Overview of the Open Symposium

Halina Abramowicz
Tel Aviv University

- About the Symposium in Granada
- Examples of addressed physics issues
- About research tools
- Challenges ahead

Reminder - organisation of the Update Process

- Decision making body – CERN Council
- Drafting of the Strategy Update document – responsibility of the European Strategy Group (ESG)
- Scientific Input to the Strategy Update – responsibility of the Physics Preparatory Group (PPG)
  - Call for input
  - Processing of the input
  - Open Symposium
  - Briefing Book
- Coordinating body – the Strategy Update Secretariat (SUS)

European Strategy Update

EPPSU 2020 timeline

2017

2018

2019

2020

organisation & input preparation by community

✓ **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 and establishes the PPG and ESG

consultation & consensus building

✓ **Dec 18.2018**
Closing submission of 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, GE

March.2020
Strategy Update to be submitted to Council

May.2020
Council to approve Strategy Update

Physics results appearing after May 2019 will be taken into account in the process

ECFA/EPS-HEPP session during EPS2019 in Ghent 13/07 afternoon

Scientific Input to the Strategy Update

- Call for inputs issued February 28, 2018 with deadline for submission December 18, 2018
- 160 submissions received

Track ID	Granada sessions	Description	Conveners		
1		Large experiments and projects	PPG/ESG		40
2		National road maps	ESG		42
7	B1	Electroweak Physics (physics of the W, Z, H bosons, of the top quark, and QED)	Keith Ellis	Beate Heinemann	21
8	B2	Flavour Physics and CP violation (quarks, charged leptons and rare processes)	Belen Gavela	Antonio Zoccoli	27
5	B3	Dark matter and Dark Sector (accelerator and non-accelerator dark matter, dark photons, hidden sector, axions)	Marcela Carena	Shoji Asai	27
3	B4	Accelerator Science and Technology	Caterina Biscari	Lenny Rivkin	51
4	B5	Beyond the Standard Model at colliders (present and future)	Gian Giudice	Paris Sphicas	20
10	B6	Strong Interactions (perturbative and non-perturbative QCD, DIS, heavy ions)	Krzysztof Redlich	Jorgen D'Hondt	31
9	B7	Neutrino Physics (accelerator and non-accelerator)	Stan Bentvelsen	Marco Zito	23
6	B8	Instrumentation and Computing	Xinchou Lou	Brigitte Vachon	35
11		Other (communication, outreach, strategy process, technology transfer, individual contributions,...)	ESG		

- The Open Symposium aimed to reach a consensus on the *scientific goals* of the community, based on the provided input, and to assess the proposed projects and technologies to achieve these goals
- ➢ The ESG needs all this input to propose a realistic update of the Strategy

Open Symposium

Discussions on 8 themes organized in Parallel Sessions (EWK Physics, Flavour/CP, Dark Sector, Accelerators, BSM at colliders, Strong Interactions, Neutrino, Instrumentation and Computing)

Parallel Sessions convened each by 2 members of the PPG

- 2 half-day sessions per theme, separated by half-day
- Each session invited 2 (3) scientific secretaries
- Focus on a few fundamental questions (posted on Granada website under "Organisation of the Symposium")
- Experts invited to summarise submitted inputs
  - About 100 speakers in total
- Plenty of time for discussions

Open Symposium

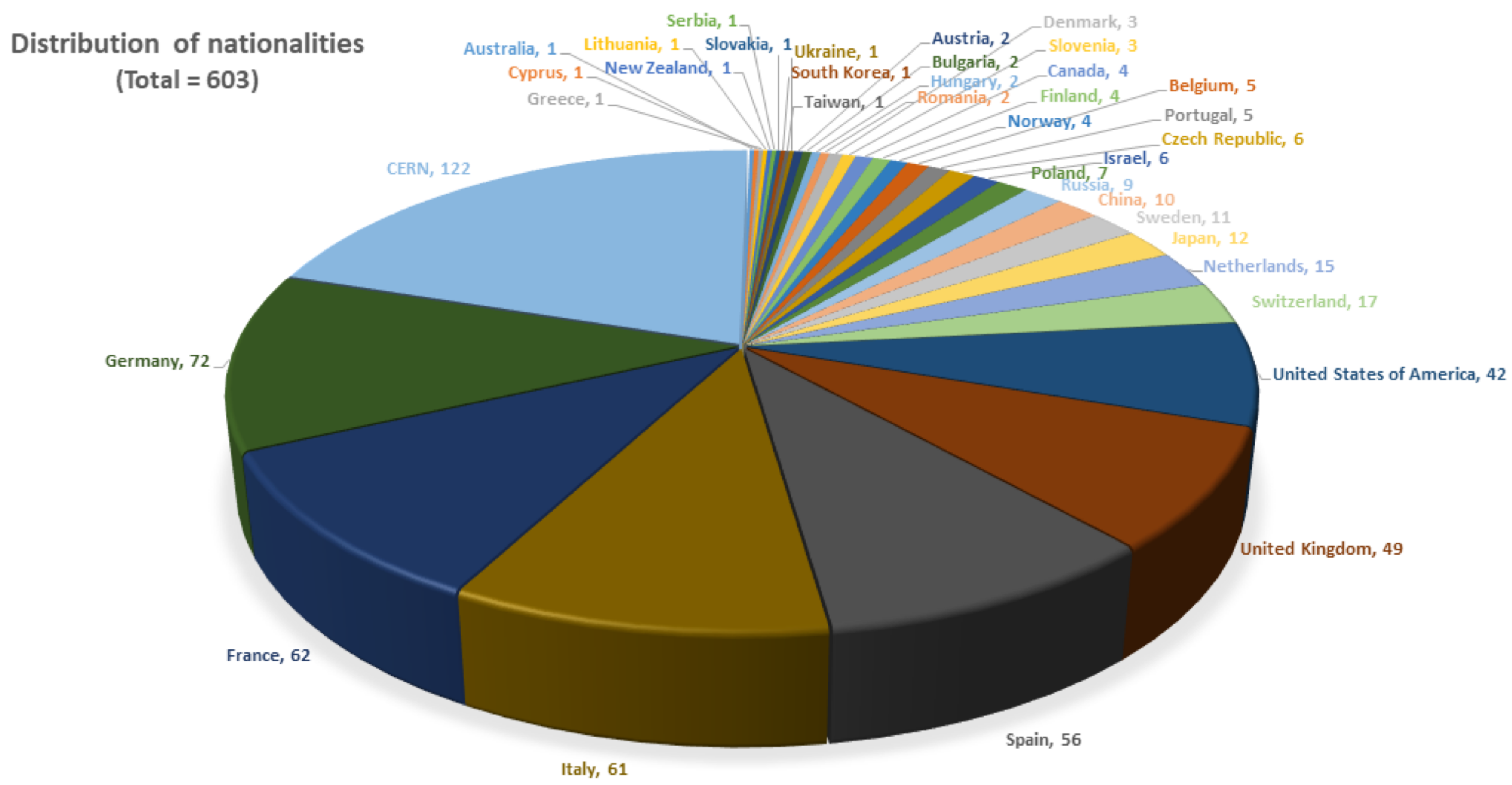
Plenary Sessions
- 2 half-days to review where we stand and what is expected of the European community, also by communities outside Europe
- Full day of summaries from the Parallel Session

- End product of the Symposium → Briefing Book based on the summaries, compiled by the PPG, assisted by scientific secretaries (aim at about 100 pages)
- Expected to be ready by September 2019
  - Executive Summary
  - Theoretical Introduction
  - Summaries of the 8 Parallel Sessions
  - Compiled synergies between various areas of research and projects
  - Addenda – list of submitted projects, their timelines, cost estimates, …
- Documents compiled for the discussions in the Parallel Sessions will be posted in *cds* or *arXiV*

Latest update – first complete drafts appeared this week

EPPSU 2020

Participants in Granada



from Vedrana Zorica

Very well attended
Expected – 500
Registration closed after 600

12% from outside Europe

Outstanding organisation

To Spain

High quality presentations

To PPG

Strategy Update

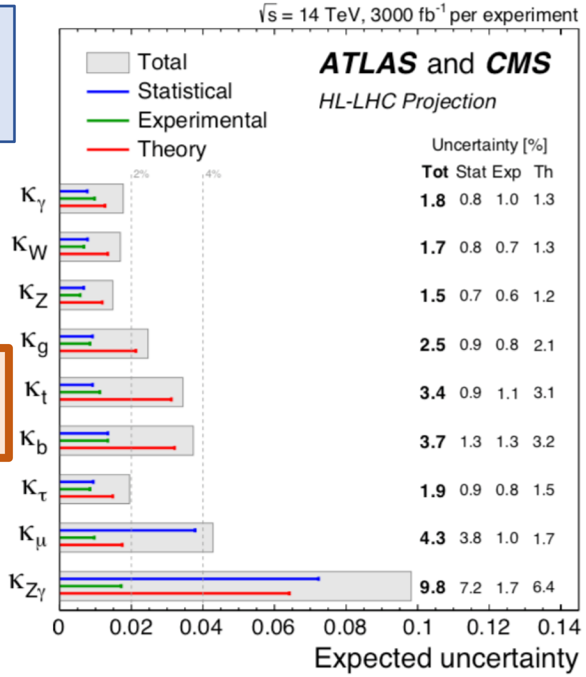
What has changed since the 2013 Strategy Update?

- ➢ The HL-LHC was approved in 2016
- ➢ The expected reach of HL-LHC has been substantially updated

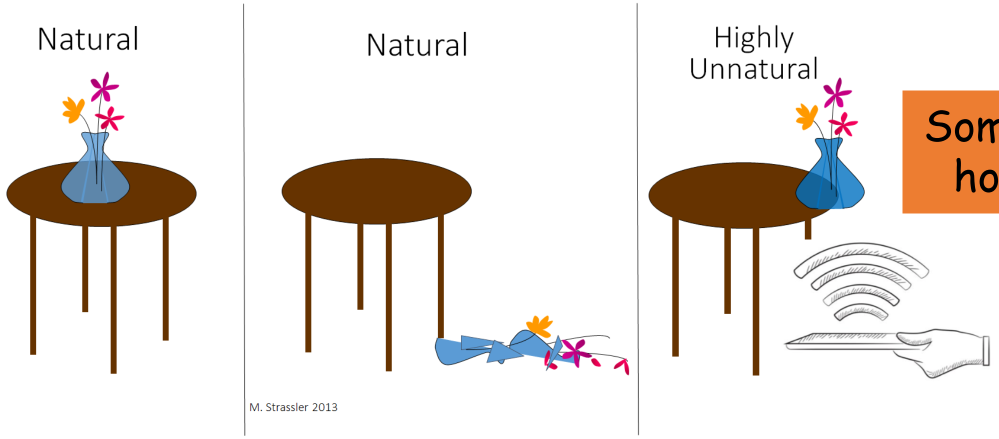
What did not change since the 2013 Strategy Update?

- No signs of BSM physics
- *Neutrinos have masses – not acquired in the SM*
- *There is dark matter in the Universe with no candidates within the SM*
- *Prevalence of matter over anti-matter*
- ➢ *Theorists believe that the theory is not complete*

Higgs couplings after HL-LHC



Largest contribution to the uncertainty from theory



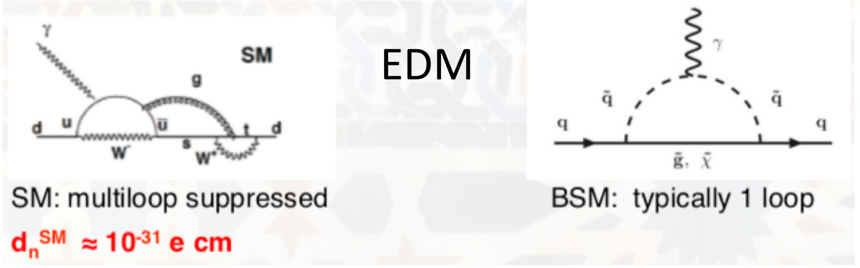
Something must be holding the vase

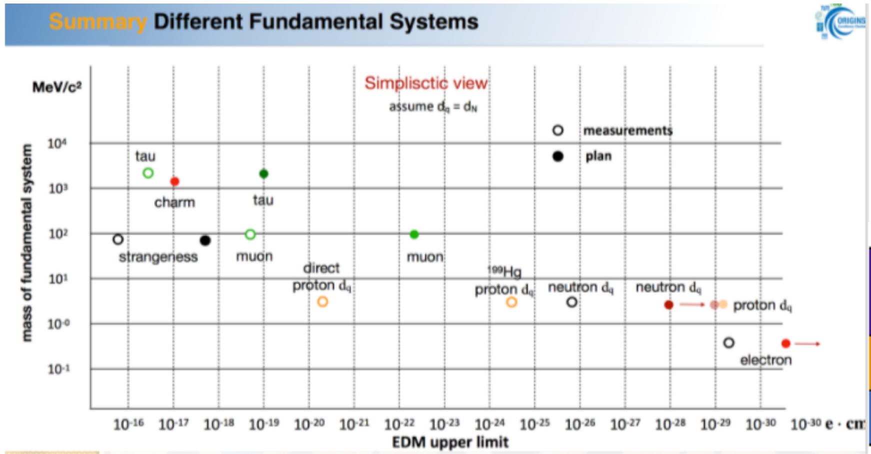
From Matt Strassler

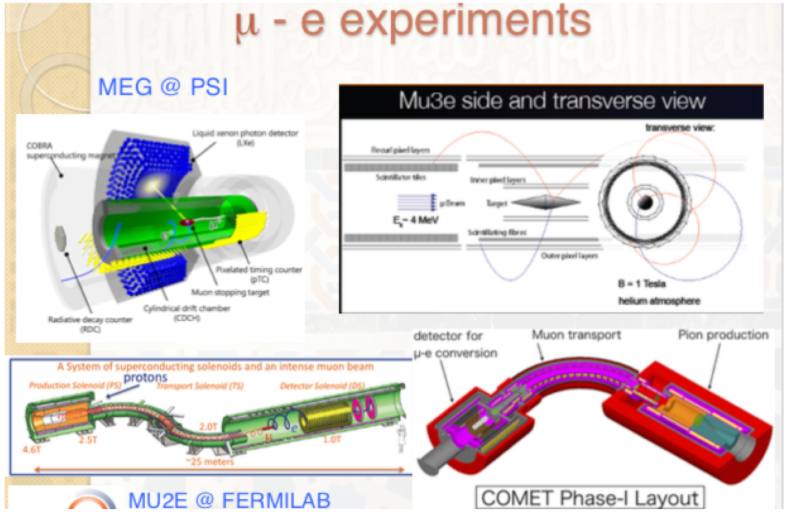
Report from Open Symposium in Granada

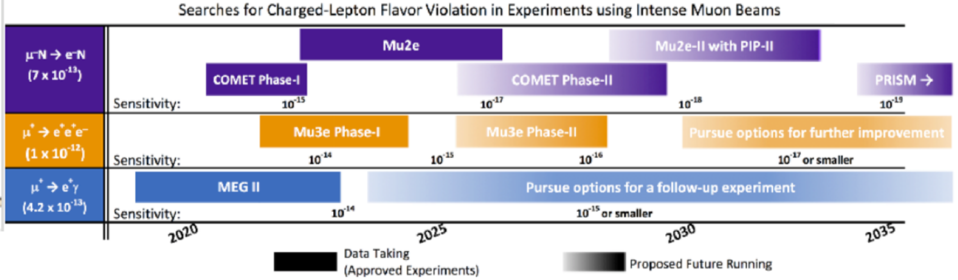
Flavour Physics and CP

- ➢ Study processes very unlikely or impossible in the SM
- ➢ Great sensitivity to Physics Beyond the Standard Model – scale beyond 10^2 – 10^5 TeV
- ➢ Complementarity of low energy high-precision and high energy frontier

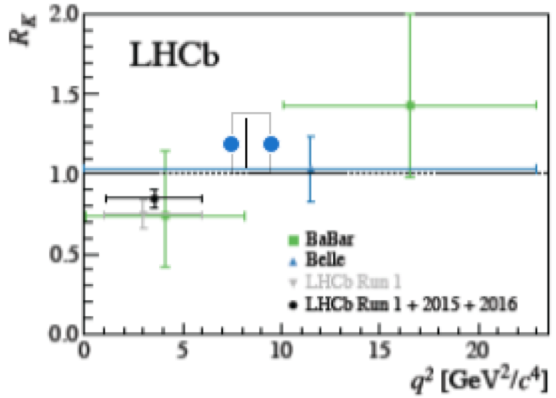








$$R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)} \stackrel{\text{SM}}{=} 1.0$$



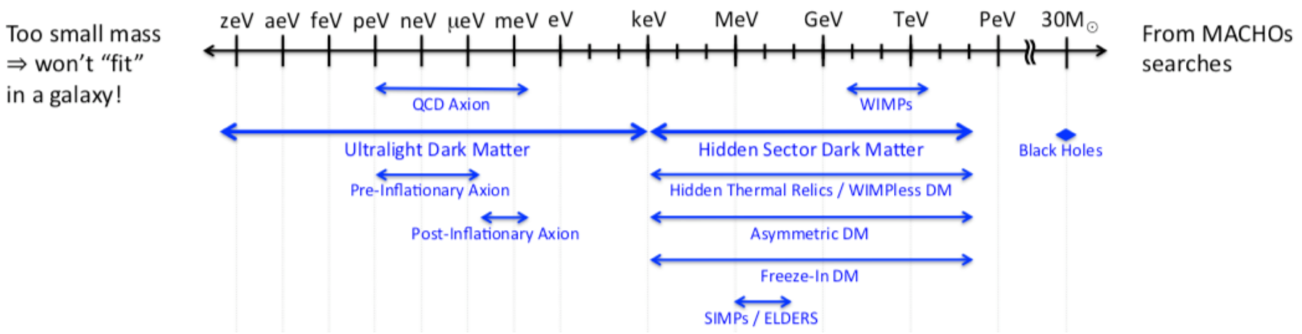
.... and more with kaon beams, charm ...

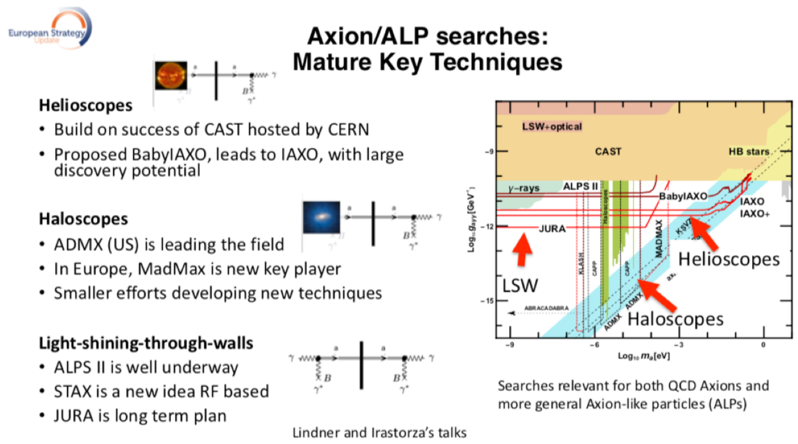
Report from Open Symposium in Granada

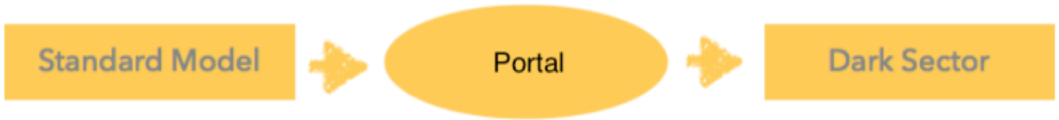
Dark matter/Dark sector

- Dark Matter
  - ➢ What if dark matter is light?

- Dark Sector
  - ➢ Search for dark photon







DP = Dark Photon
DS = Dark Scalar
HNL = Heavy Neutral Lepton
ALP = Axion-Like Particle

BEAM DUMP PROJECTS AT CERN

EXPERIMENT	PERIOD	BEAM	PARTICLES ON TARGET	SIGNATURE	MODELS
NA64++(e)	2015-24	e 100 GeV	~5 10^{12}	invisible & visible e^+e^-	DP, ALPs
eSPS/LDMX	> 2026	e 16 GeV	10^{16}	invisible	DP, ALPs
AWAKE++	> 2026	e ~50 GeV	~10^{15}	visible e^+e^-	DP, ALPs
NA62++	> 2022	p 400 GeV	10^{18}	visible	DP, DS, HNL, ALPs
SHiP	> 2026	p 400 GeV	2 10^{20}	recoil & visible	DP, DS, HNL, ALPs
NA64++(μ)	> 2022	μ 160 GeV	5 10^{13}	invisible	DZ_μ, ALPs

NB: CERN offers unique opportunities with both lepton and hadron beams

LHCb and LHC-LLP dedicated projects (FASER, milliQan, CODEX-b, MATHUSLA) have also sensitivity in similar mass range

Report from Open Symposium in Granada

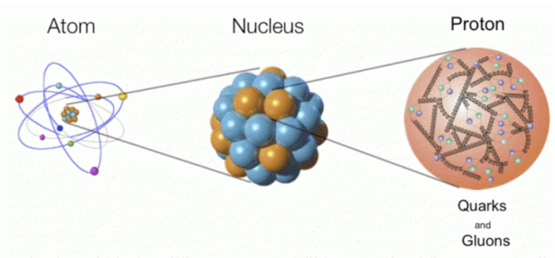
Strong Interactions (QCD)

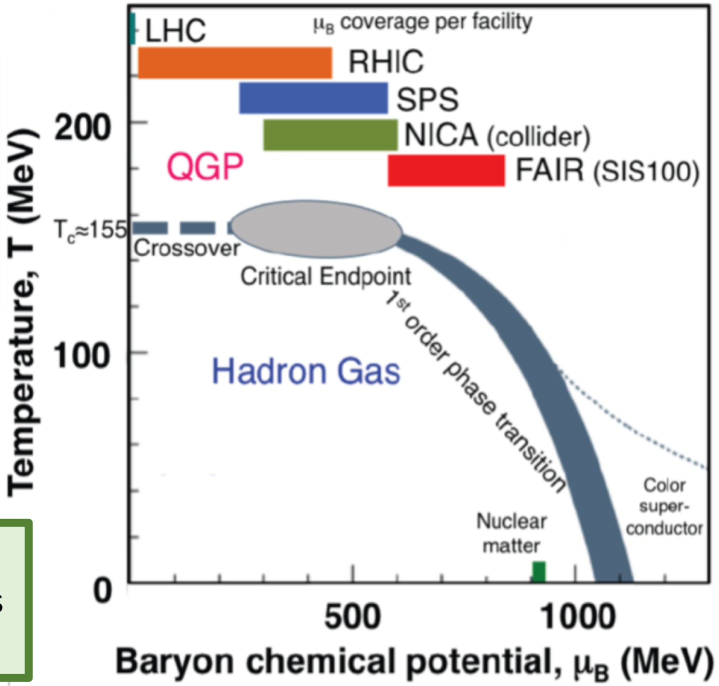
Human kind consists of 95% QCD and 5% Higgs

- Confinement
  - ➢ Hot and dense matter
  - ➢ Spectroscopy (new form of hadrons)

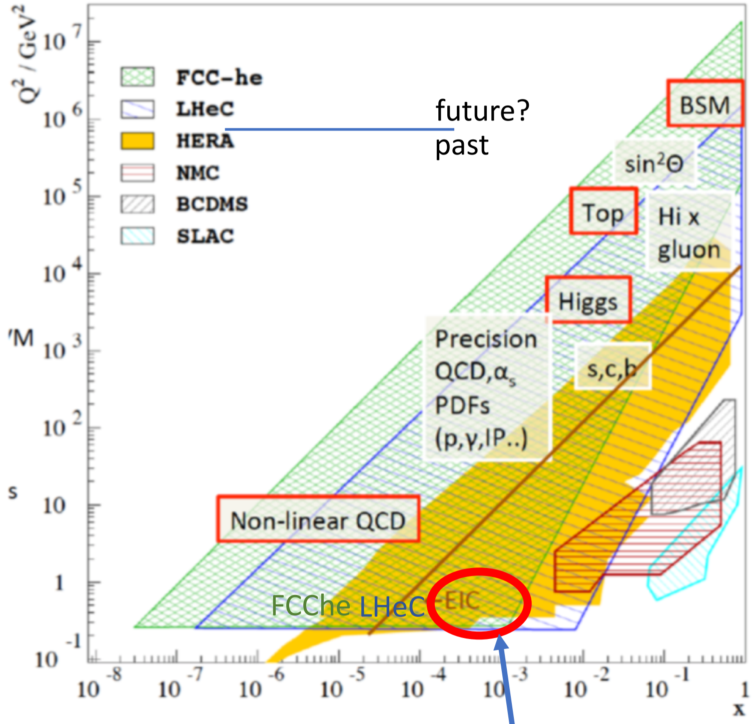
QCD is part of the SM but we have problems deciphering it!

- Perturbative regime (essence of pp machines)
  - ➢ Partonic structure of hadrons (exp)
  - ➢ Interactions of partons (theory)

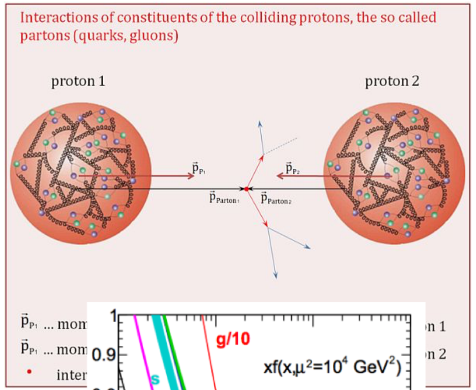


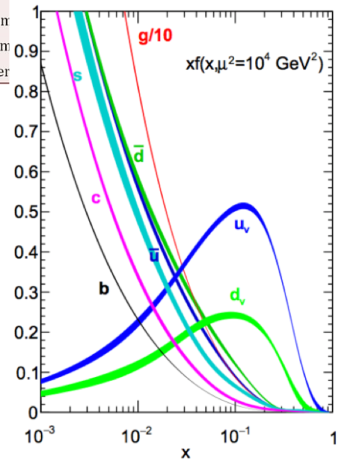


Quark gluon plasma
- Expected as gas of free partons
- Found to be a perfect liquid



US – soon?

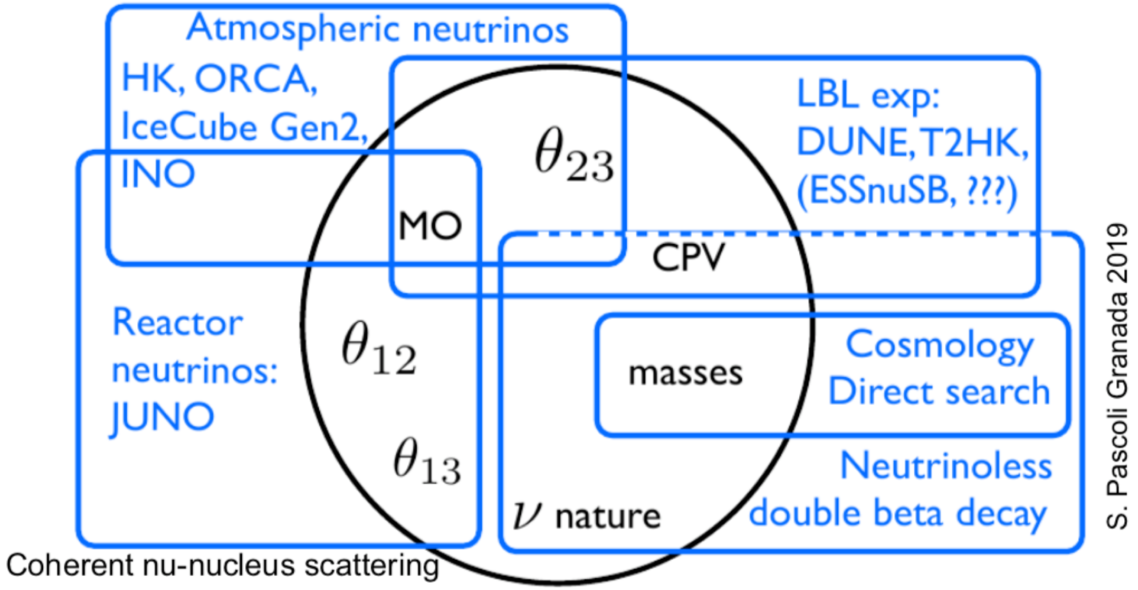




Report from Open Symposium in Granada

Neutrino physics and Astroparticle

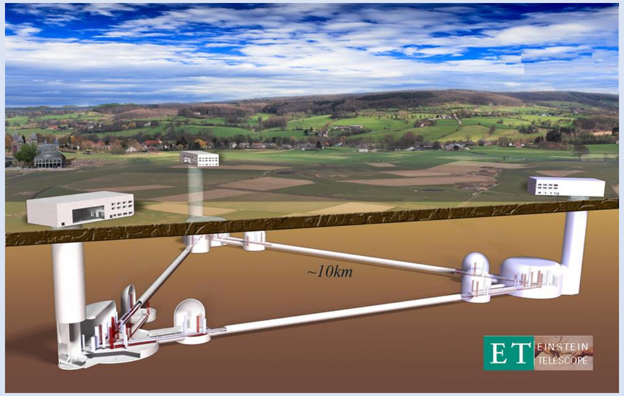
A very diverse experimental approach



Motivation : necessary to get a complete picture, make the most out of every neutrino source, test at different L/E, possible existence of new neutrino states, of Non-Standard-Interactions

Astroparticle physics

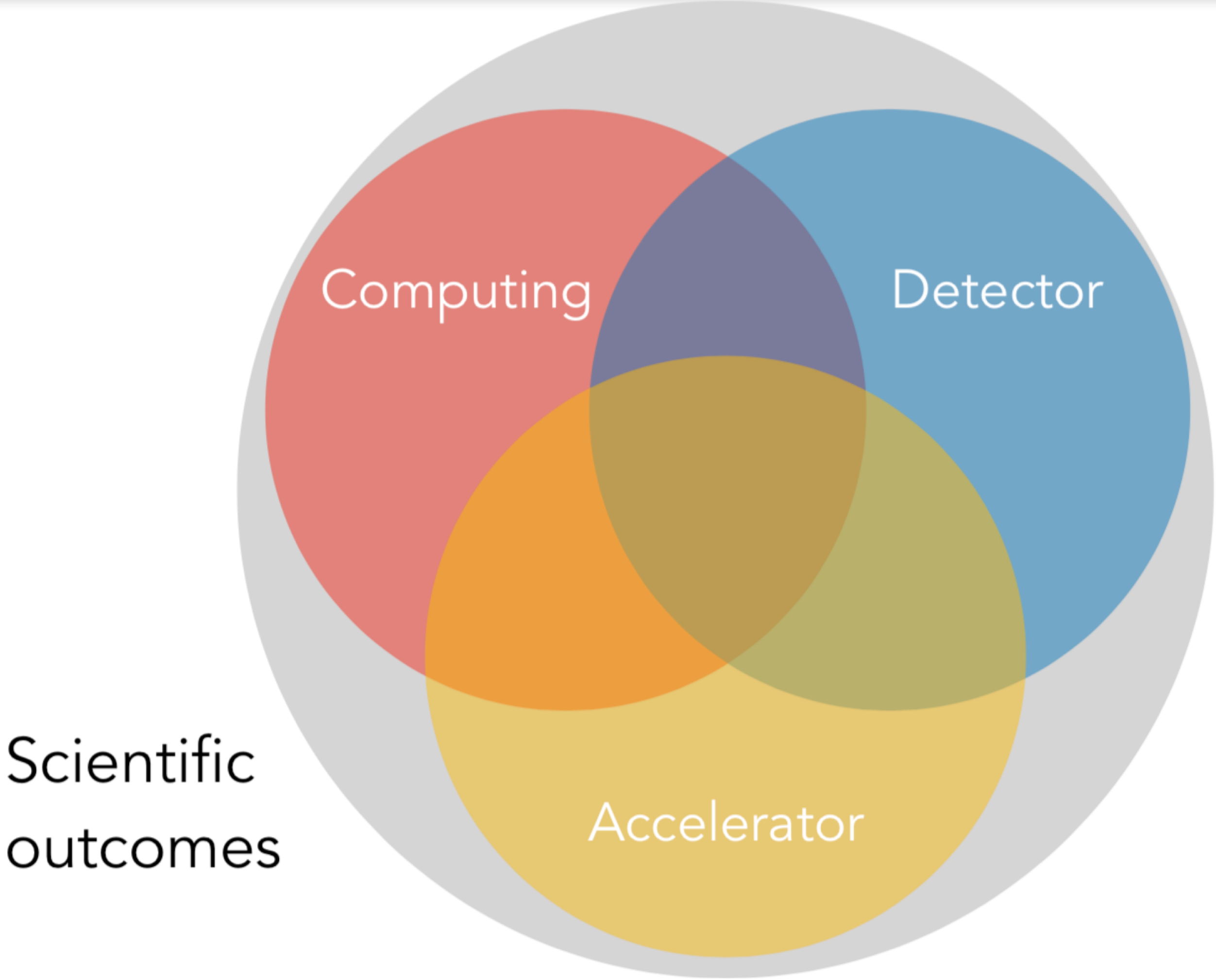
- Gravitational waves and multimessenger physics open up a new window on the Universe. Very strong physics case.
- There is a very high impact on the field of particle physics (and fundamental interactions) (eg dark matter, neutrinos, general relativity, ...)
- There is clearly an opportunity for the particle physics community and laboratories to expand their involvement in this program

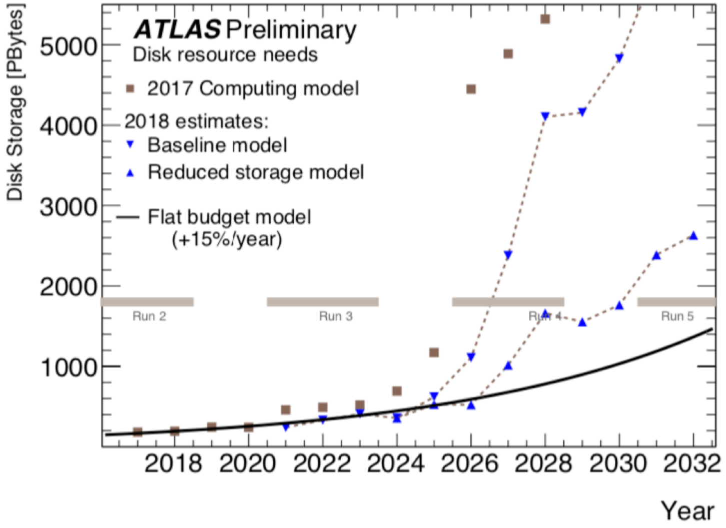


Einstein telescope needs CERN expertise
"Triangular accelerator without beam"

Report from Open Symposium in Granada

Research Ingredients





- Instrumentation and computing activities crucial t enable scientific programs.
- Important instrumentation and computing challenges ahead of us.
  - Exciting opportunities for innovation.
- Addressing these challenges will require taking into account
  - Human factor
  - R&D activities/coordination

"Small scale" projects

CERN based

ID	Name	Timeline	Cost
12	SHiP	Physics in 2027	70 MCHF
129	SPS BDF	Available 2027	156.3 MCHF
17	n_TOF	---	
36	Dark sector with primary electron beam @ CERN	eSPS commissioning 2024 (5 years after decision)	79.5 MCHF
39	EPIC / ISOLDE	Commissioning 2027	101 MCHF
58	AWAKE++	Installation in LS3	---
110	Next-generation LHC HI exp.	R&D etc. ongoing; installation during LS4 (2030)	150 MCHF
151	BSM searches with HI collisions at LHC	---	No significant investment
143	QCD facility at M2 beamline at SPS	---	10-20 MCHF
153	KLEVER	Installation 2025 (LS3)	38.95 MEUR
75	REDTOP	---	50 M$
75 / 94	LHC-LLP with MATHUSLA etc.		< 100 MCHF
	NA60++	3 years R&D, 2 years construction; data taking after LS3	15-25 M€
118	MUonE		< 10 M€
	COMPASS++	After LS3 operation	10-20 M€
154	NuStorm	Component construction starting >8 years from now	160 MCHF

Elsewhere

76	J-PARC	---	---
93	NICA @ JINR	Multi-phase setup; operational 2025?	465 M$
14	Complex Nevod	2019-26	24.6 MCHF
49	Super-Tau-Charm Factory	Operation 2029	415 MEUR
137	Short baseline neutrinos at FNAL	Physics with LArTPC end of 2020	---
30	Large-scale neutrino detectors in Russia	Full setup ready 2027	265 MEUR
124	Neutrino beam Protvino → ORCA	2018 construction start; 2027 (35) phase 1 (2) data taking	---
158	Opportunities in acc.-based neutrinos in Japan	T2K running beyond 2021; HyperK far detector construction beginning 2020.	---
64	Gravitational waves / Einstein Telescope	5 years construction	O(1000 MEUR)
11	SuperKEKB/Belle II	operation until ~2027	---
74	Electron-ion collider science and technoloy	---	---

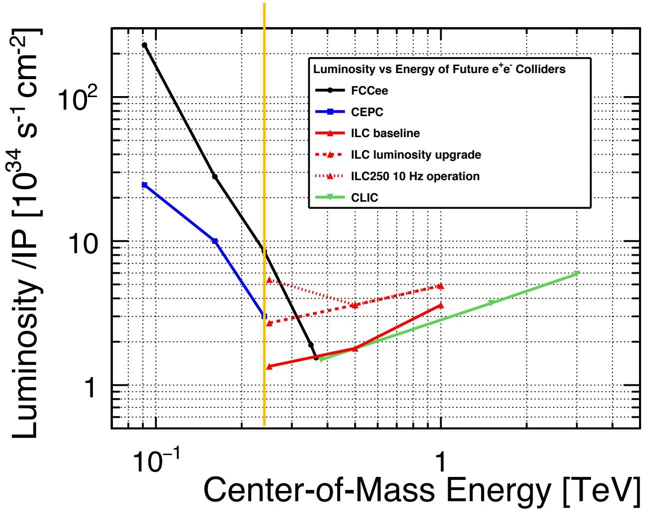
List not complete – work in progress

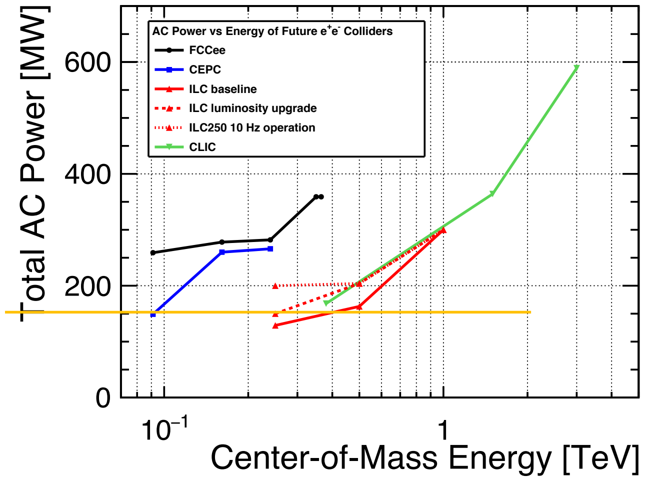
Report from Open Symposium in Granada

New accelerator projects

1 ILCU =
1 USD in 1/01/2012

Project	Type	Energy [TeV]	Int. Lumi. [a^{-1}]	Oper. Time [y]	Power [MW]	Cost
ILC	ee	0.25	2	11	129 (upgr. 150-200)	4.8-5.3 GILCU + upgrade
		0.5	4	10	163 (204)	7.98 GILCU
		1.0			300	?
CLIC	ee	0.38	1	8	168	5.9 GCHF
		1.5	2.5	7	(370)	+5.1 GCHF
		3	5	8	(590)	+7.3 GCHF
CEPC	ee	0.091+0.16	16+2.6		149	5 G$
		0.24	5.6	7	266	
FCC-ee	ee	0.091+0.16	150+10	4+1	259	10.5 GCHF
		0.24	5	3	282	
		0.365 (+0.35)	1.5 (+0.2)	4 (+1)	340	+1.1 GCHF
LHeC	ep	60 / 7000	1	12	(+100)	1.75 GCHF
FCC-hh	pp	100	30	25	580 (550)	17 GCHF (+7 GCHF)
HE-LHC	pp	27	20	20		7.2 GCHF
LE-FCC	pp.	37.5	15	20		14.9 GCHF. New at request of ESG.





LHC:
150 MW

Technical Challenges in Energy-Frontier Colliders proposed

		Ref.	E (CM) [TeV]	Luminosity [1E34]	AC-Power [MW]	Cost-estimate Value* [Billion]	B [T]	E: [MV/m] (GHz)	Major Challenges in Technology
CC hh	FCC-hh	CDR	~ 100	< 30	580	24 or +17 (aft. ee) [BCHF]	~ 16		High-field SC magnet (SCM) - Nb3Sn: Jc and Mechanical stress Energy management
	SPPC	(to be filled)	75 – 120	TBD	TBD	TBD	12 - 24		High-field SCM - IBS: Jcc and mech. stress Energy management
CC ee	FCC-ee	CDR	0.18 - 0.37	460 – 31	260 – 350	10.5 +1.1 [BCHF]		10 – 20 (0.4 - 0.8)	High-Q SRF cavity at < GHz, Nb Thin-film Coating Synchrotron Radiation constraint Energy efficiency (RF efficiency)
	CEPC	CDR	0.046 - 0.24 (0.37)	32~ 5	150 – 270	5 [B$]		20 – (40) (0.65)	High-Q SRF cavity at < GHz, LG Nb-bulk/Thin-film Synchrotron Radiation constraint High-precision Low-field magnet
LC ee	ILC	TDR update	0.25 (-1)	1.35 (– 4.9)	129 (– 300)	4.8- 5.3 (for 0.25 TeV) [BILCU]		31.5 – (45) (1.3)	High-G and high-Q SRF cavity at GHz, Nb-bulk Higher-G for future upgrade Nano-beam stability, e+ source, beam dump
	CLIC	CDR	0.38 (- 3)	1.5 (- 6)	160 (- 580)	5.9 (for 0.38 TeV) [BCHF]		72 – 100 (12)	Large-scale production of Acc. Structure Two-beam acceleration in a prototype scale Precise alignment and stabilization. timing

A. Yamamoto, 190513b

*Cost estimates are commonly for "Value" (material) only.

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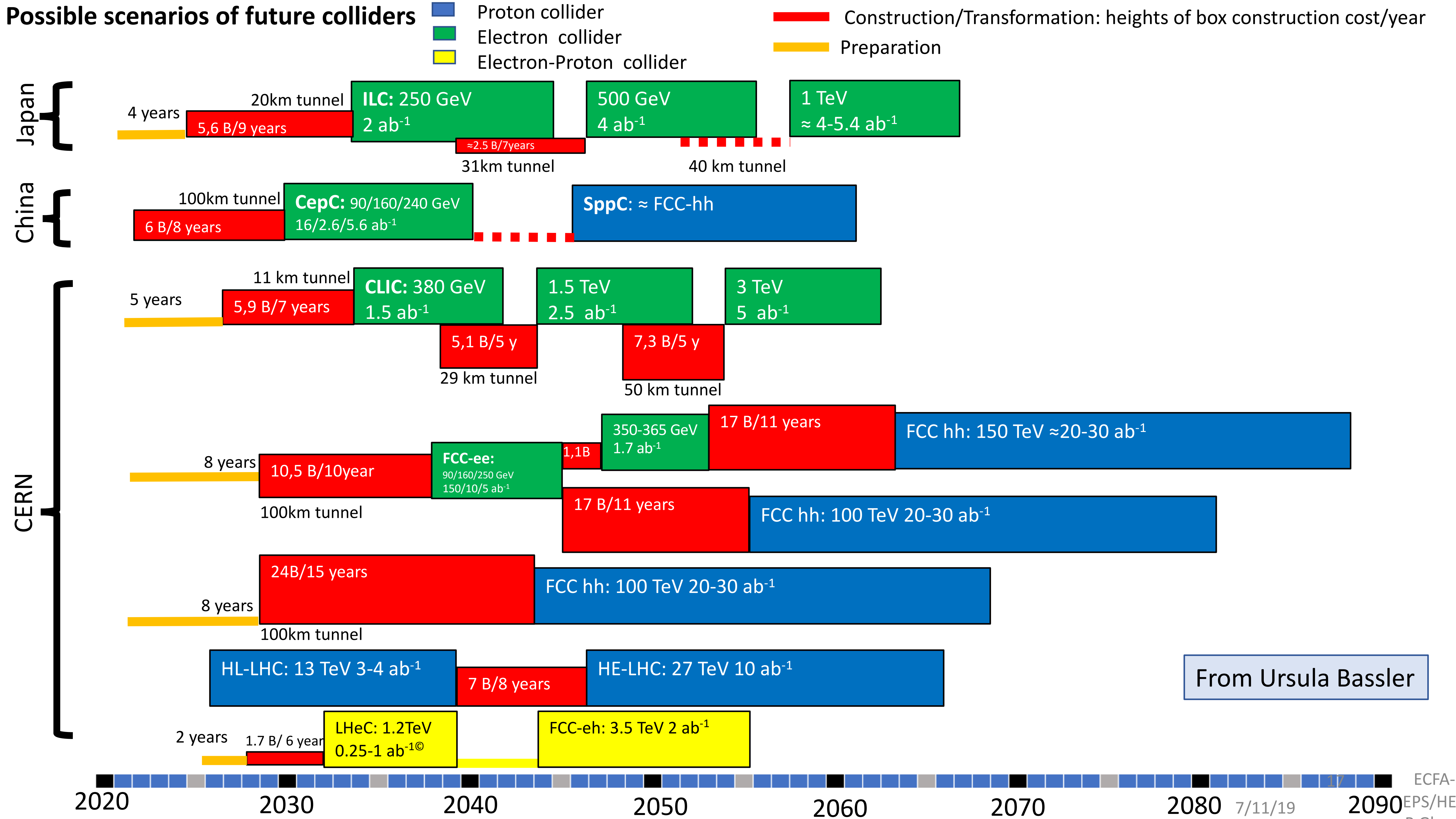


Possible scenarios of future colliders
Proton collider
Electron collider
Electron-Proton collider
Construction/Transformation: heights of box construction cost/year
Preparation
Japan
4 years
20km tunnel
5,6 B/9 years
ILC: 250 GeV
2 ab-1
≈2.5 B/7years
31km tunnel
500 GeV
4 ab-1
40 km tunnel
1 TeV
≈ 4-5.4 ab-1
China
100km tunnel
6 B/8 years
CepC: 90/160/240 GeV
16/2.6/5.6 ab-1
SppC: ≈ FCC-hh
CERN
5 years
11 km tunnel
5,9 B/7 years
CLIC: 380 GeV
1.5 ab-1
5,1 B/5 y
29 km tunnel
1.5 TeV
2.5 ab-1
7,3 B/5 y
50 km tunnel
3 TeV
5 ab-1
8 years
10,5 B/10year
100km tunnel
FCC-ee:
90/160/250 GeV
150/10/5 ab-1
1,1B
350-365 GeV
1.7 ab-1
17 B/11 years
FCC hh: 150 TeV ≈20-30 ab-1
17 B/11 years
FCC hh: 100 TeV 20-30 ab-1
8 years
24B/15 years
100km tunnel
FCC hh: 100 TeV 20-30 ab-1
HL-LHC: 13 TeV 3-4 ab-1
7 B/8 years
HE-LHC: 27 TeV 10 ab-1
From Ursula Bassler
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
2090

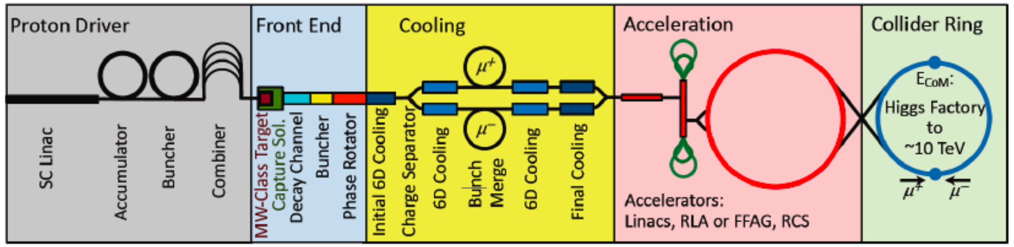
Report from Open Symposium in Granada

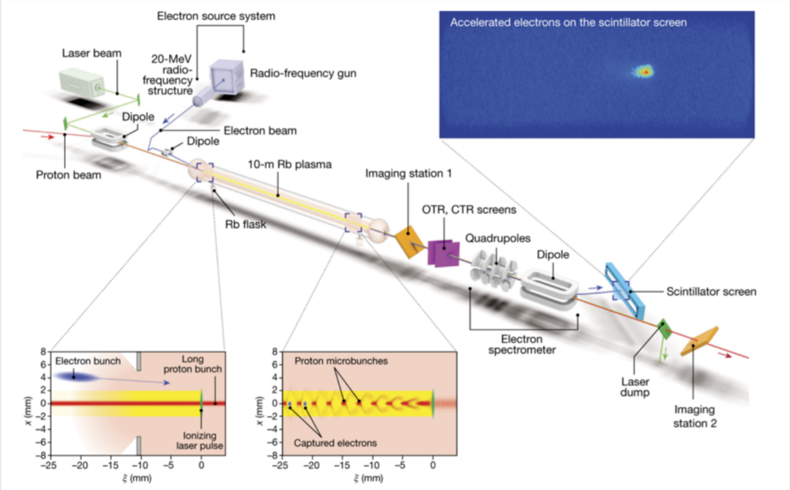
Future developments

Very interesting R&D projects

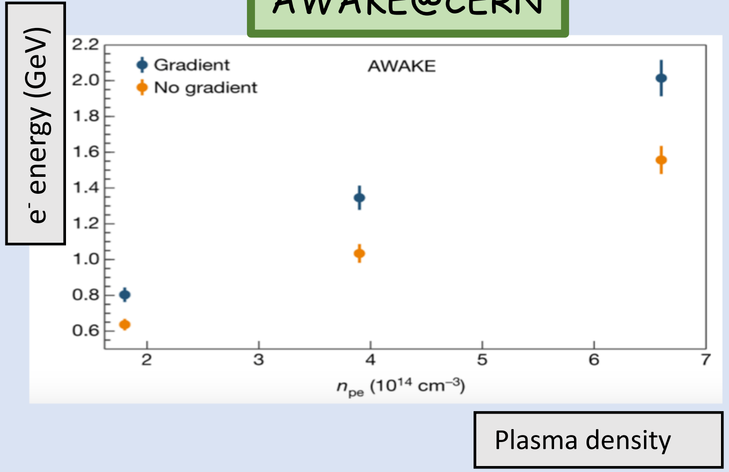
- Muon collider:
  - from proton beam (rcooling success: MICE)
  - from e+e- production (LEMMA)
- Plasma wakefield acceleration:
  - High gradients possible: ~100 GV/m
  - R&D progressing well but many challenges

Muon-based technology represents a unique opportunity for the future of high energy physics research: the multi-TeV energy domain exploration.





AWAKE@CERN



Achieved 2 GeV over 10m
Gradient 200 MV/m

Precision physics with the Higgs

Why precision physics with the Higgs boson

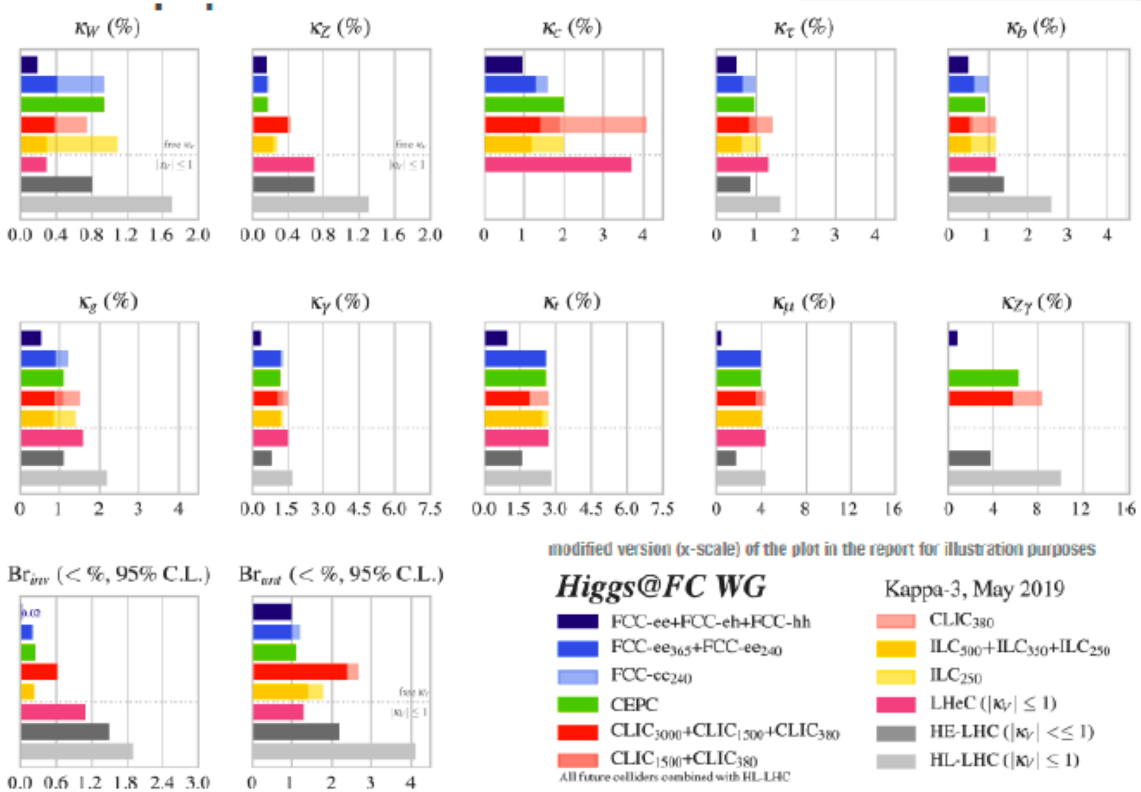
- H as a scalar couples to all the fundamental particles

Comparison of Colliders: kappa-framework

Some observations:

- **HL-LHC achieves precision of ~1-3% in most cases**
  - **In some cases model-dependent**
- **Proposed e^+e^- and ep colliders improve w.r.t. HL-LHC by factors of ~2 to 10**
- **Initial stages of e^+e^- colliders have comparable sensitivities (within factors of 2)**
- **ee colliders constrain $BR \rightarrow$ *untagged* w/o assumptions**
- **Access to κ_c at ee and eh**

arXiv:1905.03764



Various collider options relative to HL-LHC

of "largely" improved H couplings (EFT)

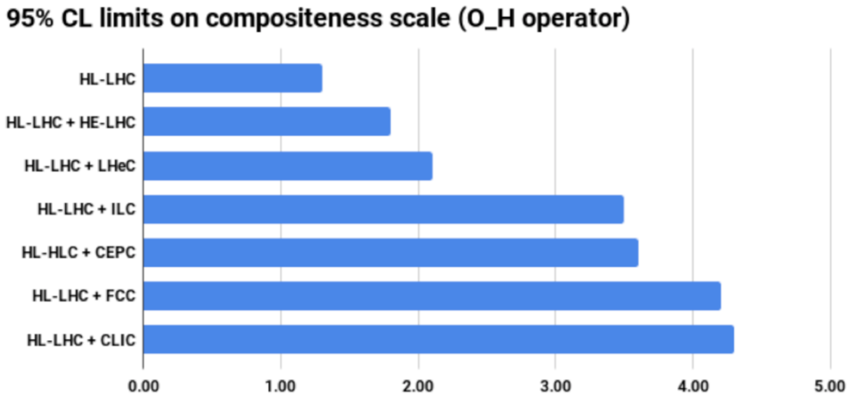
		Factor ≥2	Factor ≥5	Factor ≥10	Years from T_0
Initial run	CLIC380	9	6	4	7
	FCC-ee240	10	8	3	9
	CEPC	10	8	3	10
	ILC250	10	7	3	11
2nd/3rd Run ee	FCC-ee365	10	8	6	15
	CLIC1500	10	7	7	17
	HE-LHC	1	0	0	20
	ILC500	10	8	6	22
hh	CLIC3000	11	7	7	28
ee,eh & hh	FCC-ee/eh/hh	12	11	10	>50

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

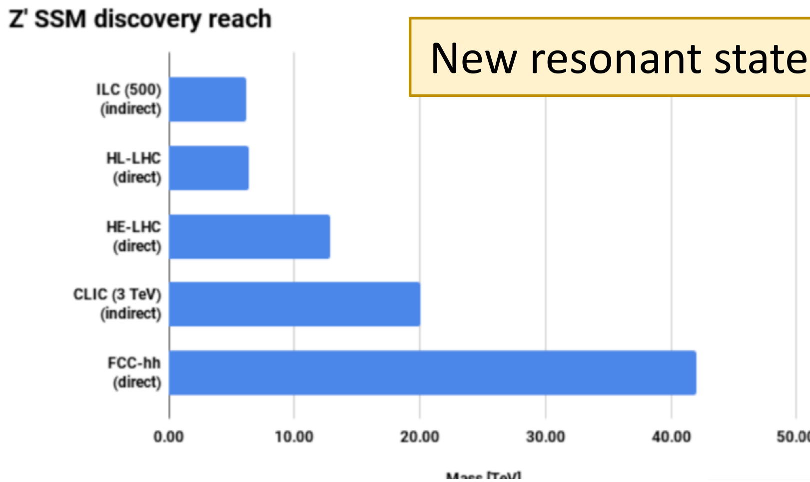
BSM at colliders

Higgs compositeness scale

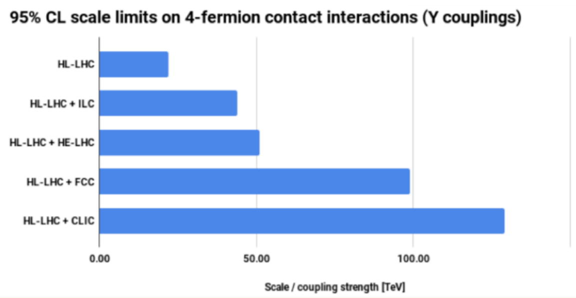


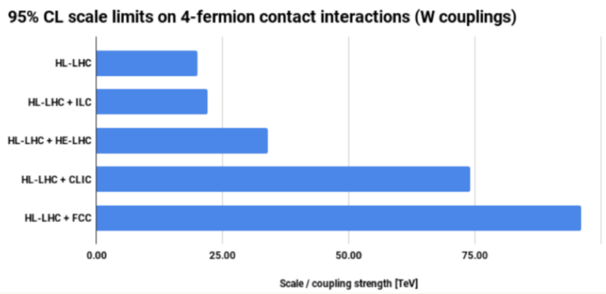
Maximum sensitivities from CLIC and FCC(ee+eh+hh)

New resonant states



Contact Interactions

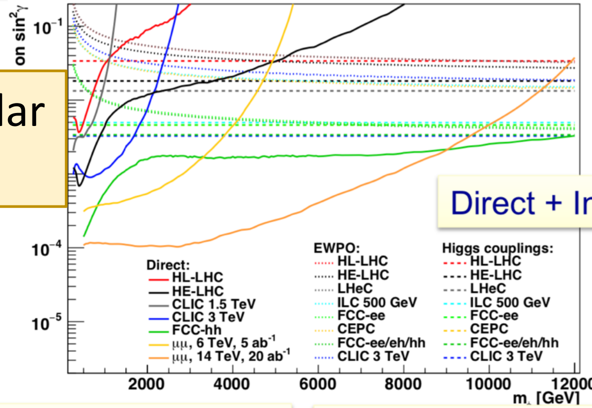




Sensitivity for ee colliders enhanced for couplings ≳ 1
(weak couplings → direct searches become more sensitive)
Searches for W' & charged fermion currents more effective at hadron colliders

Extended scalar sector

Direct searches: pp: main LHC result ZZ; hadron colliders: extrap in √s; $e^+e^- \to \nu\nu\varphi$; $\varphi \to hh \to bbbb$



Direct + Indirect

And much more

Challenges for the European Strategy Group

Recommend future facility in Europe

Are we ready? **NO, but**

- Guidance from the Briefing Book
- Projects assessment of technological readiness, time scales, financial profile, operational costs, innovation, reach, …
- National Inputs (pre-Granada) – subject to interpretation, however
  - ✓ Clear preference for an e^+e^- collider as the next facility
  - ✓ R&D for future high energy colliders (new technologies)
  - ✓ Hadron collider beyond LHC
  - ✓ Support for diversity programme
  - ✓ Synergies with Astroparticle Physics

Plan to return to community with post-Granada scenarios

Challenges for the European Strategy Group

Additional aspects to be considered

- Ensure adequate dynamism in the particle physics science to remain attractive (long time scales)
  Many interesting ideas to complement energy frontier with precision measurements
  (EDMs, rare decays, low energy DM like dark mediators or axions, neutrinos,…, QCD)
- Ensure adequate support for theory development and related tools (career path)
  Difficult to convince Academia – National Labs may help (CERN included)
- Ensure preservation of expertise in detector, accelerator and computing sciences
  See above; enhance the role of National Institutions
- Communicate interest of science to other fields of research and to society
  Seek synergies with ApPEC, NuPPEC, but also material science, light sources…
  Help with ECO (Education/Communication/Outreach) with dedicated funding
- … Think about innovative ways to increase funding !!!!

Strategy Secretariat

- H. Abramowicz (Chairperson)
- J. D'Hondt (ECFA Chairperson, *ECFA: European Committee for Future Accelerators*)
- K. Ellis (SPC Chairperson, *SPC: Science Policy Committee @ CERN*)
- L. Rivkin (European LDG Chairperson, *LDG: Lab Directors Group*)

Contact: EPPSU-Strategy-Secretariat@cern.ch

Physics Peparatory Group

- *Strategy Secretariat*
- Caterina Biscari (ES), Belen Gavela (ES), Beate Heinemann (DE), Krzysztof Redlich (PL) – *delegates nominated by SPC*
- Stan Bentvelsen (NL), Paris Sphicas (GR), Marco Zito (FR), Antonio Zoccoli (IT) – *delegates nominated by ECFA*
- Gian Giudice (*CERN*) – *nominated by CERN*
- Shoji Asai (Japan) and Xinchou Lou (China) - *delegates from Asia nominated by ICFA*
- Marcela Carena (US) and Brigitte Vachon (Canada) - *delegates from the Americas nominated by ICFA*

Responsible to organize the Open Symposium and to deliver to the European Strategy Group (ESG) a Briefing Book.

Composition of the ESG

European Strategy Group (ESG) composition, adopted by Council, December 2013:

- the Strategy Secretary (acting as Chairperson),
- one representative appointed by each CERN Member State,
- one representative for each of the Laboratories participating in the major European Laboratory Directors' meeting, including its Chairperson,
- the CERN Director-General,
- the SPC Chairperson,
- the ECFA Chairperson.

Responsible to deliver a draft Strategy Update to Council.

Invitees

- the President of the CERN Council,
- one representative from each of the Associate Member States,
- one representative from each Observer State,
- one representative from the European Commission and JINR,
- the Chairpersons of ApPEC, FALC, ESFRI, and NuPECC,
- the members of the Physics Preparatory Group.