# European Particle Physics Strategy Update 2020

Halina Abramowicz
Tel Aviv University

- About CERN and the European Strategy
- About the Symposium in Granada
- Examples of addressed physics issues
- About research tools
- Challenges ahead

# Organisation of the European Particle Physics

## CERN

CERN was established in 1954 in post-war Europe with 12 member states, as the European Organisation for Nuclear Research (Conseil européen pour la recherche nucléaire).

CERN main role is to provide particle accelerators and other infrastructure for high energy physics research, complementary to existing national infrastructures.

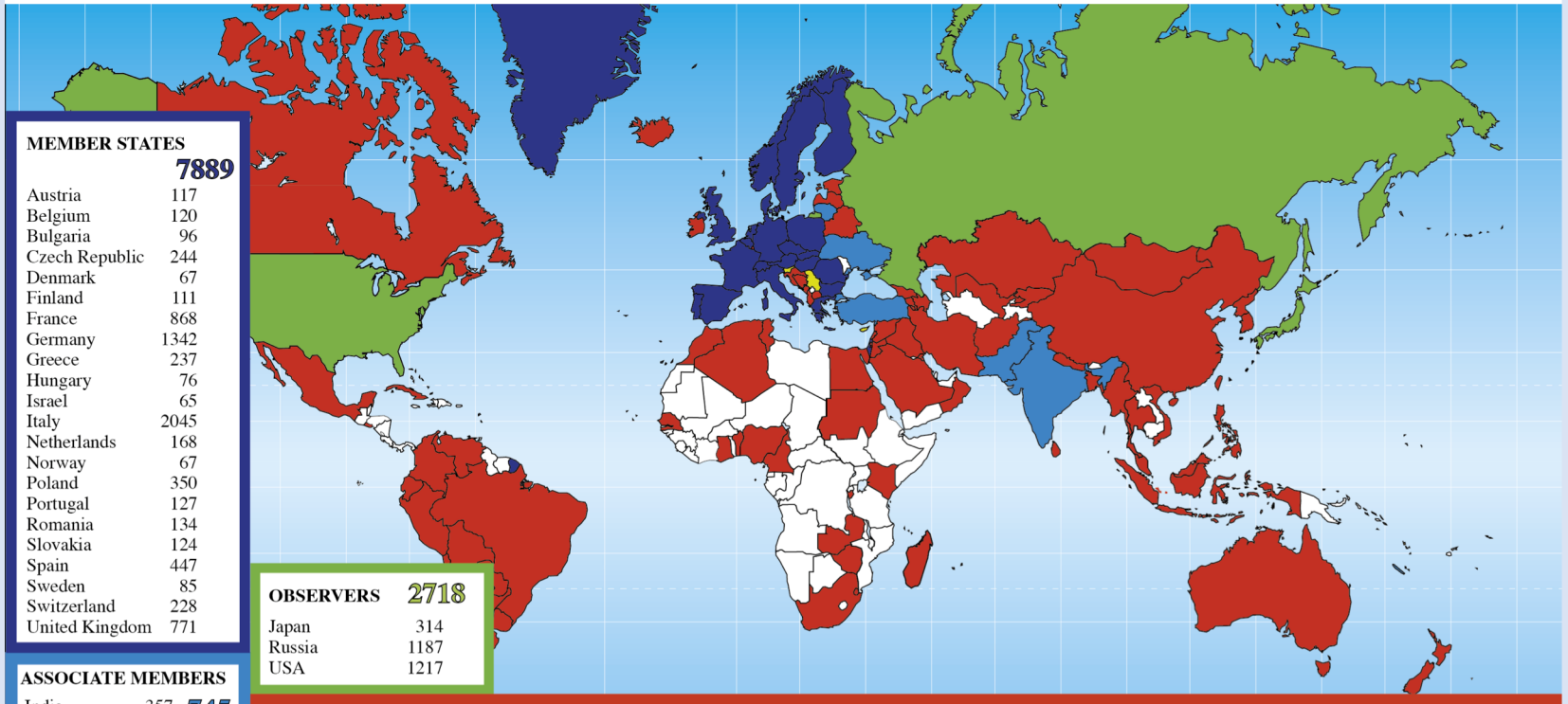
CERN employs about 2500 scientific, technical and administrative staff members. It has the status of an international organization.

CERN has special programmes to host young (fellows) and senior scientists (research associates) mainly from Europe, for extended periods of time. It has many short and long term training programmes in science and technology.

With time and increase in the size and cost of the accelerators, CERN and in particular the CERN Council became the coordinating body for the science of particle physics in Europe.

# CERN Users

## Distribution of All CERN Users by Nationality on 24 January 2018



**MEMBER STATES** 7889

| | |
|---|---|
| Austria | 117 |
| Belgium | 120 |
| Bulgaria | 96 |
| Czech Republic | 244 |
| Denmark | 67 |
| Finland | 111 |
| France | 868 |
| Germany | 1342 |
| Greece | 237 |
| Hungary | 76 |
| Israel | 65 |
| Italy | 2045 |
| Netherlands | 168 |
| Norway | 67 |
| Poland | 350 |
| Portugal | 127 |
| Romania | 134 |
| Slovakia | 124 |
| Spain | 447 |
| Sweden | 85 |
| Switzerland | 228 |
| United Kingdom | 771 |

**OBSERVERS** 2718

| | |
|---|---|
| Japan | 314 |
| Russia | 1187 |
| USA | 1217 |

**ASSOCIATE MEMBERS** 745

| | |
|---|---|
| India | 357 |
| Lithuania | 35 |
| Pakistan | 65 |
| Turkey | 173 |
| Ukraine | 115 |

**ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP** 118

| | |
|---|---|
| Cyprus | 26 |
| Serbia | 57 |
| Slovenia | 35 |

**OTHERS** 1872

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Afghanistan | 1 | Bolivia | 4 | Egypt | 31 | Kazakhstan | 5 | Mongolia | 2 | Philippines | 3 | Thailand | 22 |
| Albania | 3 | Bosnia & Herzegovina | 2 | El Salvador | 1 | Kenya | 3 | Montenegro | 11 | Saint Kitts | | T.F.Y.R.O.M. | 2 |
| Algeria | 14 | Brazil | 135 | Estonia | 15 | Korea Rep. | 185 | Morocco | 20 | and Nevis | 1 | Tunisia | 5 |
| Argentina | 27 | Burundi | 1 | Georgia | 46 | Kyrgyzstan | 1 | Myanmar | 1 | Saudi Arabia | 2 | Uruguay | 1 |
| Armenia | 19 | Cameroon | 1 | Ghana | 1 | Latvia | 2 | Nepal | 10 | Senegal | 1 | Uzbekistan | 4 |
| Australia | 31 | Canada | 161 | Hong Kong | 1 | Lebanon | 23 | New Zealand | 5 | Singapore | 4 | Venezuela | 10 |
| Azerbaijan | 10 | Chile | 20 | Iceland | 3 | Luxembourg | 2 | Nigeria | 3 | South Africa | 56 | Viet Nam | 13 |
| Bangladesh | 11 | China | 510 | Indonesia | 11 | Madagascar | 4 | North Korea | 1 | Sri Lanka | 6 | Zambia | 1 |
| Belarus | 48 | Colombia | 45 | Iran | 51 | Malaysia | 15 | Oman | 3 | Sudan | 1 | Zimbabwe | 2 |
| Benin | 1 | Croatia | 41 | Iraq | 1 | Malta | 9 | Palestine (O.T.). | 7 | Swaziland | 1 | | |
| | | Cuba | 12 | Ireland | 16 | Mauritius | 1 | Paraguay | 2 | Syria | 1 | | |
| | | Ecuador | 6 | Jordan | 1 | Mexico | 82 | Peru | 7 | Taiwan | 51 | | |

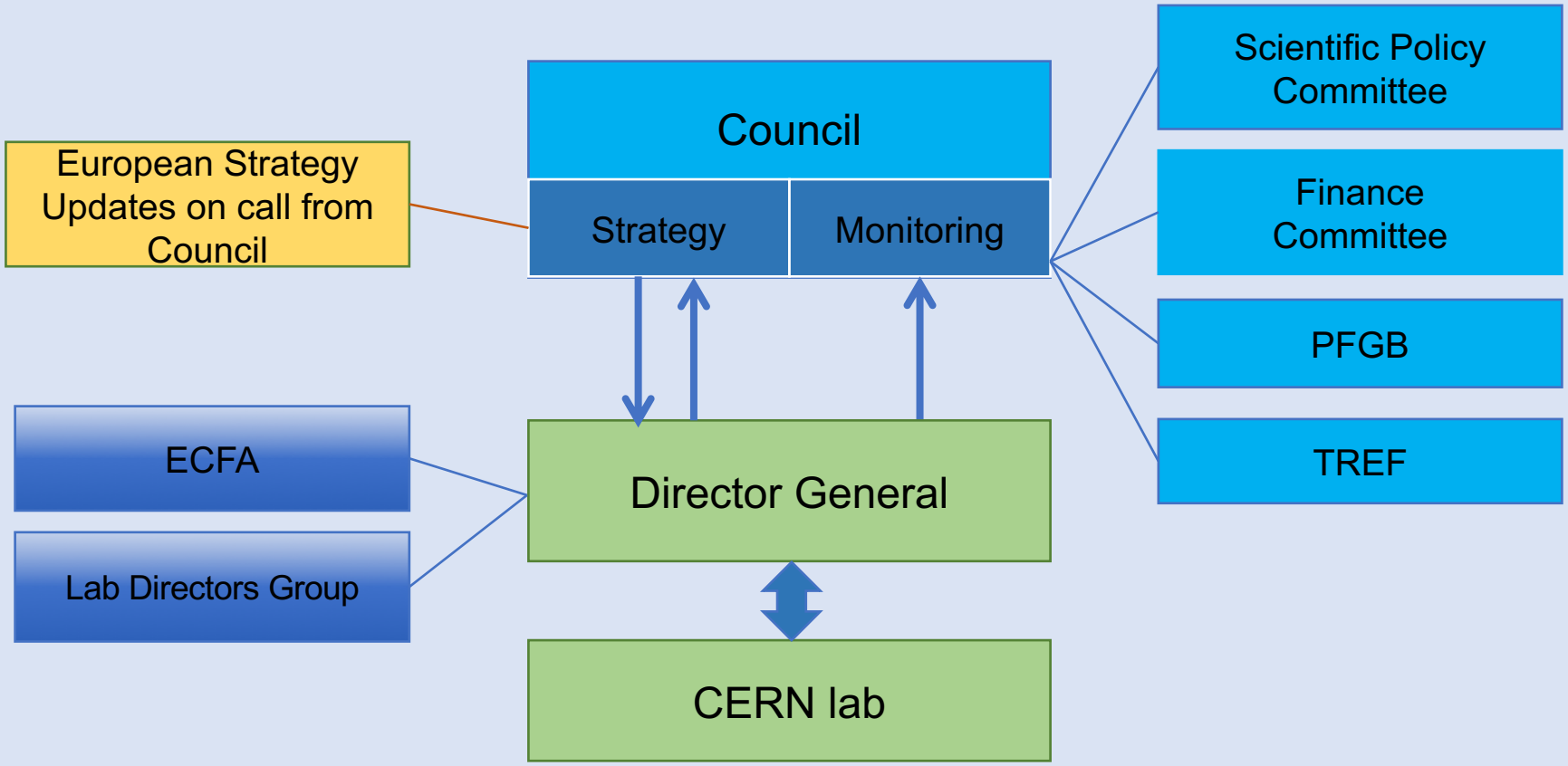
Total: 13342 users

Observer States
20%

Others
14%

US 1217 users
9%

# European Particle Physics Organisation and Governance




Based on a slide from the President of Council, at the FALC meeting, Cambridge (UK), March 8, 2018

# Why European Strategy for Particle Physics?

- Relation between ESFRI and CERN had to be clarified within the European Commission
  - ESFRI, the European Strategy Forum on Research Infrastructures (initiated in 2002, mandated in 2004), is a strategic instrument to develop the scientific integration of Europe and to strengthen its international outreach.
  - CERN's Convention mandates coordination of infrastructure of particle physics for Member States
- First ESFRI roadmap published in 2006, with 35 projects, the Roadmap was updated in 2008 bringing the number of RIs of pan-European relevance to 44. Later updates 2010, 2016, 2018 (49+6 new)
- First European Particle Physics Strategy (EPPS) called by CERN Council in 2005 and endorsed in 2006, latest update in 2013… next in 2020.

A regional strategy implemented in a worldwide context

*the Director-General is responsible for the implementation of the European Strategy for Particle Physics*

# Organisation of the EPP 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)

# Typical Remit for the Strategy

## Strategy Group Remit for the 2006 EPPS

**The Strategy Group shall aim:**

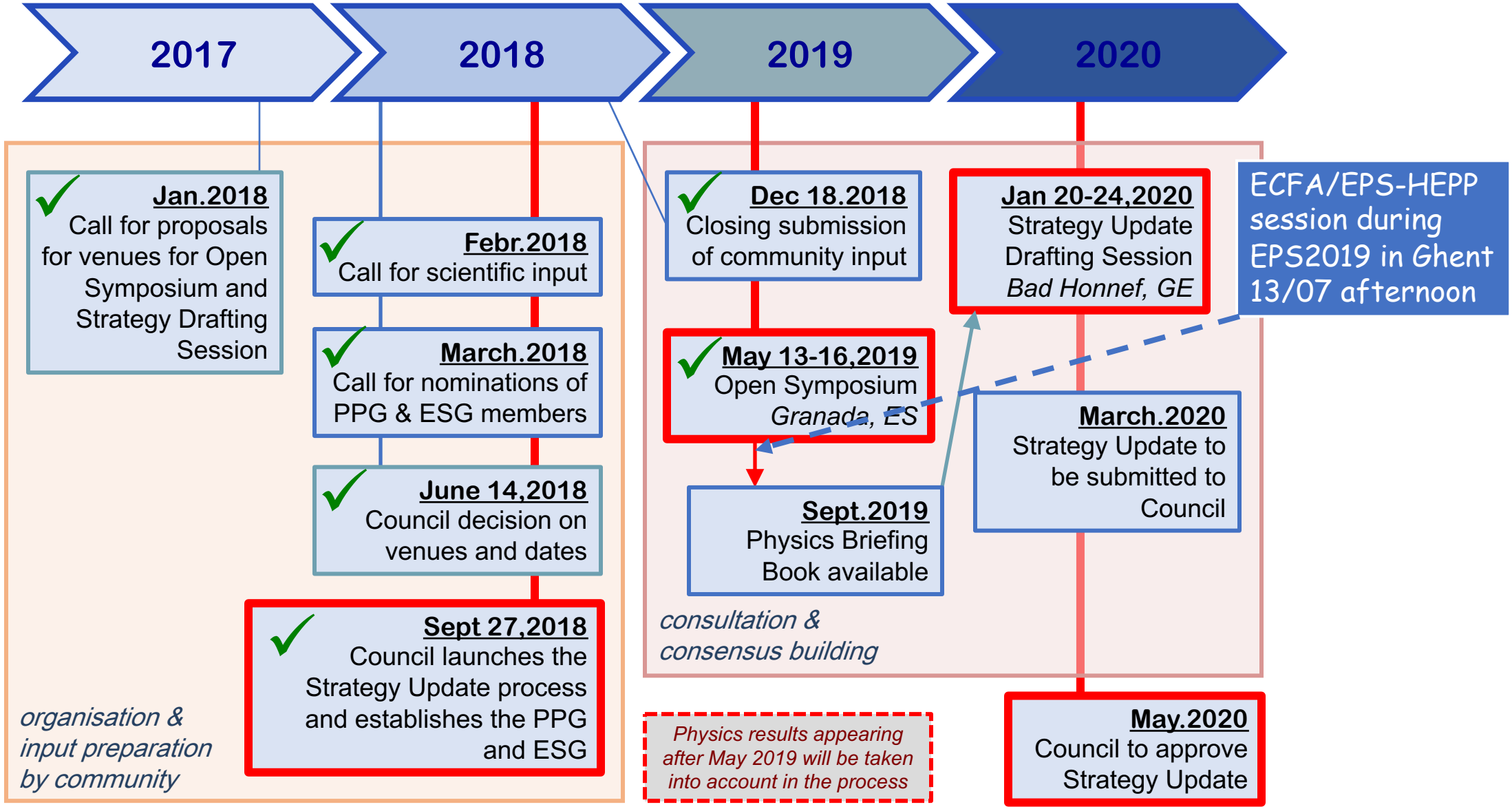
- to enhance the visibility of existing European particle physics programs;
- to foster increased collaboration among Europe's particle physics laboratories and institutes;
- to promote a coordinated European participation in world-wide projects;
- to encourage knowledge transfer to other disciplines, industries, and society;

- to outline priorities, at least implicitly;

- to consider time scales;

- to follow a thematic or project approach, whichever is more appropriate.

# EPPSU 2020 timeline



# 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

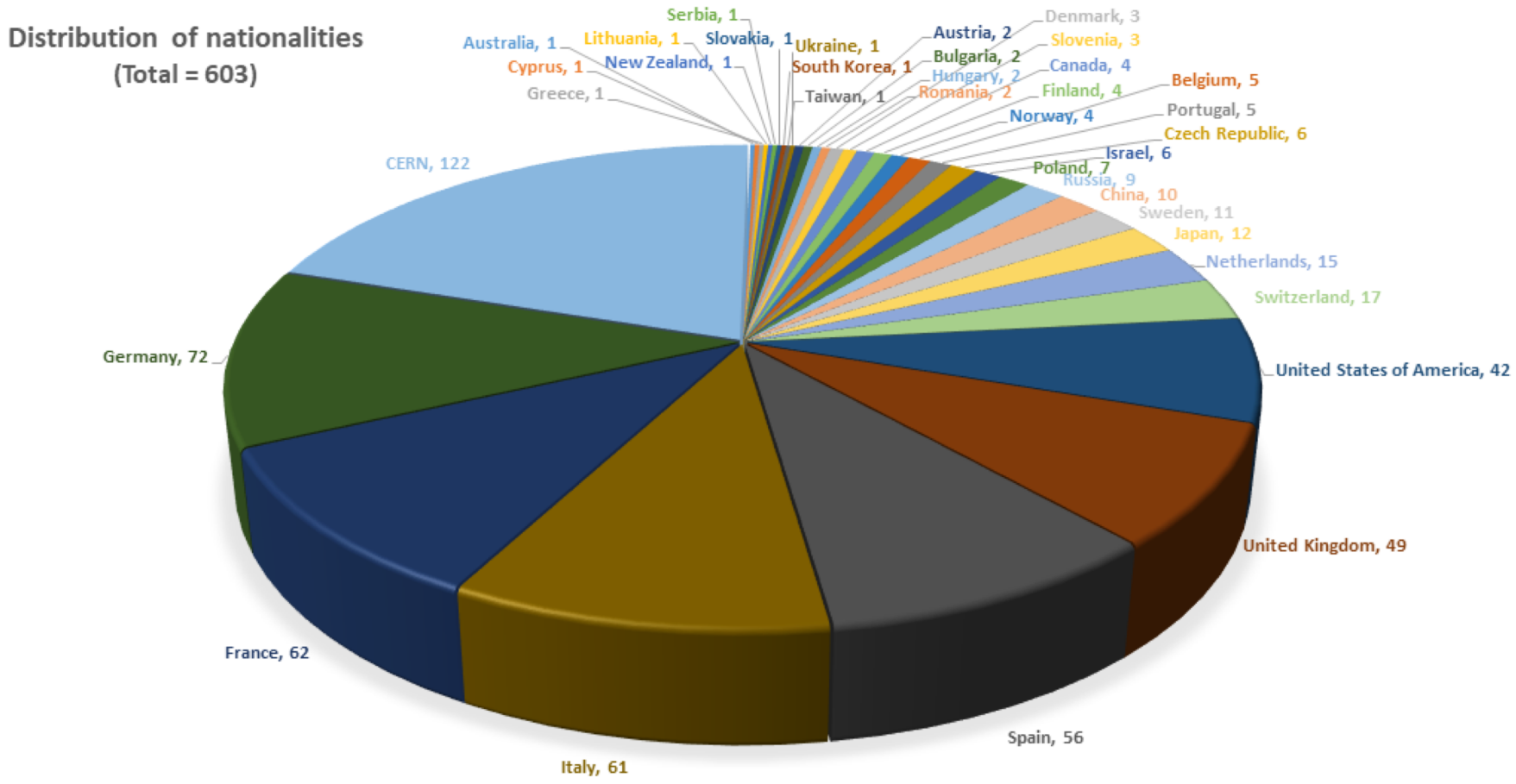
**Plenary Sessions**

- 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 draft of the Briefing Book

# 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

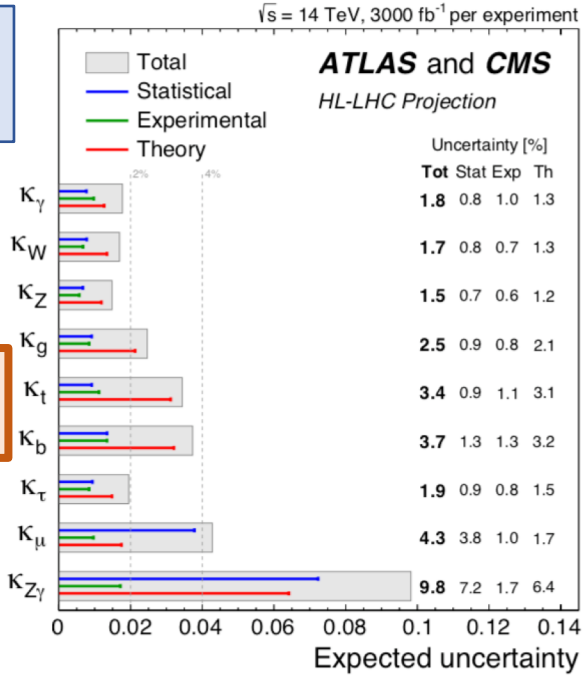
**What has changed since the 2013 Strategy Update?**

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

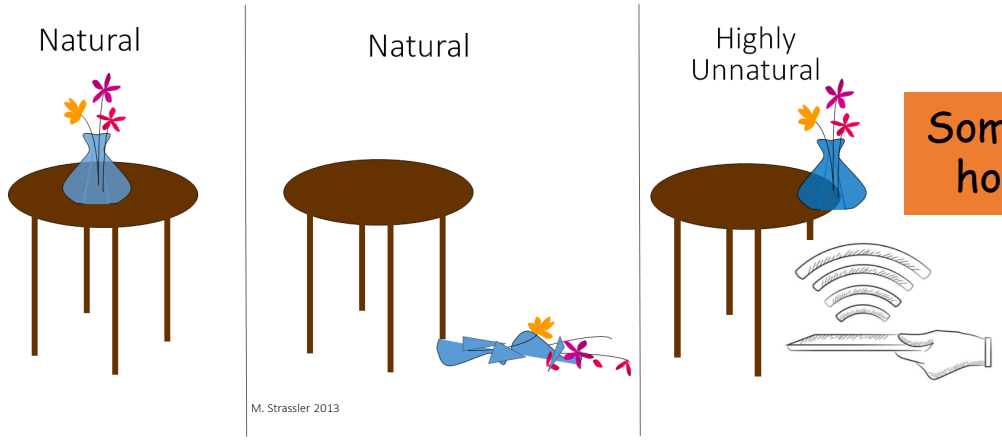
What did not change since the 2013 Strategy Update?

- 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



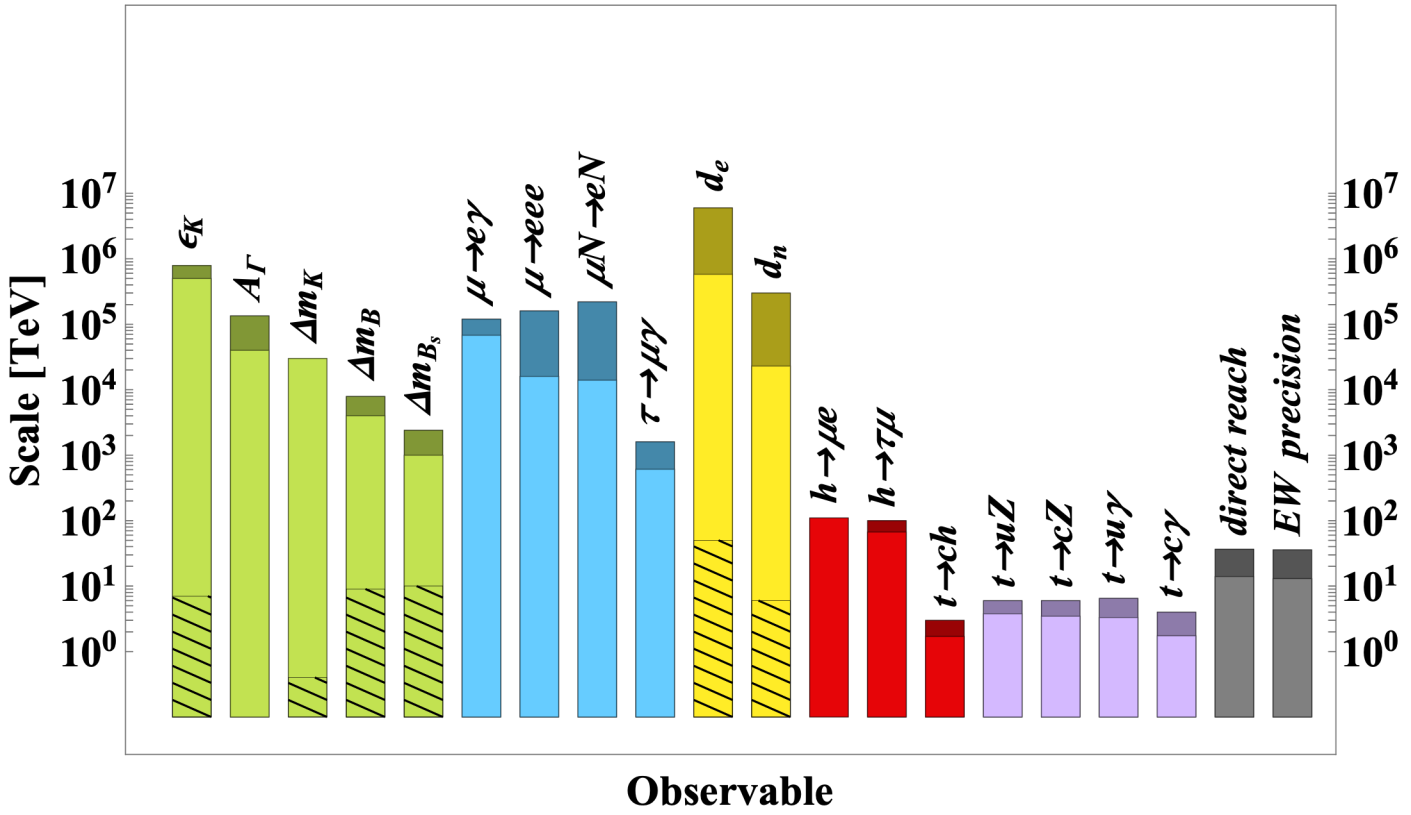

Something must be holding the vase

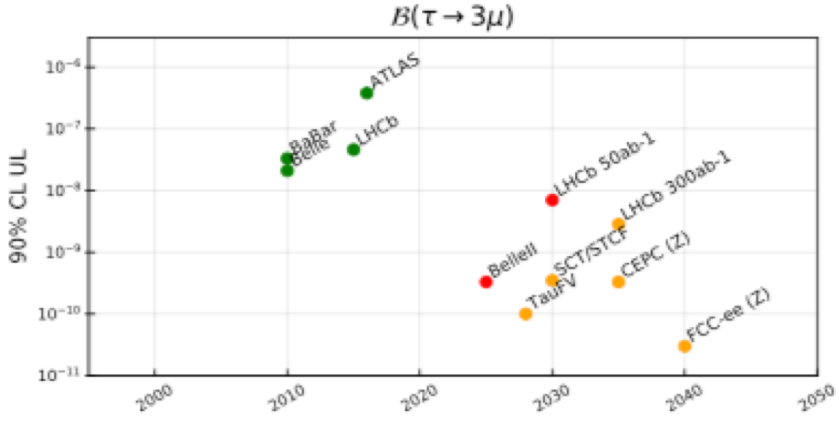
From Matt Strassler

# Report from Open Symposium in Granada

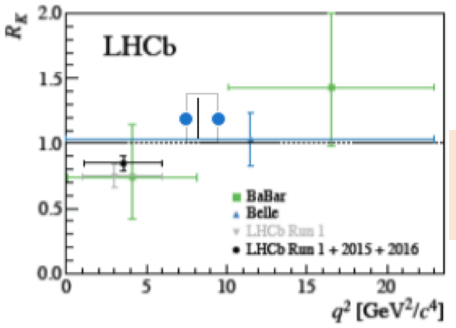
## Flavour Physics and CP

- 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




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



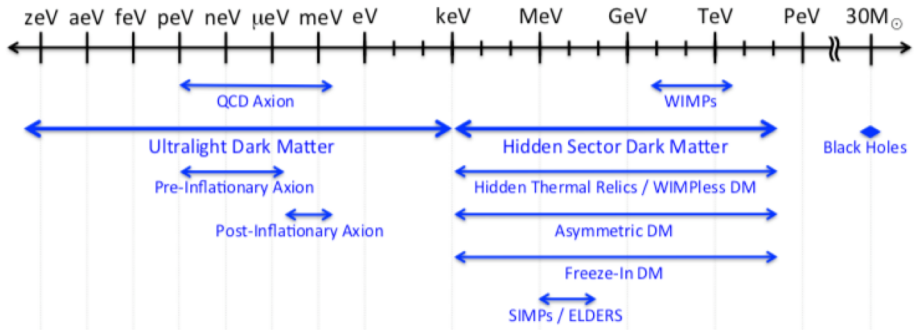

…. and more with kaon beams, charm …

# Report from Open Symposium in Granada

## Dark matter/Dark sector

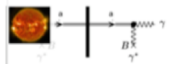
- Dark Matter
  - ➢ What if dark matter is light?
- Dark Sector
  - ➢ Search for dark photon

Too small mass ⇒ won't "fit" in a galaxy!




From MACHOs searches

### Axion/ALP searches: Mature Key Techniques

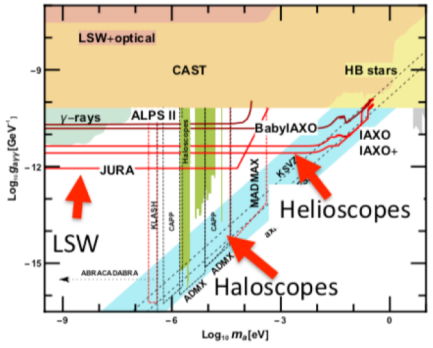


**Helioscopes**
- Build on success of CAST hosted by CERN
- Proposed BabyIAXO, leads to IAXO, with large discovery potential

**Haloscopes**
- ADMX (US) is leading the field
- In Europe, MadMax is new key player
- Smaller efforts developing new techniques

**Light-shining-through-walls**
- ALPS II is well underway
- STAX is a new idea RF based
- JURA is long term plan

Lindner and Irastorza's talks




Searches relevant for both QCD Axions and more general Axion-like particles (ALPs)

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 | $DZ_\mu$, ALPs |

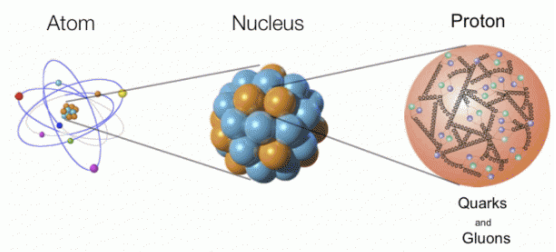
*NB: CERN offers unique opportunities with both lepton and hadron beams*
**LHCb and LHC-LLP dedicated projects (FASER, milliQan, CODEX-b, MATHUSLA) have also sensitivity in similar mass range**

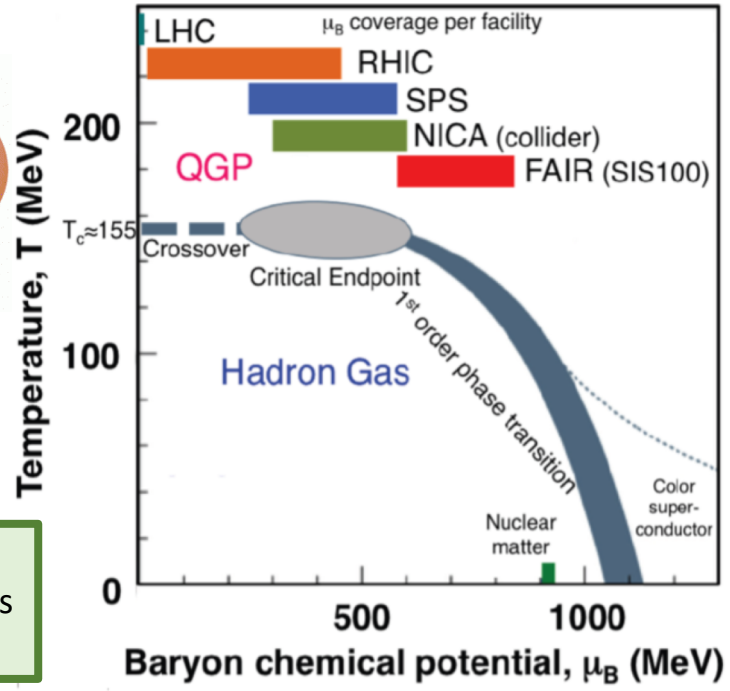
# Report from Open Symposium in Granada

## Strong Interactions (QCD)

Human kind consists of 95% QCD and 5% Higgs

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

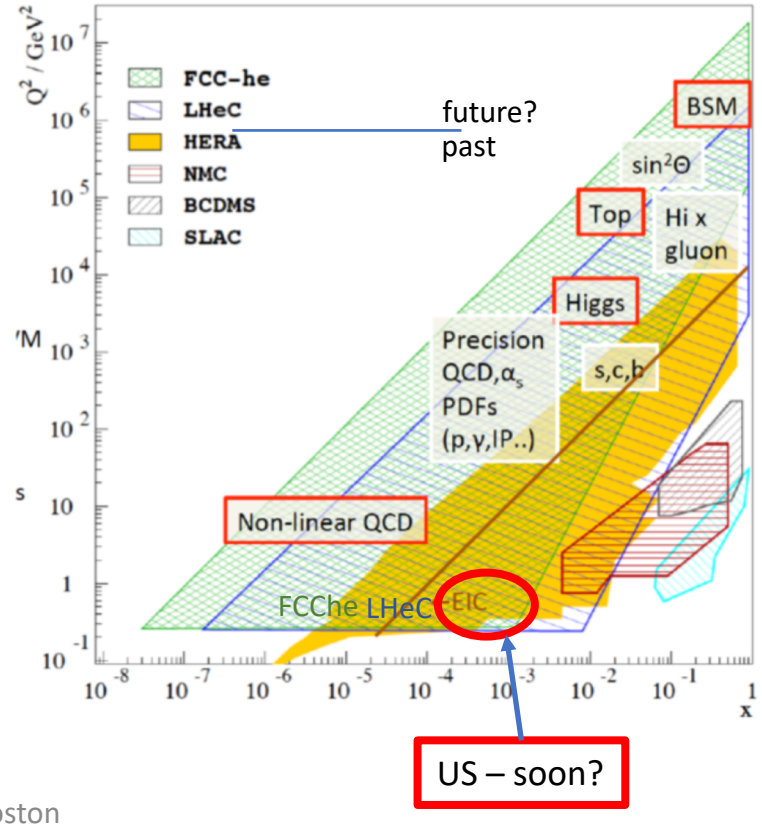


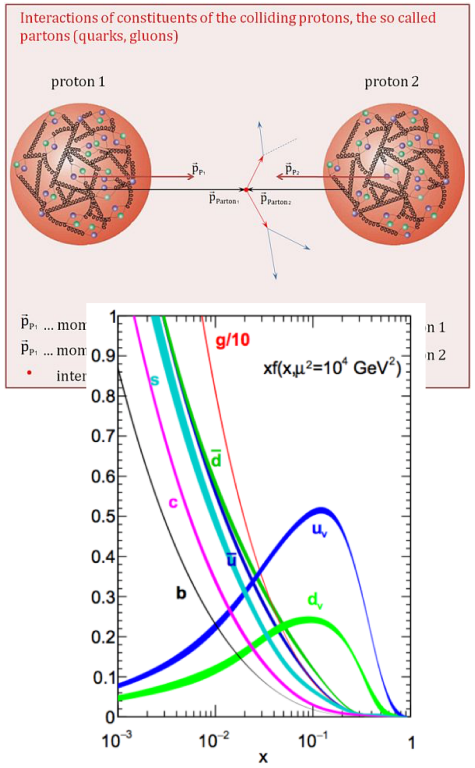

Quark gluon plasma
- Expected as gas of free partons
- Found to be a perfect liquid

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)



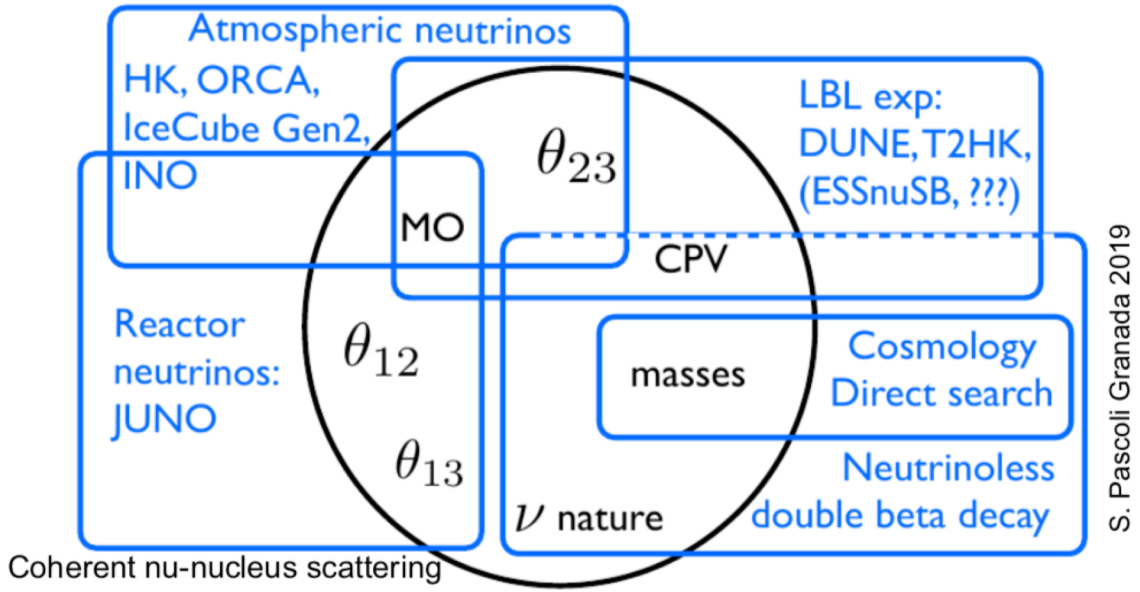

US – soon?



# Report from Open Symposium in Granada

## Neutrino physics and Astroparticle

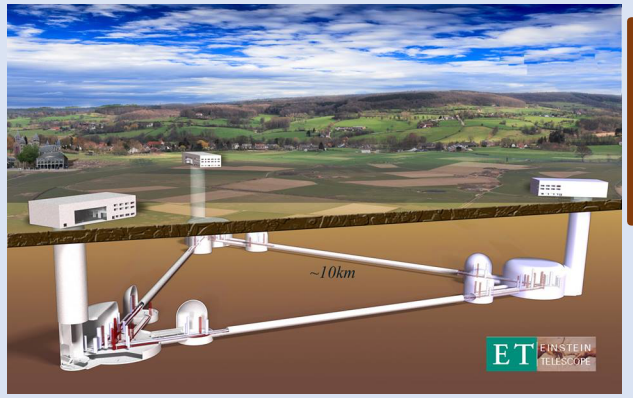
### A very diverse experimental approach




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

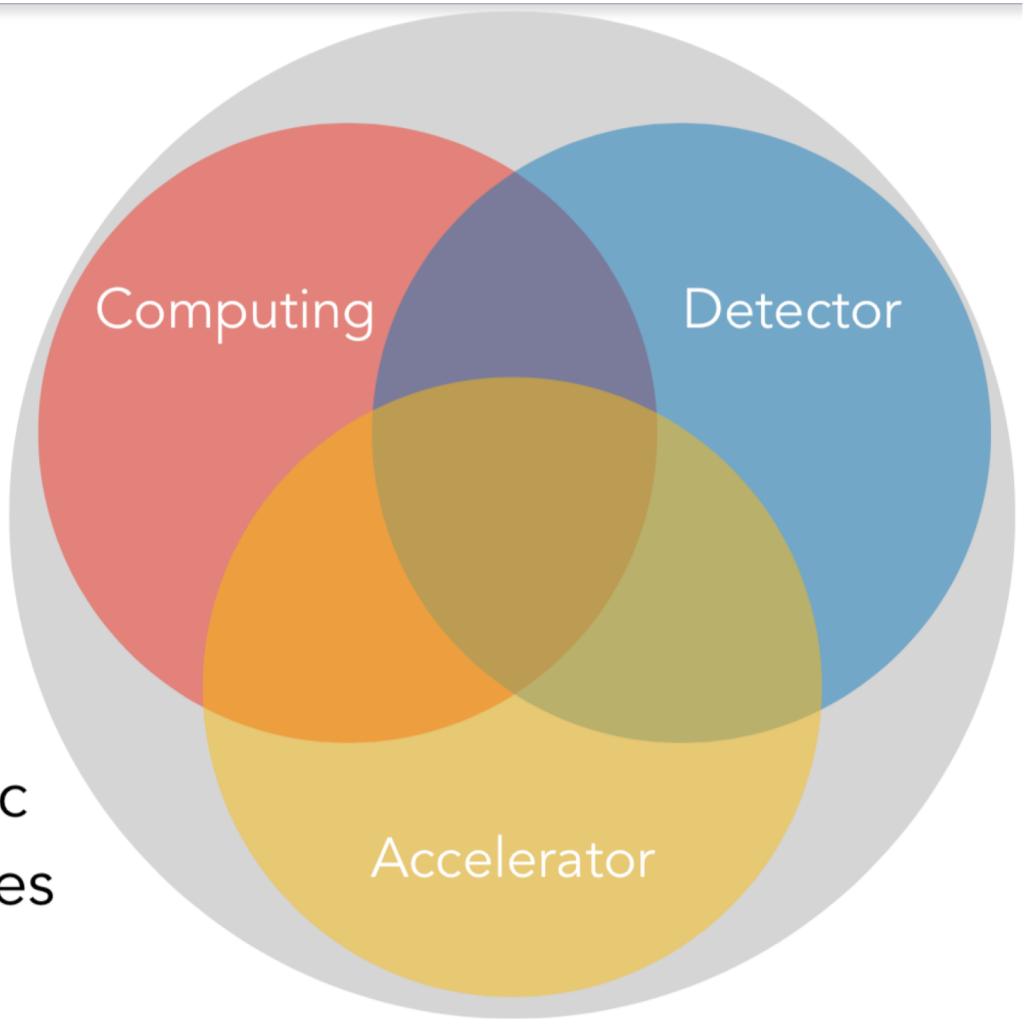
- Gravitational waves and multimessenger physics open up a new window on the Universe. Very strong physics case.
- There is a very high impact on the field of particle physics (and fundamental interactions) (eg dark matter, neutrinos, general relativity, ...)
- There is clearly an opportunity for the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



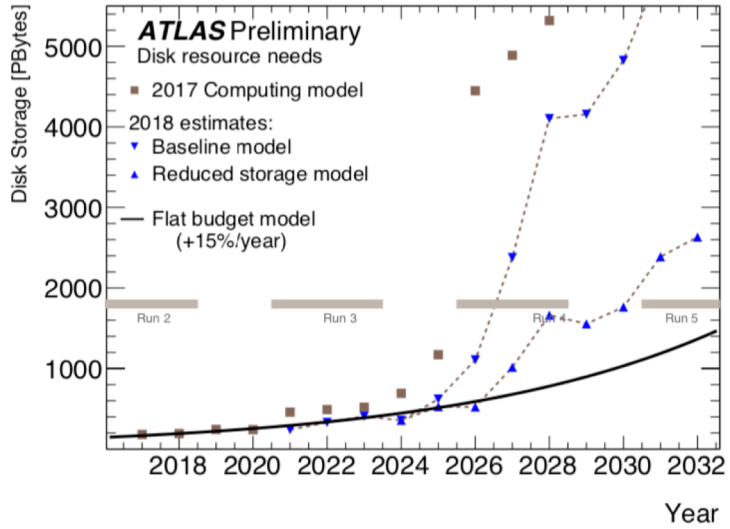

Einstein telescope needs CERN expertise
*"Triangular accelerator without beam"*

# Report from Open Symposium in Granada

## Research Ingredients




Scientific outcomes



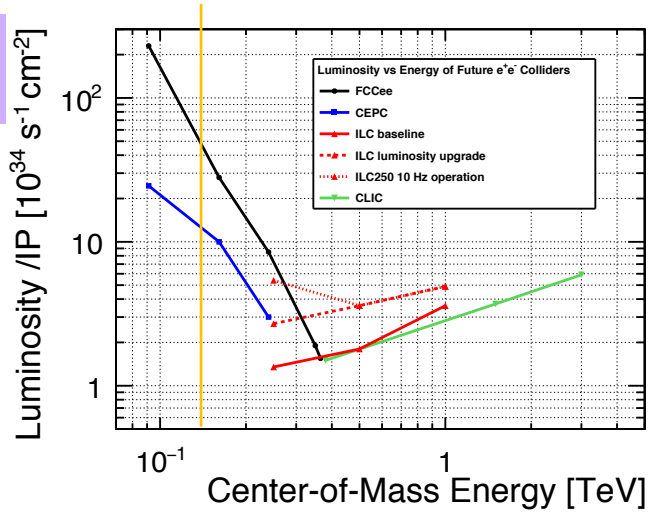

- Instrumentation and computing activities crucial t enable scientific programs.
- Important instrumentation and computing challenges ahead of us.
  - Exciting opportunities for innovation.
- Addressing these challenges will require taking into account
  - Human factor
  - R&D activities/coordination

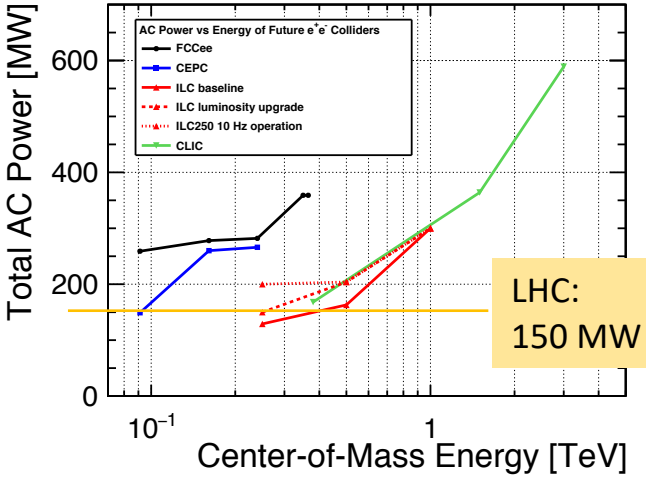
# Report from Open Symposium in Granada

## 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 | 15+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) |
| ***FCC-NbTi*** | *pp* | *37.5* | *10* | *20* | *240* | *14 GCHF (including tunnel)* |
| **HE-LHC** | pp | 27 | 20 | 20 | | 7.2 GCHF |




LHC:
150 MW

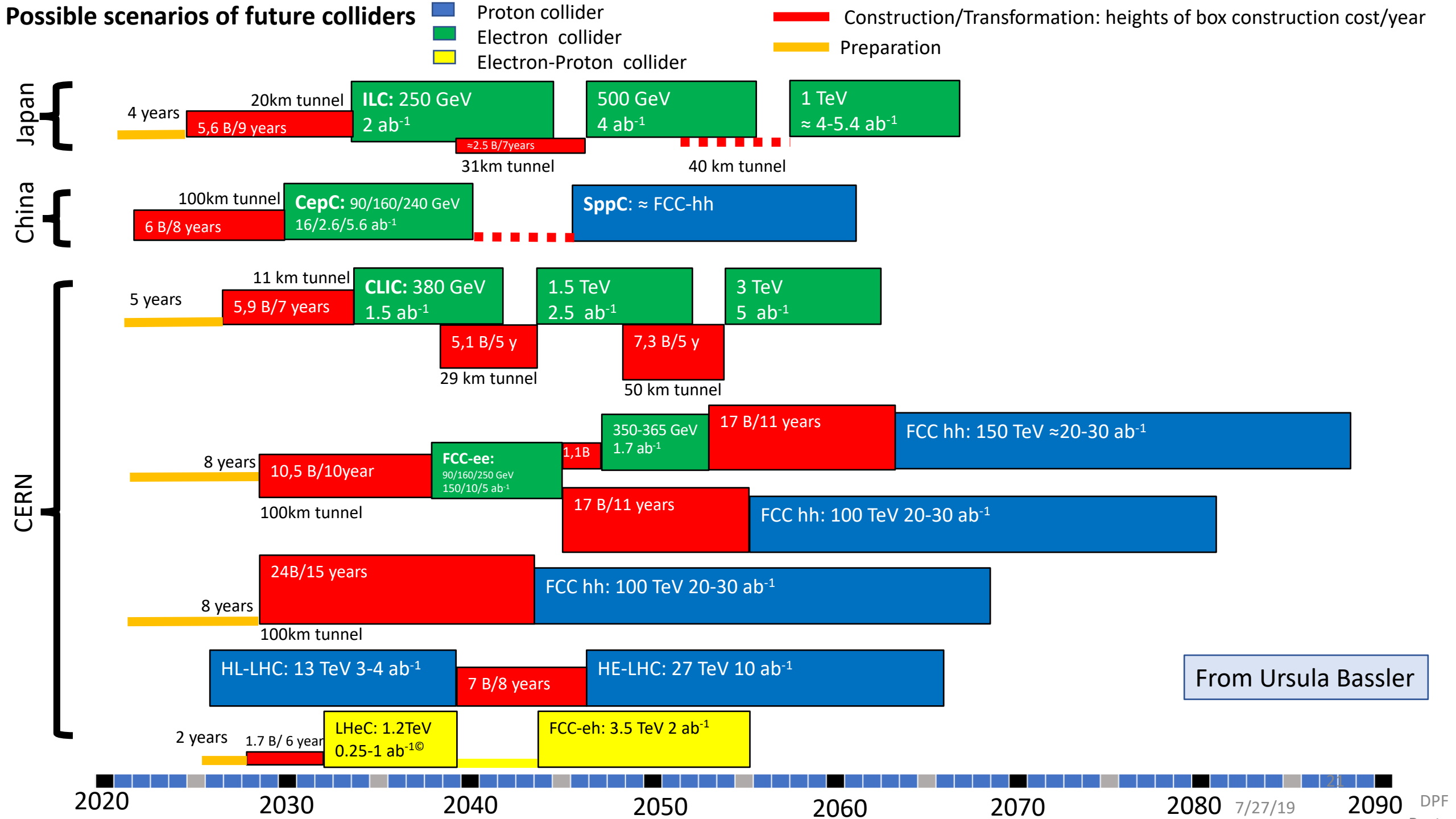
# Technical Challenges in Energy-Frontier Colliders proposed

| | | Ref. | E (CM) [TeV] | Luminosity [1E34] | AC-Power [MW] | Cost-estimate Value* [Billion] | B [T] | E: [MV/m] (GHz) | Major Challenges in Technology |
|---|---|---|---|---|---|---|---|---|---|
| C C hh | FCC-hh | CDR | ~ 100 | < 30 | 580 | 24 or +17 (aft. ee) [BCHF] | ~ 16 | | High-field SC magnet (SCM)<br>- Nb3Sn: Jc and Mechanical stress<br>Energy management |
| | SPPC | (to be filled) | 75 – 120 | TBD | TBD | TBD | 12 - 24 | | High-field SCM<br>- IBS: Jcc and mech. stress<br>Energy management |
| C C 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<br>Synchrotron Radiation constraint<br>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<br>Synchrotron Radiation constraint<br>High-precision Low-field magnet |
| L C 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<br>Higher-G for future upgrade<br>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<br>Two-beam acceleration in a prototype scale<br>Precise alignment and stabilization. timing |

A. Yamamoto, 190513b

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

# Possible scenarios of future colliders




From Ursula Bassler

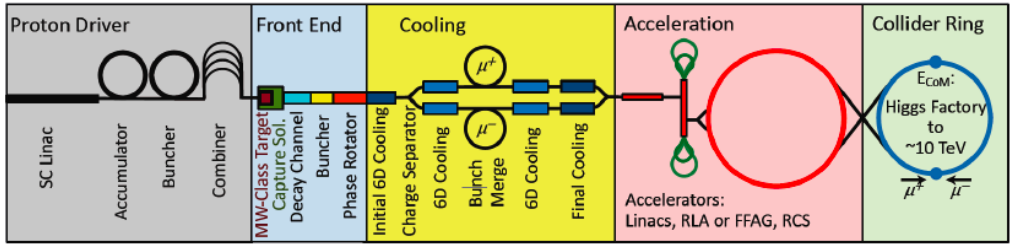
# Report from Open Symposium in Granada

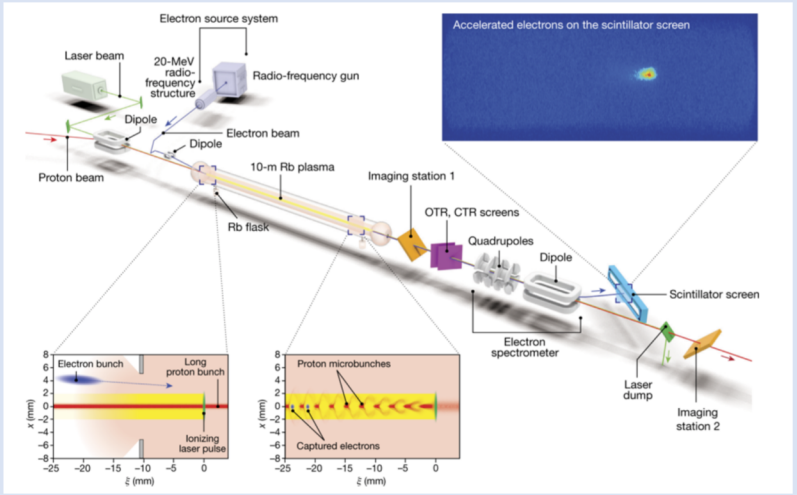
## Future developments

### Very interesting R&D projects

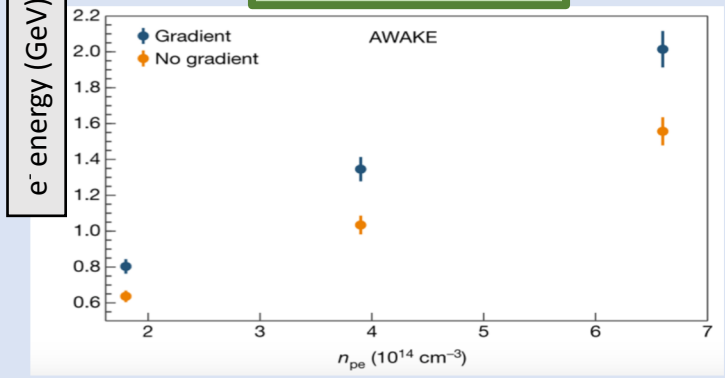
- Muon collider:
  - from proton beam (rcooling success: MICE)
  - from e+e- production (LEMMA)
- Plasma wakefield acceleration:
  - High gradients possible: ~100 GV/m
  - R&D progressing well but many challenges

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




AWAKE@CERN




Plasma density

Achieved 2 GeV over 10m
Gradient 200 MV/m

# Precision physics with the Higgs

Why precision physics with the Higgs boson

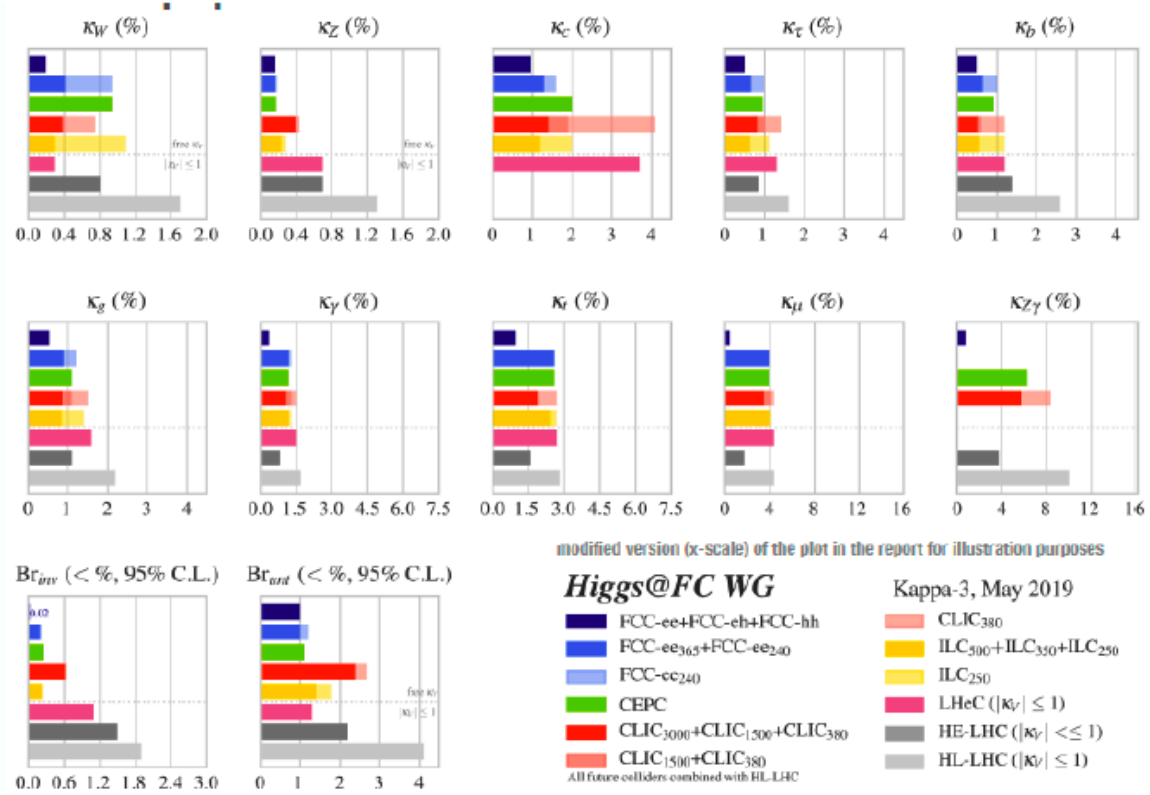
- H as a scalar couples to all the fundamental particles

## 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 $\kappa_c$ at ee and eh**

*arXiv:1905.03764*



# Report from Open Symposium in Granada

## 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 |

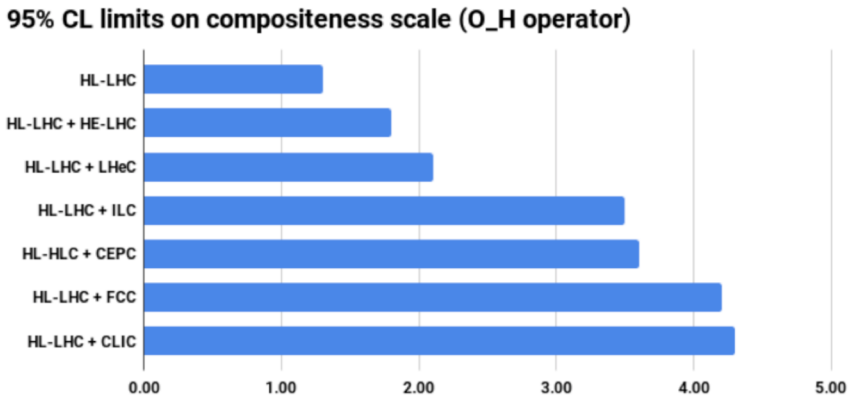
13 quantities in total

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

# Report from Open Symposium in Granada

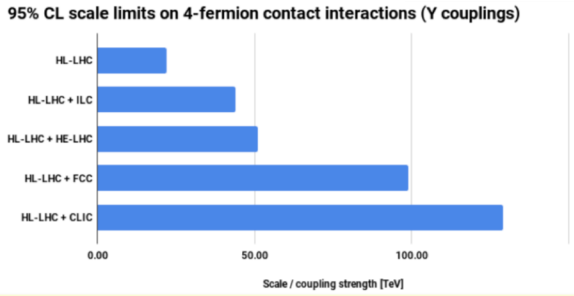
## BSM at colliders

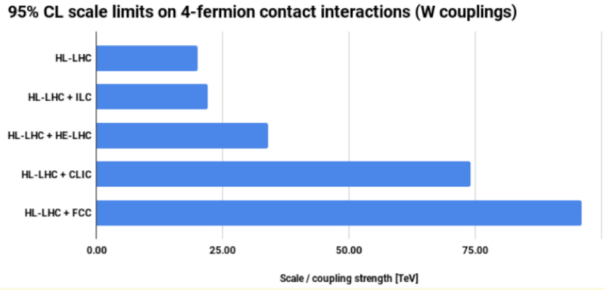
Higgs compositeness scale




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

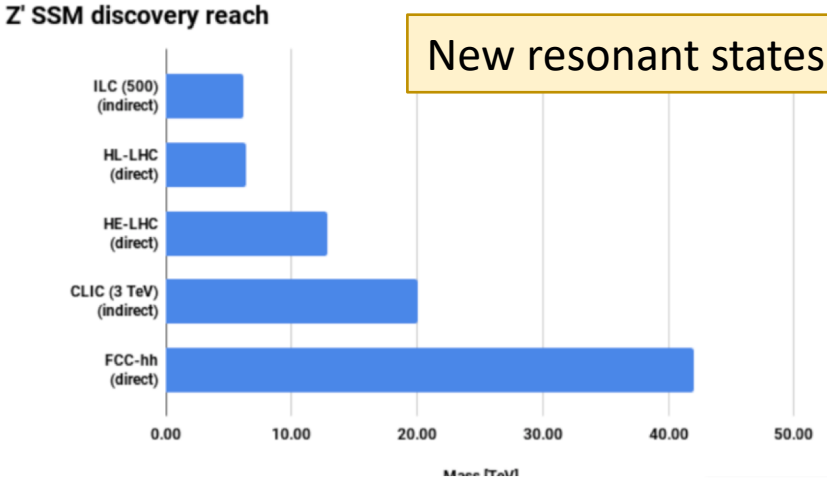
Contact Interactions



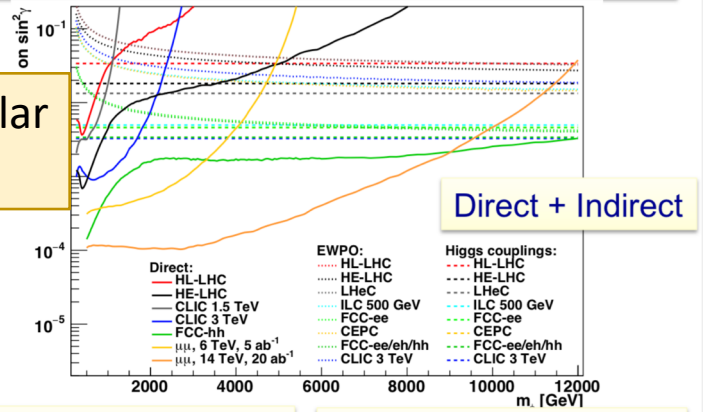

**Sensitivity for ee colliders enhanced for couplings ≳ 1**
**(weak couplings → direct searches become more sensitive)**
**Searches for W' & charged fermion currents more effective at hadron colliders**

New resonant states




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

Extended scalar sector




And much more

# Challenges for the European Strategy Group

**Recommend future facility in Europe**

Are we ready? **NOT YET, 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.