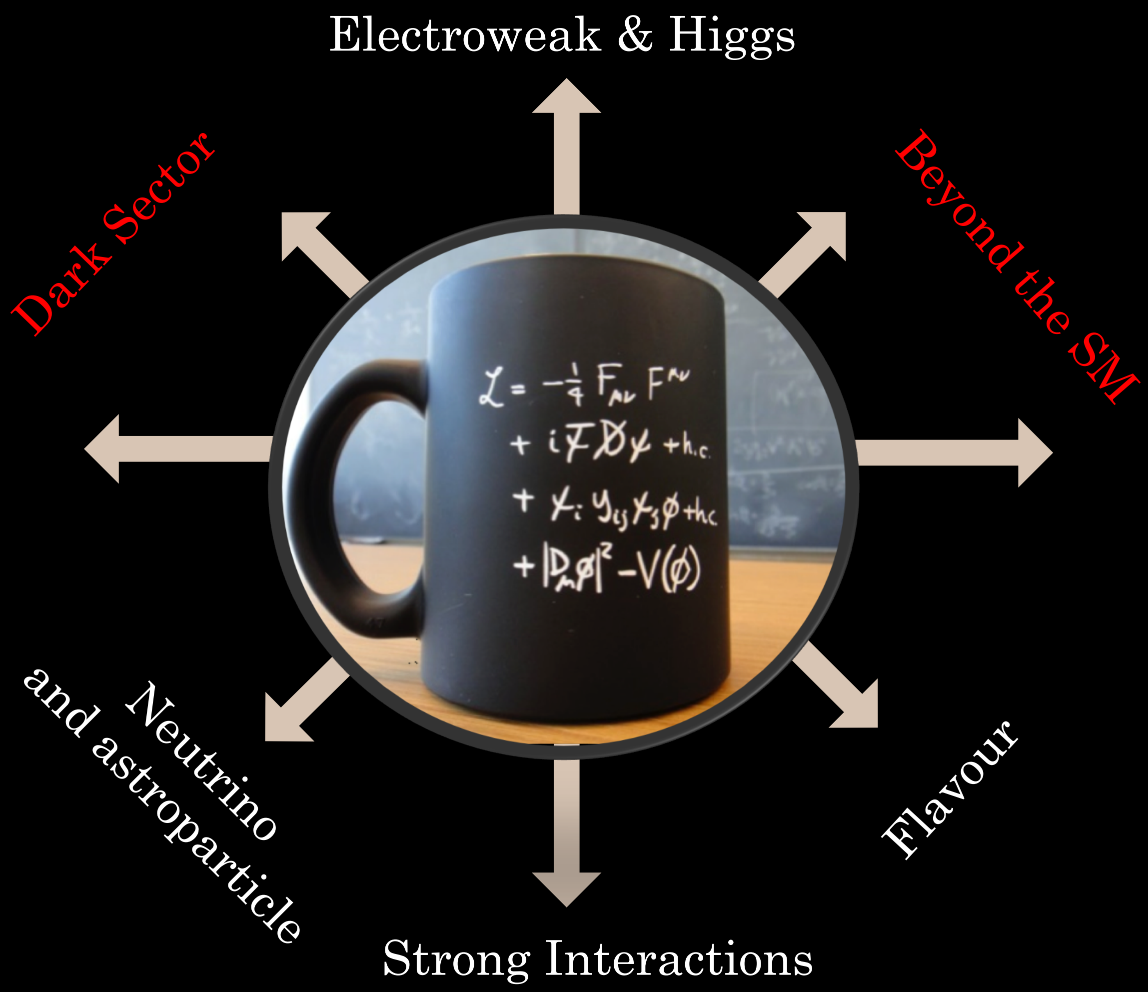
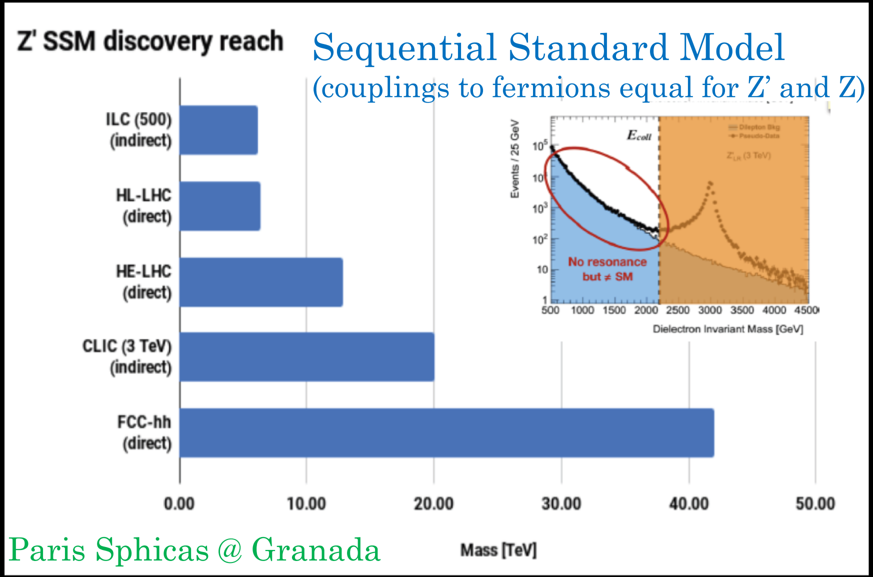
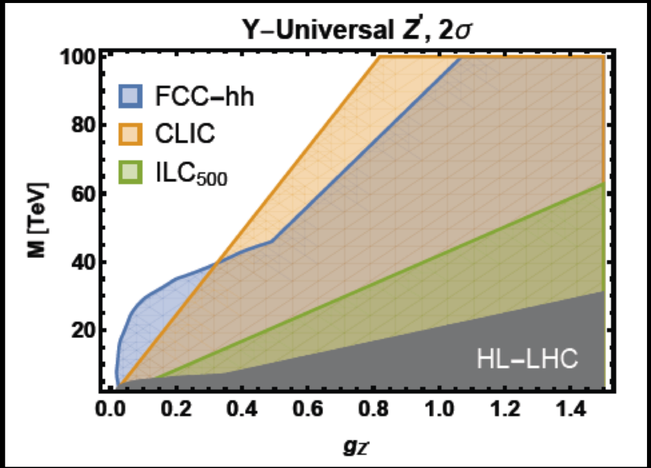
Dark Sector



Are there new interactions or new particles around or above the electroweak scale?



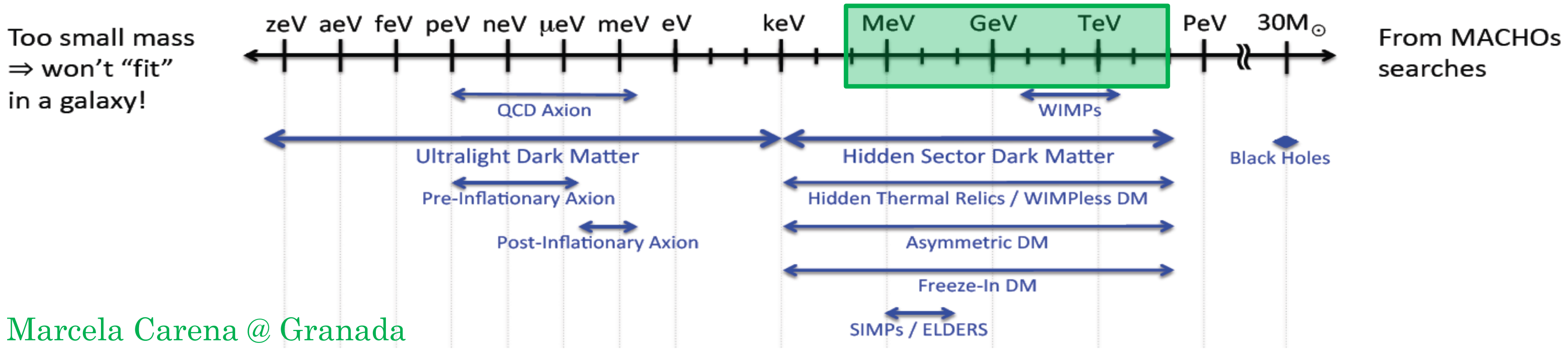
- In general, if the couplings become large the sensitivity at lepton colliders is enhanced
- For weak couplings the direct search at hadron colliders dominates the picture



Paris Sphicas @ Granada

Many more models are compared…

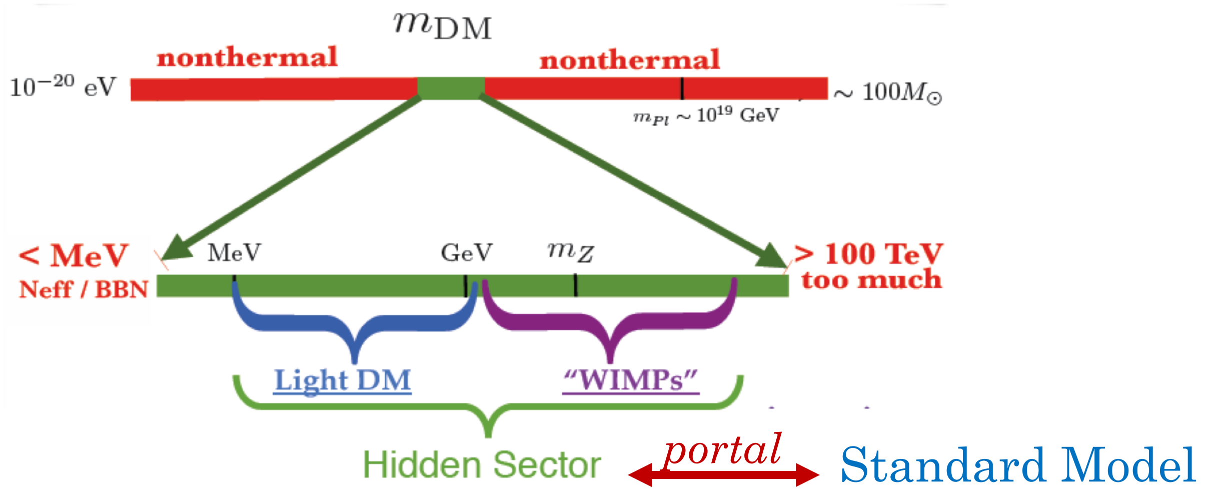
Dark Matter: Where to start looking? Very little clue on mass scale…



Marcela Carena @ Granada

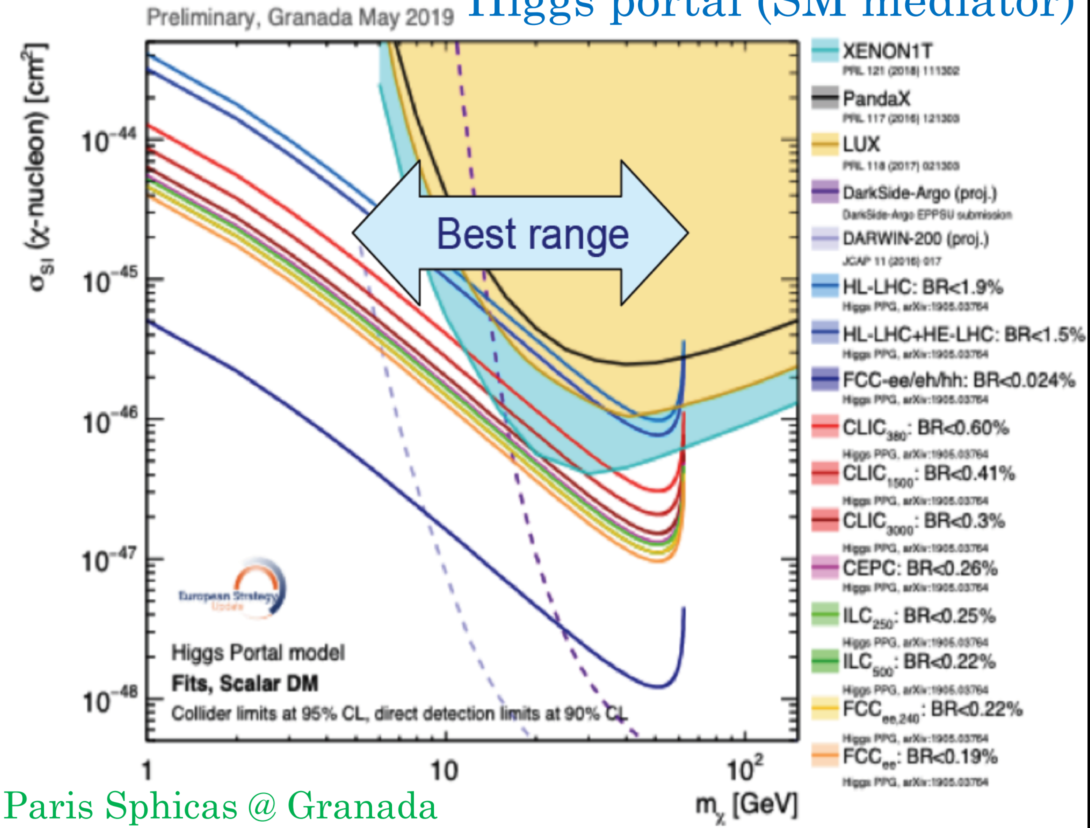
The assumption of Thermal Equilibrium in the early Universe narrows the viable mass range.

Interesting phenomena like long-lived particles and feebly interacting particles.



What cases of thermal relic WIMPs are still unprobed and can be fully covered by future collider searches?

Higgs portal (SM mediator)



Paris Sphicas @ Granada

A collider discovery will need confirmation from DD/ID for cosmological origin

A DD/ID discovery will need confirmation from colliders to understand the nature of the interaction

A future collider program that optimizes sensitivity to invisible particles coherently with DD/ID serves us well. Need maximum overlap with DD/ID.

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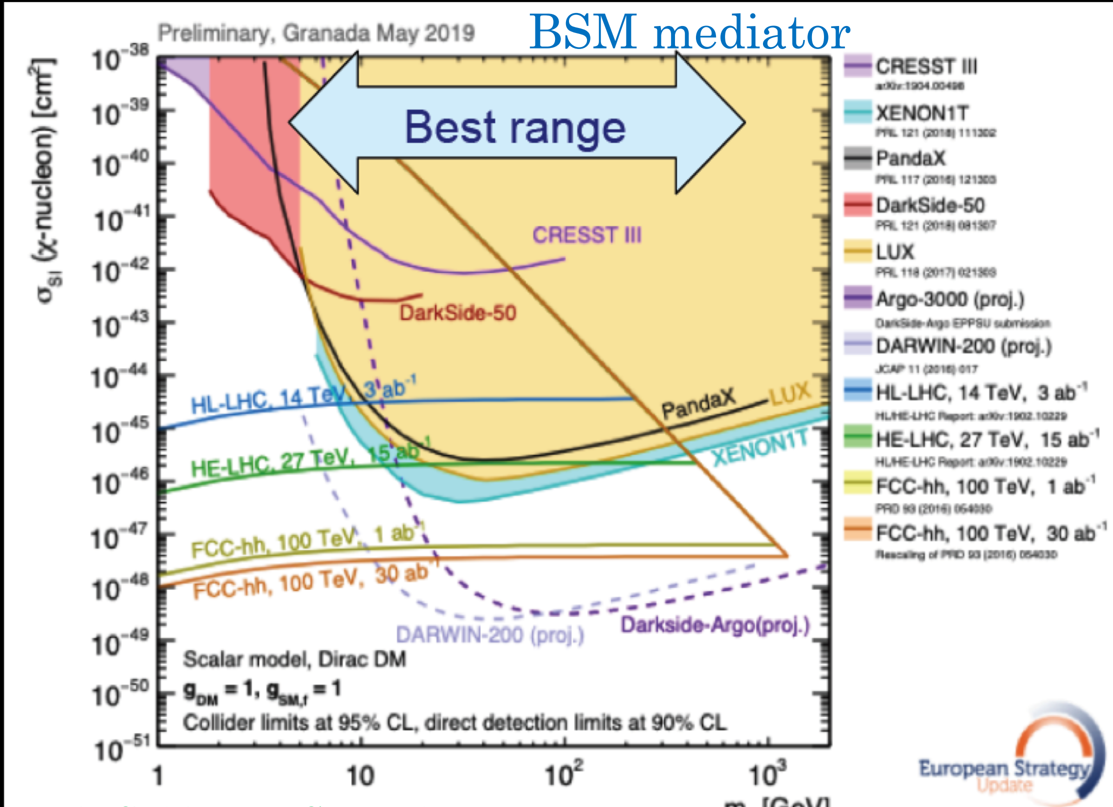

Paris Sphicas @ Granada

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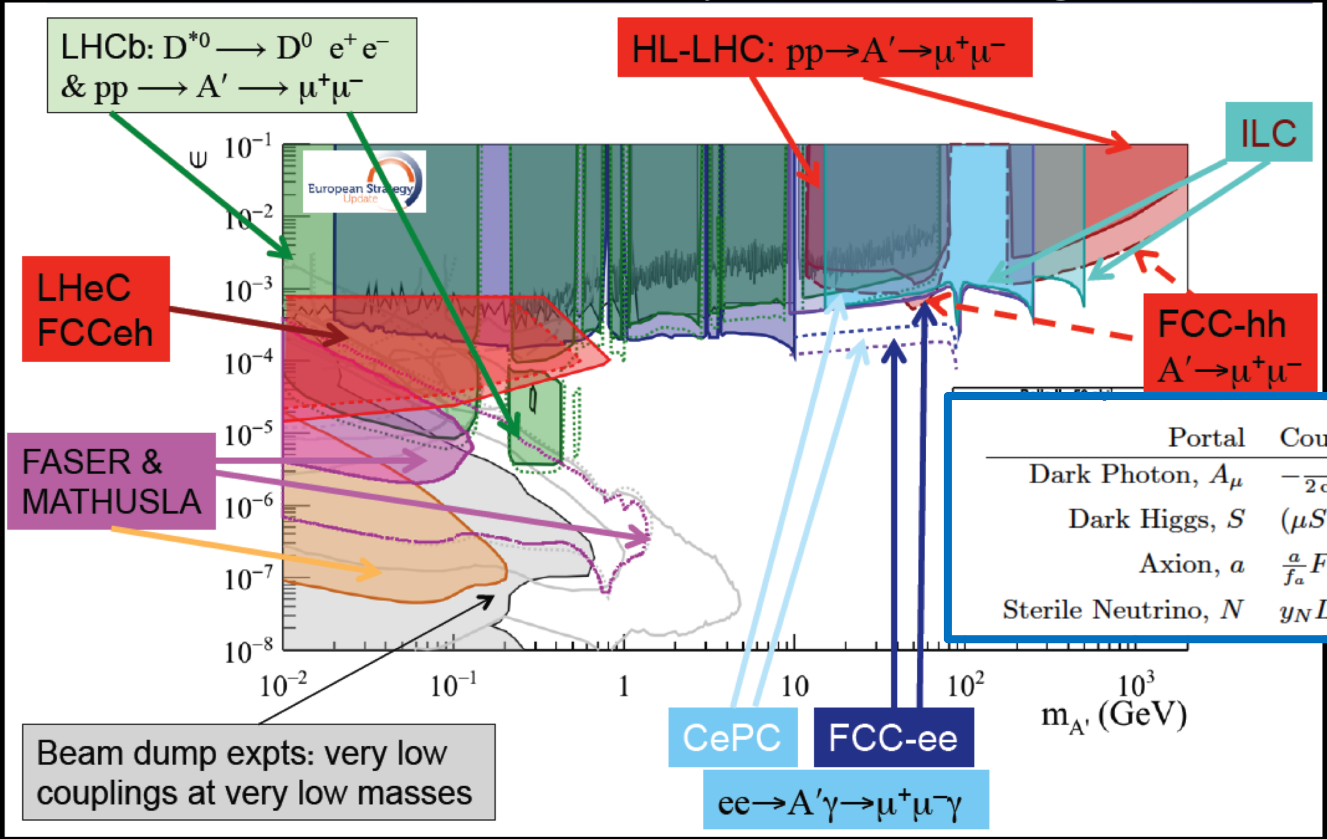
To what extent can current or future accelerators probe feebly interacting sectors?



Use four simplified models ("portals") from which benchmarks are identified to evaluate experimental sensitivity

PBC report, arXiv:1901.09966

Portal	Coupling
Dark Photon, A_μ	$-\frac{\epsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$
Dark Higgs, S	$(\mu S + \lambda S^2) H^\dagger H$ (Relaxion toy model, mixes \w Higgs)
Axion, a	$\frac{a}{f_a} F_{\mu\nu}\tilde{F}^{\mu\nu}$, $\frac{a}{f_a} G_{i,\mu\nu}\tilde{G}_i^{\mu\nu}$, $\frac{\delta_\mu a}{f_a}\overline{\psi}\gamma^\mu\gamma^5\psi$
Sterile Neutrino, N	$y_N L H N$

Dark Photon case

The Granada themes

Beyond the SM

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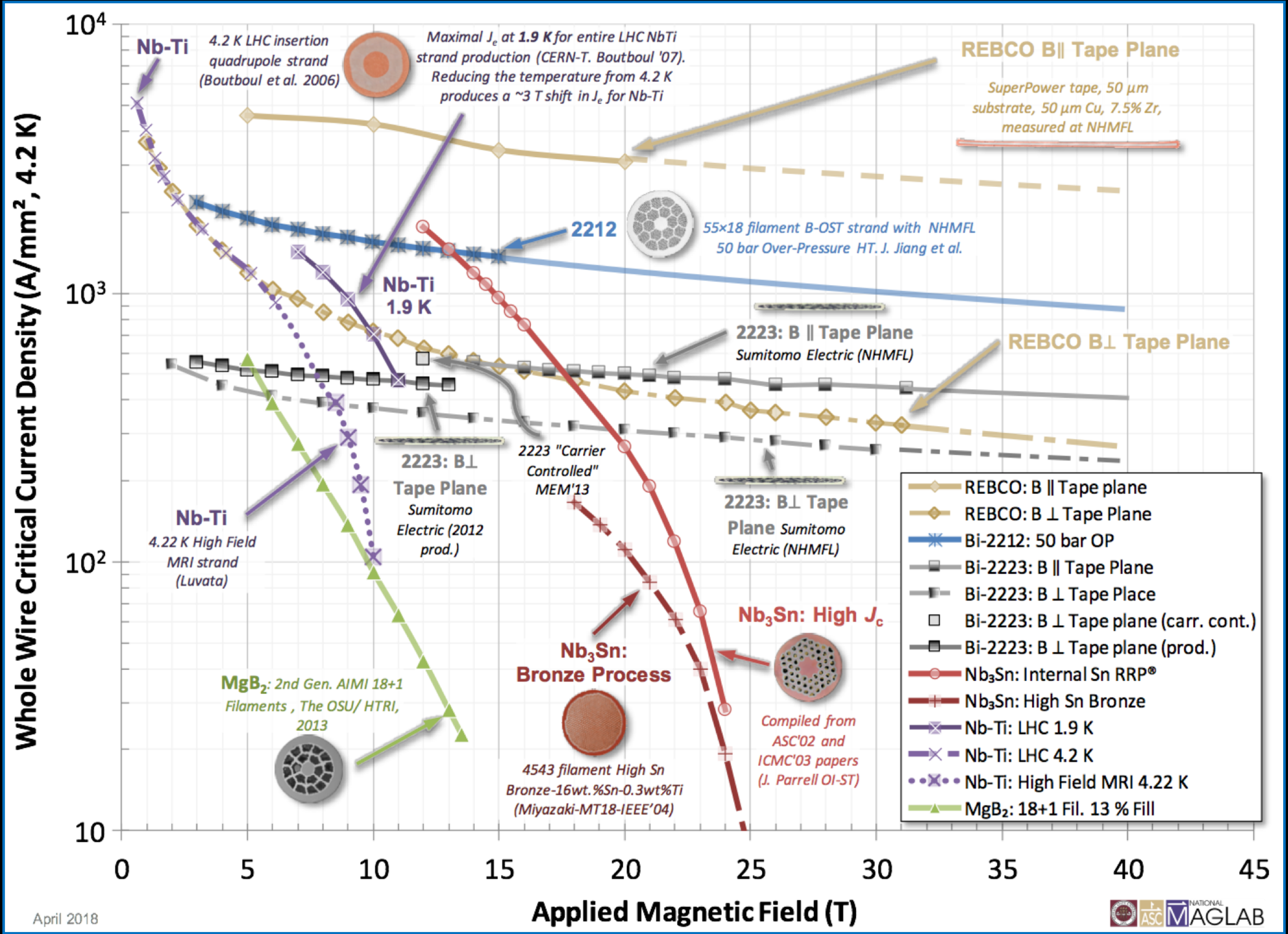
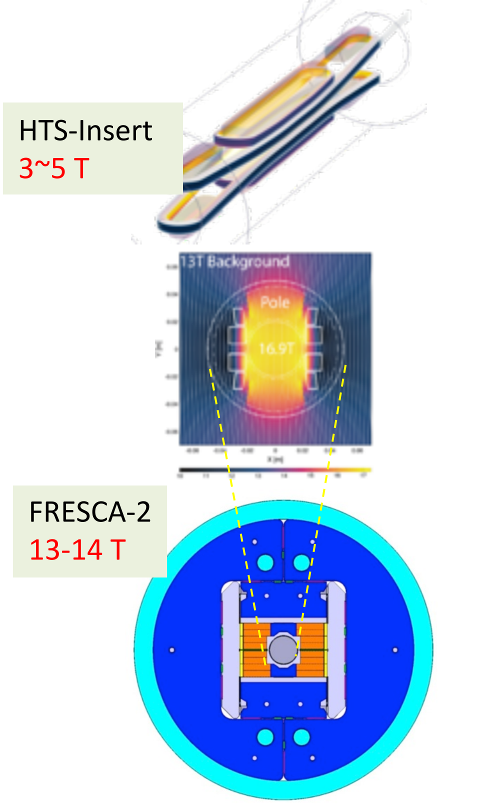
Dark Sector

- In the absence of concrete guidance, the parameter space for new physics is vast…
- Exploring synergies and coordination with adjacent fields is necessary, e.g. with the direct and indirect dark matter detection communities for common interpretation of results
- Complementarity between lepton and hadron colliders for dark matter searches provide the best sensitivity for the benchmarks
- Complementarity between beam dump and collider experiments for feebly interacting particles

SC Magnet R&D – *alternative materials for high-J_c at high magnetic field*





Eucard2: HTS-insert to be tested in 2019
(3-5) + (13-14)T : > 16 T