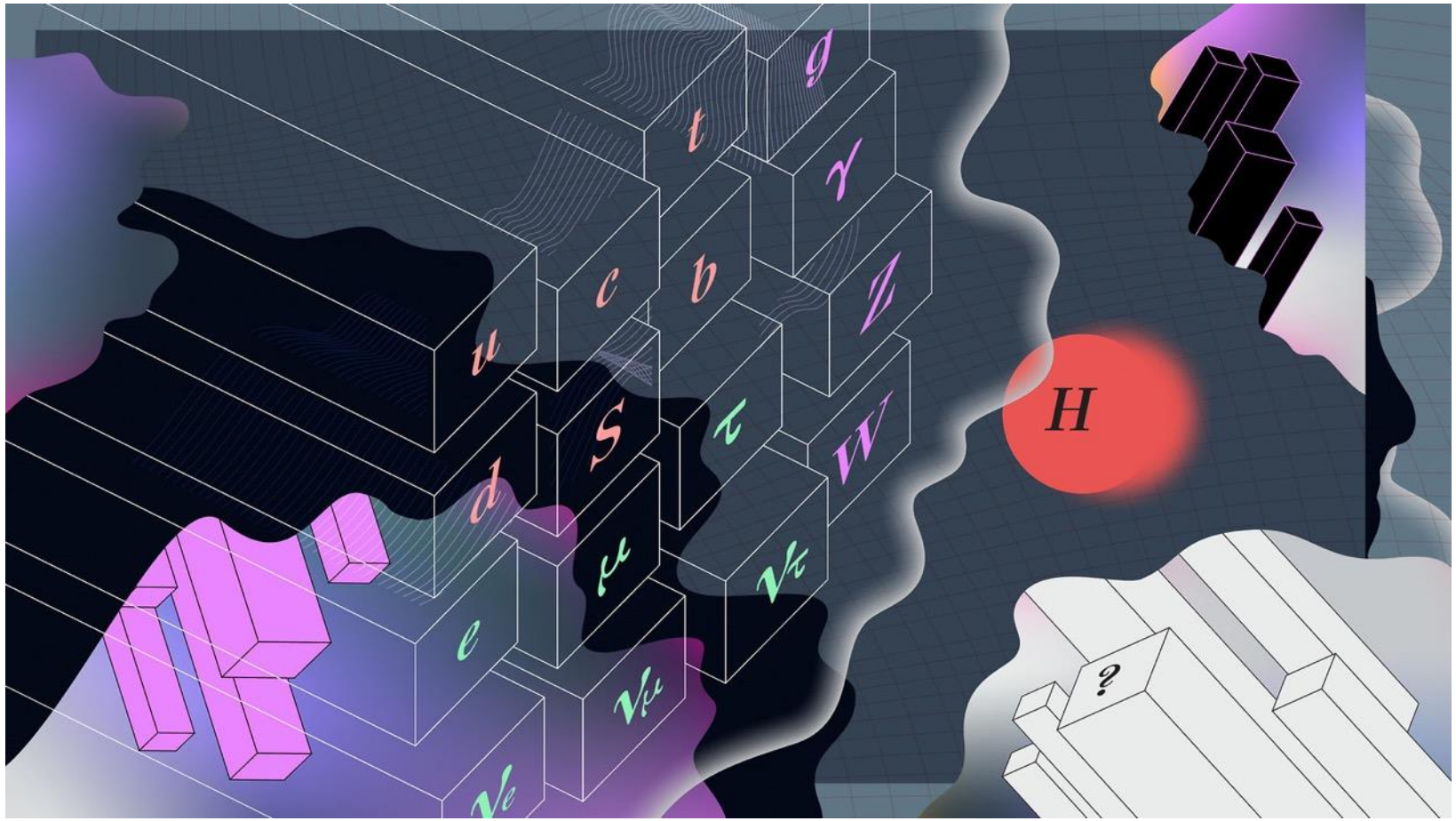
Strategia europeană pentru fizica particulelor – stadiul actual și perspective

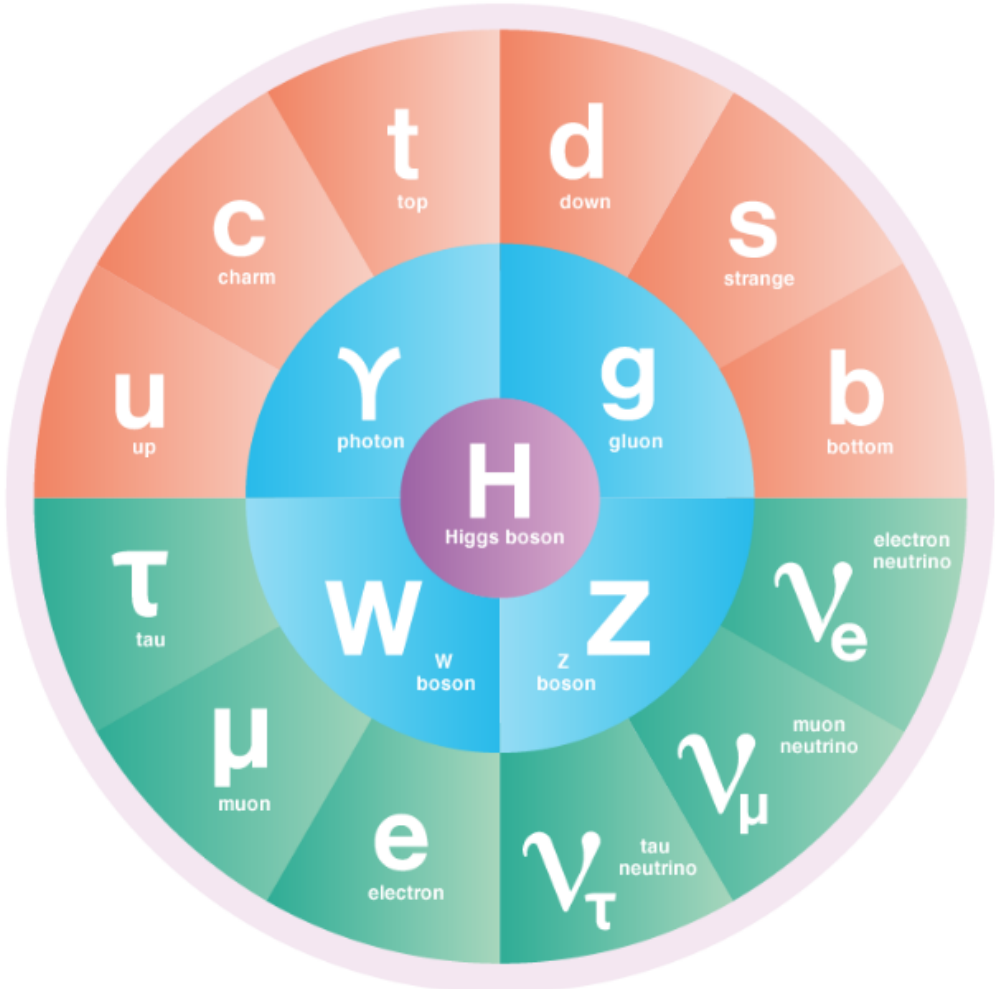
Călin Alexa, Fizica Particulelor Elementare, IFIN-HH



What are the fundamental forces and building blocks of the universe?

Why do they have the properties that we observe?

https://www.symmetrymagazine.org/standard-model/



The Standard Model of Particle Physics

The Standard Model is a kind of periodic table of the elements for particle physics. But instead of listing the chemical elements, it lists the fundamental particles that make up the atoms that make up the chemical elements, along with any other particles that cannot be broken down into any smaller pieces.

The complete Standard Model took a long time to build. Physicist J.J. Thomson discovered the electron in 1897, and scientists at the Large Hadron Collider found the final piece of the puzzle, the Higgs boson, in 2012.

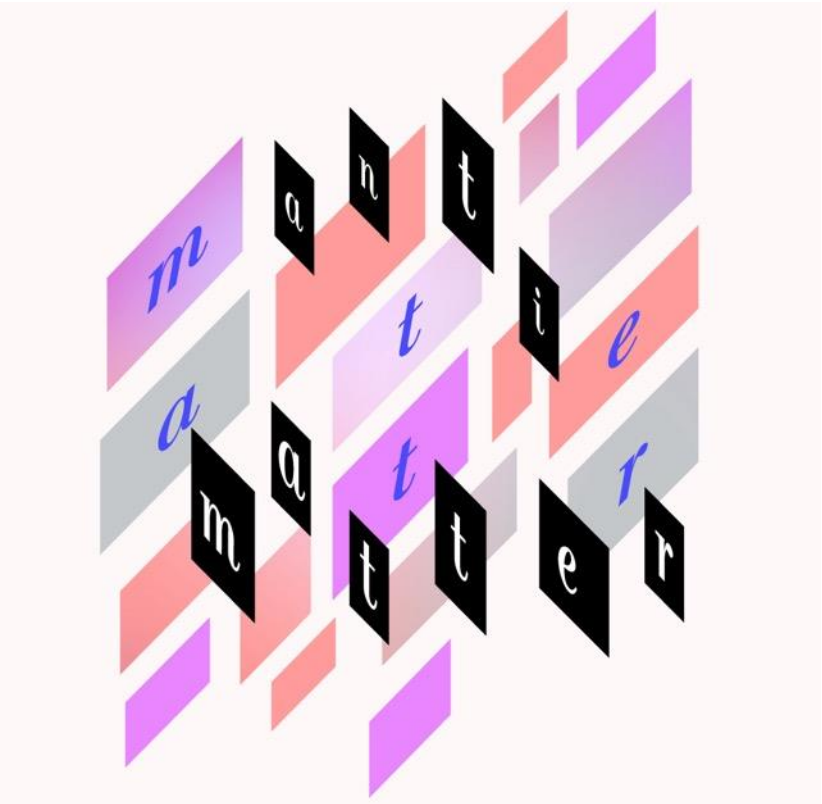
Use this interactive graphic to explore the different particles that make up the building blocks of our universe.

Return to symmetry article

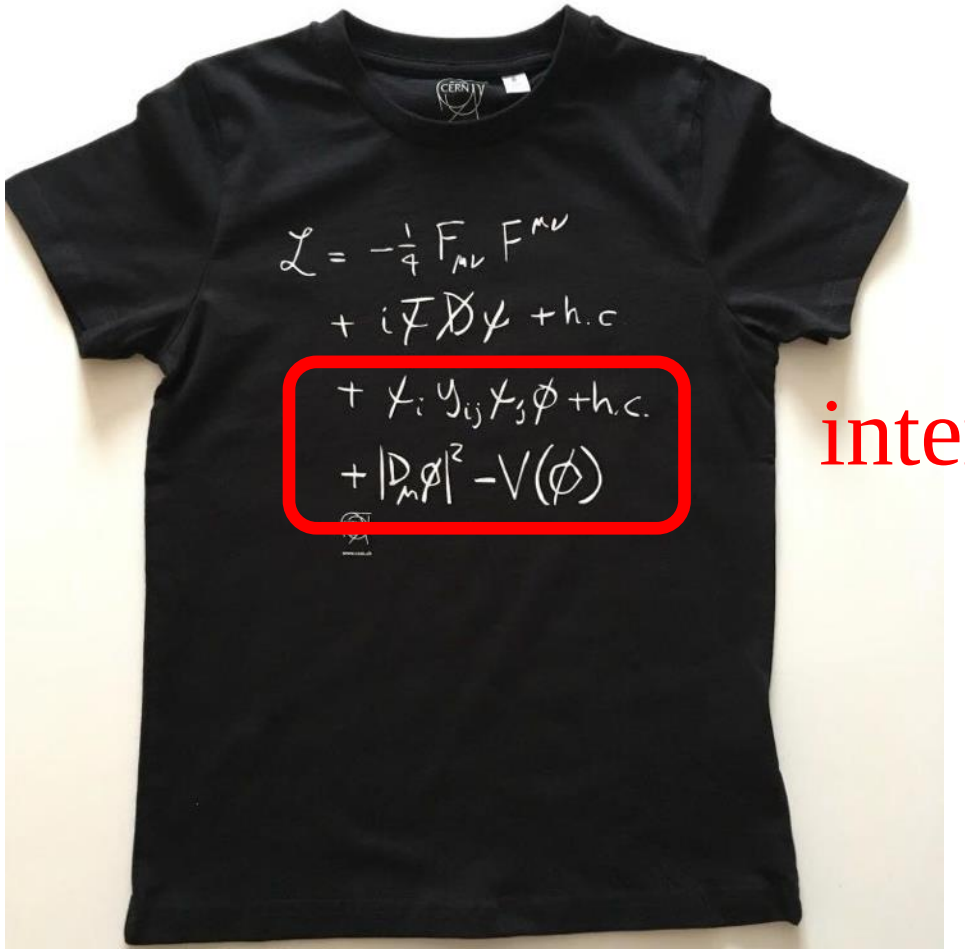
https://www.symmetrymagazine.org/article/five-mysteries-the-standard-model-cant-explain?language_content_entity=und

Mysteries the Standard Model can't explain

1. Why do neutrinos have mass?
2. What is dark matter?
3. Why is there so much matter in the universe?
4. Why is the expansion of the universe accelerating?
5. Is there a particle associated with the force of gravity?
6. …

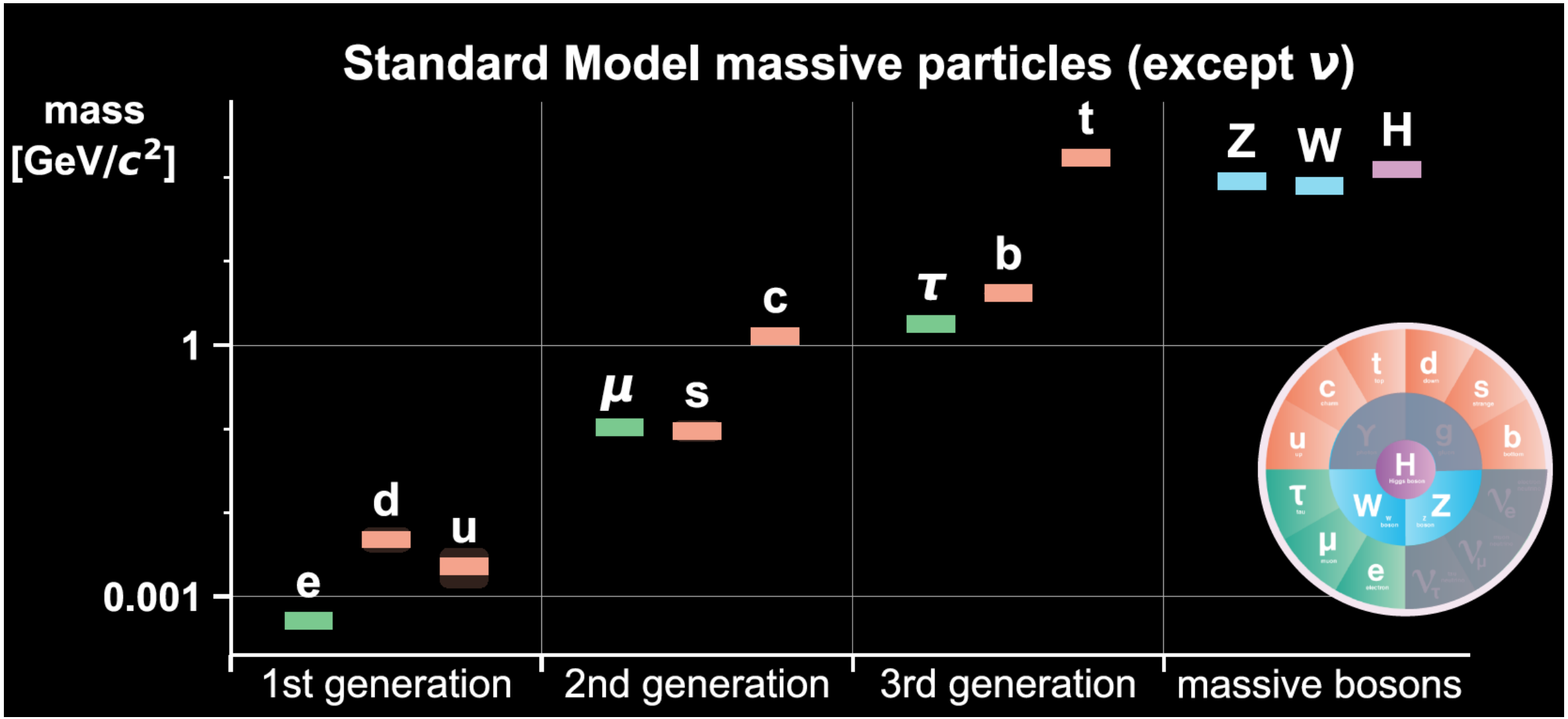


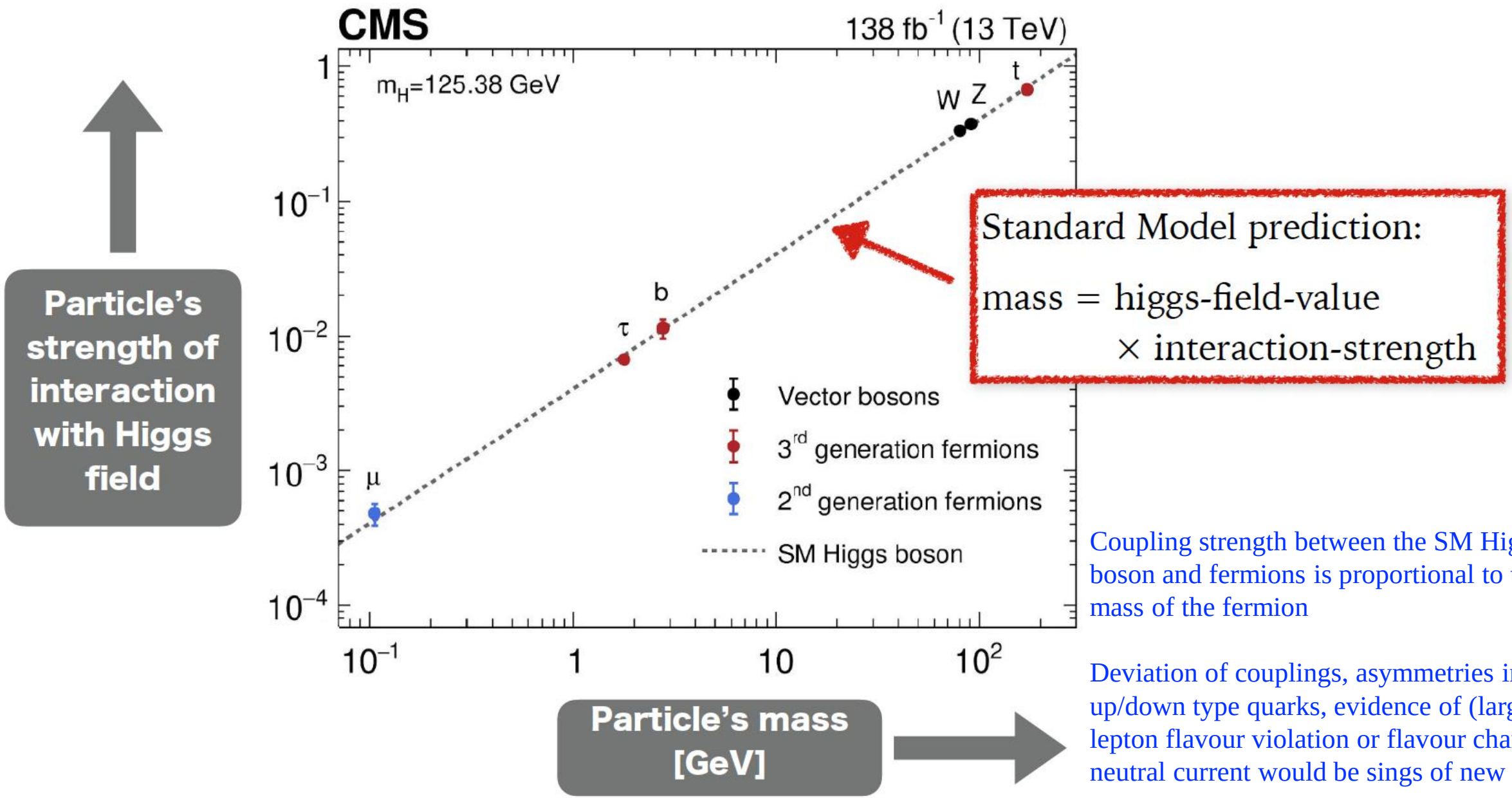
fundamental particles get their mass from interaction with the Higgs field



interactions

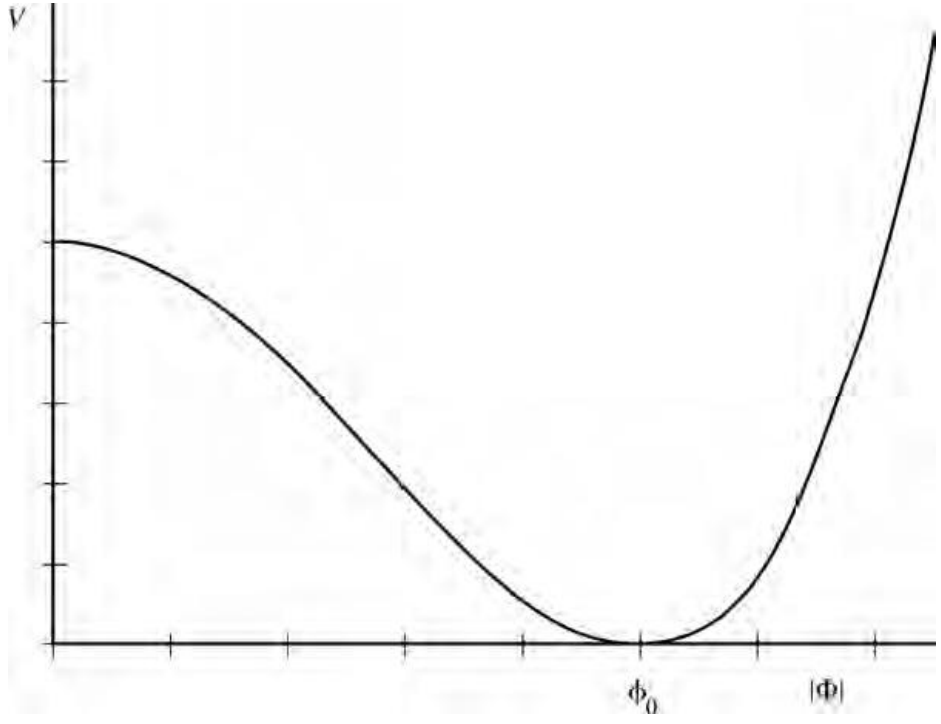
Standard Model massive particles (except ν)




CMS
138 fb^{-1} (13 TeV)
m_H=125.38 GeV
t
W Z
b
τ
μ
Vector bosons
3rd generation fermions
2nd generation fermions
SM Higgs boson
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-1}
1
10
10^2
Particle's strength of interaction with Higgs field
Particle's mass [GeV]
Standard Model prediction:
mass = higgs-field-value × interaction-strength
Coupling strength between the SM Higgs boson and fermions is proportional to the mass of the fermion
Deviation of couplings, asymmetries in up/down type quarks, evidence of (large) lepton flavour violation or flavour changing neutral current would be sings of new physics

fundamental particles only get mass if the Higgs field is non-zero

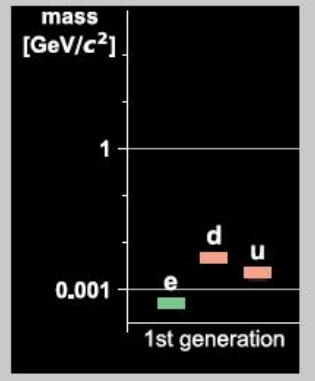
Why is the Higgs field non-zero?



Almost every problem of the Standard Model originates from Higgs interactions

$$\mathscr{L} = y\,H\psi\bar{\psi} + \mu^2|H|^2 - \lambda|H|^4 - V_0$$

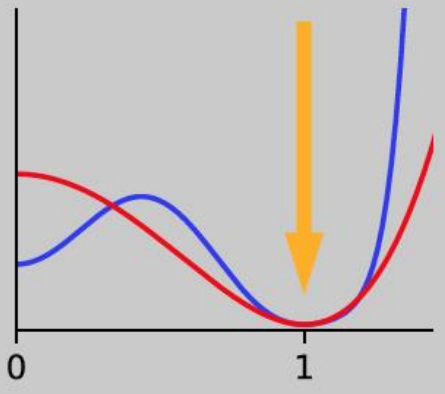
flavour



naturalness

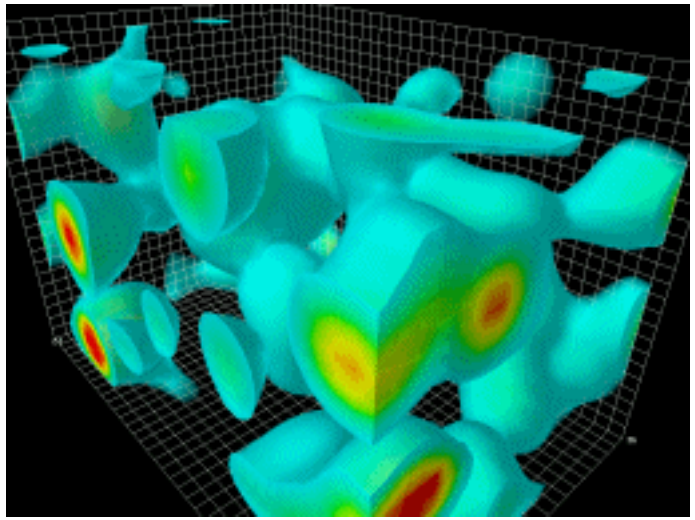
?

stability



cosmological constant

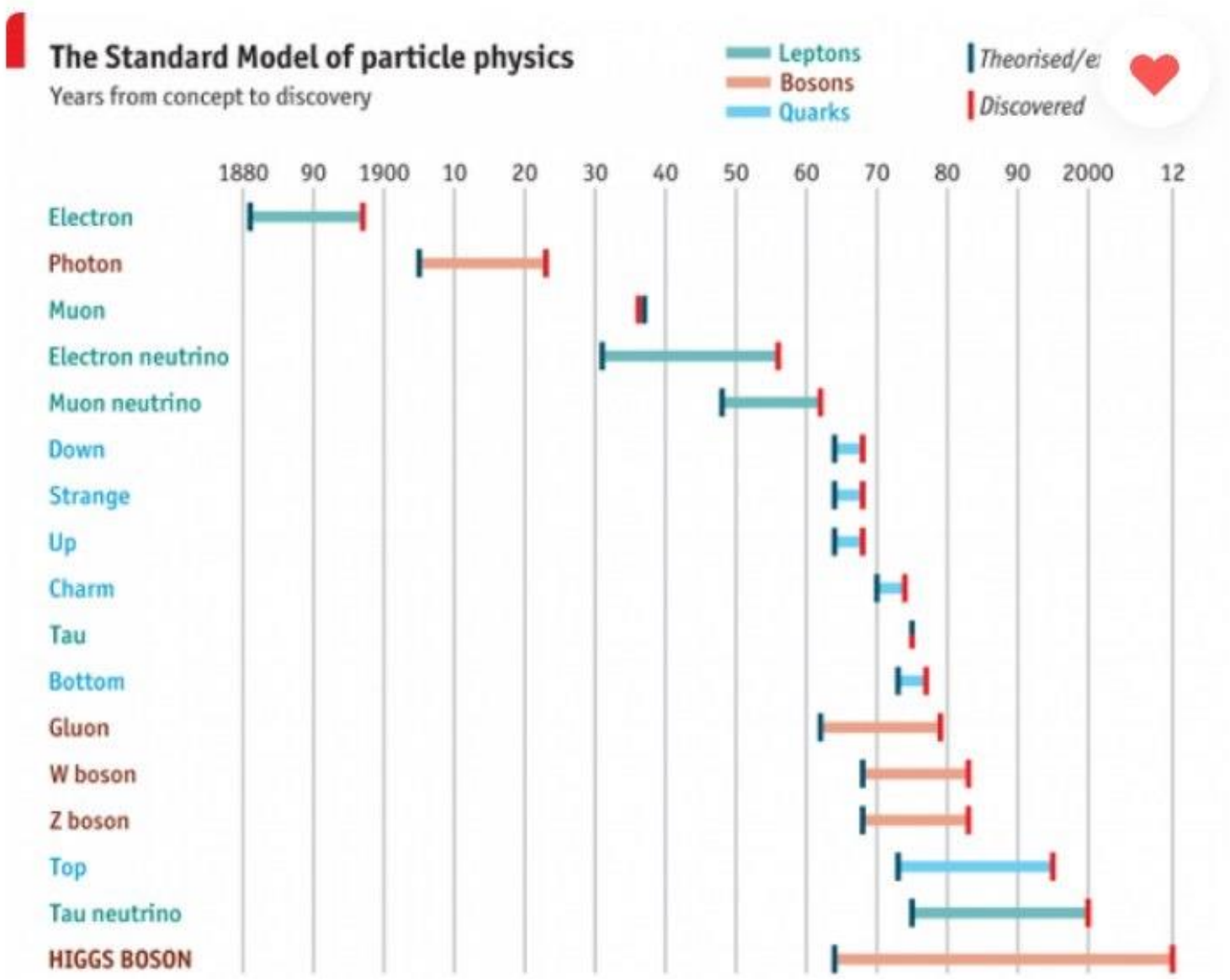
Naturalness in particle physics



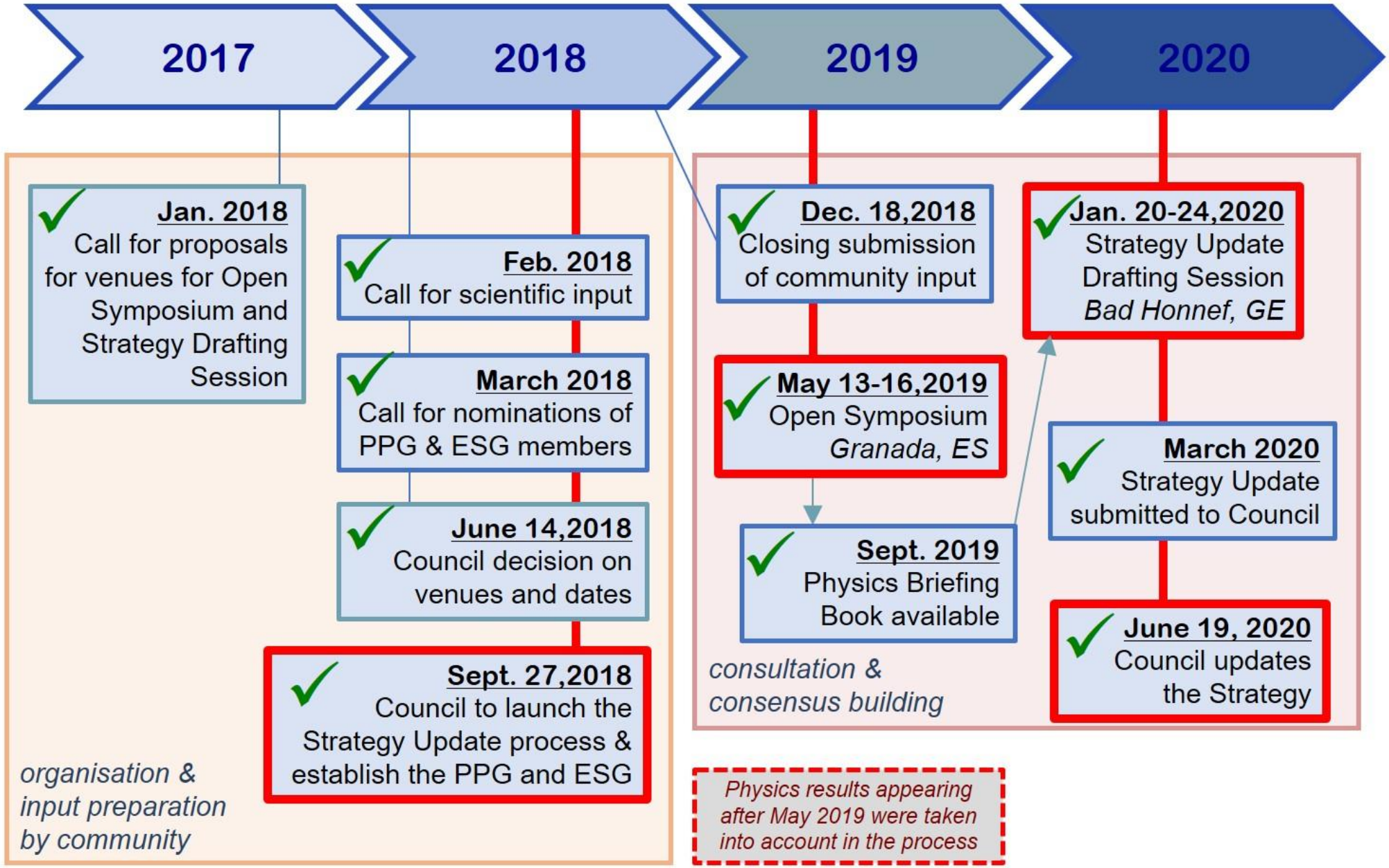
http://www.physics.adelaide.edu.au/theory/staff/leinweber/VisualQCD/Nobel/index.html

- quantum fluctuations act on the Higgs sector, trying to drive up the Higgs boson's mass, as far as it can go
- widespread belief among physicists: only thing that could provide an upper limit is some yet-to-be discovered new physics
- and it shouldn't be too much heavier than the Higgs mass (i.e. accessible at LHC or next colliders)
- an alternative is some huge cosmic coincidence; or that we have a deep misunderstanding of underlying physics

De ce o strategie pe termen lung?



European Paricle Physics Strategy *Update*



European Strategy for Particle Physics Update 2018 - 2020

https://europeanstrategy.cern/european-strategy-for-particle-physics

High-priority future initiatives

A. An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge technology:

- *the particle physics community should ramp up its R&D effort focused on advanced accelerator technologies, in particular that for high-field superconducting magnets, including high-temperature superconductors;*

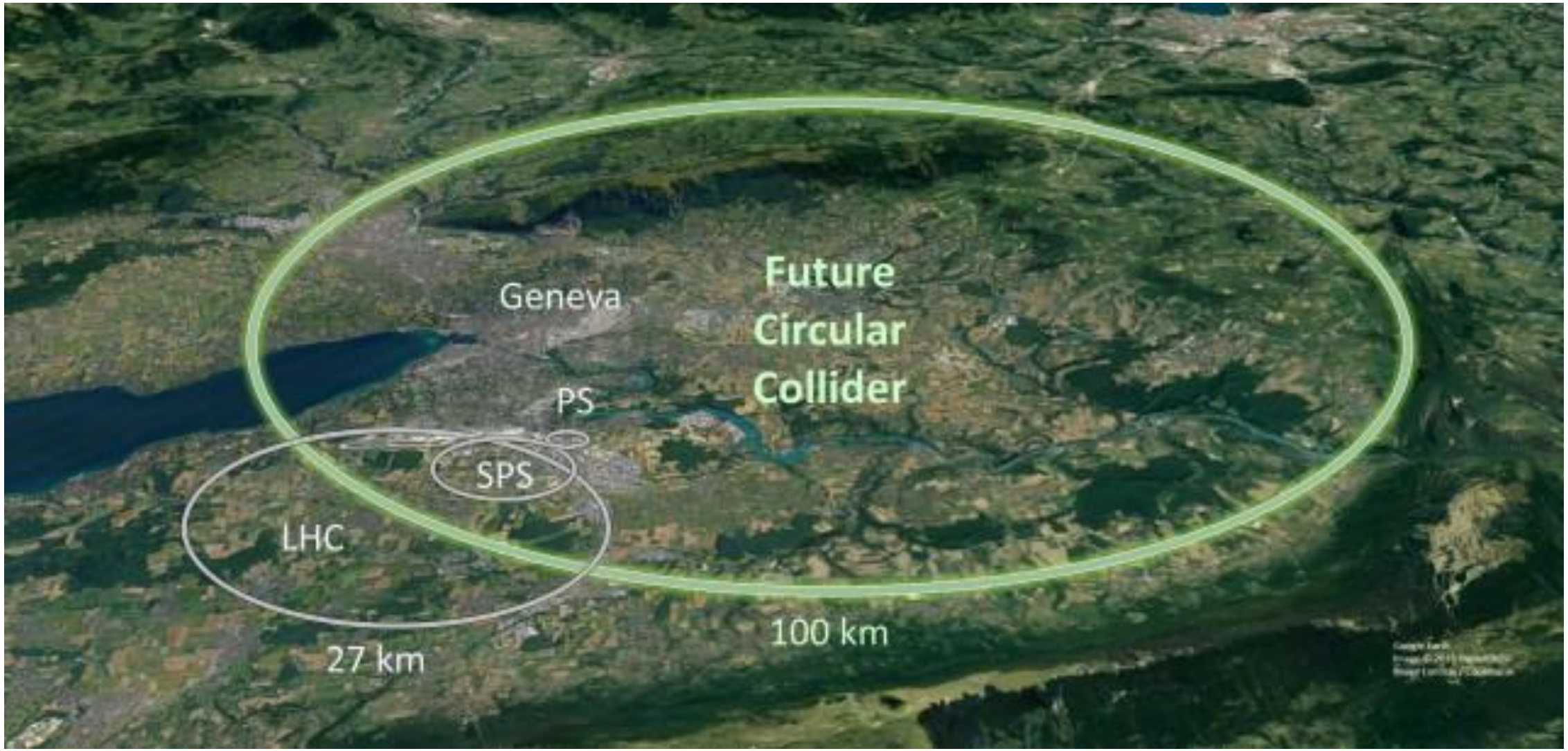
- *Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage. Such a feasibility study of the colliders and related infrastructure should be established as a global endeavour and be completed on the timescale of the next Strategy update.*

The timely realisation of the electron-positron International Linear Collider (ILC) in Japan would be compatible with this strategy and, in that case, the European particle physics community would wish to collaborate.

B. Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders. It is also a powerful driver for many accelerator-based fields of science and industry. The technologies under consideration include high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures, bright muon beams, energy recovery linacs.

The European particle physics community must intensify accelerator R&D and sustain it with adequate resources. A roadmap should prioritise the technology, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry. Deliverables for this decade should be defined in a timely fashion and coordinated among CERN and national laboratories and institutes.

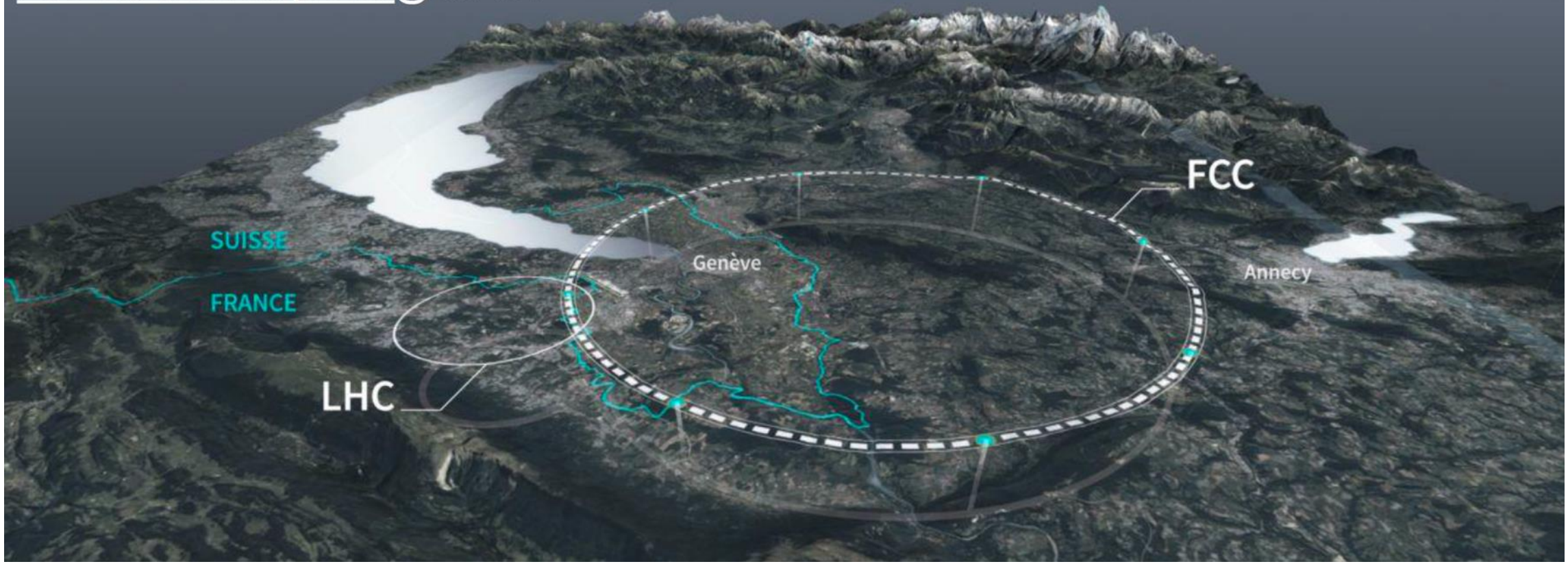
FCC Feasibility Study (2021 - 2025)



FUTURE CIRCULAR COLLIDER

FCC research infrastructure for the 21st century

A new 91 km tunnel to host multiple colliders
100 – 300 m under ground, 8 surface sites
FCC-ee: electron-positron @ 91, 160, 240, 365 GeV
FCC-hh: proton-proton @ 100 TeV, and heavy-ions (Pb) @39 TeV
FCC-eh: electron-proton@ 3.5 TeV

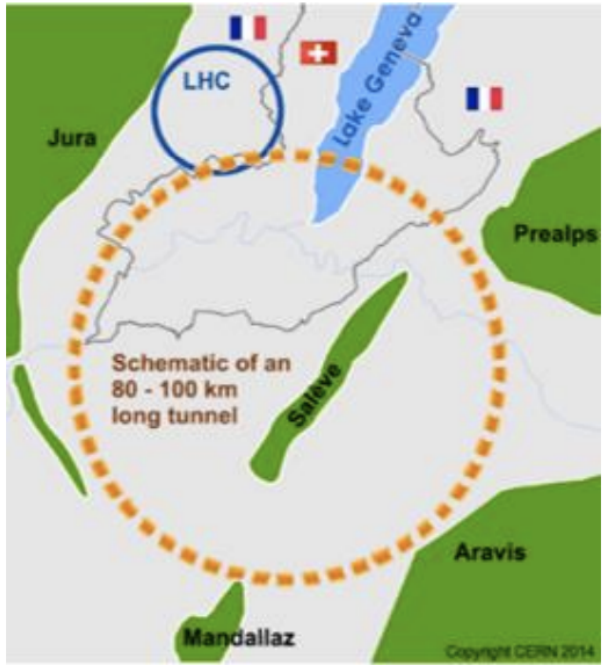


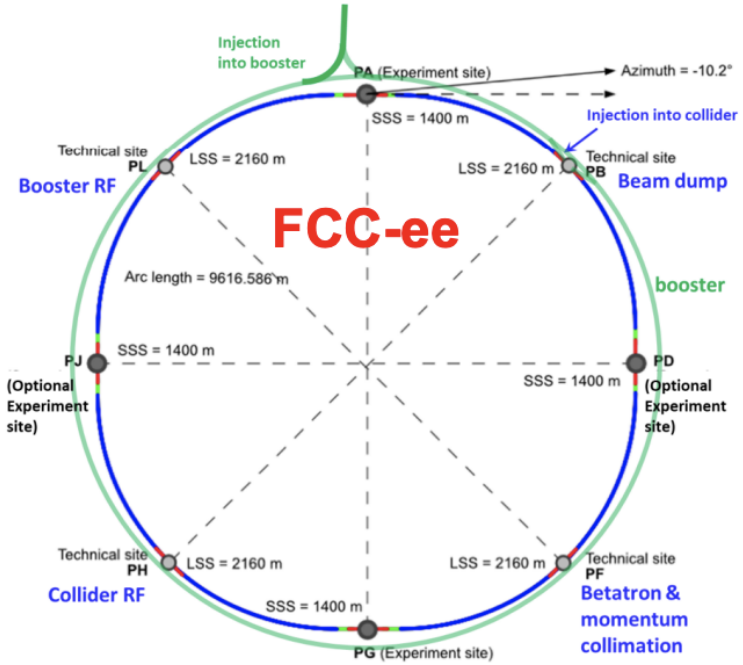
FUTURE CIRCULAR COLLIDER

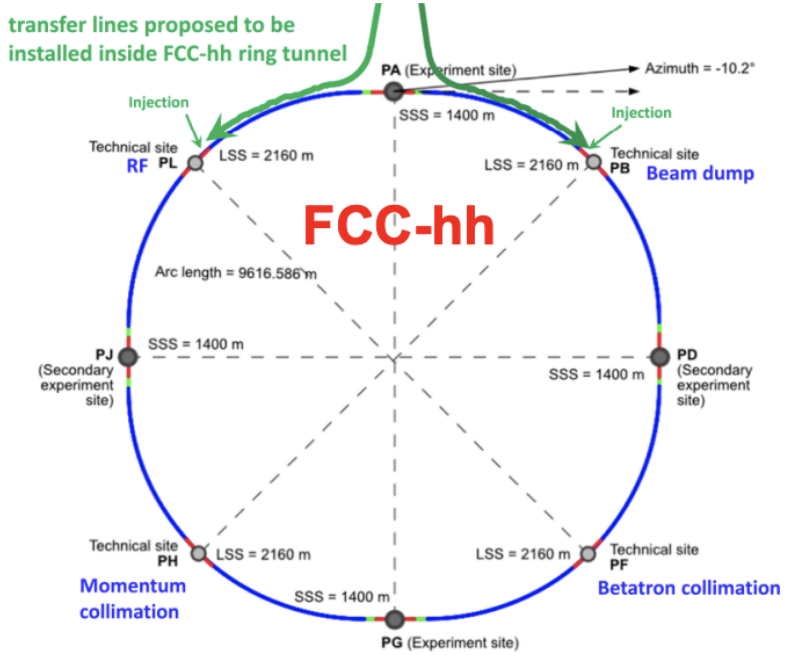
FCC integrated program

comprehensive long-term program maximizing physics opportunities

- **stage 1: FCC-ee (Z, W, H, tt̄) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, pp & AA collisions; e-h option**
- highly synergetic and complementary programme boosting the physics reach of both colliders (e.g. model-independent measurements of the Higgs couplings at FCC-hh thanks to input from FCC-ee; and FCC-hh as "energy upgrade" of FCC-ee)
- common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure
- FCC integrated project allows the start of a new, major facility at CERN within a few years of the end of HL-LHC

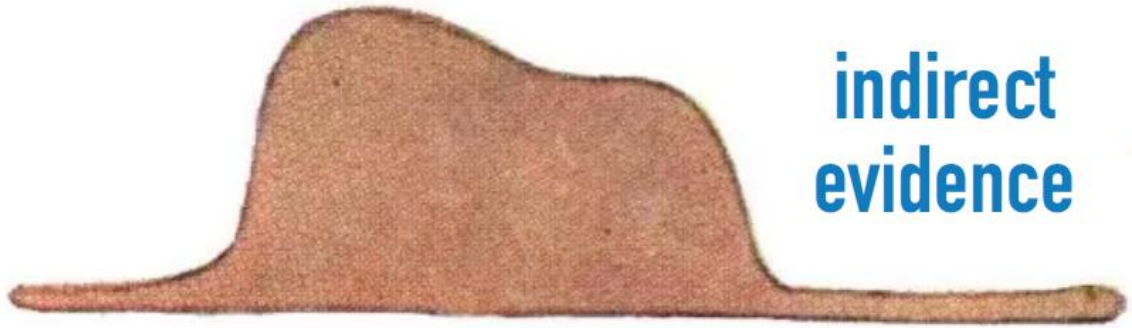






2020 - 2040 | 2045 - 2063 | 2070 - 2095

Mon dessin numéro 1



indirect evidence

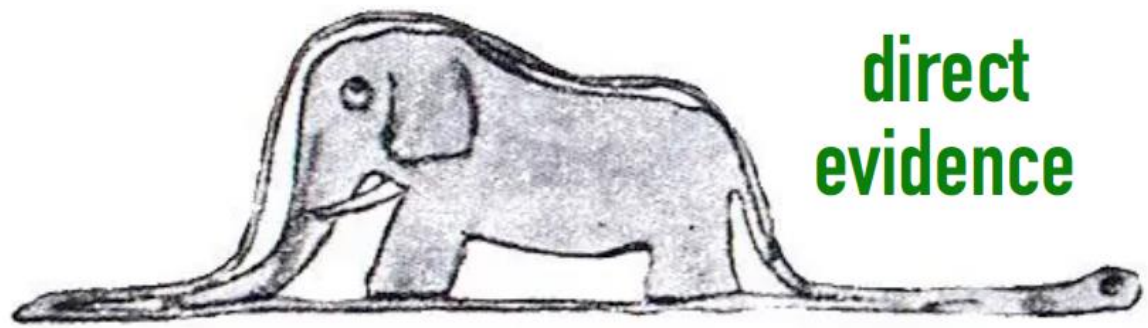
« Pourquoi un chapeau ferait-il peur ? »

"Why should any one be frightened by a hat?"

Le Petit Prince, Antoine de Saint-Exupéry

« Mon dessin ne représentait pas un chapeau. Il représentait un serpent boa qui digérait un éléphant. »

"My drawing was not a picture of a hat. It was a picture of a boa constrictor digesting an elephant."



direct evidence

Mon dessin numéro 2

LHC

pp, 13 TeV, 3000 fb^{-1}

Exclusion limit ~ 6.7 TeV

(electron and muon channels, single experiment)

× 6.1

replicated across myriad search channels

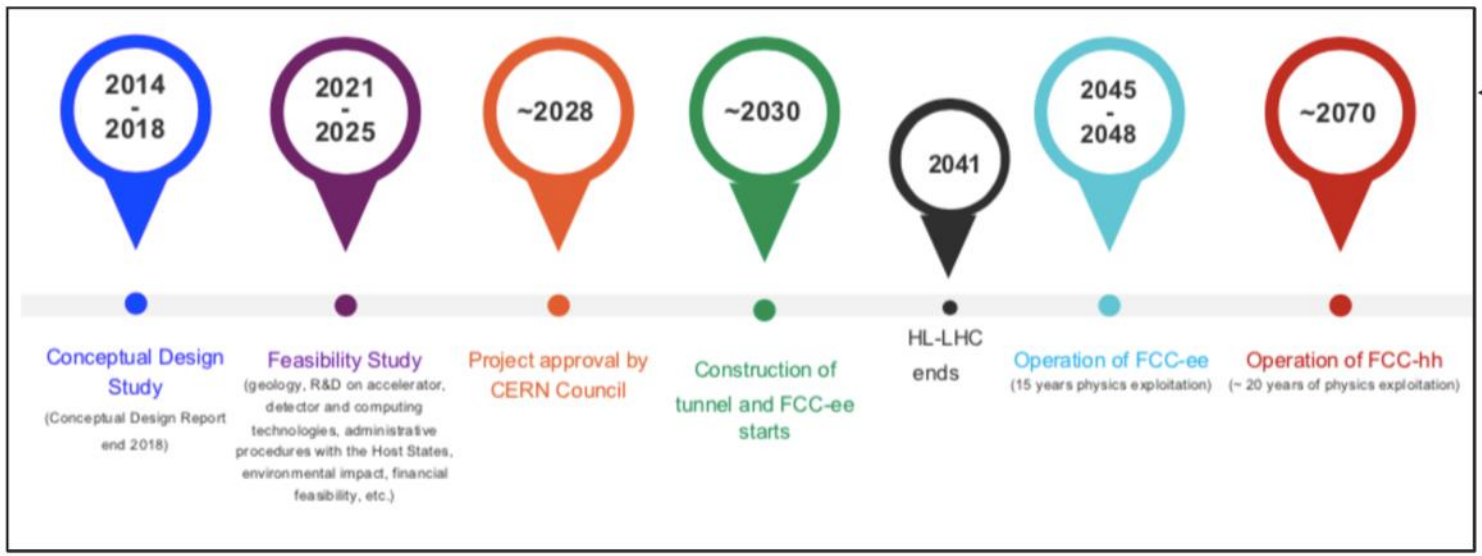
FCC-hh

pp, 100 TeV, 20 ab^{-1}

Exclusion limit ~ 41 TeV

(based on PDF luminosity scaling, assuming detectors can handle muons and electrons at these energies)

FCC estimated timeline



"Realistic" schedule taking into account:

- ❑ past experience in building colliders at CERN
- ❑ approval timeline: ESPP, Council decision
- ❑ that HL-LHC will run until 2041

→ **ANY future collider at CERN cannot start physics operation before ~ 2045**

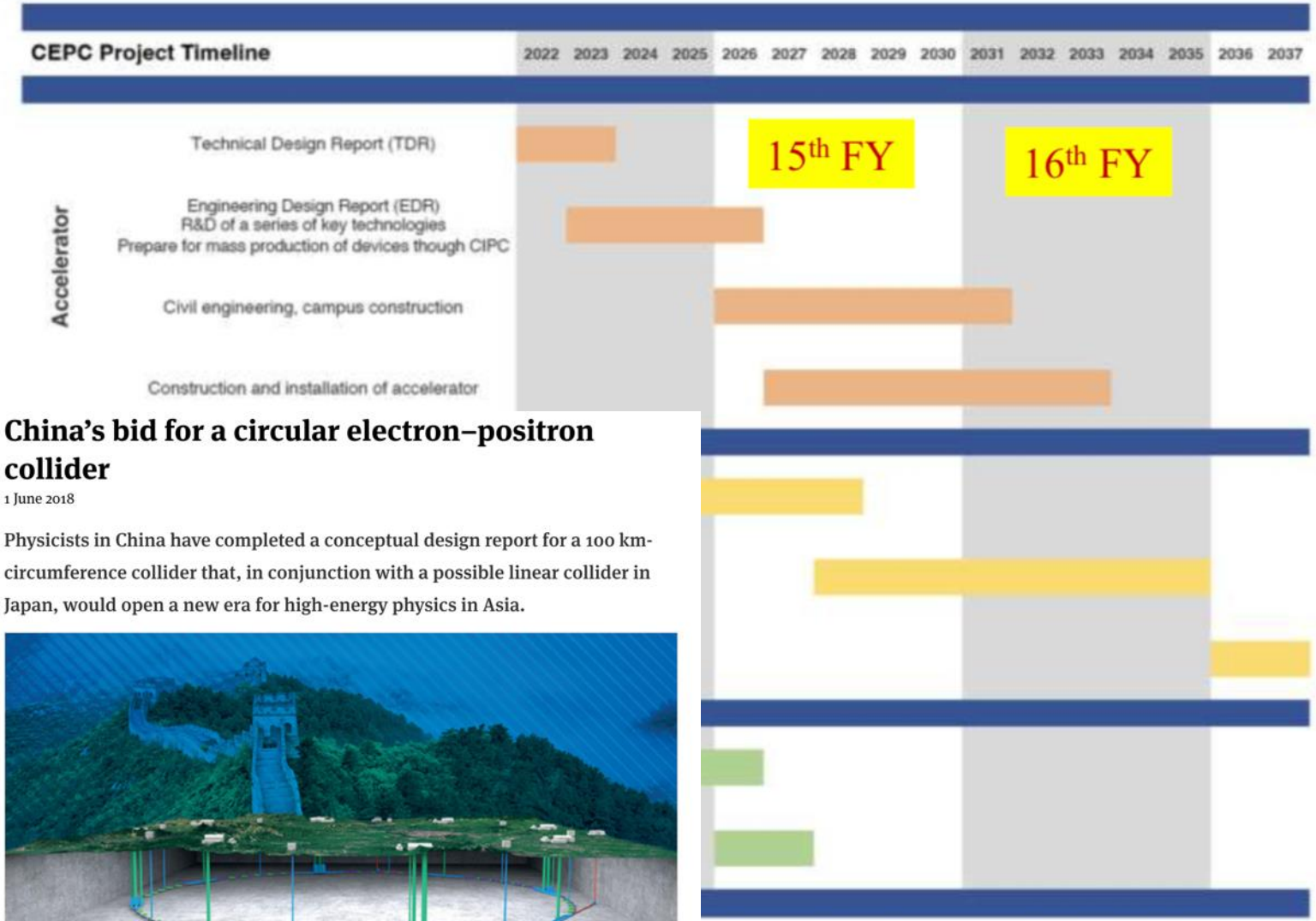
1st stage collider, FCC-ee: electron-positron collisions 90-360 GeV
Construction: 2033-2045 → Physics operation: 2048-2063

2nd stage collider, FCC-hh: proton-proton collisions at ≥ 100 TeV
Construction: 2058-2070 → Physics operation: ~ 2070-2095

Note:
Care should be taken when comparing to other proposed facilities, for which in some cases only the (optimistic) technical schedule is shown

Status of CEPC in China

J. Gao, ICFA seminar, DESY, 30/11/2023



China's bid for a circular electron–positron collider

1 June 2018

Physicists in China have completed a conceptual design report for a 100 km-circumference collider that, in conjunction with a possible linear collider in Japan, would open a new era for high-energy physics in Asia.

Several sites in China are currently under study for a possible 100 km-circumference collider.
Image credit: IHEP

- ❑ 2 Interaction Points
- ❑ Operation starts at ZH energy
- ❑ Initially 30 MW, upgradable to 50 MW

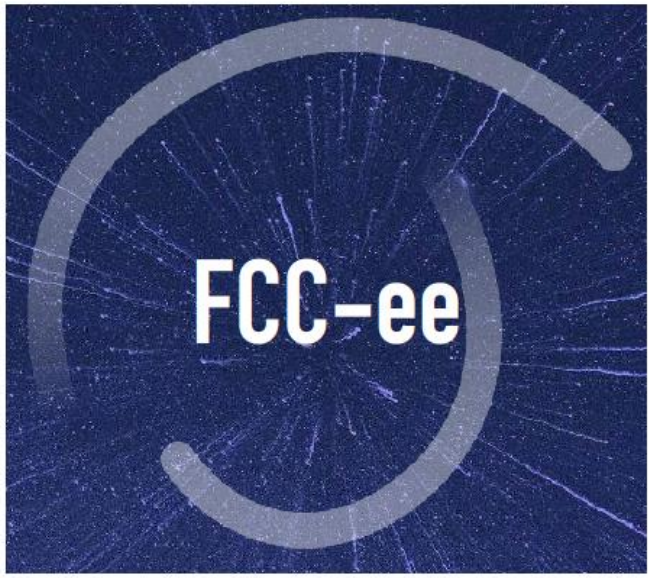
Impressive technical progress recently:
SCRF, injectors, power source, etc.
Synergies between CEPC R&D and HEPS (High-Energy Photon Source) being built in Beijing.

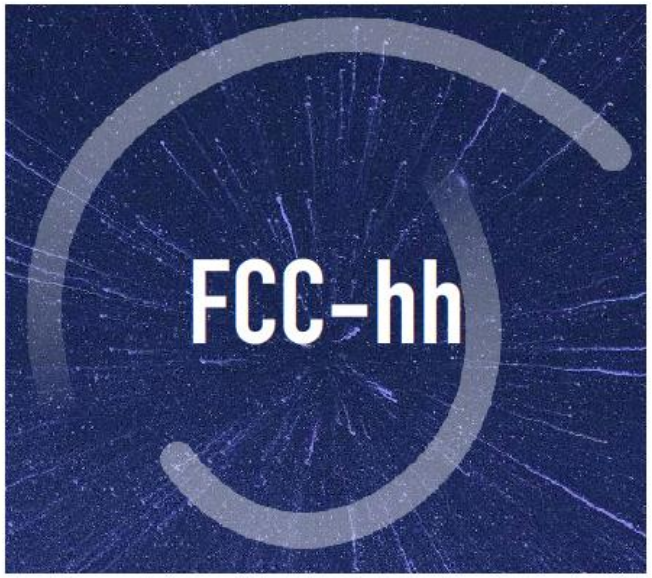
CAS (Chinese Academy of Science) review:
4 different committees have classified CEPC first of all projects in nuclear and particle physics

Current plan:
- ❑ Accelerator TDR: to be released Dec 2023
- ❑ EDR: 2024-2027
- ❑ Application for 5-year funding: 2025
- ❑ Construction: 2027-2035
- ❑ Operation start: 2036

Such a schedule (if realistic) requires acceleration of FCC-ee to start early 2040s (if approved).
CERN Management is reflecting on how to achieve this → more at March SPC

HiLumi
HL-LHC PROJECT





2029–2041

proton–proton
14,000 GeV energy
10× more collisions
than LHC

2045–2060(c.)

electron–positron
91–365 GeV energy
300,000× more
collisions than LEP

[or CEPC@China,
ILC, CLIC]

2070–2090(c.)

proton–proton
~100,000 TeV energy
10× more collisions
than HL-LHC

or SppS@China
or muon collider

III. Strategy update timeline: the main steps

Based on the considerations set out in Section II above, the general timeline for the next Strategy update is proposed as follows:

March 2024 Council
- Council decision on the timeline for the Strategy update
- Call for nominations for the Strategy Secretary
- Call for nominations for the members of the ESG and PPG
- Announcement to the community that March 2025 is the deadline to submit input.

June 2024 Council
- Council appointment of the Strategy Secretary and establishment of the Strategy Secretariat
- Council establishment of the ESG
- Call for venues for the Open Symposium and the Strategy Drafting Session

September 2024 Council
- Council appointment of the members of the PPG

December 2024 Council
- Council decision on the venues for the Open Symposium and the Strategy Drafting Session

March 2025
- Deadline for the submission of input from the community

Early July 2025
- Open Symposium

End of September 2025
- Submission of the "Briefing Book" to the ESG

Early December 2025
- Strategy Drafting Session

End January 2026
- Submission of the Draft Strategy Document to the Council for feedback

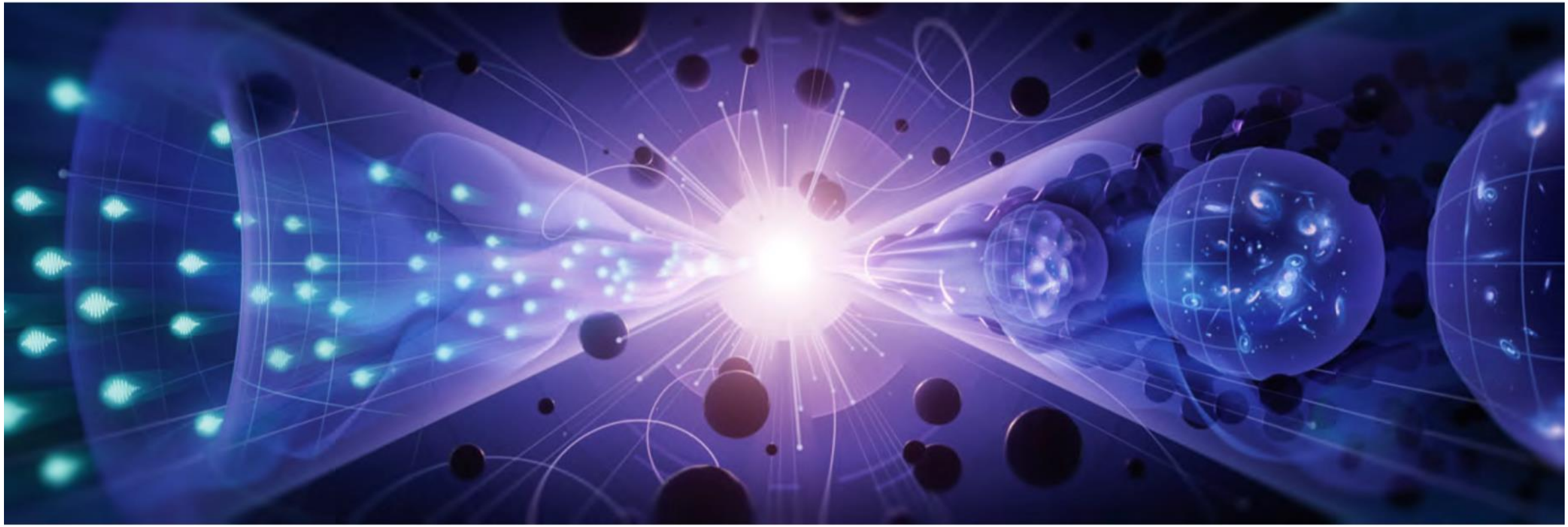
March-June 2026 Council Sessions
- Discussion of the Draft Strategy Document by the Council followed by the updating of the Strategy by the Council.

https://www.usparticlephysics.org/2023-p5-report/

Exploring the Quantum Universe

Pathways to Innovation and Discovery in Particle Physics

Report of the Particle Physics Project Prioritization Panel 2023



- Addressing the profound scientific inquiries within particle physics, from understanding the fundamental building blocks of nature to mapping out the evolution of the universe, requires a creative and technologically advanced workforce operating in an environment of mutual trust.

- The inherent curiosity driving our exploration of the natural world is a universal aspect of human nature.

- This shared curiosity serves as the driving force behind our commitment to strengthening and expanding this workforce and prompts us to actively seek talent from all corners of society and all regions of the country, and the world.