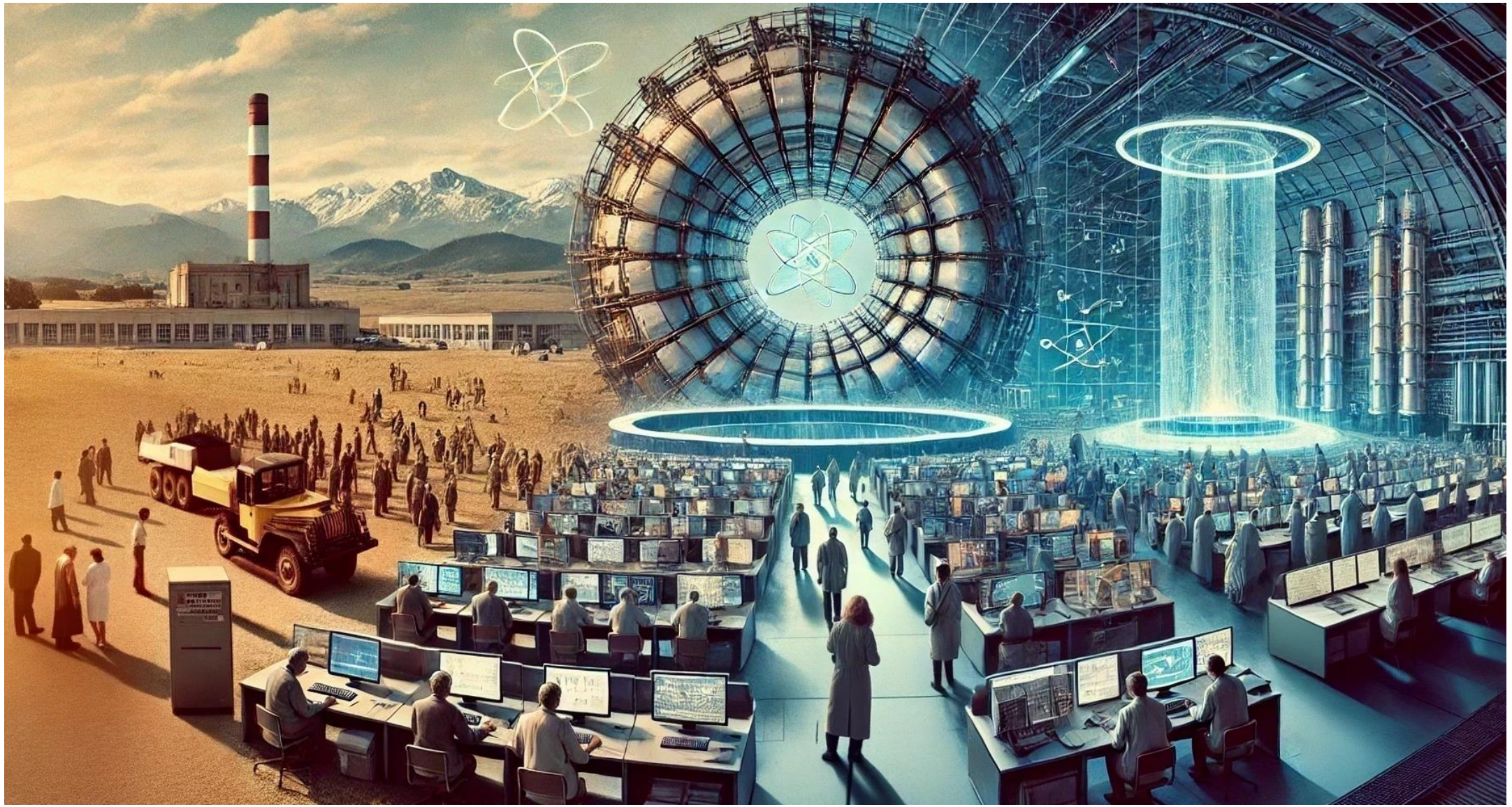
# CERN:
# past, present, future

**Prof. Dr. Günther Dissertori**
ETH Zurich
10 September 2024, Zurich



DALL-E, courtesy G. Kortemeyer

# The origins

See also https://timeline.web.cern.ch/timeline-header/89

# The first steps

Following the example of international organizations, a handful of visionary scientists imagined creating a European atomic physics laboratory (R. Dautry, P. Auger, L. Kowarski, E. Amaldi, N. Bohr, I. Rabi, L. de Broglie)

- **9 Dec 1949**: First official proposal at the European Cultural Conference in **Lausanne**, by L. de Broglie.
- **Dec 1951**: intergovernmental meeting of UNESCO in Paris – first resolution concerning the establishment of a **European Council for Nuclear Research** was adopted. Two months later, 11 countries signed an agreement establishing the provisional council – the **acronym CERN (Conseil Européen pour la Recherche Nucléaire)** was born.
- **May 1952:** first meeting of the CERN Council, headed by **P. Scherrer**.
- **Oct 1952**: Geneva was selected as the site for the CERN Laboratory at the third session of the provisional council

**Louis De Broglie**

*"A laboratory where it would be possible to carry out **scientific work** above and **beyond** the framework of the various nations taking part ……*

***an engine for peaceful collaboration across borders"***

from F. Pauss

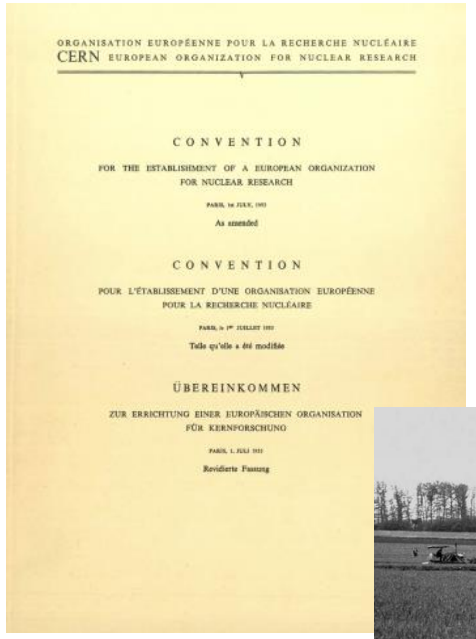
Third session of the provisional CERN Council, Amsterdam, Oct 1952

See also https://timeline.web.cern.ch/timeline-header/89

# The first steps….

- **29 June 1953**: Draft convention completed and approved unanimously by the representatives of the eleven countries that had signed the original agreement plus the UK.
  The Convention established financial contributions, which are calculated on the basis of net national income over recent years so that each Member State pays according to their means.
- **17 May 1954:** the first shovel of earth dug on the Meyrin site in Switzerland
- **29 Sep 1954:** The **European Organization for Nuclear Research** officially came into being, following ratification of the convention by the 12 founding Member States:
  Belgium, Denmark, France, Federal Republic of Germany, Greece, Italy, Netherlands, Norway, Sweden, Switzerland, United Kingdom, Yugoslavia → **as of Aug 30, 2024: 24 member states**

The **provisional CERN** was dissolved **but the acronym remained**.


ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CONVENTION

FOR THE ESTABLISHMENT OF A EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PARIS, 1st JULY, 1953

As amended

CONVENTION

POUR L'ÉTABLISSEMENT D'UNE ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE

PARIS, le 1er JUILLET 1953

Telle qu'elle a été modifiée

ÜBEREINKOMMEN

ZUR ERRICHTUNG EINER EUROPÄISCHEN ORGANISATION FÜR KERNFORSCHUNG

PARIS, 1. JULI 1953

Revidierte Fassung

17 May 1954, Meyrin

**Sir Ben Lockspeiser**

*"Scientific research lives and flourishes in an **atmosphere of freedom** – freedom to **doubt**, freedom to **enquire** and freedom to **discover**. These are the conditions under which this new laboratory has been established."*

from F. Pauss

# Lessons (learned or to be learned)

- Besides being a scientific project, CERN was also started as a

  **piece project, uniting people**

- You need **visionary people** and **great scientists**

- You need a **strong Council** and a strong will by all involved (scientists, politicians, public)
  - Then things can even go fast….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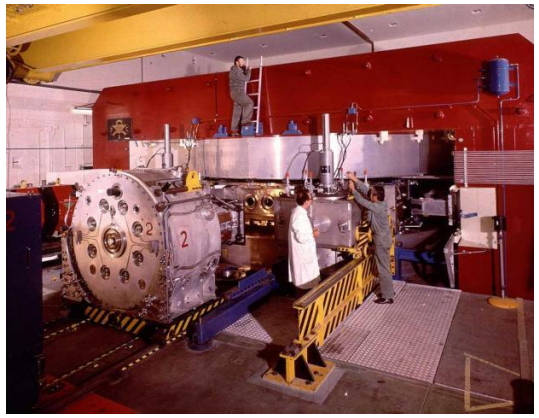
**ARTICLE II, paragraph 1**: "The Organization shall provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto. The Organization shall have no concern with work for military requirements and the results of its experimental and theoretical work shall be published or otherwise made generally available."

# Some highlights from CERN‘s past

See also https://timeline.web.cern.ch/timeline-header/89, https://cern70.cern/history/

# Accelerators and related infrastructures

- May 1957: 600 MeV **Synchrocyclotron (SC)**, CERN's first accelerator
- Nov 1959: 24 GeV **Proton Synchrotron (PS)**, to become CERN's first big accelerator. A workhorse, till today, and world's most versatile particle juggler.
- Jan 1971: the world's first interactions from colliding protons at the **Intersecting Storage Rings (ISR)**
- May 1976: **Super Proton Synchrotron (SPS)**, protons to 400-450 GeV, 7 km circumference, 40m underground, next work horse (electrons, positrons, protons, antiprotons, heavy nuclei, production of neutrino beams).
- April 1981: first proton-antiproton collisions in the ISR, followed by the SPS.



SC

Start-up of PS: J. Adams et al.

ISR

https://cerncourier.com/a/cerns-isr-the-worlds-first-hadron-collider/

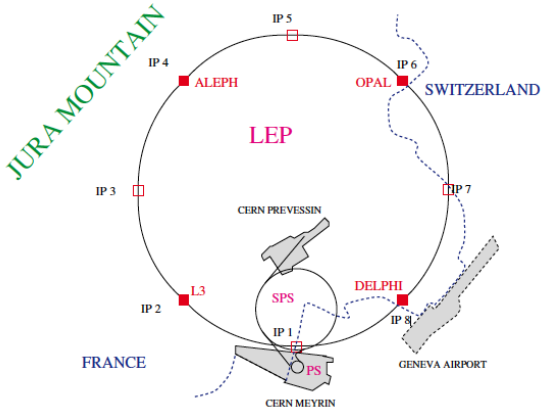
SPS

See also https://timeline.web.cern.ch/timeline-header/89, https://cern70.cern/history/

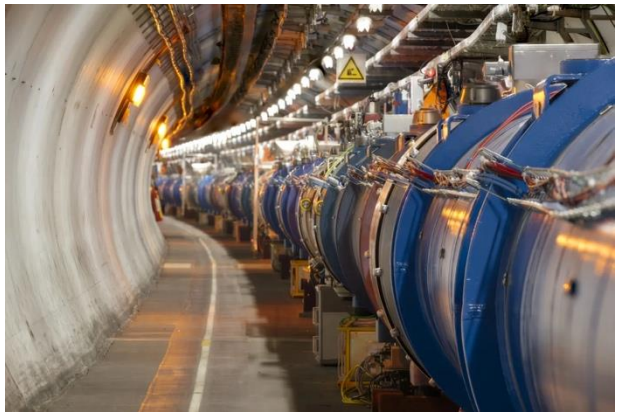
# Accelerators and related infrastructures...

- July 1989: **Large Electron-Positron (LEP)** collider, first injection; 27 km circumference, 100m underground, largest electron–positron accelerator ever built (so far), Centre-of-mass energies ~90-209 GeV. Stopped in 2000.
- Sep 2008: The **Large Hadron Collider (LHC)** starts up, in the same tunnel as LEP, so far world's largest and most powerful proton collider **First collisions in 2010**, after magnet incident in Sep 2008. Centre-of-mass energies 7 – 13.6 TeV
- Not to be forgotten:
  - Low-Energy Antiproton Ring (**LEAR**)
  - Antiproton Accumulator (**AA**)
  - Antiproton Decelerator (**AD**)
  - **ISOLDE** (Radioactive Ion Beam facility)

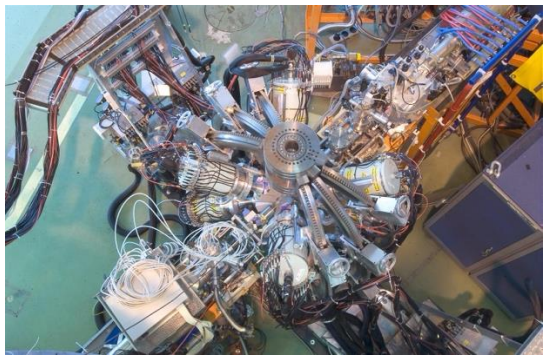
July 1989: first injection in LEP




https://cds.cern.ch/record/2638017



LHC



ISOLDE

AD

# Some anectodes and observations

- Birthday of the PS: 24 Nov 1959
- SPS: record time (4y) civil engineering and installation work; started **two years ahead of schedule** !!
  - Similarly impressive: the speed of construction of the UA1/2 exps.
  - Since then: non-linear growth of approval and construction times?
  - Note: there were proposals to build the SPS somewhere else, eg. „a second lab in the Provence, because the lab was already growing old“ → **importance of long-term stability!**
- LEP: The two ends of the 27-kilometre ring came together with **just one centimetre of error**.
- The long (!) lifetime, versatility and re-usability of the accelerators and related infrastructure (tunnels etc.)
- **Tech** advancements and innovations related to accelerator developments (superconducting magnets, cryogenics, RF, touch screens, WWW…), in **close collaboration with industry**

July 1974: SPS tunnel completed

LEP tunnelling crew

Date?: FCC tunnel completed (DALL-E)

See also https://timeline.web.cern.ch/timeline-header/89, https://cern70.cern/history/

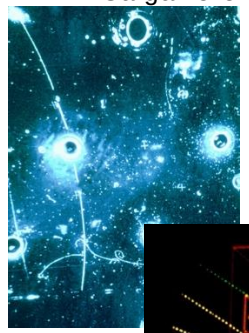
# Some key achievements

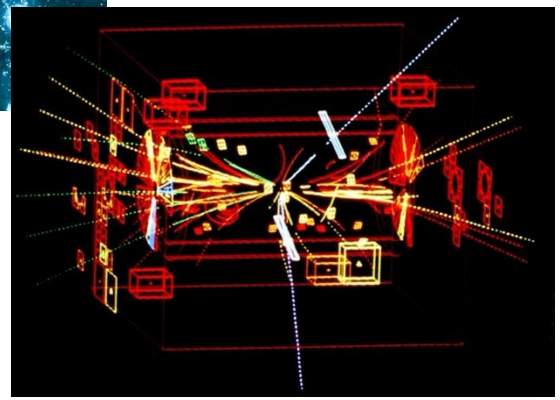
(apologies for the many more that are omitted here …)

- 1968: **G. Charpak** invents the **multiwire proportional chamber**
  (Nobel Prize 1992) → revolution for particle detection
- 1973: **Discovery of neutral currents** with **Gargamelle**
- 1983: **Discovery of the W and Z bosons**,
  UA1 and UA2 experiments at the SPS; Nobel Prize in 1984 for C. Rubbia (spokesperson UA1 and instigator for the SPS as proton-antiproton collider) and Simon van der Meer (inventor of the stochastic cooling technique).
- 1989-2000: **Precision studies at LEP**
  probing the SM at the quantum loop level
- 2012: **Discovery of the Higgs boson**
  by the ATLAS and CMS experiments at the LHC; Nobel Prize 2013 for P. Higgs and F. Englert.

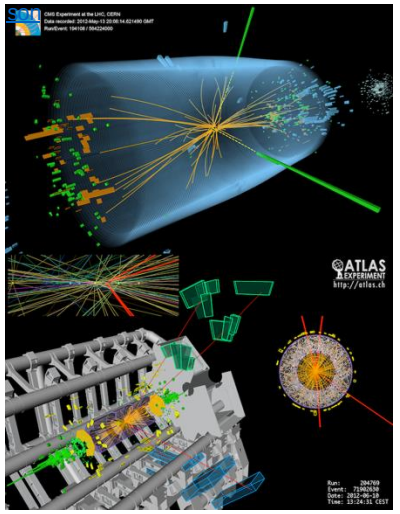
G. Charpak

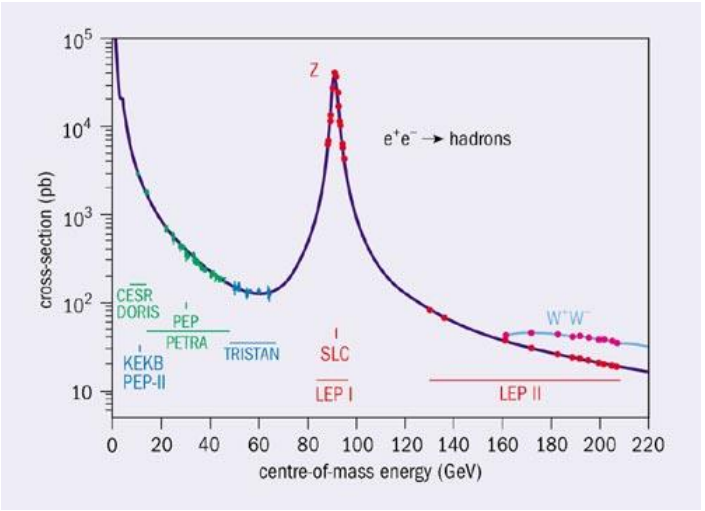
Gargamelle





https://en.wikipedia.org/wiki/Higgs_bo



# CERN‘s pivotal role in understanding electroweak interactions

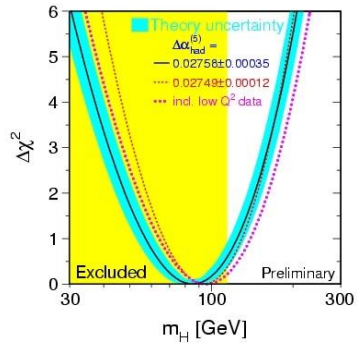
Dieter Haidt CERN Symposium October 31, 2023

## 50 years paving the Electroweak Way

| | | | | | |
|---|---|---|---|---|---|
| The crown | | | | | |
| Higgs | 2012 | LHC | ATLAS and CMS | 2 x 5500 | Standard Model<br>Full SU(2)⊗U(1) gauge theory |
| The pillars | | | | | |
| W and Z | 1983 | SPS<br>SppS | UA1 and UA2 | 150 + 50 | GSW<br>Model with parameter $sin^2\theta_W$ |
| The fundament | | | | | |
| Neutral Currents | 1973 | PS<br>ν-beam | Gargamelle<br>Bubble chamber | 60 | QED + Weak Interactions<br>Weinberg’s model of leptons<br>QPM |

1989 – 2000:
Precision EW studies

at LEP



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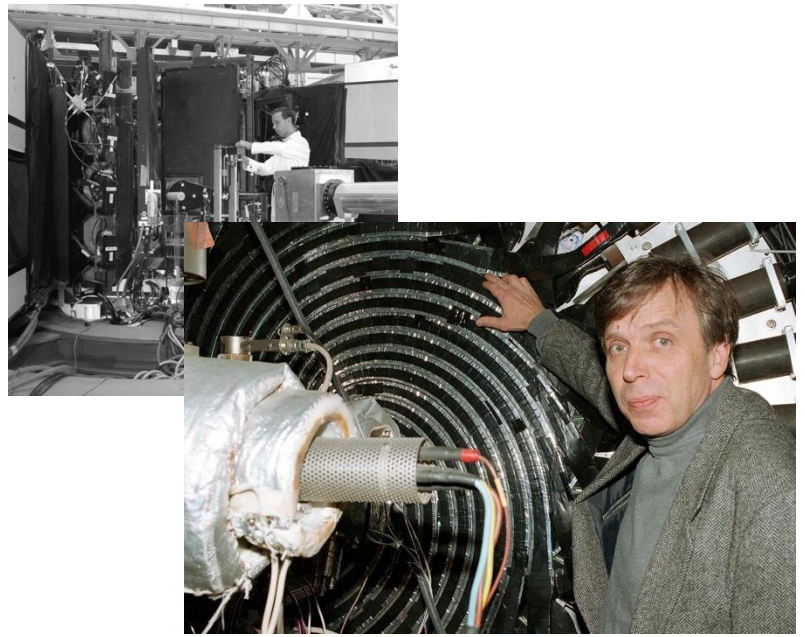
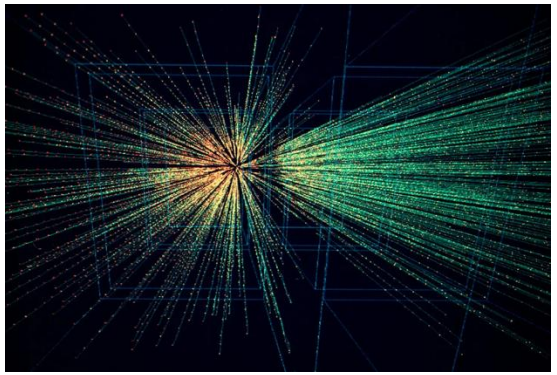
# Further key achievements

- 1958: CERN‘s **first experiment and discovery** (with the SC)
  pion to electron-neutrino decay, one month after startup.
- 1965: First observation of **anti-nuclei** (anti-deuterium) at the PS
  (Zichichi et al), simultaneously with a team at BNL.
- 1995: First ever **anti-atoms** produced, at LEAR

  today many ongoing precision experiments probing
  neutral anti-matter systems.
- Precision studies **of CP violation using Kaons**
  (NA31, NA48)
- 2000: First evidence of the **Quark-Gluon Plasma**
  (NA49)
- Many pivotal contributions to **theoretical physics**
  including fundamental aspects of Quantum Mechanics
  (J. Bell, 1964)



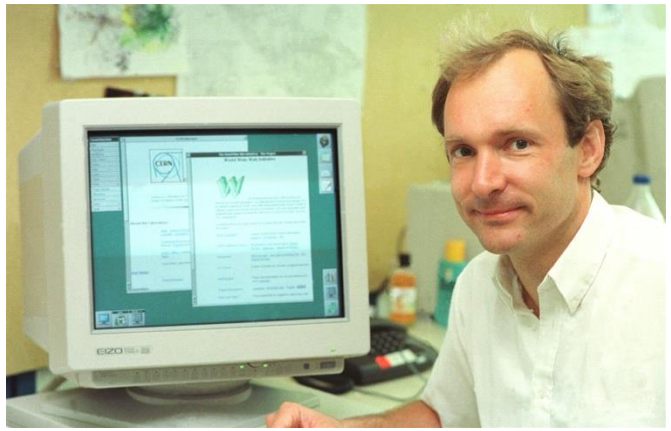
W. Oelert, leader of the anti-hydrogen experiment



J. Bell

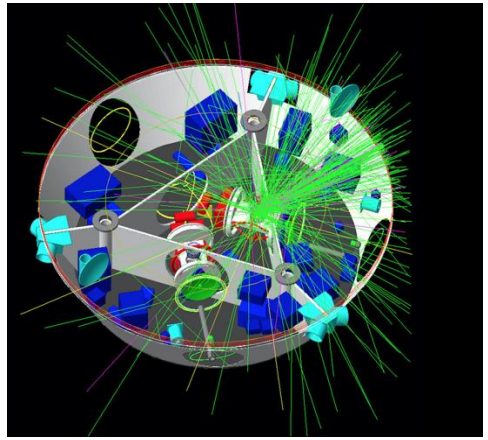
See also https://timeline.web.cern.ch/timeline-header/89, https://cern70.cern/history/

# And not to be forgotten…

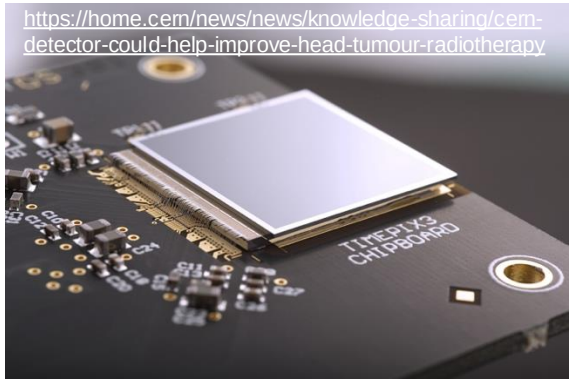


Tim Berners-Lee

https://kt.cern/technologies/geant4



https://home.cern/news/news/knowledge-sharing/cern-detector-could-help-improve-head-tumour-radiotherapy




- 1989: first proposal by Tim Berners-Lee for the **WWW**
- **Medical applications** (imaging, therapy)
  - Detector technologies for Positron-Emission Tomography
  - Detector readout (eg. Medipix, Timepix3)
  - Radiotherapy, eg. FLASH (innovative electron radiotherapy)
  - Radioisotopes
- **Simulations** (GEANT, FLUKA)
- And as mentioned earlier: many technologies related to accelerator and detector development, **hand-in-hand with industry**

See also https://timeline.web.cern.ch/timeline-header/89, https://cern70.cern/history/

# And NOT AT ALL to be forgotten…

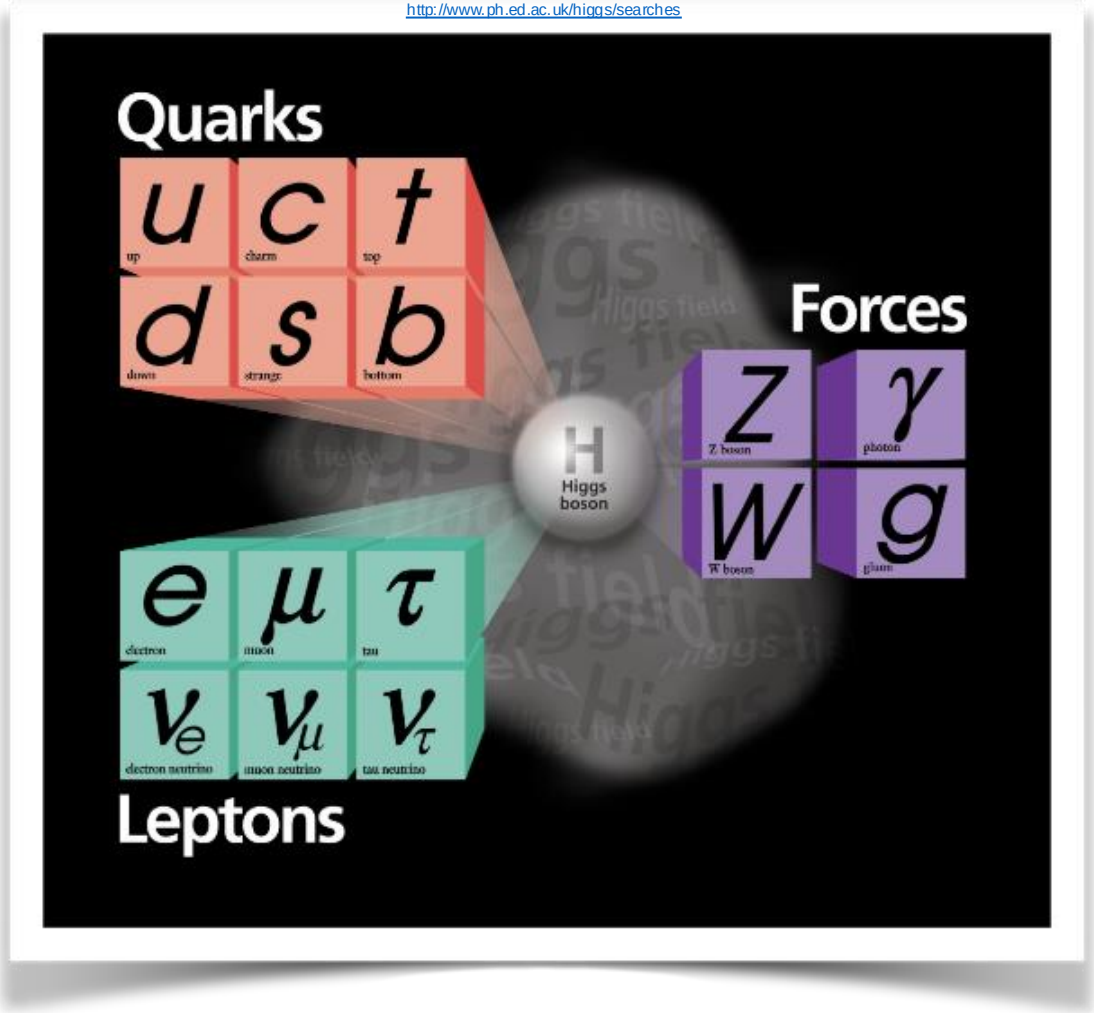
- **People:** many generations of highly-trained young talents (competitive international setting)
- **Governance:** THE example of how to organize, fund and execute very large-scale, complex, first-of-their-kind science projects
- A unique social experiment (**uniting people**)

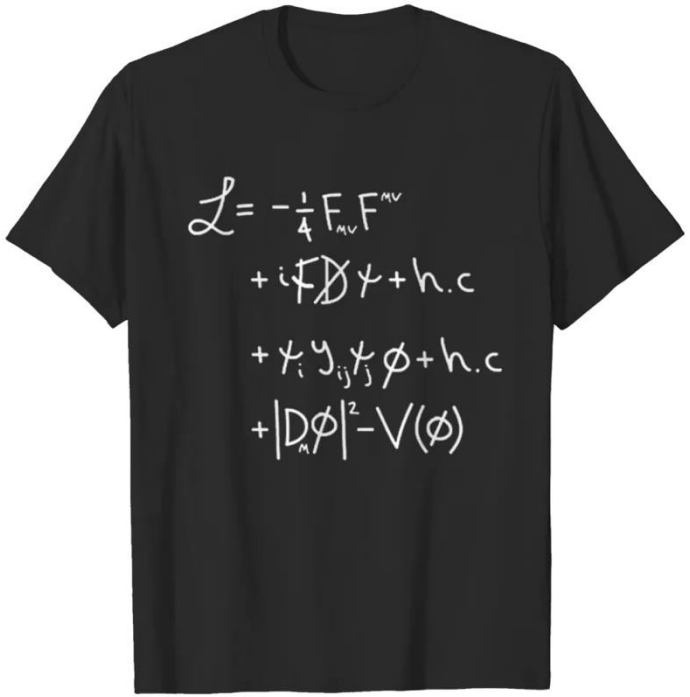
https://cerncourier.com/a/standing-out-from-the-crowd/

# Where do we stand now?

# The Standard Model of Particle Physics

http://www.ph.ed.ac.uk/higgs/searches



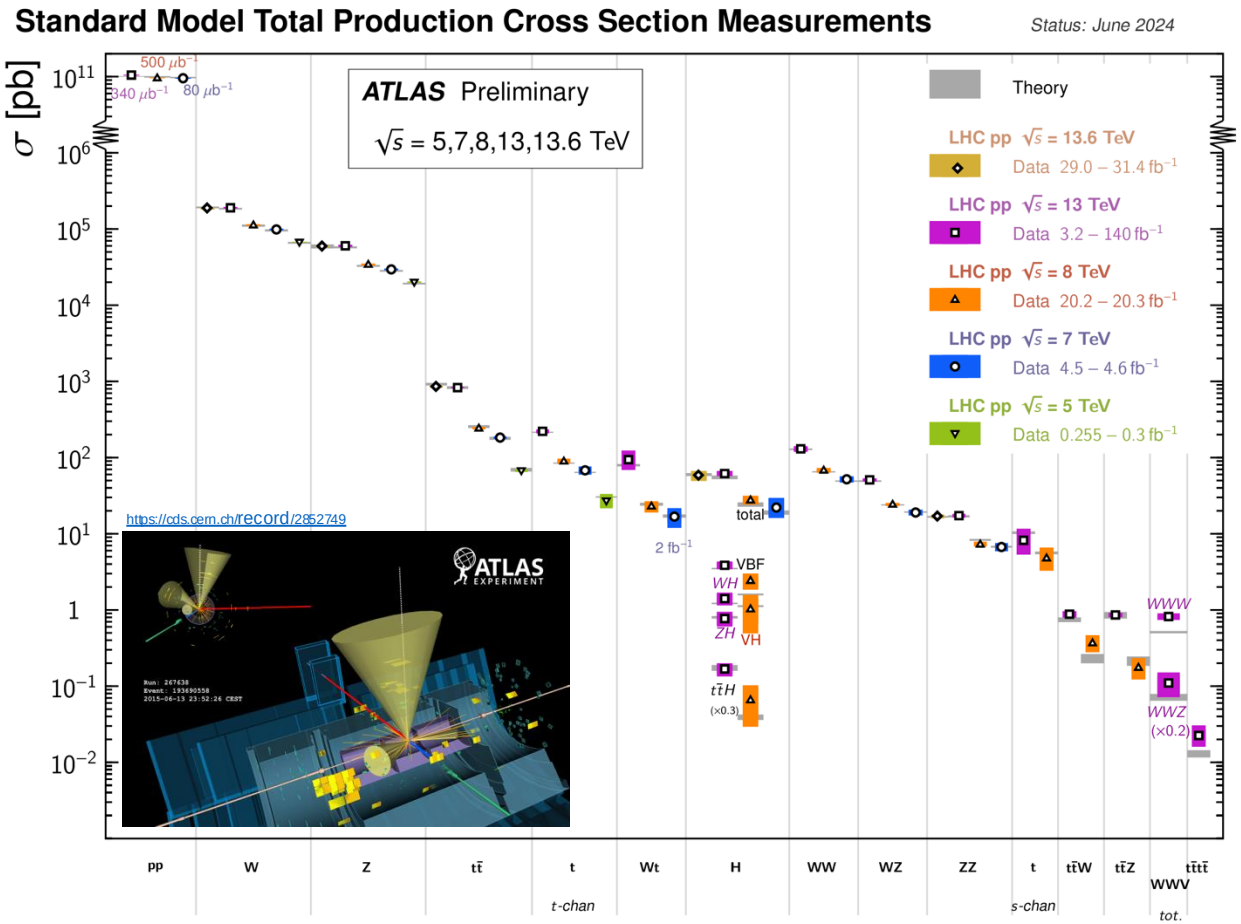



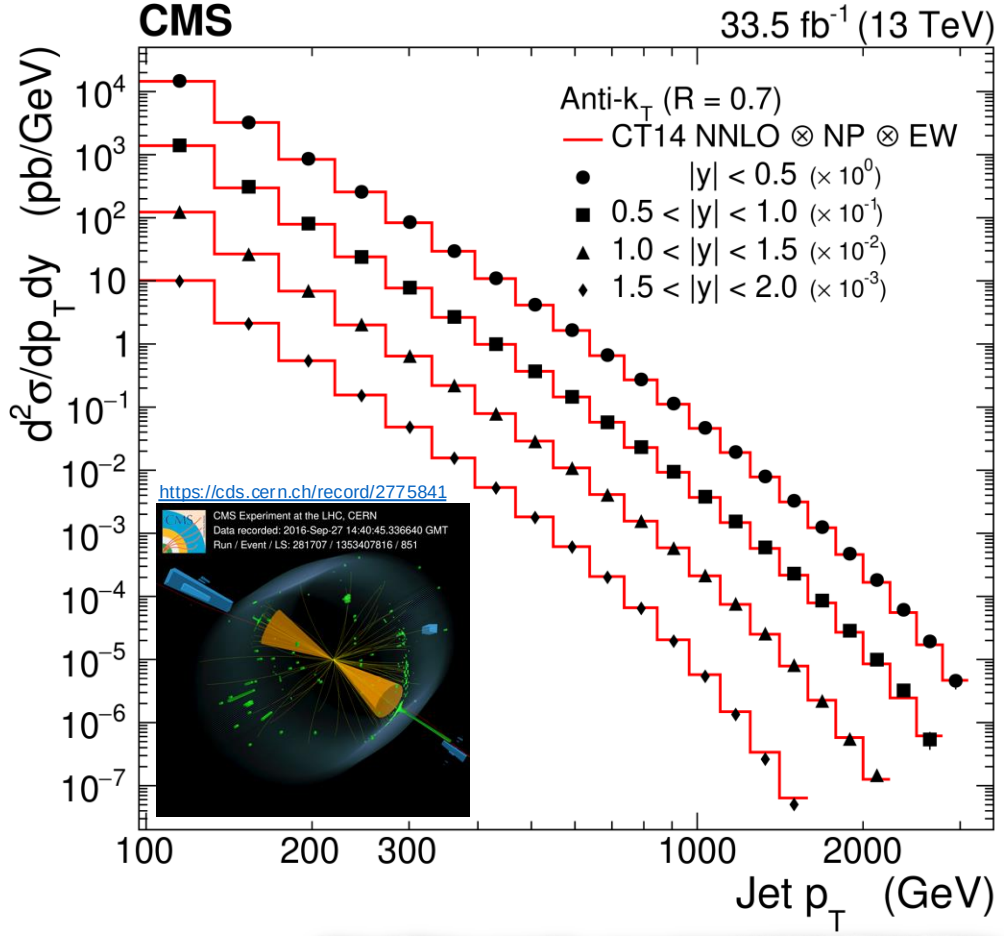

A renormalizable **Quantum Field Theory**, built on the powerful principle of **gauge theories**, with great predictive power

**“It works”**

as shown, eg. by the results from the first decade of the LHC

# The SM: Tested to greatest precision

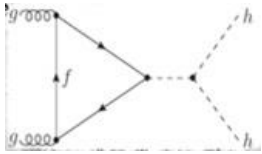


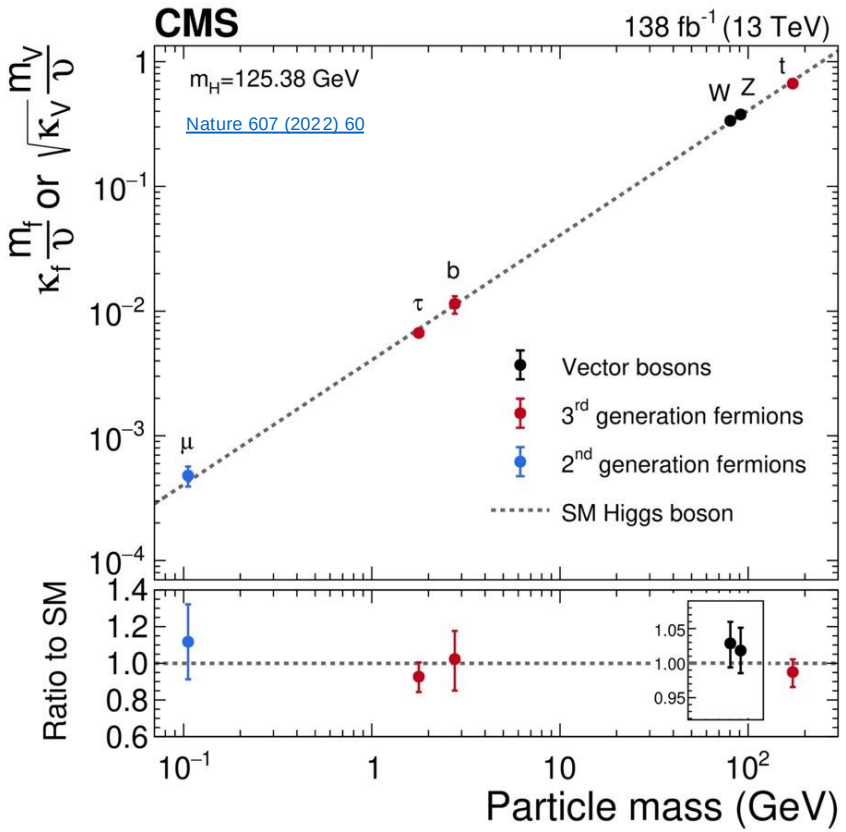



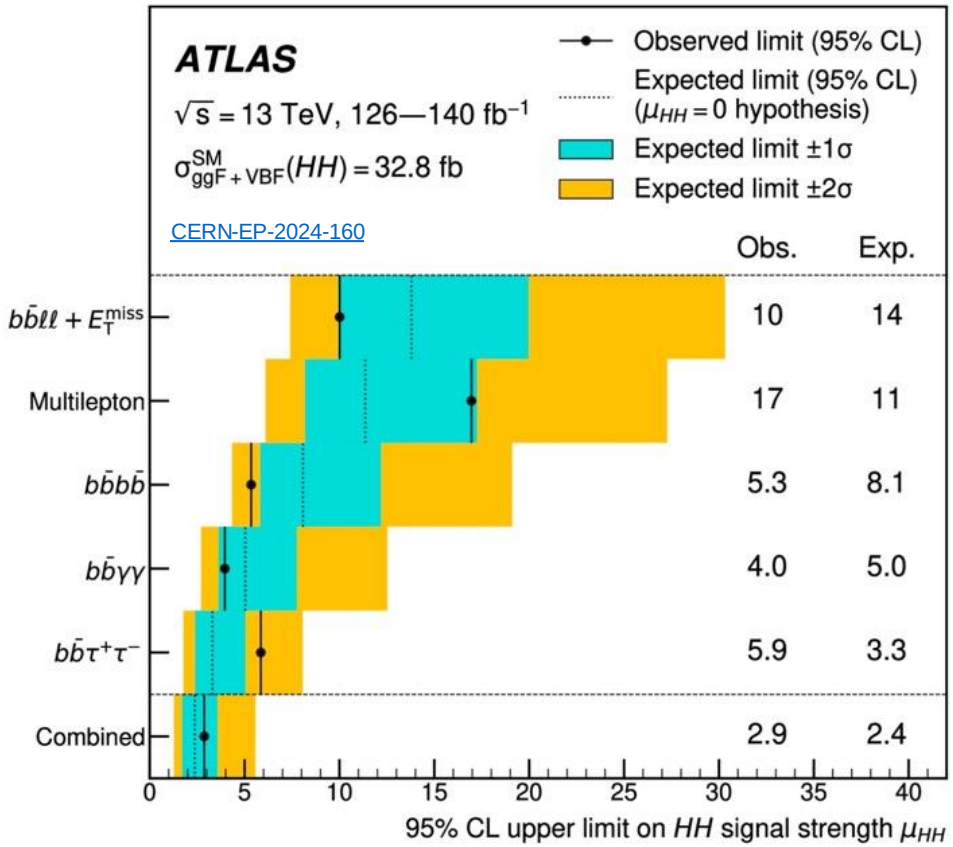

**probing distance scales of $10^{-19}$ m !**

# The Higgs boson: a fundamentally new tool and future “precision probe“

$$-\frac{1}{4}F_{\mu\nu}F^{\mu\nu} \qquad +\psi_i y_{ij}\psi_j\phi + h.c \qquad +|D_\mu\phi|^2 - V(\phi)$$

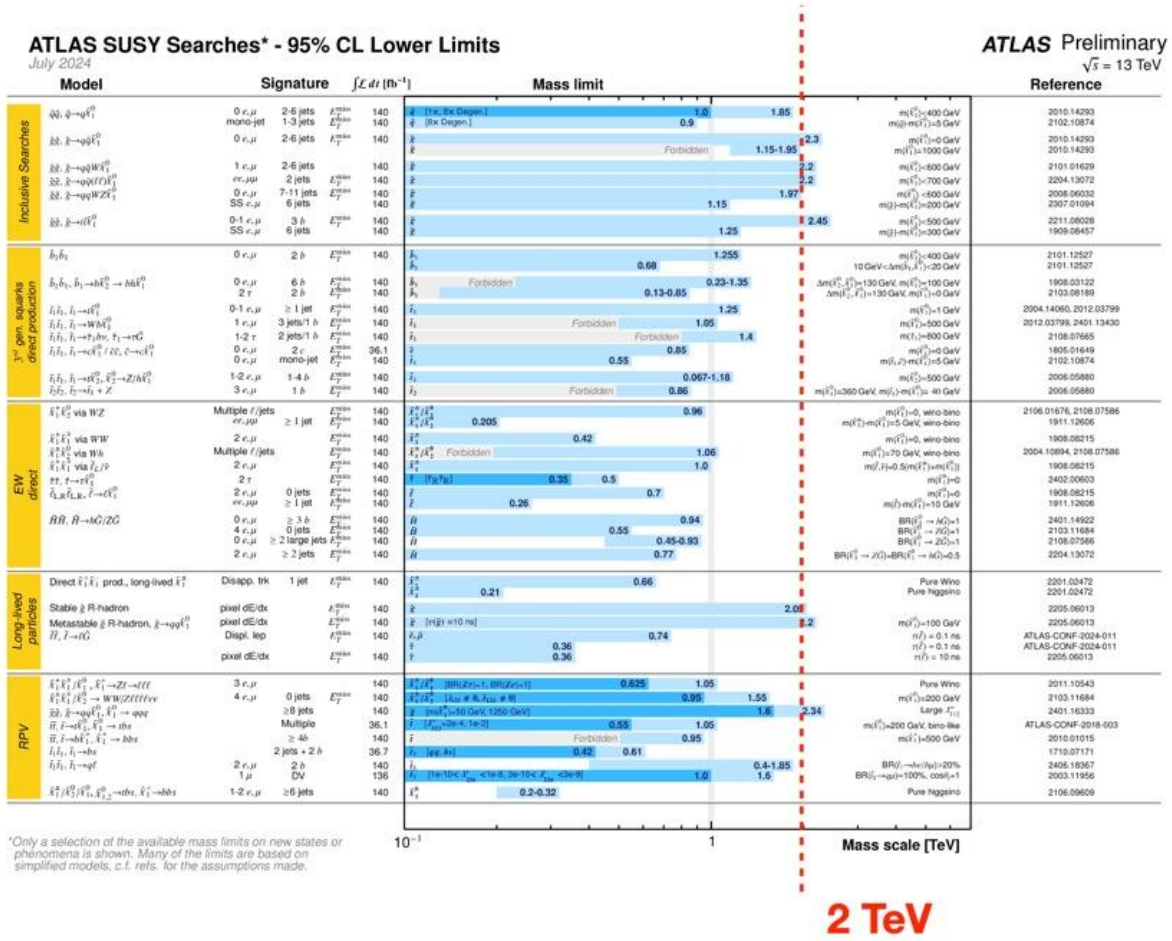


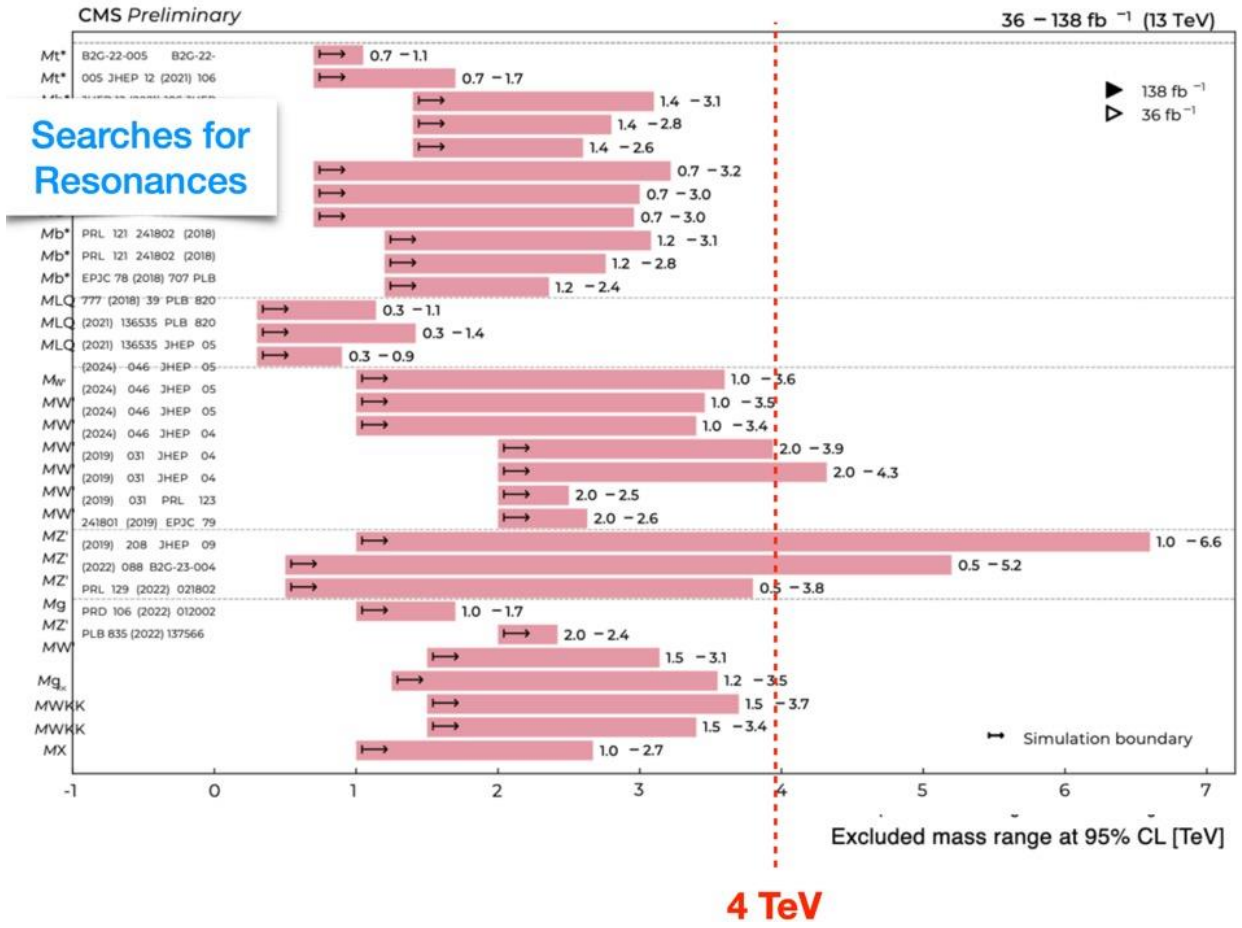



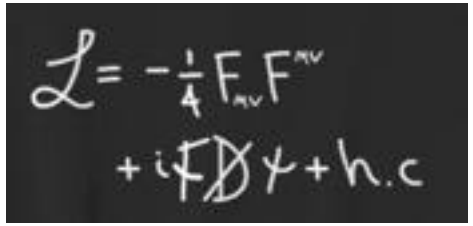
# Enormous „clean up“ of Beyond-SM model/parameter space: an achievement probably not valued enough

See talks by Livia Soffi and Marumi Kado, ICHEP 2024

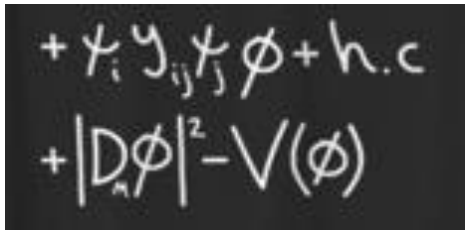


# The SM: Highly successful, **but**….




Simplicity, governed by symmetries, few free parameters

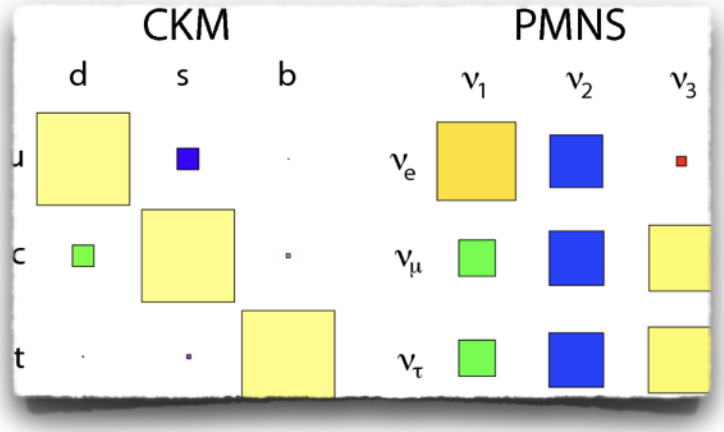


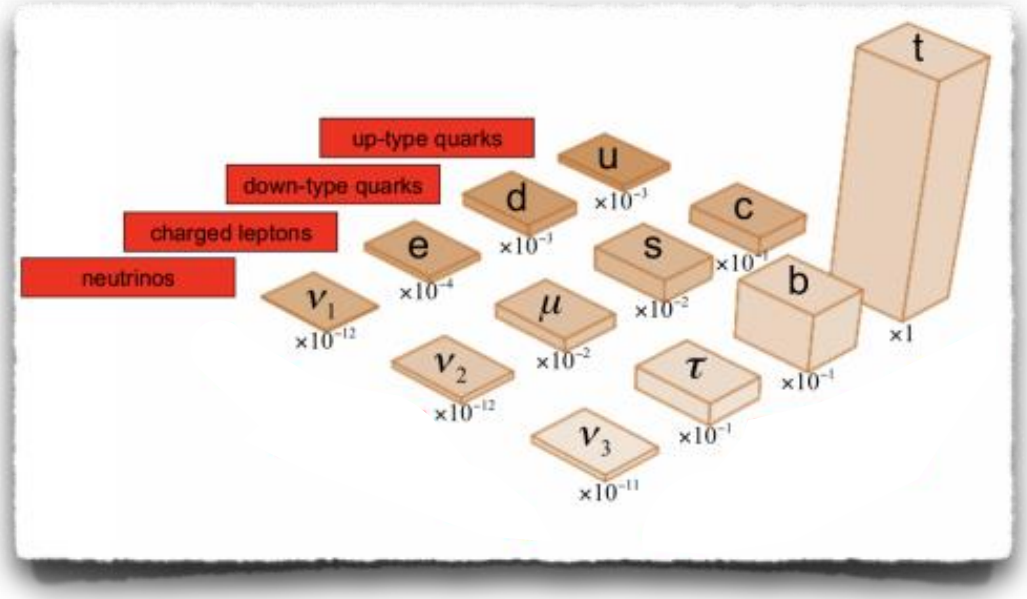

Not governed by symmetries
**many (!) parameters**
**set by the "hand" of experiments!**

Why is the Higgs boson so light?

No dark matter candidate in the model on the left !

We have no clue about the (possible) underlying principle of flavour!



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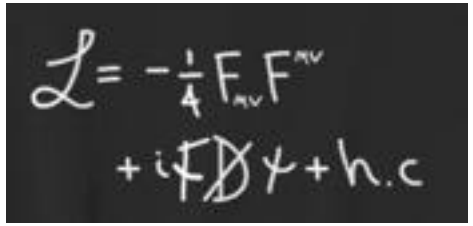


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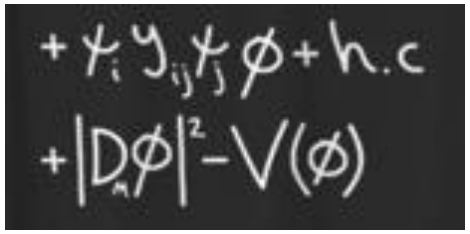


Not governed by symmetries
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Why is the Higgs boson so light?

No dark matter candidate in the model on the left !

We have no clue about the (possible) underlying principle of flavour!

Is there a unification of forces?

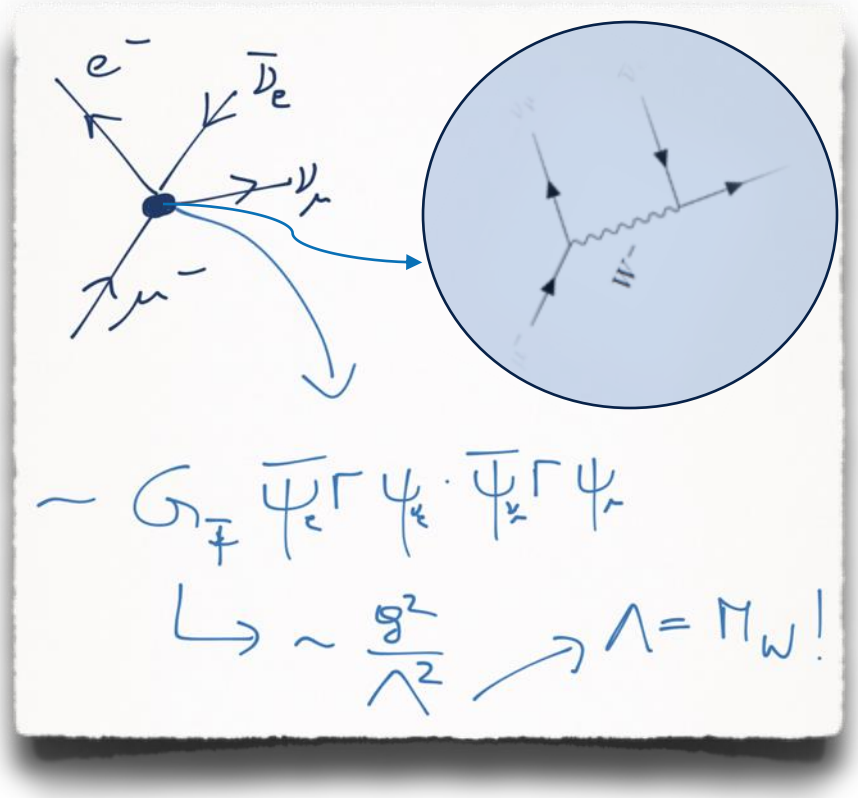
Why is gravity so much weaker?

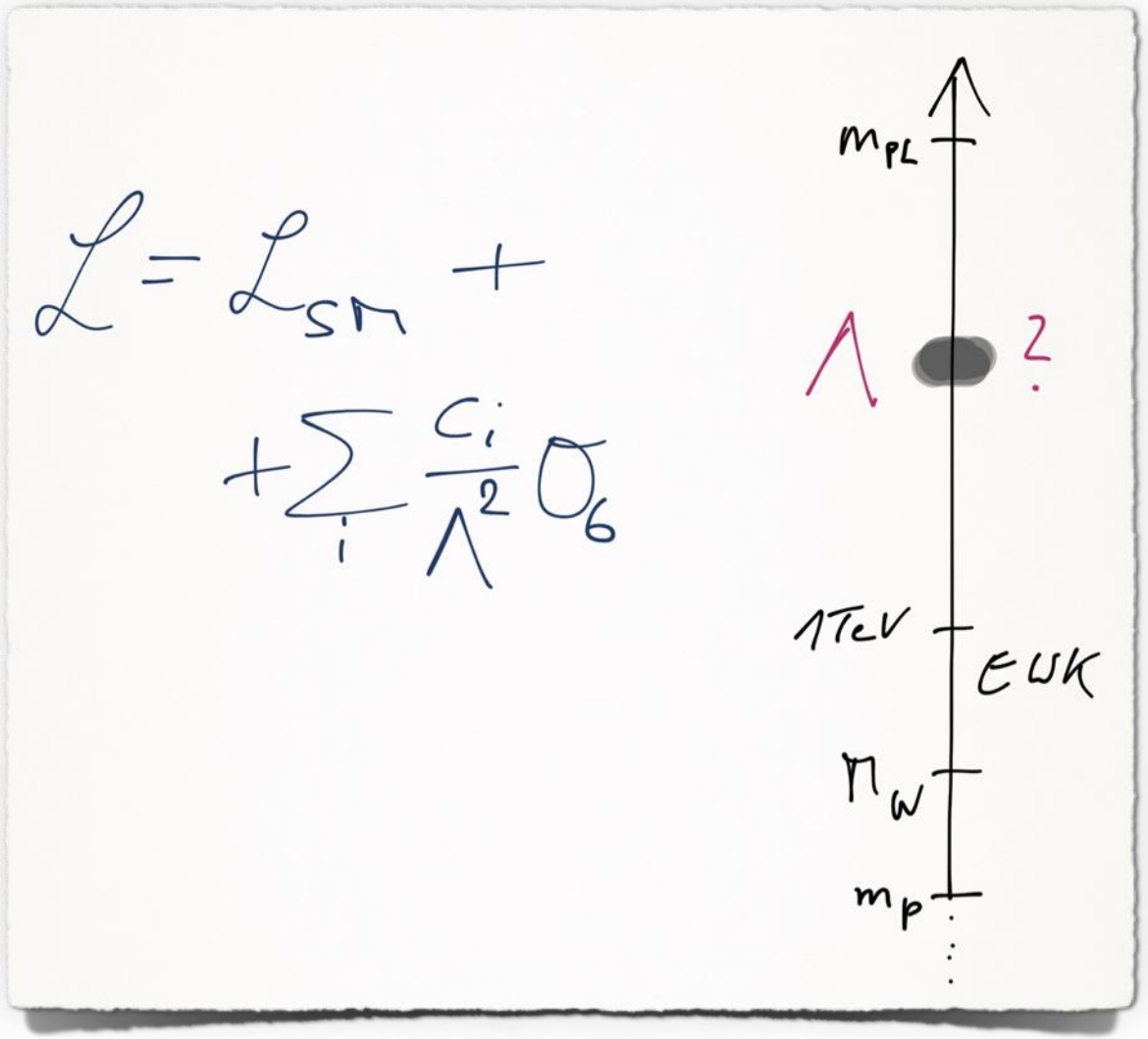
Why are neutrinos so light?

Matter-Antimatter asymmetry?

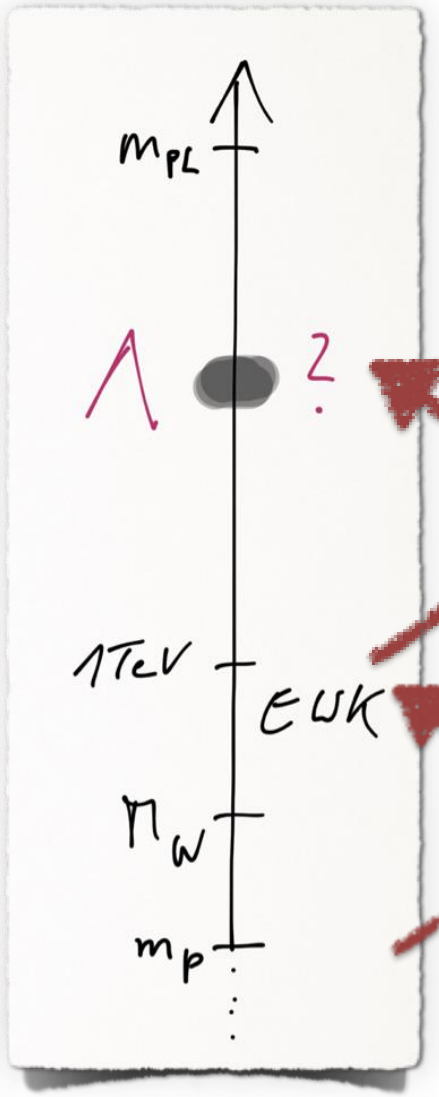
# New physics needed, but where is it?

i.e. what is the scale of New Physics?



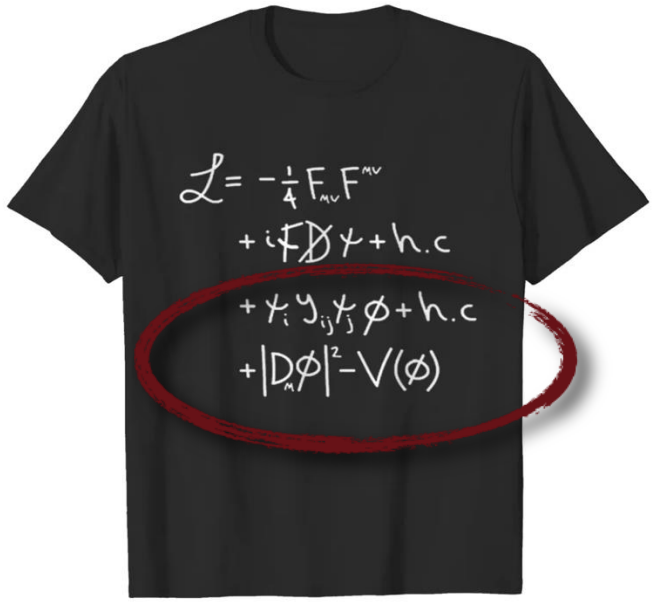



# New physics needed, but where is it?




combination of precision and higher energy

precision measurements and higher energy




Could the Higgs boson be a gateway to it?

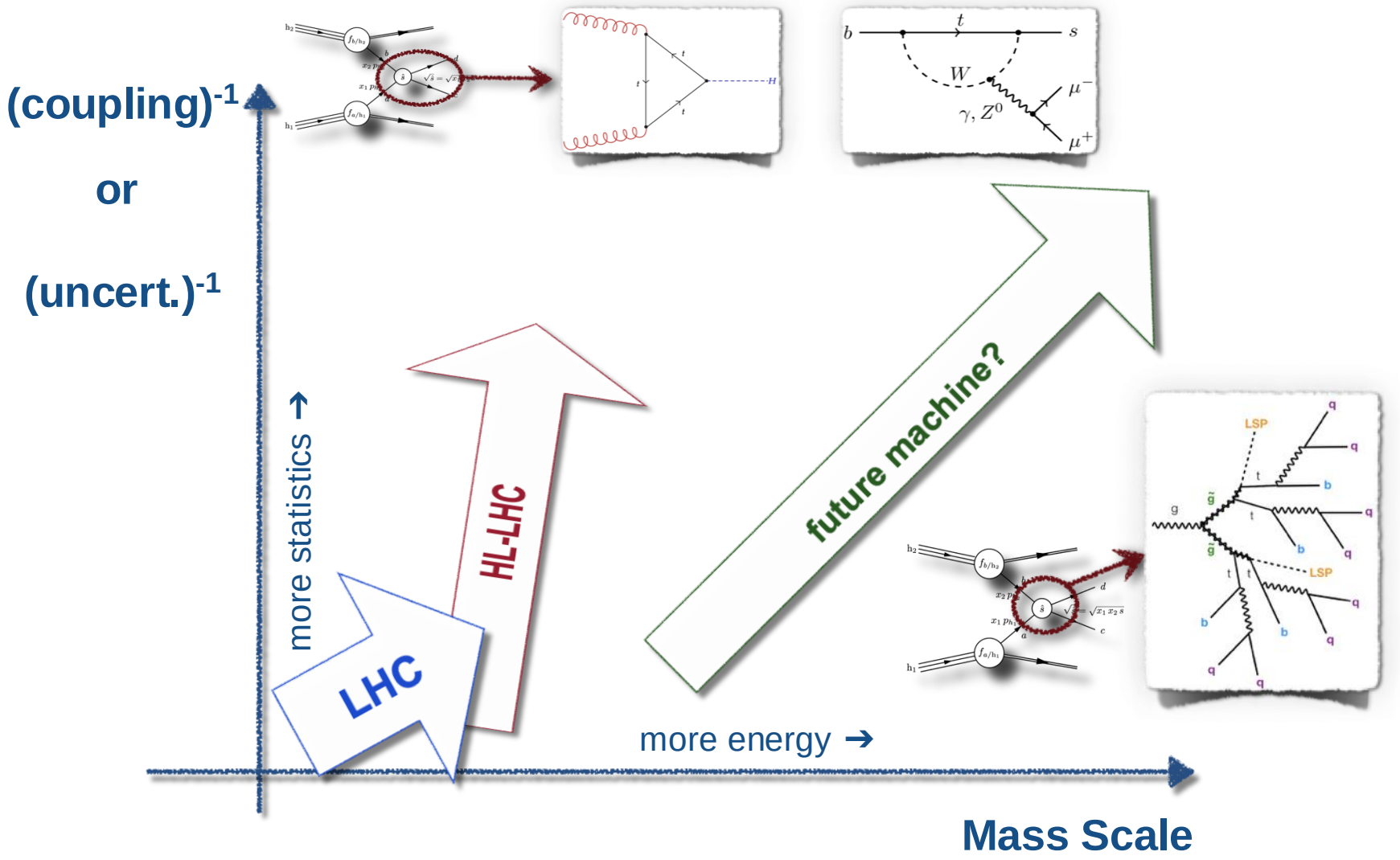
Consensus (?) regarding a

$e^+e^-$ Higgs factory as next step, beyond HL-LHC

**In any case: We are in an exploratory phase!**

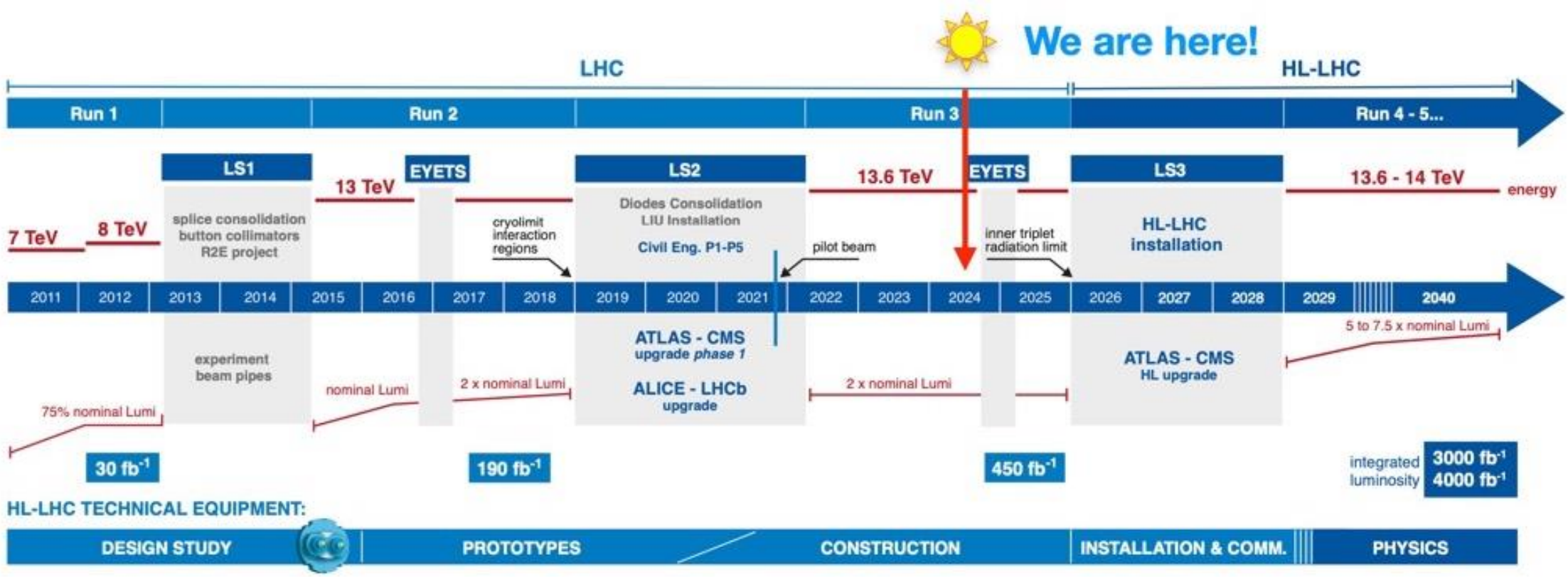
**Actually, this is the "normal" case…**

# How to explore the unknown



# The future (?)

# The imminent future, HL-LHC: Failure is not an option….

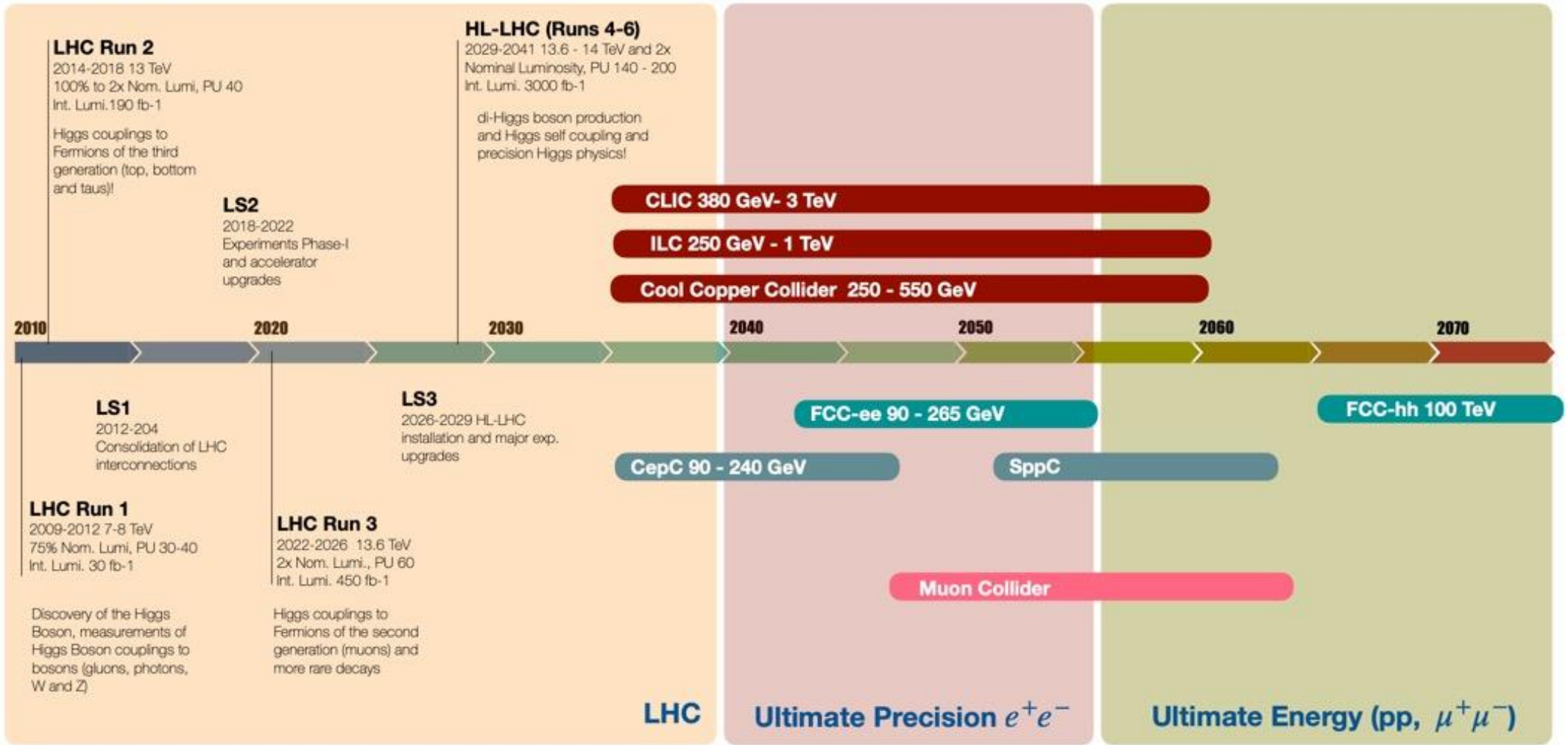



Marumi Kado, ICHEP 2024

**Current challenge**: in parallel data taking, data analyses and upgrades

# A Scientific Mission for the 21st Century

Rende Steerenberg



# If you are in an exploratory regime….

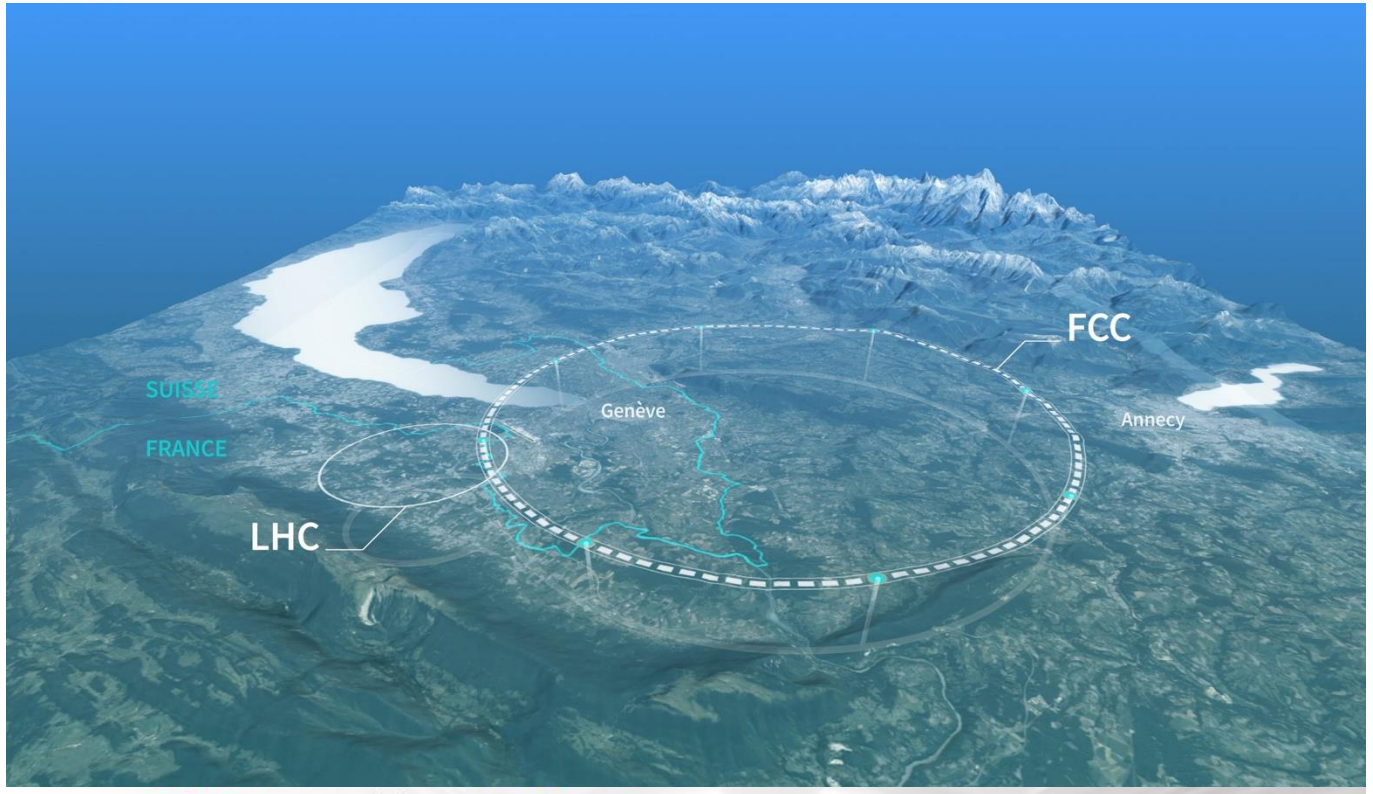
or

?

The **full FCC programme** (ee then hh, and more than one experiment) is the most versatile toolbox among all options on the table!

# The FCC programme

https://home.cern/science/accelerators/future-circular-collider




- Stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as a Higgs factory, electroweak & top factory at highest luminosities
- Stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, proton-proton with options


## FCC IN A NUTSHELL

### Timeline

- **2025**: Completion of the FCC Feasibility Study
- **2027–2028**: Decision by CERN Member States and international partners

### Tunnel

- **90.7 km** circumference
- **200 m** average depth
- **8 surface points** (7 in France, 1 in Switzerland)

### Two stages

- **FCC-ee** (precision measurements) about 15 years from the **mid-2040s**
- **FCC-hh** (high energy) about 25 years from the **2070s**

### Costs/benefits

- **15 billion CHF**, spread over at least **15 years** for FCC-ee with four experiments
- Estimated benefit–cost ratio of **1.66**
- About **800 000** person-years of employment created

Rende Steernberg, ICHEP 2024

# The biggest challenges

- Obviously, the **finances** (note: not the first science project of the “10 billion class“)
- **Sustainability aspects** (energy consumption) → public **acceptance**
- **People**
  - Make sure that we will be able to (still) attract the brightest young minds, especially in a (hopefully not too long) transition phase
  - Make sure that the (still) existing technical know-how (accelerators, detectors) is efficiently transferred to the next generations; mind the long time scales
- Make sure that, besides such a (timely) flagship project, there remains an **attractive portfolio of other projects at CERN** (like in the past).

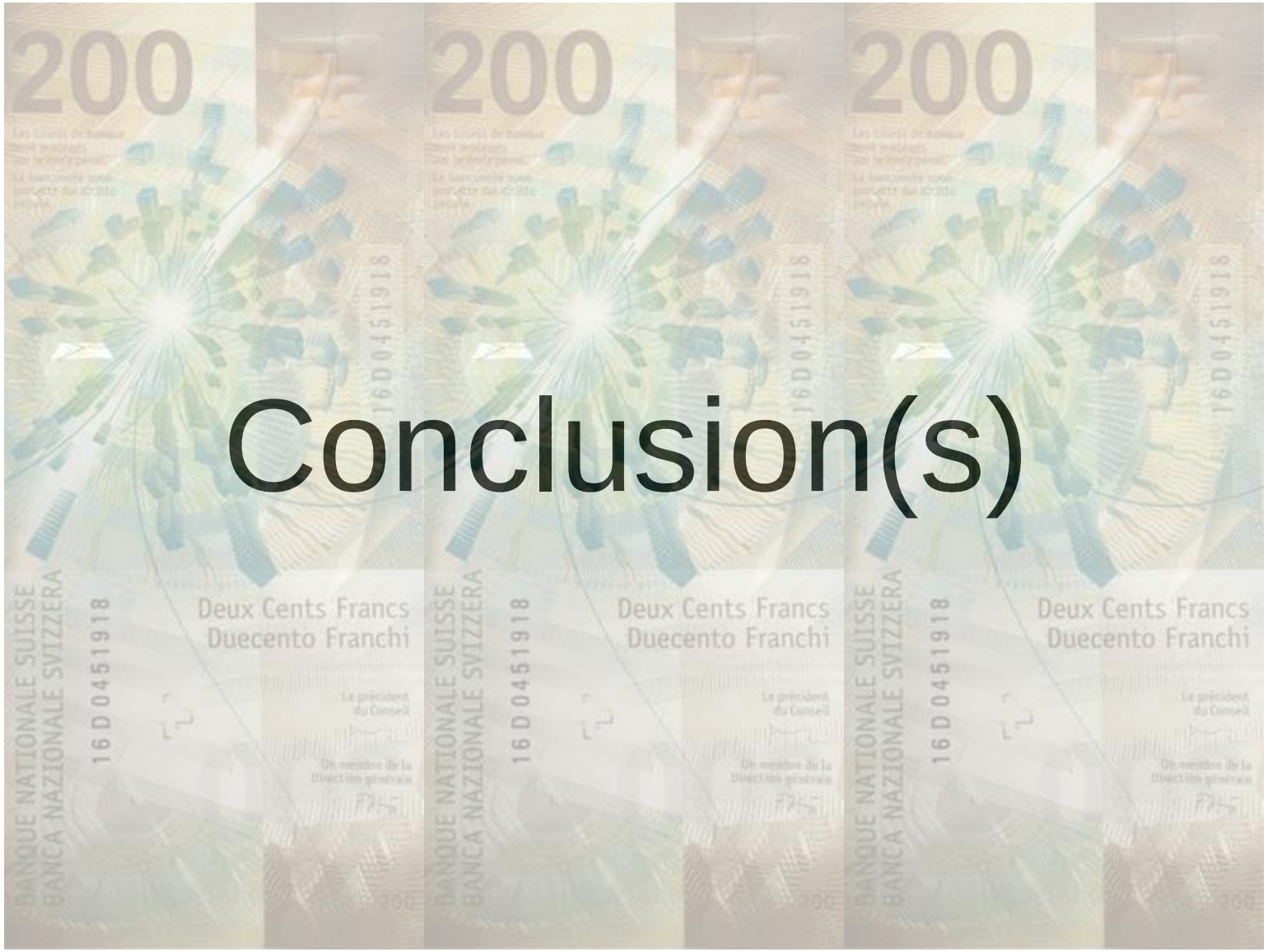
# What will be needed

- A **strong and united Council**, supporting a strong management
- Visionary and top **quality scientists**
  - never compromise on the quality of the people
- **Highly motivated young people**
- A **united community**


https://home.cern/news/news/knowledge-sharing/updating-european-strategy-particle-physics

A remark regarding the upcoming **European Strategy exercise**:

There is only one question to be answered: **do you envision a bright future for CERN?**
No need to repeat the entire discussions of the last time – the physics situation is clear, basically no change since last time. Fight the entropy.




# Conclusion(s)

# Concluding statements

- CERN has been **a success story**, at the European and world-wide level
  - in terms of international cooperation for large research infrastructures
  - in terms of advancements in our understanding of the fundamental building blocks of matter and their interactions
  - in terms of providing a fantastic training ground for highly skilled young scientists and engineers, and in terms of close collaboration with industry
  - in terms of spin-offs from fundamental research with major impact on society
- This is **a crucial phase in CERN‘s history**
  - Its future could be bright, but this future is not yet secured
  - An institution like CERN definitely needs a flagship project for a bright future
- I wish that all stakeholders realize what actually is at stake, and will **act** accordingly

DALL-E