Physics at CERN

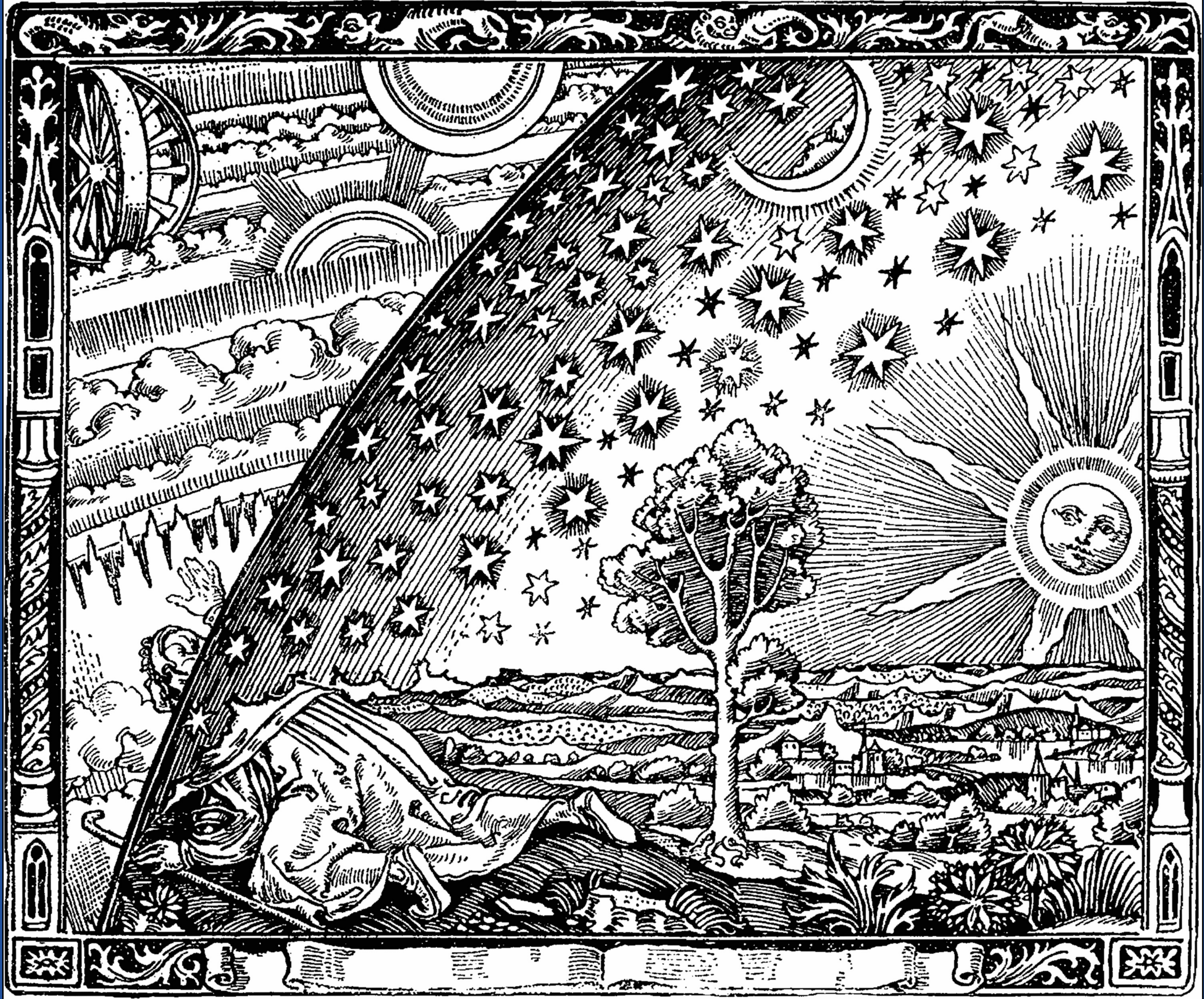
or how to find answers to the fundamental questions of the Universe?

Physikerinnen Tagung - DESY

Ursula Bassler

CERN Council President

IN2P3 - CNRS



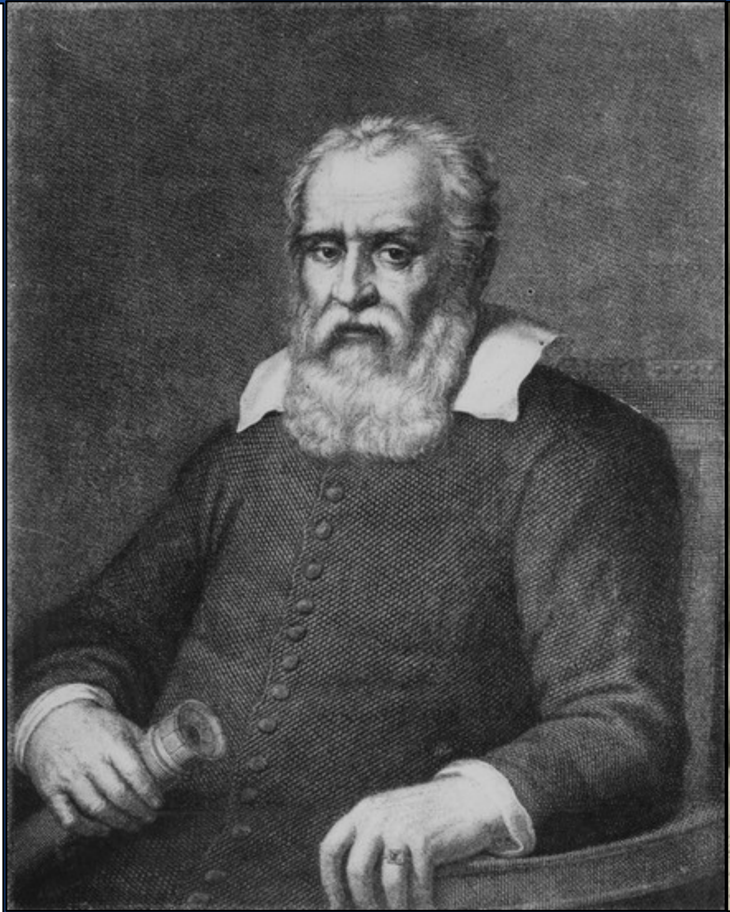
Since the dawn of time, humans explore the world around and try to explain the origin of the Universe, its evolution and everything it contains.

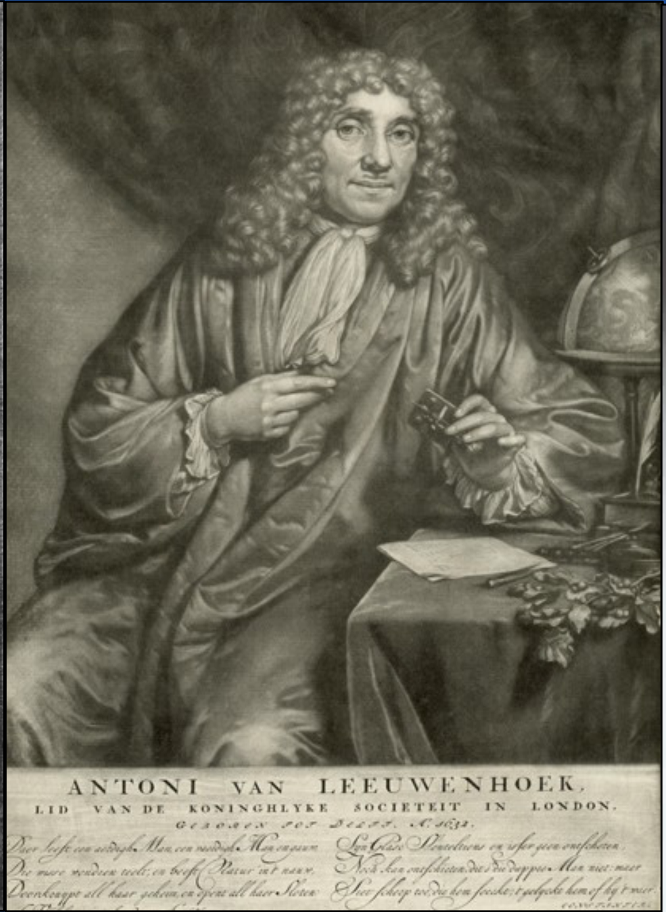
For a long time, science was mixed up with religious believes, philosophical considerations and factual observations.

Renaissance: a new era for science

Galileo Galilée – 1564-1642 :
« Measure what is measurable, and make measurable what is not so »

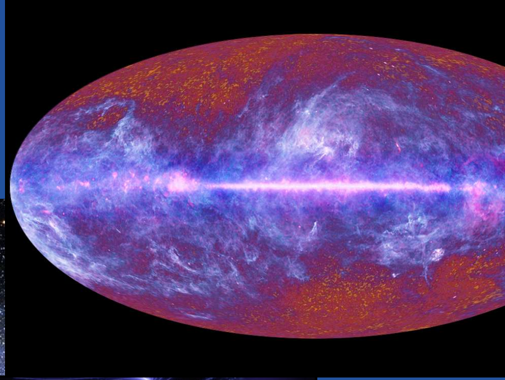
Antoni van Leeuwenhoek – 1632-1723 :
« My work, which I've done for a long time, was not pursued in order to gain the praise I enjoy now, but chiefly from a craving after knowledge, which I notice resides in me more than in most other me





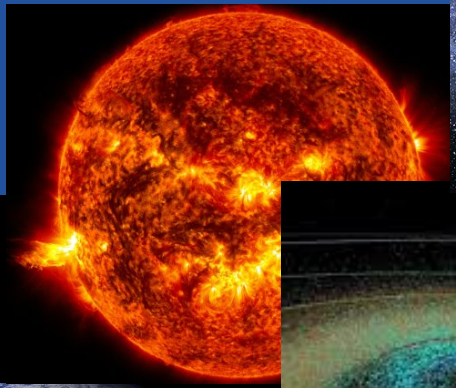
Explore from the infinitely big to the infinitely small...

10^{27}m

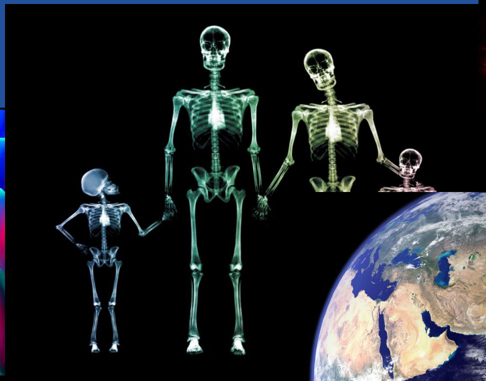


10^{16}m

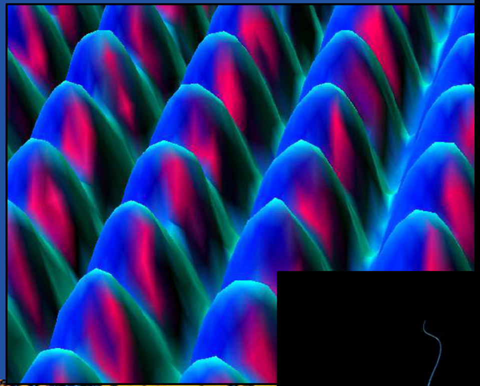
10^{9}m

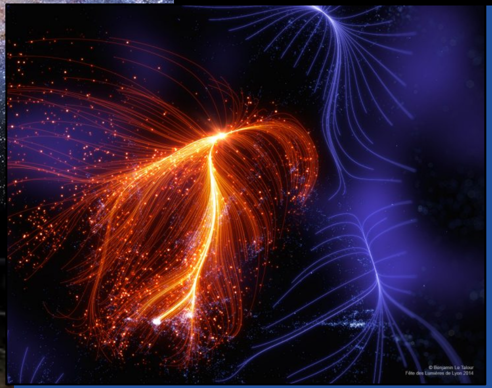


Taille: 1m

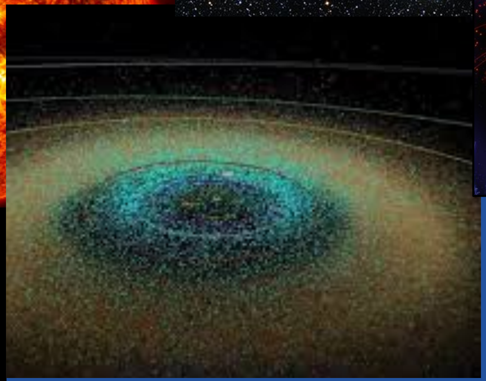


10^{-10}m





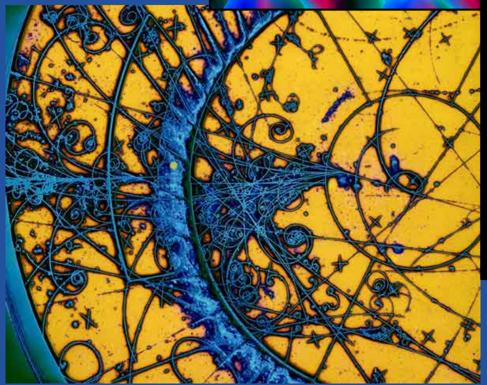
10^{24}m

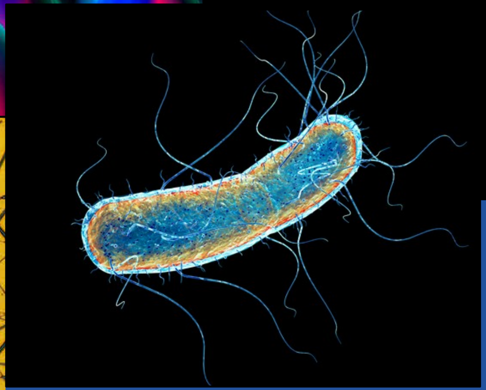


10^{13}m

10^{5}m

10^{-15}m





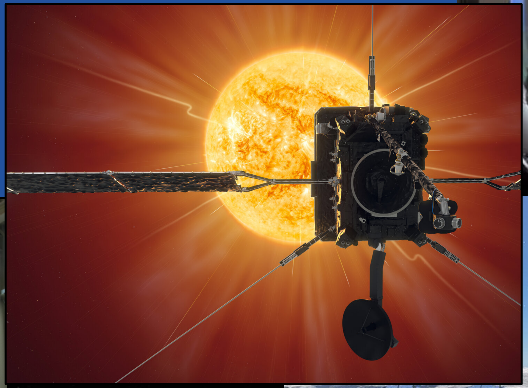
10^{-5}m

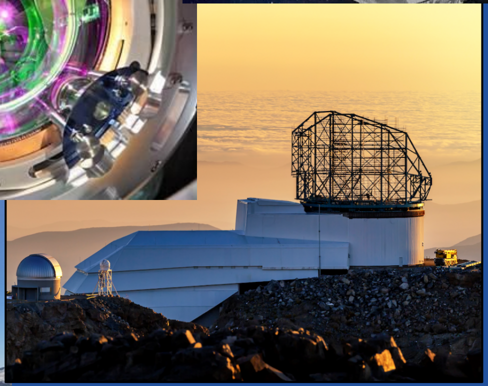
…thanks to large research infrastructures

LIGO/VIRGO

PLANCK

SOLAR ORBITOR

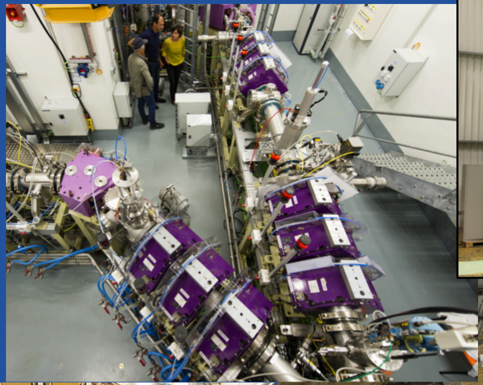


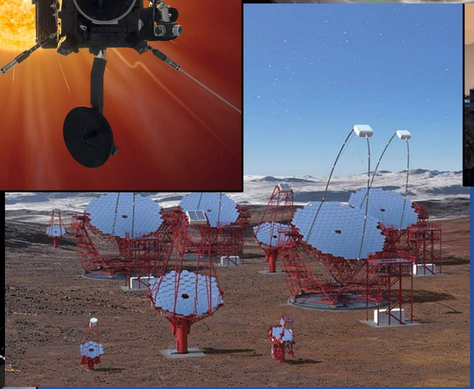


LSST

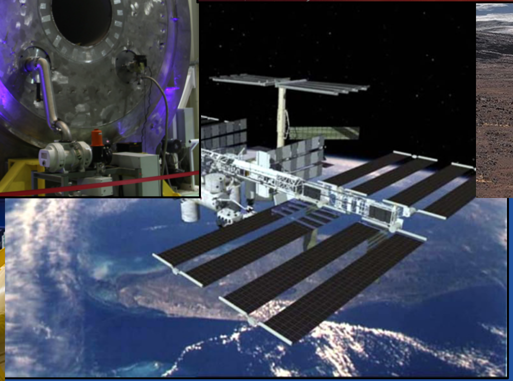
NEUROSPIN

SPIRAL 2



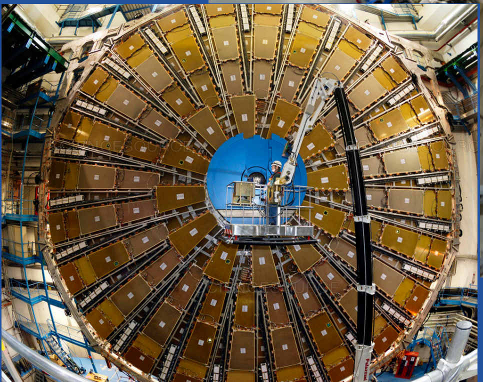


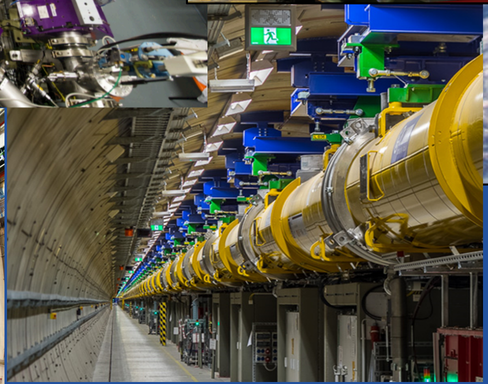
CTA



ISS

LHC





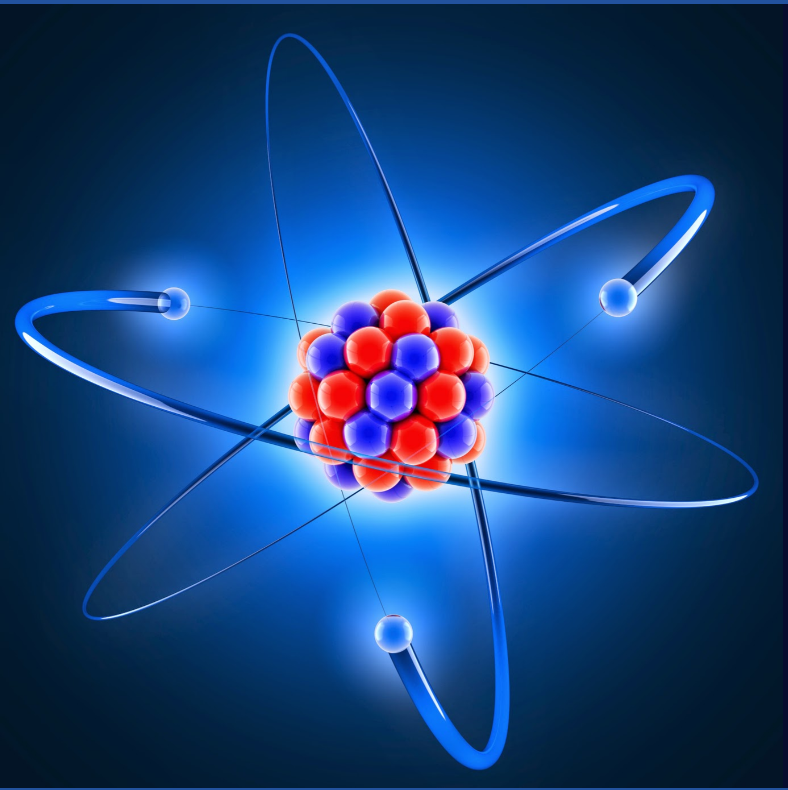
X-FEL

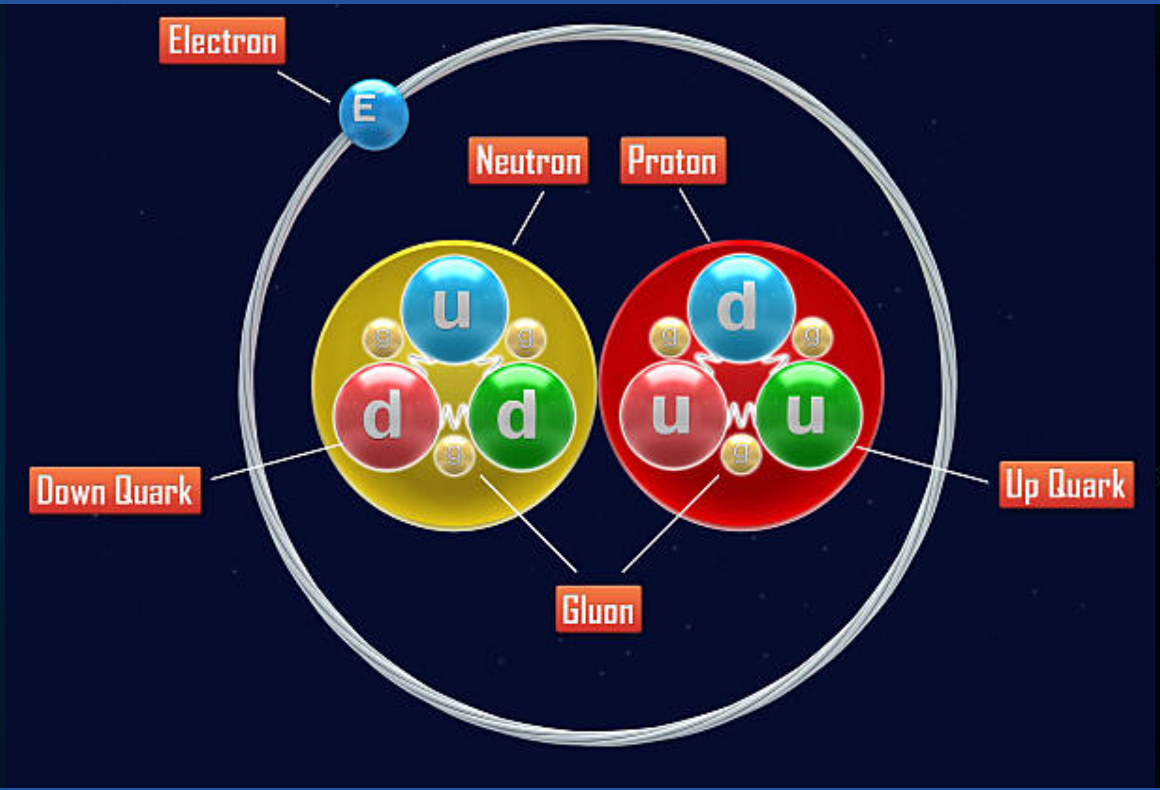
The structure of matter

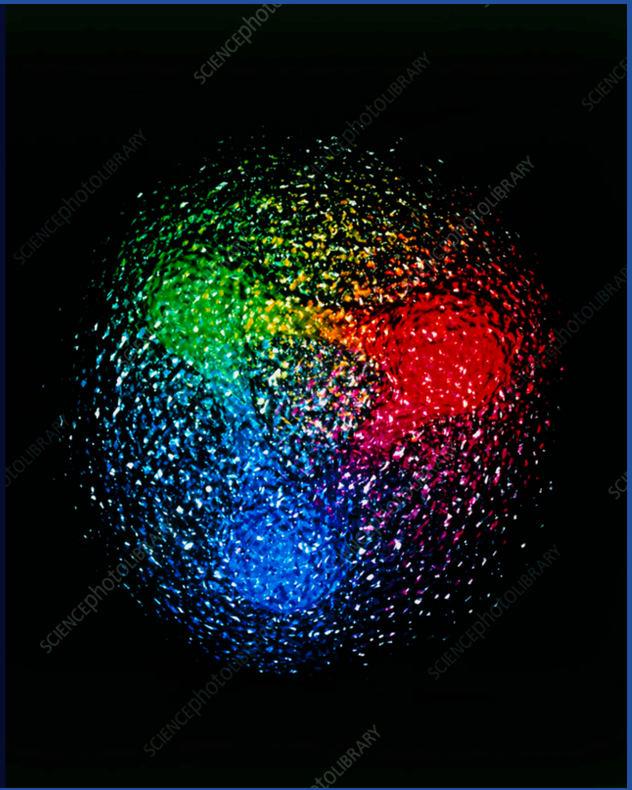
The atom

The nucleons

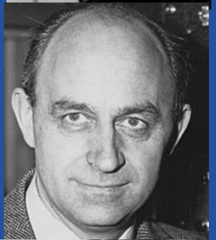
Quarks and gluons

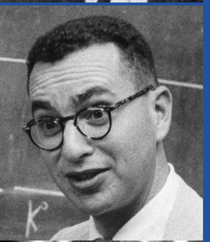
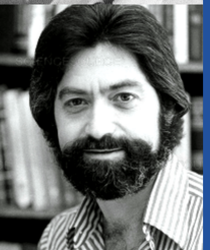






From a particle zoo to the Quark Model

1940-1960: First hints of π–mesons in cosmic ray picture (Bibha Chowdhuri)

→ discovery of many hadronic particles :

π, K, Λ, Δ, Ξ, ρ, φ, Σ, η, ω, Ω…

Enrico Fermi to his student Leon Lederman:

> *"Young man, if I could remember the names of these particles, I would have been a botanist."*

→ searching for underlying structure in a zoo of particles: quest for beauty and simplicity?

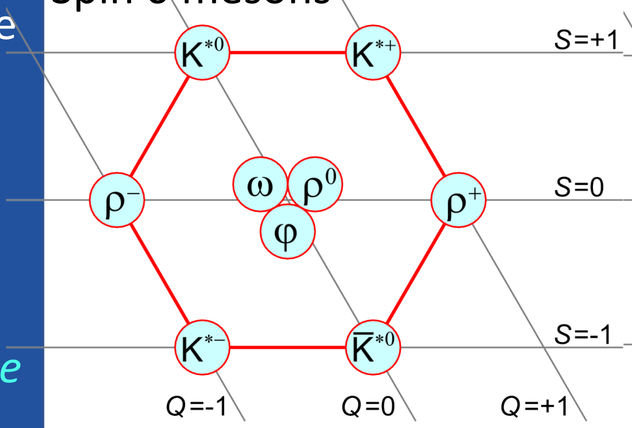
Murry Gell-Mann and Kazuhiko Nishijima (1961) :

→ "Eight-fold Way"

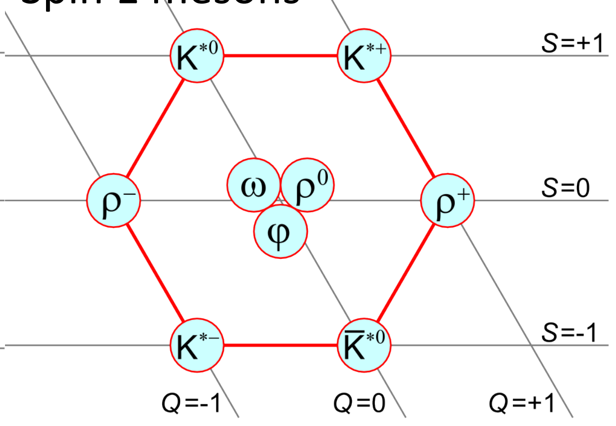
Gell-Mann and George Zweig (1964):

→ model with an underlying structure of 3 quarks

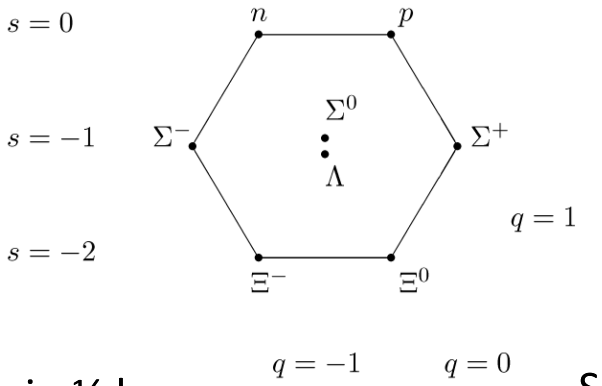
→ Considered first as a mathematical construct with no underlying physical reality



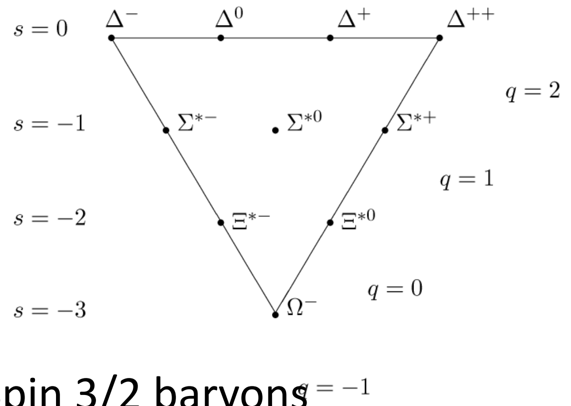
Spin 0 mesons



Spin 1 mesons



Spin ½ baryons



Spin 3/2 baryons

QCD: Quantum Chromodynamics

Experiment at SLAC in 1968 (Jerome Friedman, Henry Kendal, Richard Taylor)

→ The elastic cross-section would be expected to drop at higher energy, but it stays stable: it "scales"

James Bjorken in 1967:

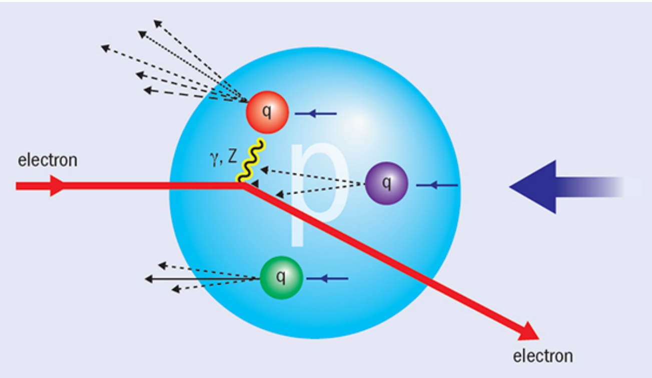
"scaling" indicates *« that the nucleon consists of a certain number of 'elementary constituents' »*

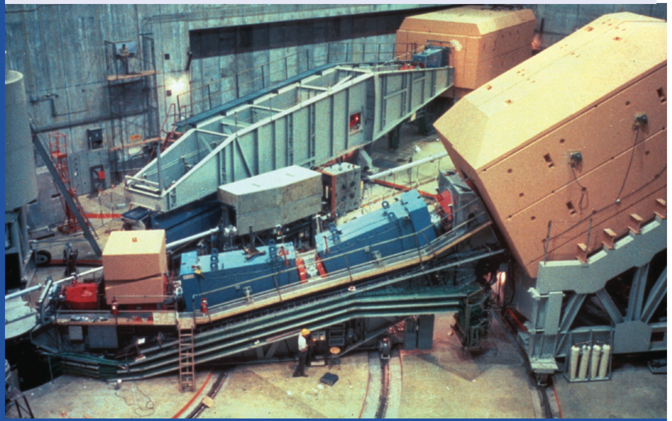
Friedman's comment:

« Bjorken's results were based on current algebra, which we found as highly esoteric »

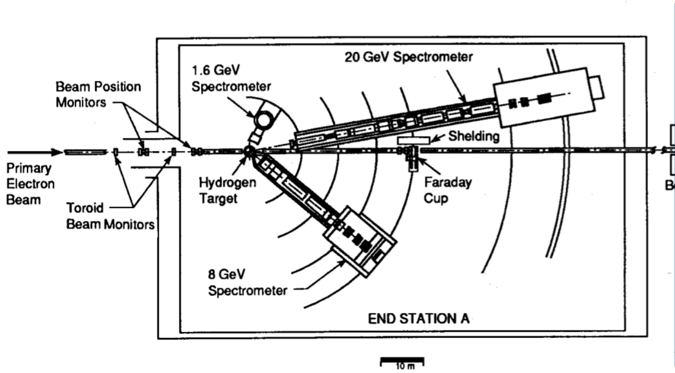
1973 : Harald Fritzsch and Heinrich Leutwyler proposes that quarks carry a **color charge**

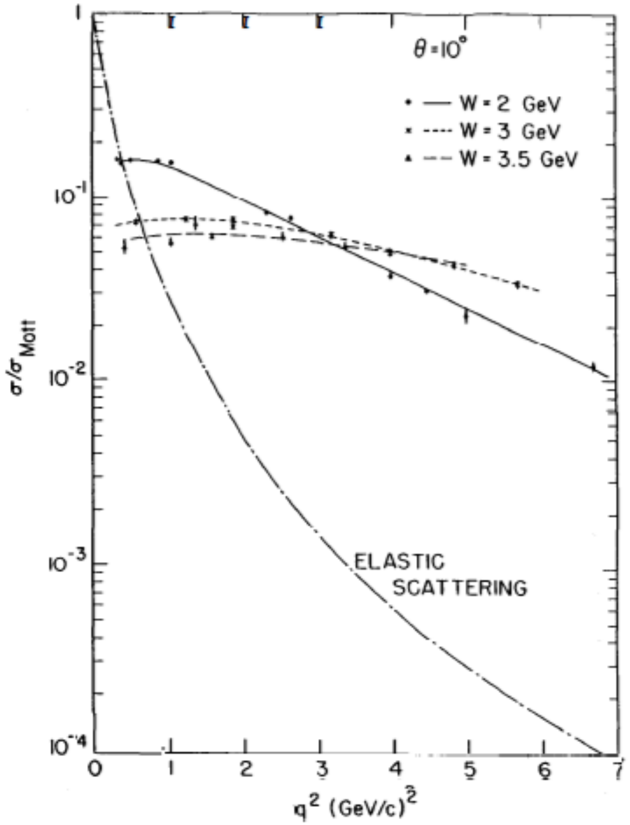
David Gross, David Politzer and Frank Wilczek discover **asymptotic freedom** explain why quarks are not observable as free particles but behave as such in high energy interactions





Wilczek : *« In theoretical physics, paradoxes are good… When our physical theories lead to paradox we must find a way out. Paradoxes focus our attention, and we think harder »*





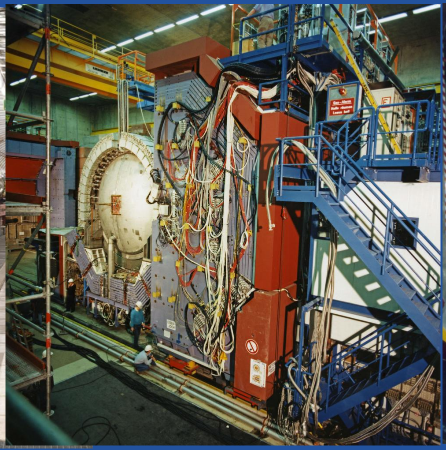
Proton structure at HERA (1991-2007)

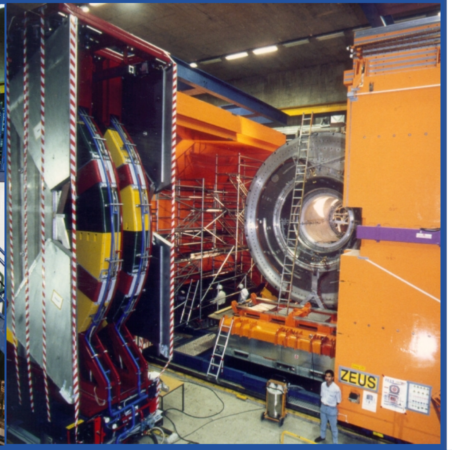
.. Some 40 years later:

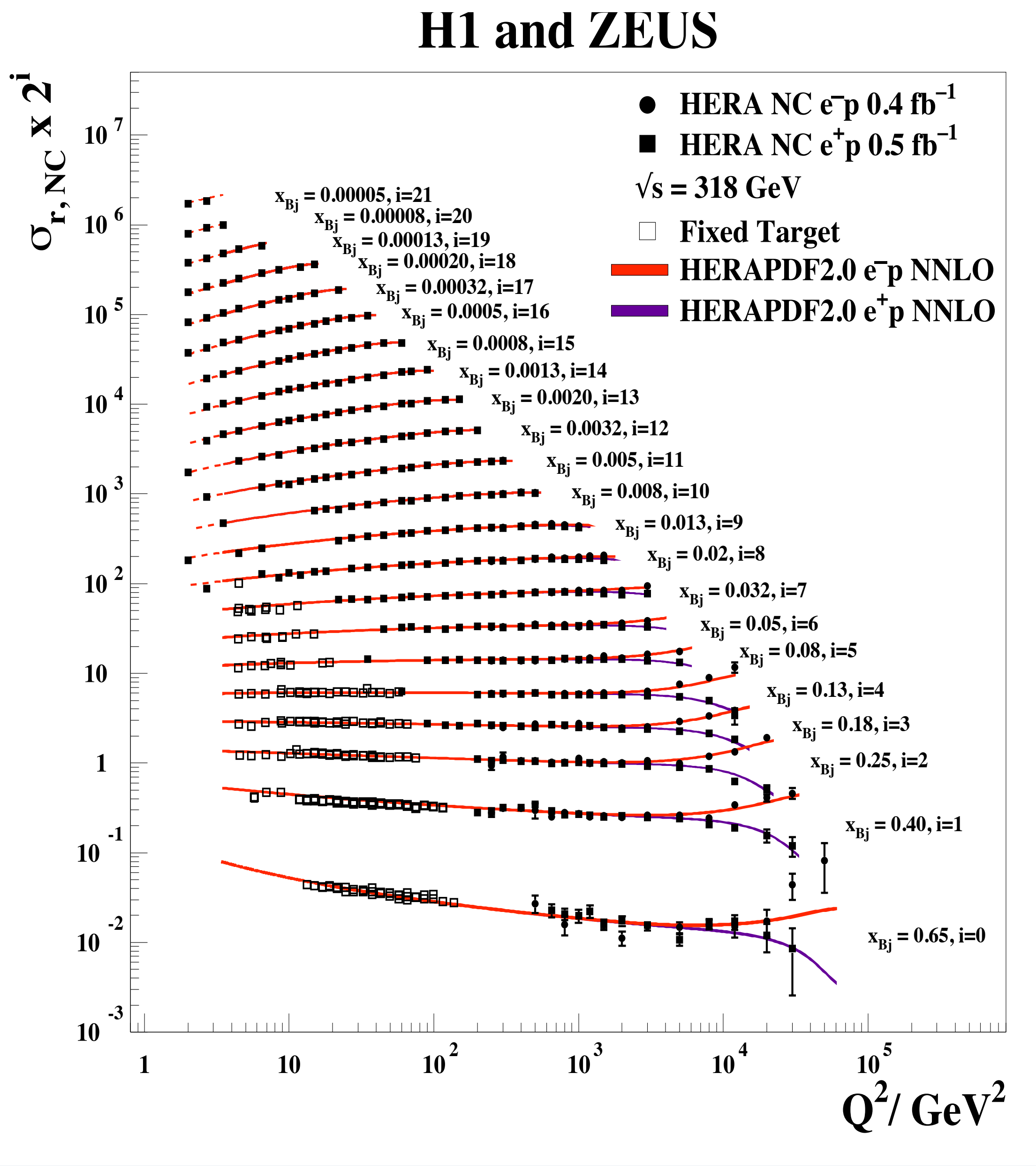
Results from Deep Inelastic Scattering: **HERA collider**

→ Observation of Scaling when the electron interacts with a constituent quark of the proton

→ Observation of scaling violations when the electron interactions with a gluon or a quarks from quark-antiquark production







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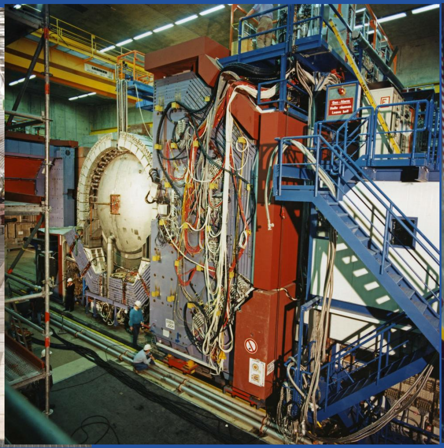
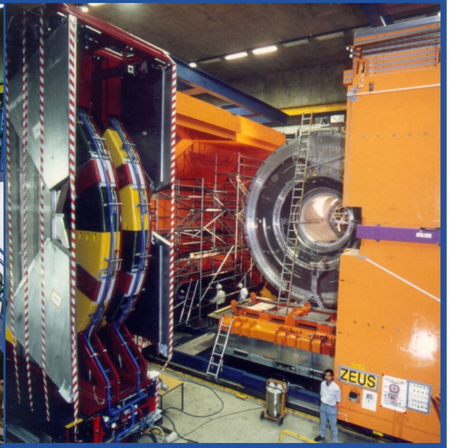
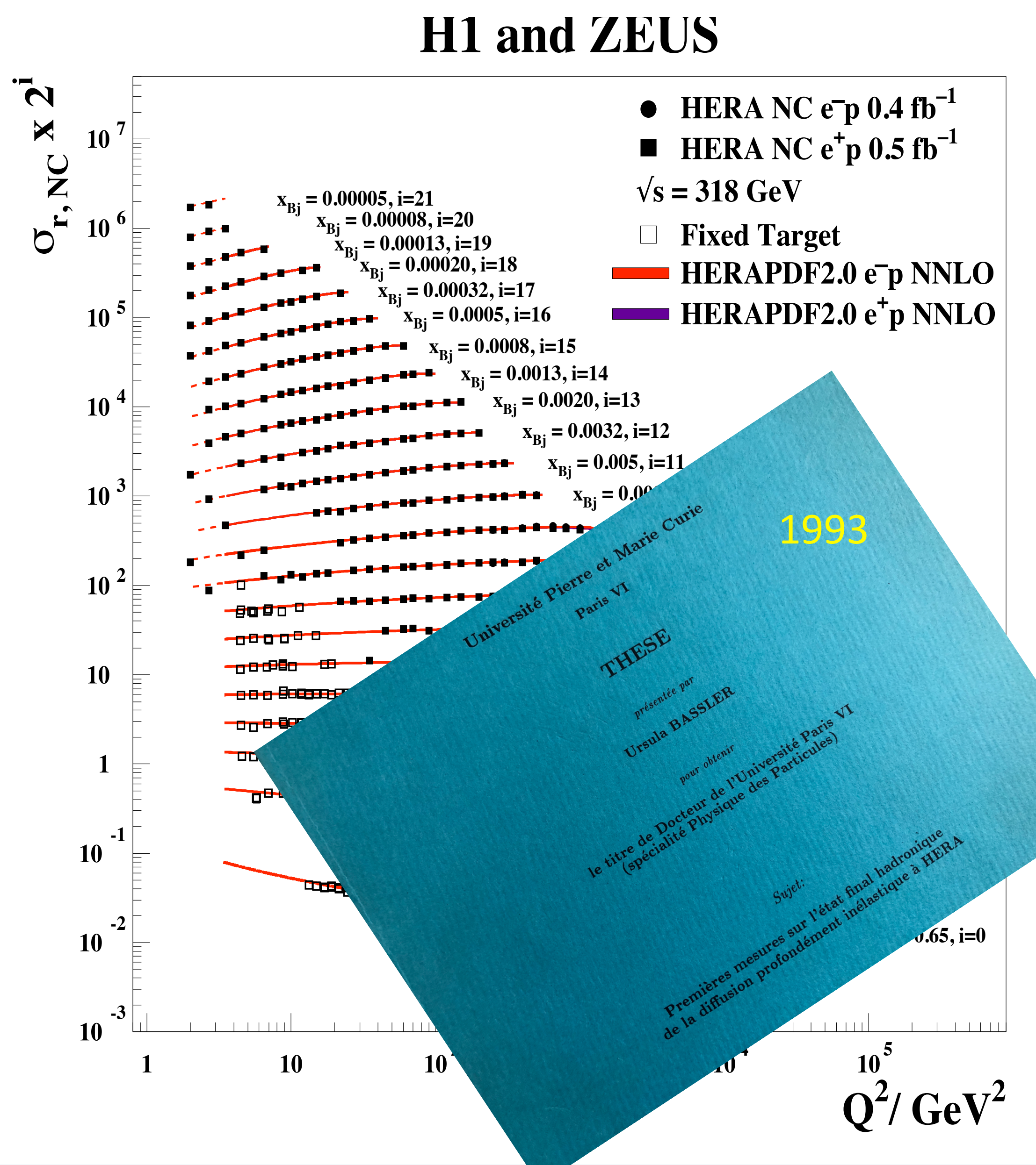
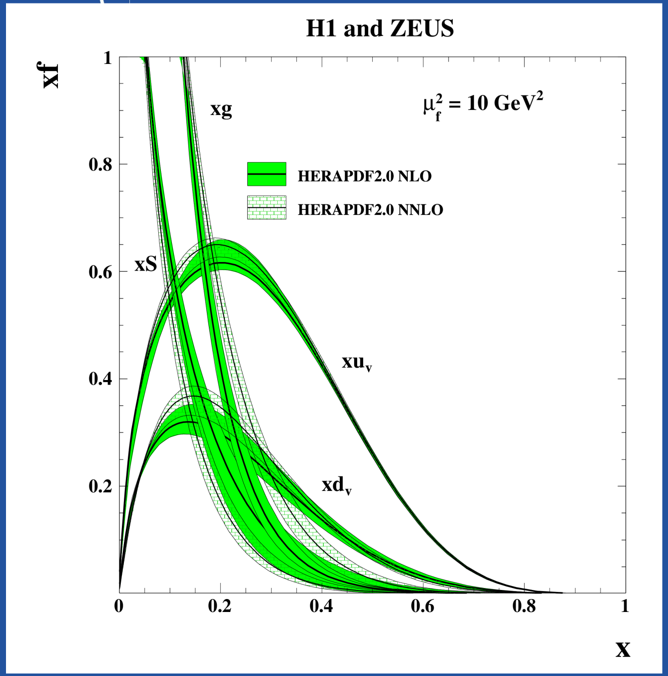






Parton distribution functions



Combination of data from Deep inelastic scattering and other processes observed in different experiments (jet production, single flavour production…)

- Parton distribution function of the proton :

→used in all simulations to describe interactions at LHC

→used for air show simulation of cosmic rays

Observation : gluon density rises dramatically at very small x

➔ Will there be a saturation effect?

→ **Further improvements from QCD measurements at LHC!**

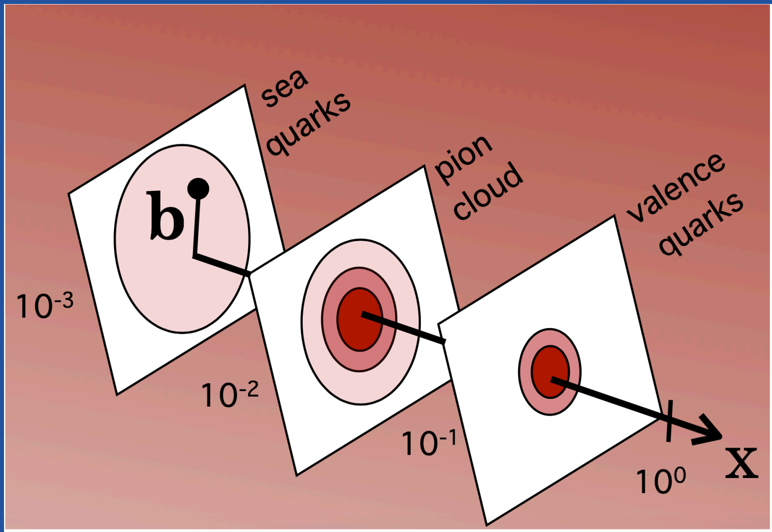
Also f.ex. at CERN: **Compass** experiment (taking data since 2002):

- Looking at the proton at lower energy: proton tomography

➔Resolving the proton structure in the position space

- Generalized Parton Distribution functions

➔Soft particles surround a hard core of valence quarks



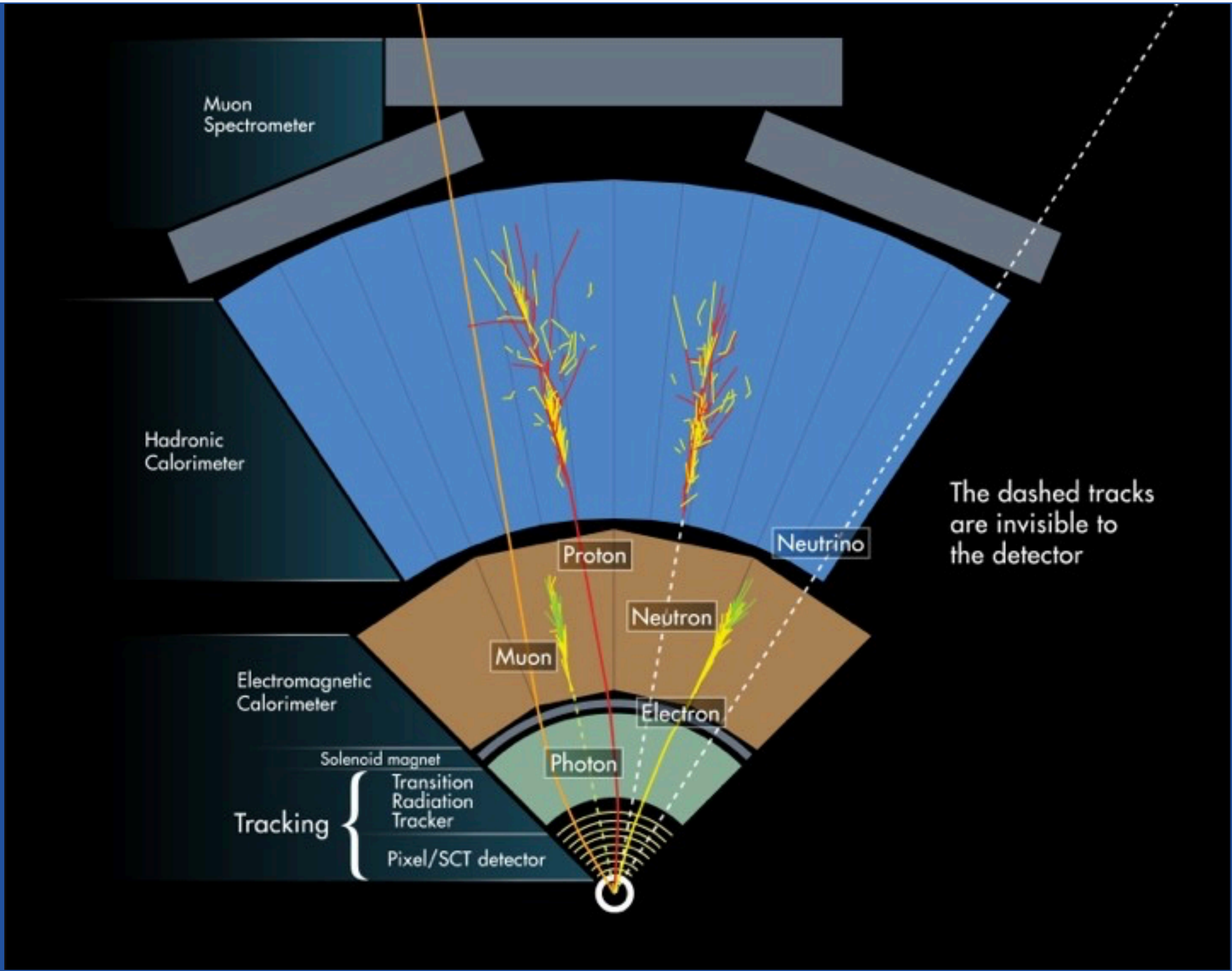
Instruments in HEP

Particle Physics requires huge instruments:
- Particle colliders
- Particle detectors

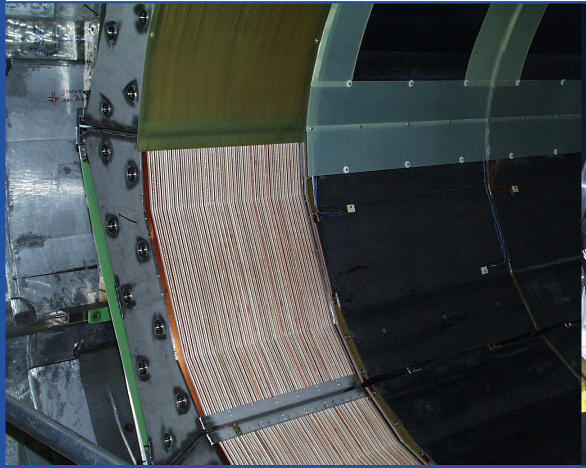
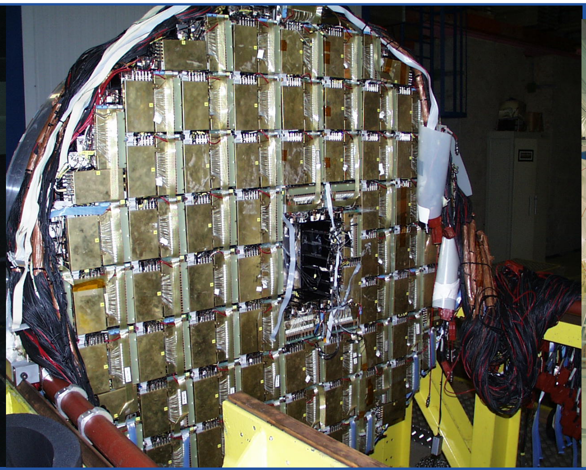
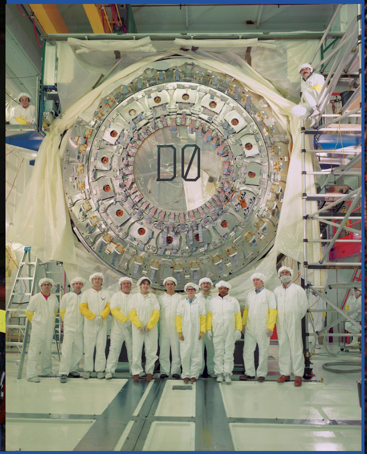
Every instrument is unique, built by the collaboration in the participating institutes all over the world based on a best effort principle

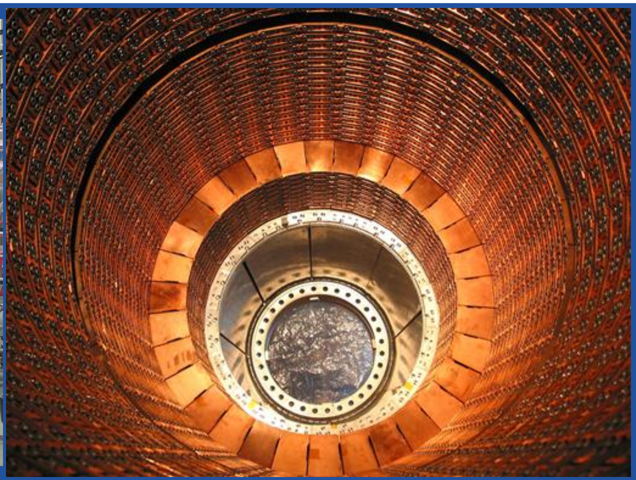
Detection principle: mainly ionisation
- in low density materials → tracking
  possible for charged particles
  electrical charge measurement du to
  magnetic field
- In high density materials → calorimetry

Aim: gather as much information as necessary and as few as possible



Calorimeters

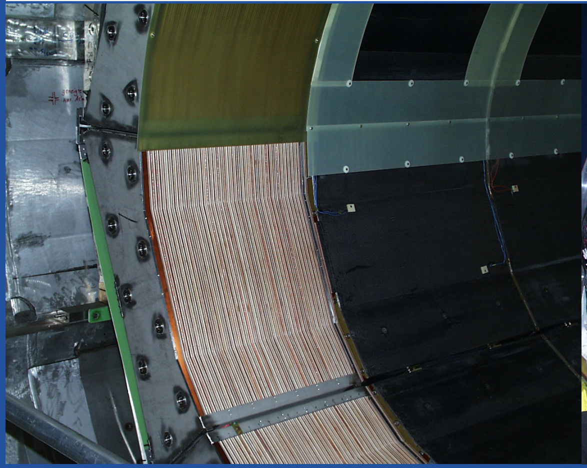




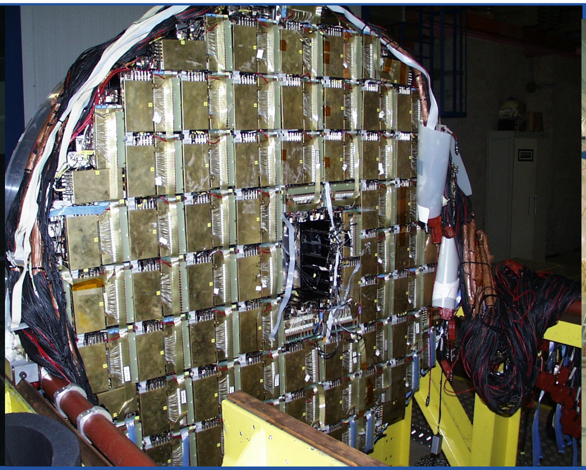


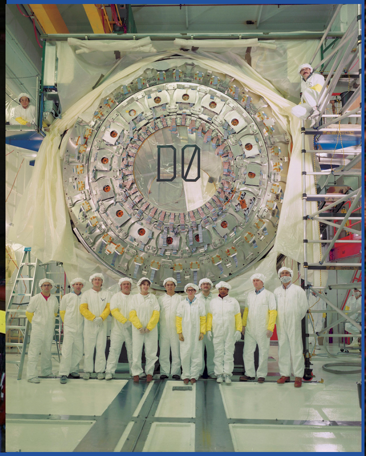
- Design and construction
- Electronics to trigger and read-out the signals
- Calibration system to ensure linearity and uniformity of the signals
- Reconstruction to convert electric signal to energy
- Reduce ”noise”
- Identify objects as electrons, photons, jets
- Combine with information from other detectors

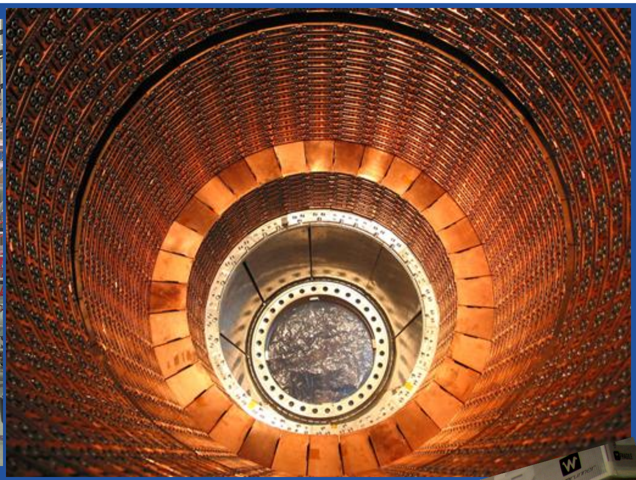
➔ Major effort to operate the detectors on a daily basis over 2-3 decades

Calorimeters









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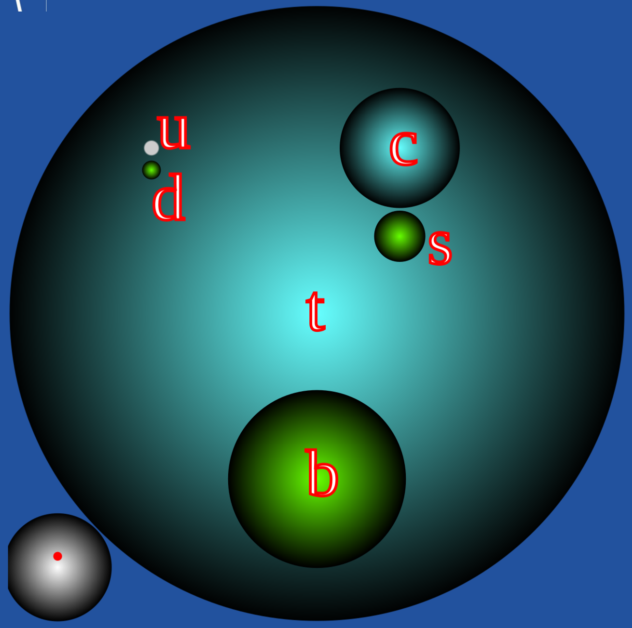
Top quark



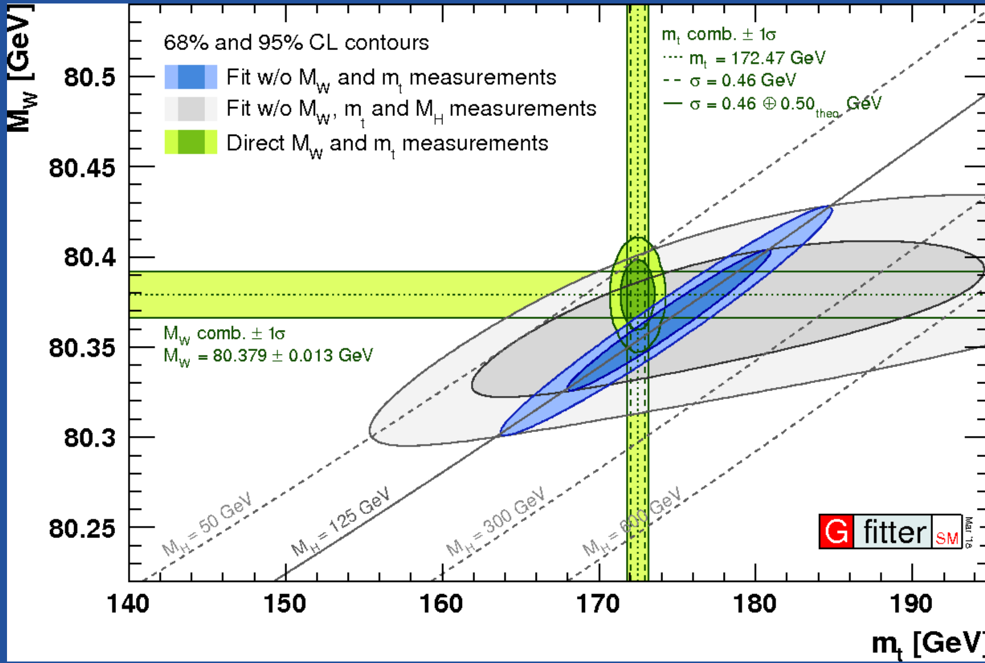
Quarks in the Standard model:

6 quarks with masses ranging from ≈ 2MeV – 173 000 MeV (≈3 10^{-23} kg)

Quark discoveries: c-quark → J/Psi meson 1974 by Burton Richter and Samuel Ting 2007

b-quark → Y meson 1977 by Leon Lederman

top-quark → 1995 by CDF and D0 collaborations



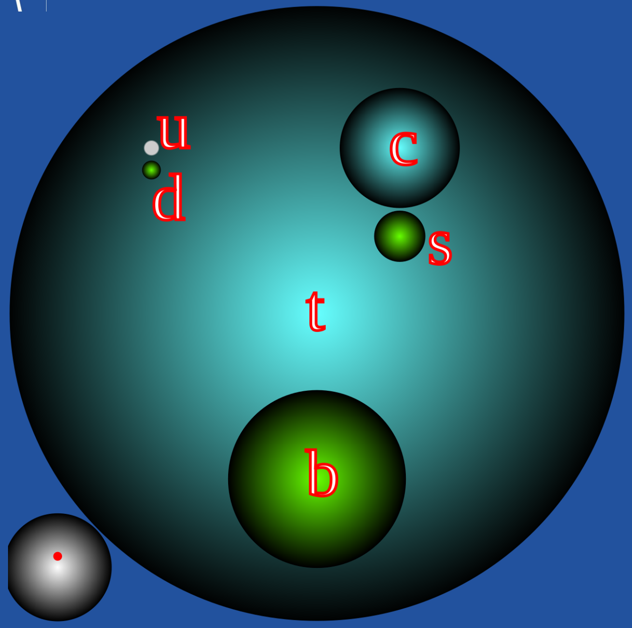
Top quark properties:

- mass as high as a gold-atom!
- lifetime so short, it cannot create a bound state

→ In the Standard Model, the Higgs mass can be computed from the masse of the W-boson and the top-quark: prediction and consistency check!

→ LHC: top factory!

Top quark



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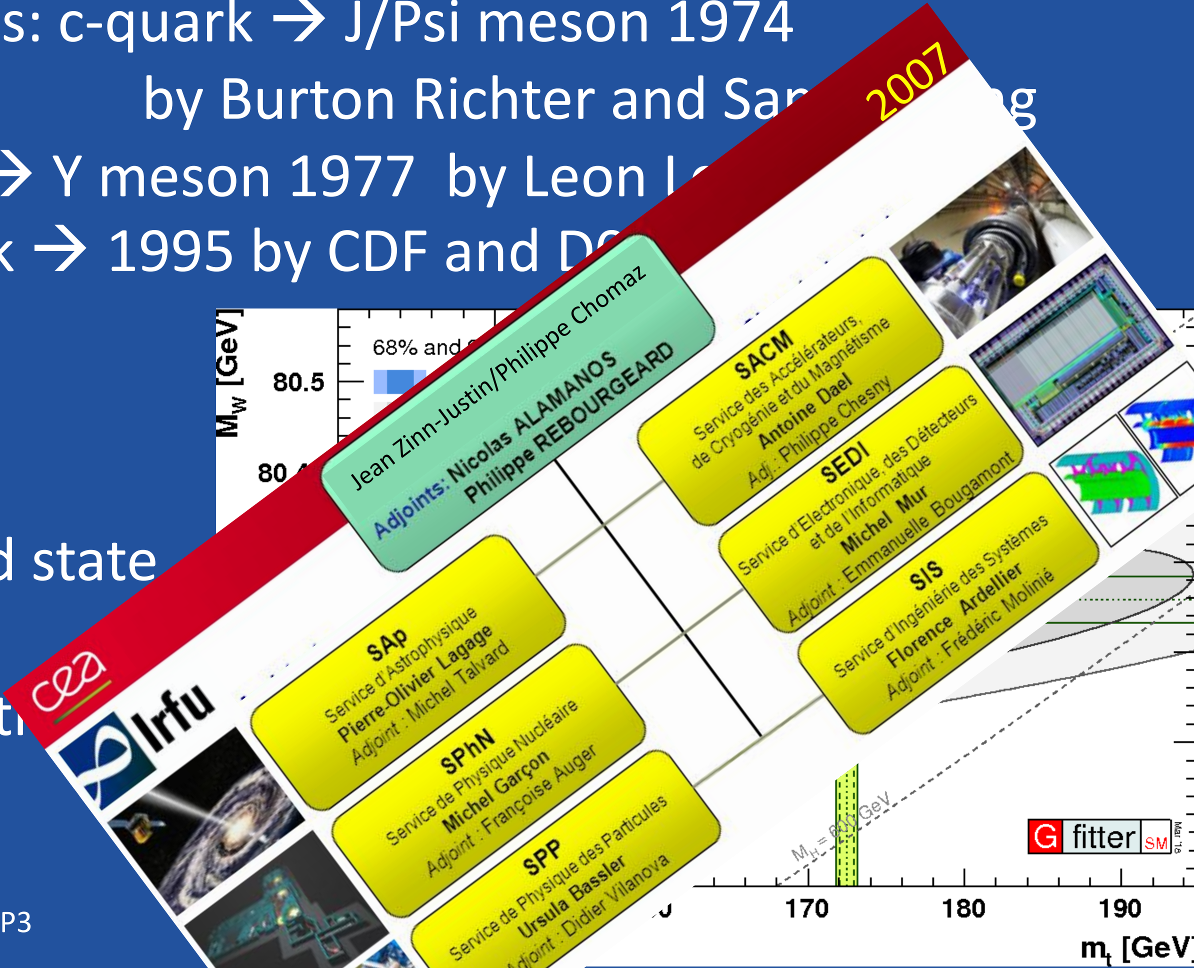
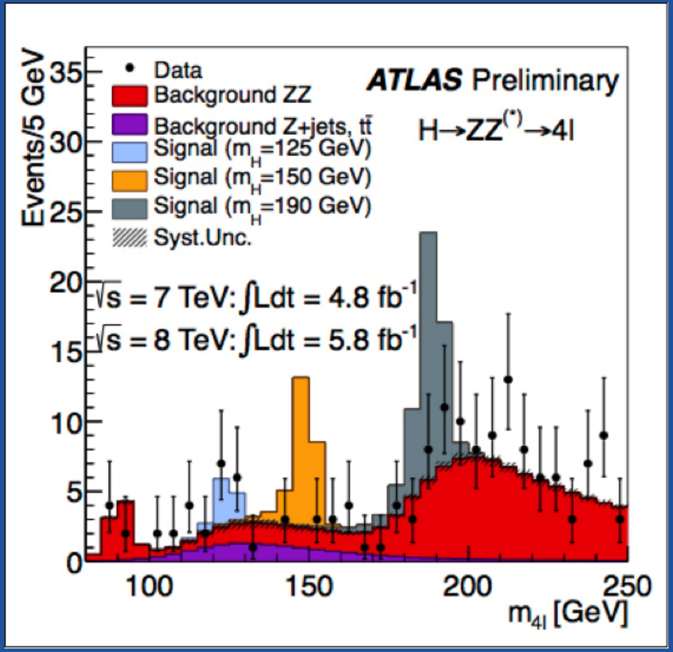
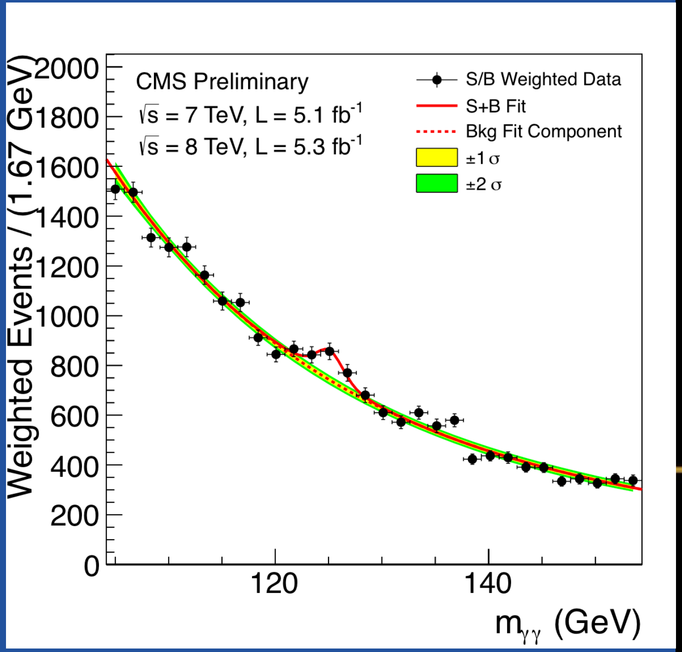
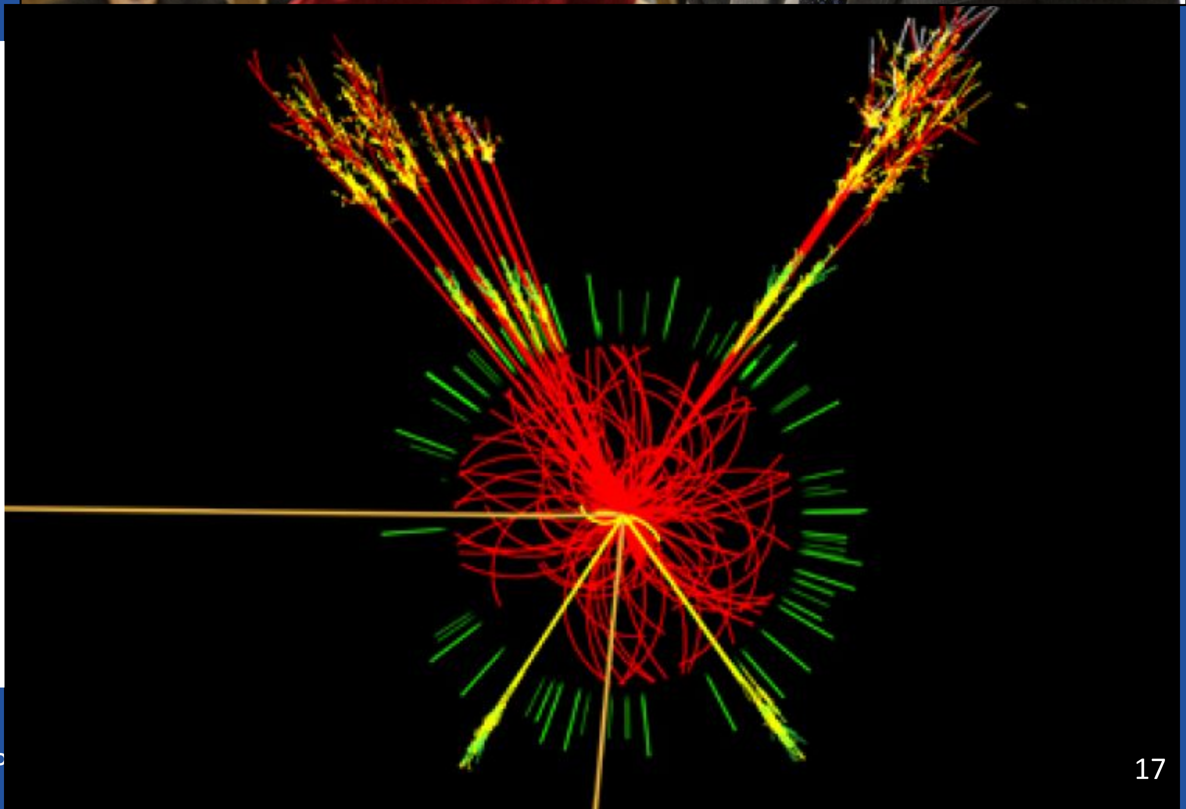


Higgs Discovery

Announcement on the 4th of July 2012 by the Atlas and CMS collaborations :
6000 physicists sign the discovery publications
The standard model is completed !







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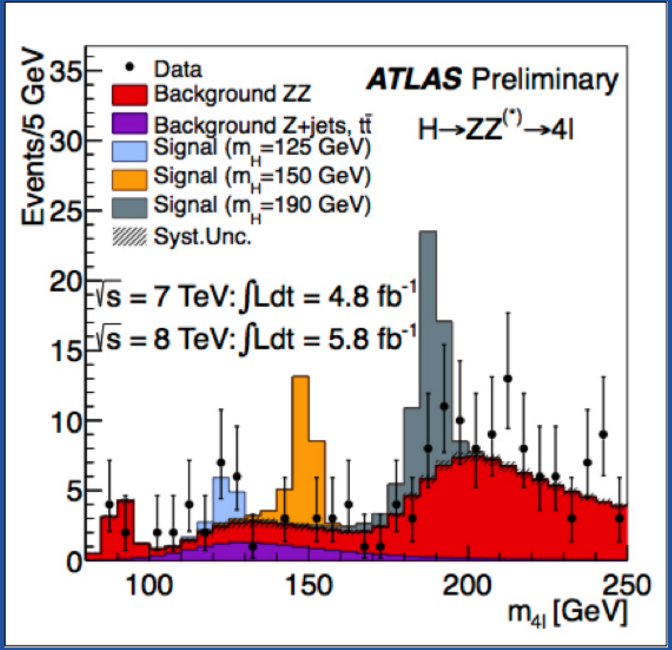
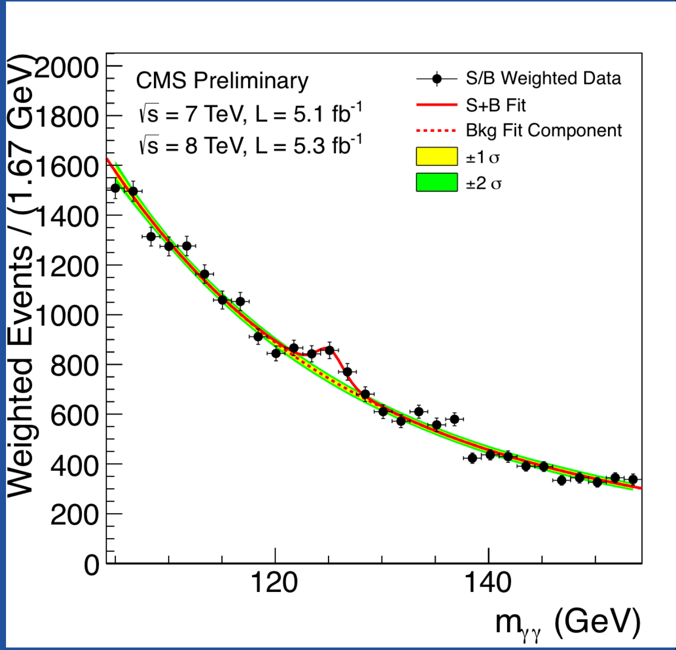
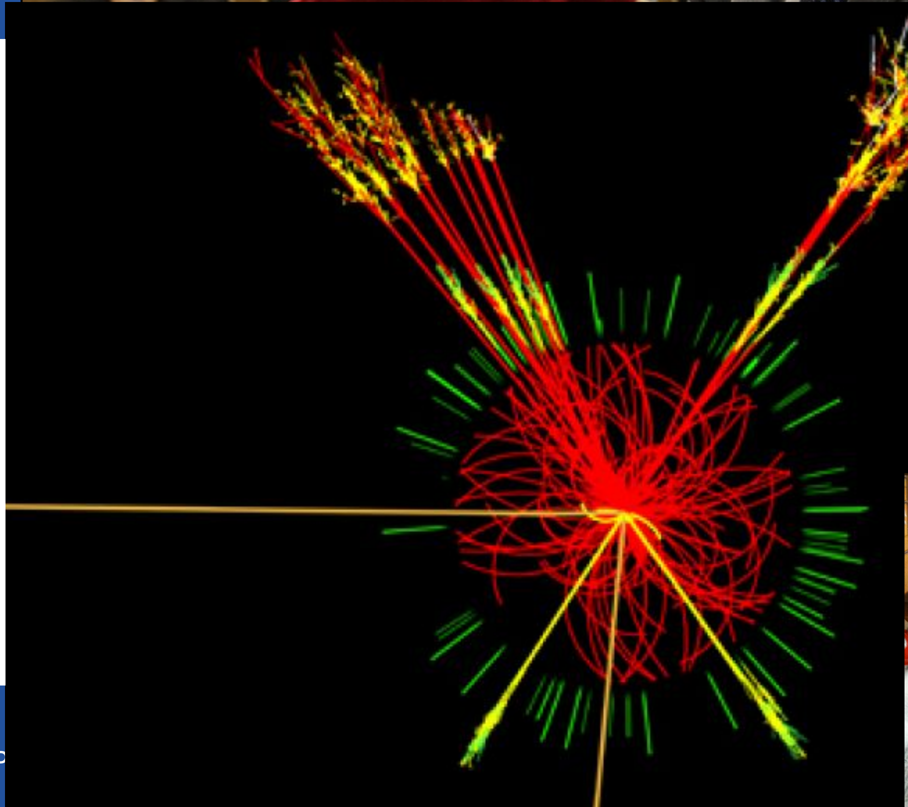







THE AUSTRALIAN
INDEPENDENT
CHINA DAILY
Le Monde
LA DÉPÊCHE
La «particule de Dieu» existe
le dauphiné
L'Univers livre enfin ses secrets
Carbon dealing not over for Labor
One point means seventh heaven for Maroons, another year of agony for Blues
Milhares de moradores de bairros sociais em risco de perderem RSI
EUREKA!
Partícula de Deus Estamos mais perto de conhecer a origem do Universo
Jornal de Notícias
The Japan Times
Libération
La masse est dite
L'ECHO
Découverte du boson de Higgs
Particule élémentaire !
la Nouvelle République
La particule qui fait accélérer notre histoire
CORRIERE DELLA SERA
The Sydney Morning Herald
Another year of pain for Blues
Il Messaggero
Patto tra Monti e Merkel
i
Scientists prove existence of 'God particle'
The Gazette
THE JERUSALEM POST
The New York Times
THE TIMES
Free inside
Eureka magazine
Diamond refuses to take blame for rate fix
Frankfurter Allgemeine
EL PAÍS
Hallada la partícula clave para la comprensión del universo
IL GAZZETTINO
מעריב
Cancellata metà delle Province
The Dallas Morning News
LA DÉPÊCHE
La «particule de Dieu» existe
International Herald Tribune
LA RAZON
El Gobierno obligará por ley a las autonomías a hacer más ajustes
LA VANGUARDIA
El juez imputa a Rato y 32 consejeros de Bankia
L'EST RÉPUBLICAIN
DIE WELT
LA STAMPA
la Croix
Le boson de Higgs enfin cerné
GULF NEWS
THE TIMES OF INDIA
Big bang moment: Scientists may have found 'God particle'
Adarsh scam: Finally, CBI chargesheets 13
gazeta
l'Unità
MK
ПОСЛЕДНИЙ КИРПИЧ В СТЕНУ МИРОЗДАНИЯ

It’s been a long way…

VOLUME 13, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1964

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

In a recent note[1] it was shown that the Goldstone theorem,[2] that Lorentz-covariant field theories in which spontaneous breakdown of symmetry under an internal Lie group occurs contain zero-mass particles, fails if and only if the conserved currents associated with the internal group are coupled to gauge fields. The purpose of the present note is to report that, as a consequence of this coupling, the spin-one

about the “vacuum” solution $\varphi_1(x)=0$, $\varphi_2(x)=\varphi_0$:

$$\partial^\mu\{\partial_\mu(\Delta\varphi_1)-e\varphi_0A_\mu\}=0, \qquad (2a)$$

$$\{\partial^2-4\varphi_0^2V''(\varphi_0^2)\}(\Delta\varphi_2)=0, \qquad (2b)$$

$$\partial_\nu F^{\mu\nu}=e\varphi_0\{\partial^\mu(\Delta\varphi_1)-e\varphi_0A_\mu\}. \qquad (2c)$$

A PHENOMENOLOGICAL PROFILE OF THE HIGGS BOSON

John ELLIS, Mary K. GAILLARD * and D.V. NANOPOULOS **
CERN, Geneva

Received 7 November 1975

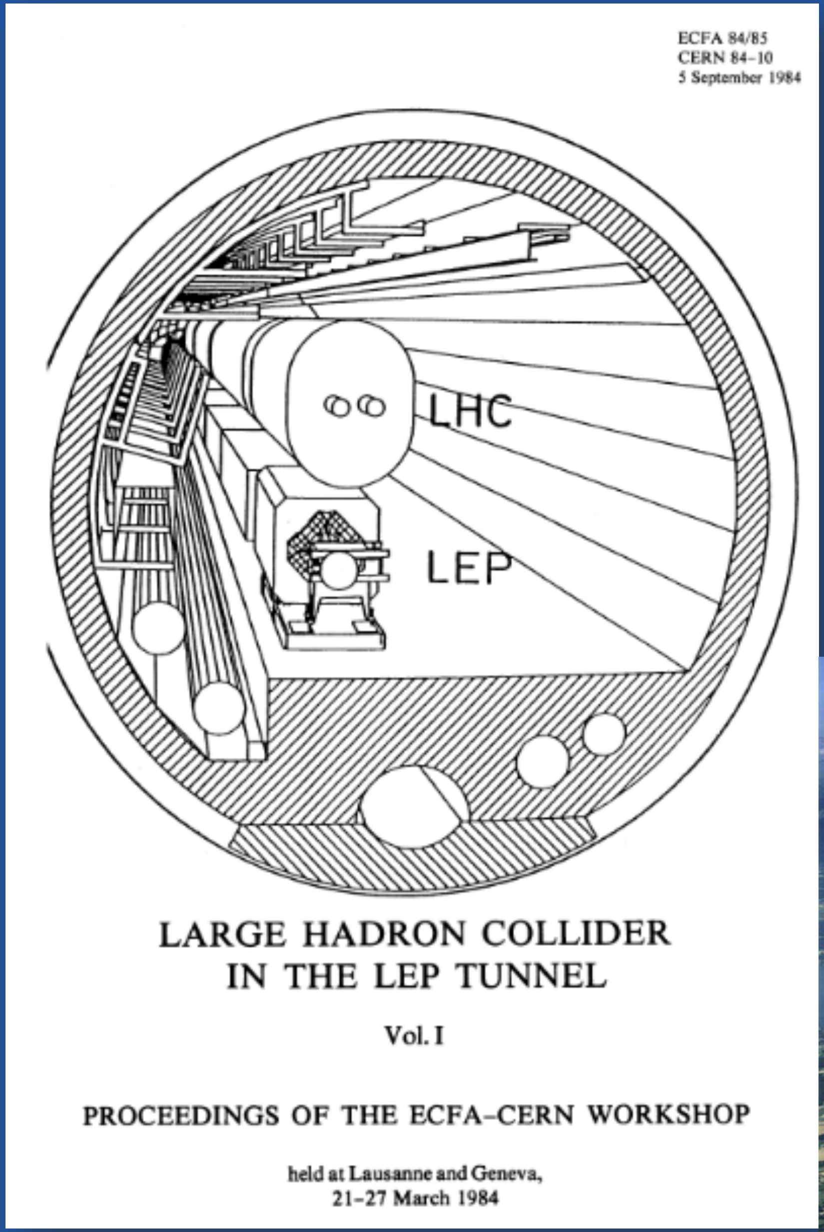
We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the Higgs boson, unlike the case with charm [3,4] and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up.

… to disover the Higgs boson

1964 : Independent publications of theoretical papers by Brout and Englert and Higgs on "Electroweak symmetry breaking".

1975: publication by Ellis, Gaillard, Nanopoulos
2013: Noble Prize to François Englert and Peter Higgs

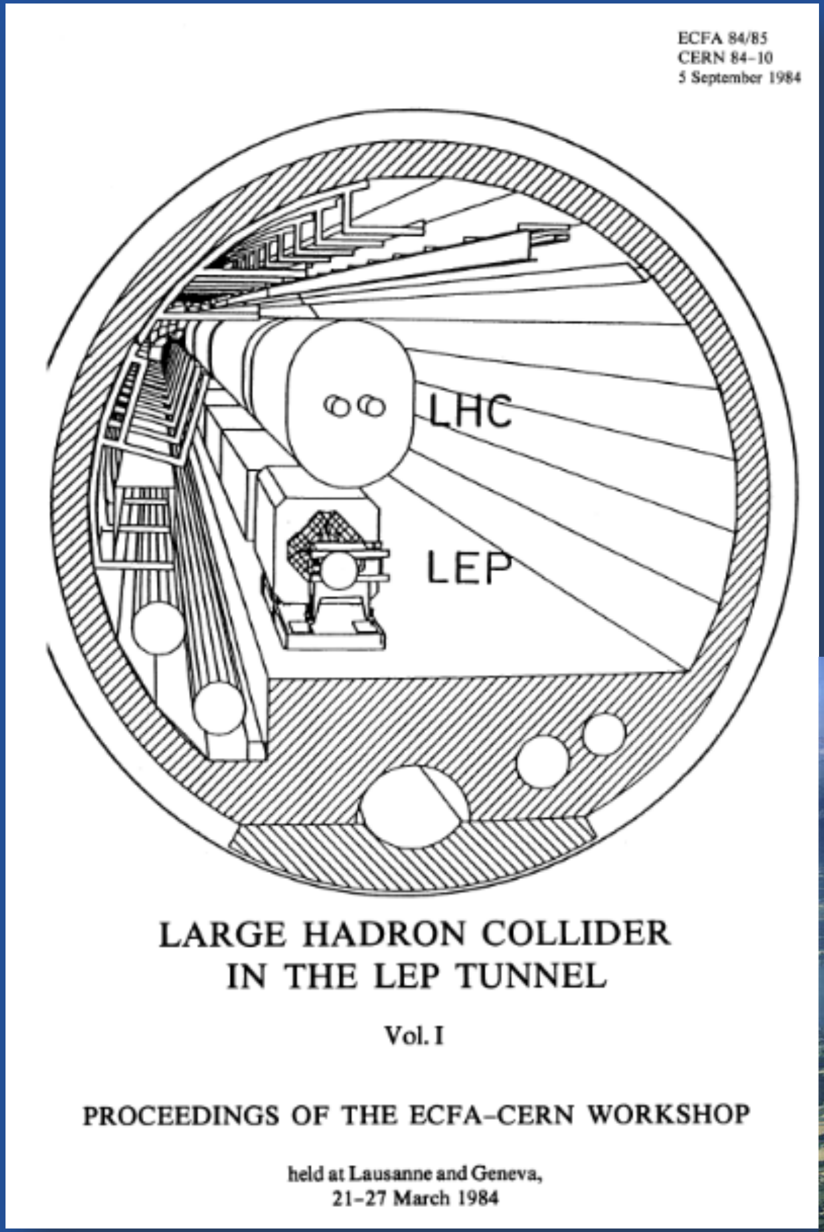
It’s been a long way…



… to built the LHC!

1984 : founding workshop in Lausanne
1996 : LHC approval: total cost about 5€
2008 : first LHC- beam → Incident
2009: first collisions
≈2025: High-luminosity LHC
≈2038: end of data taking

It’s been a long way…



ECFA 84/85
CERN 84-10
5 September 1984

LARGE HADRON COLLIDER
IN THE LEP TUNNEL

Vol. I

PROCEEDINGS OF THE ECFA-CERN WORKSHOP

held at Lausanne and Geneva,
21-27 March 1984

… to built the LHC!

1984 : founding workshop in Lausanne
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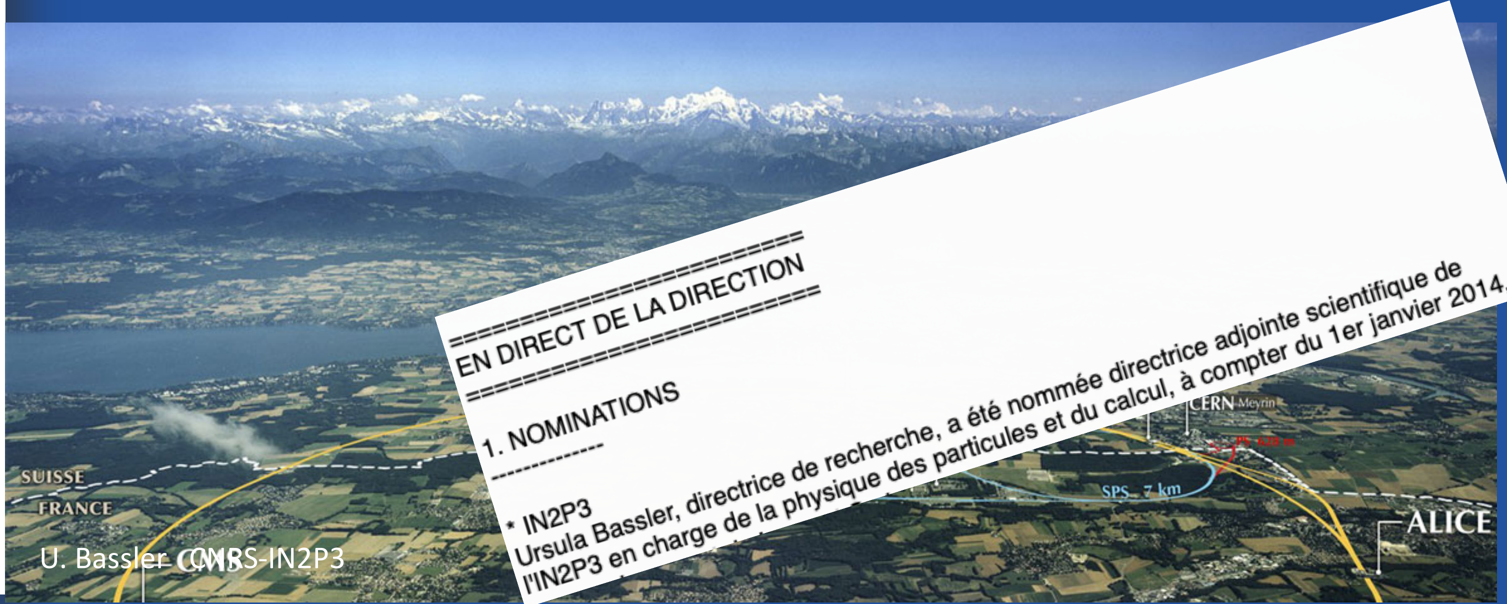
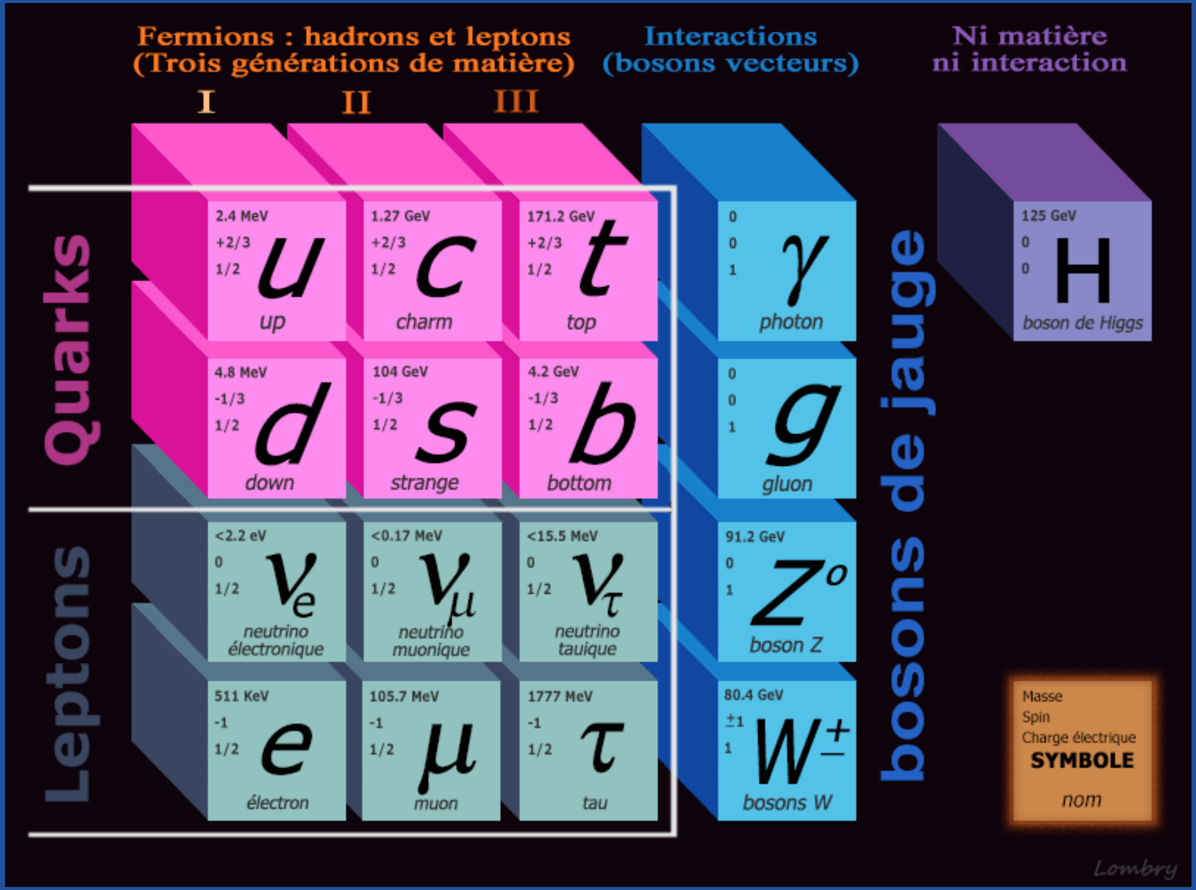
2008 : first LHC- beam → Incident
2009: first collisions
≈2025: High-luminosity LHC
≈2038: end of data taking

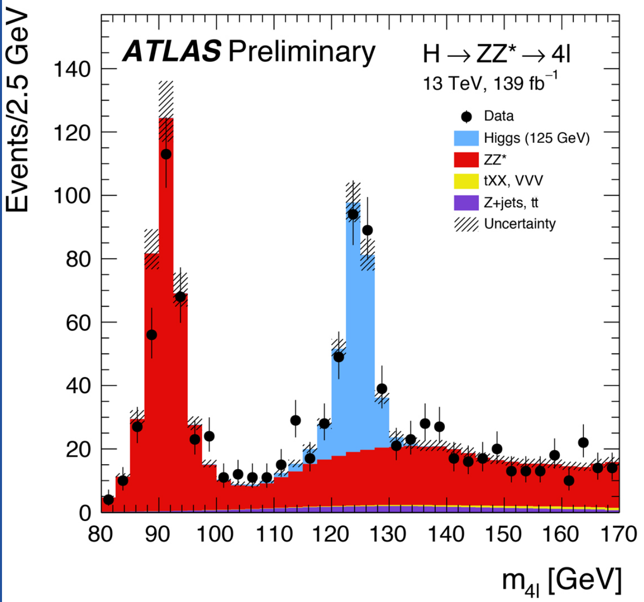


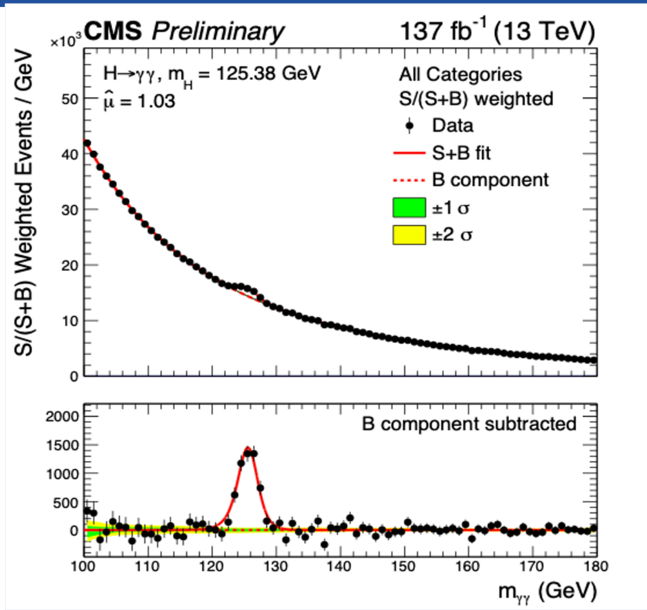
Higgs boson: been there, done it?



Or: why a discovery is just the beginning

- Higgs boson completes the standard model
- Why is it interesting to study the Higgs?
- What can we learn with more statistics?





Imagine: the Higgs field

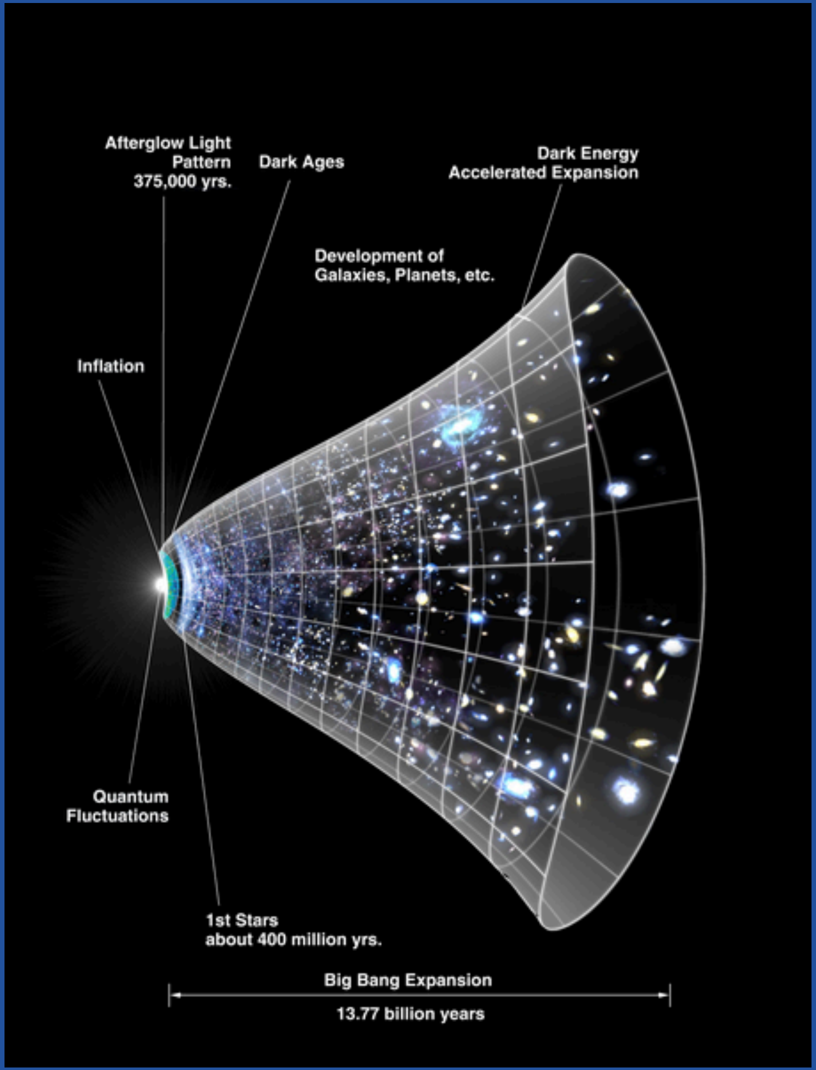
The Universe is filled with fields.
In the vacuum pairs of particles-antiparticles are constant created and annihilate
The mean value of the energy of this process is 0.

The Universe is also filled with the Higgs field.
It is a scaler field: no electric charge, no spin.
In the vacuum, scaler fields can have a nonzero energy.
Higgs field: <vev> = 246 GeV

The Higgs particle is the "quantum excitation" associate to this field.
All massive particles interact with the Higgs:
the strength of their coupling determines their mass

BUT: 99% of the mass of particles such as protons and neutrons is due to the binding energy of QCD

Higgs: scaler field and inflation?



Inflation could describe the very early expansion of the Universe:

- Expansion would be due to the scaler inflaton-field
  - scaler fields have a ground state with an energy ≠ 0 !
  - potential of the inflaton-field would decrease over time
  → creation of matter-antimatter particles creates negative pression

Good news: scaler fields exist !

Bad news: doesn't look to be the Higgs field : Higgs is to heavy

Higgs-inflaton oscillations → not observed (yet) at the LHC

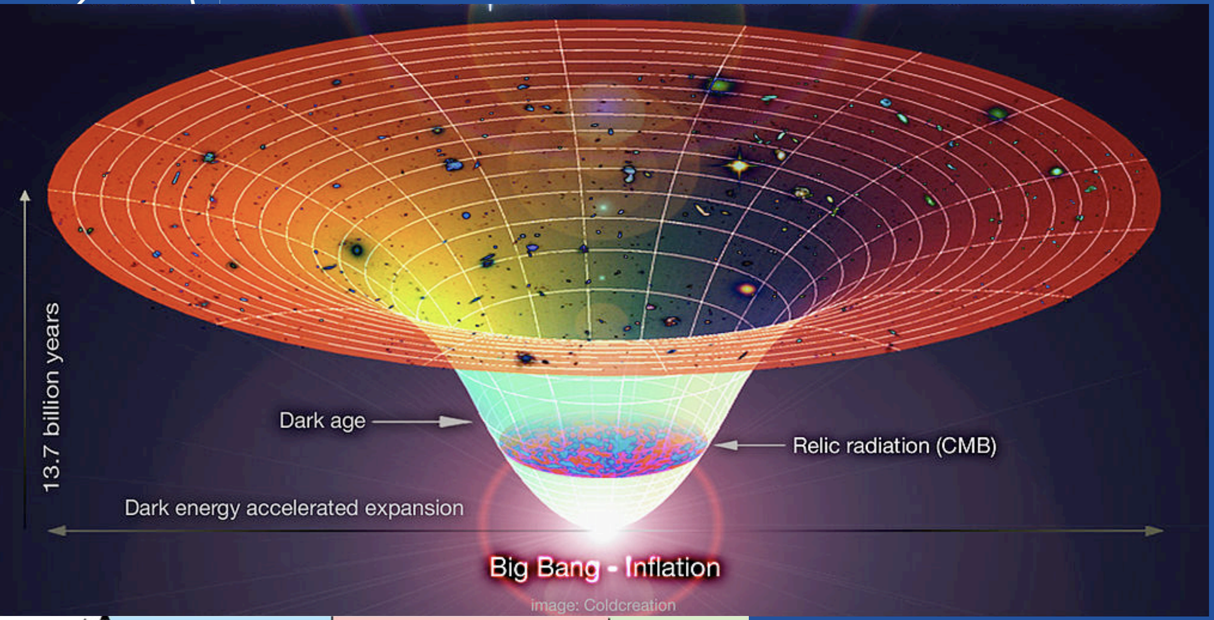
Future investigations on inflation:

- Inflation should have produced primordial gravitational wave

→ Polarised CMB

or observation of cosmic gravitational wave background

Expansion of the Universe



- Expansion of the Universe theorized in the beginning of the 20th century

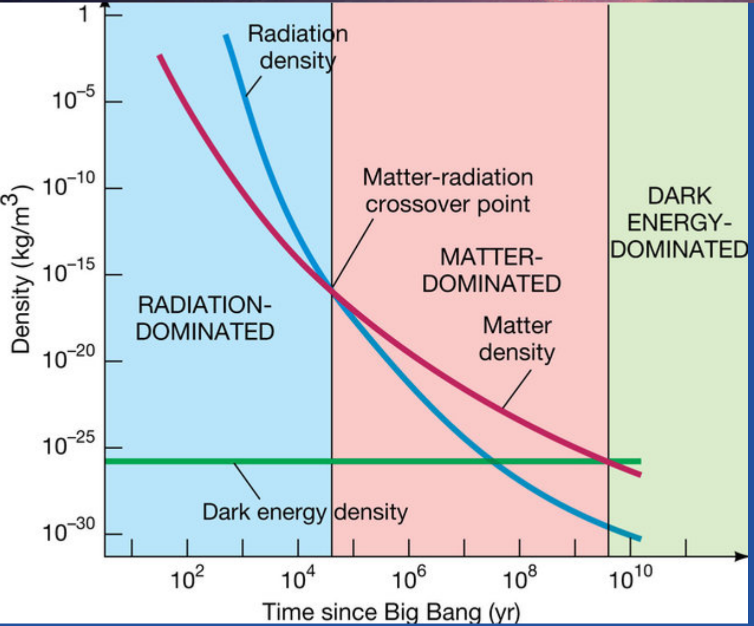
What causes the expansion?

- Vacuum energy? ≈10^{120} times to high !!!

« worst theoretical prediction ever »

- Accelerated expansion of the Universe discovered in 1998

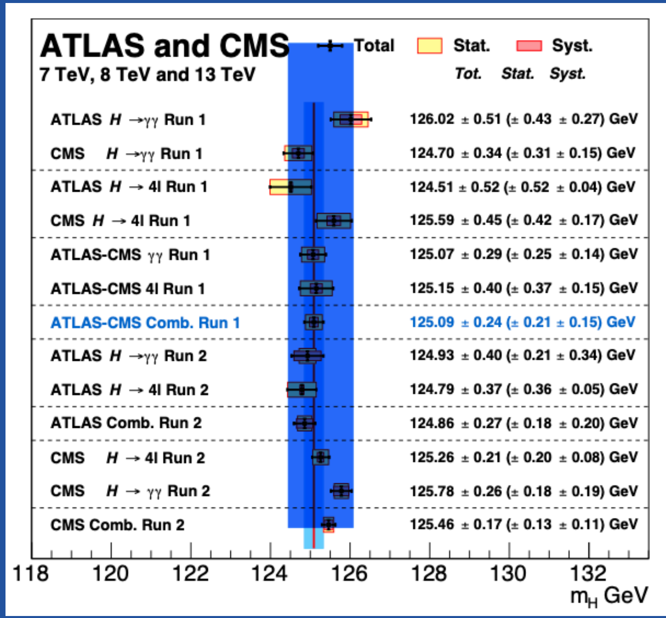
→ Noble Prize for Perlmutter and Riess in 2011



ΛCDM model: accelerated expansion due to "dark energy" – corresponding to a cosmological constant ➔ scaler field?

Expansion of the Universe quantified by the Hubble Constant:
- Expansion rate measurements show disagreement between "near sources"(Cepheides) and "far away sources" (CMB, BAO, SN)

Higgs boson: mass measurements

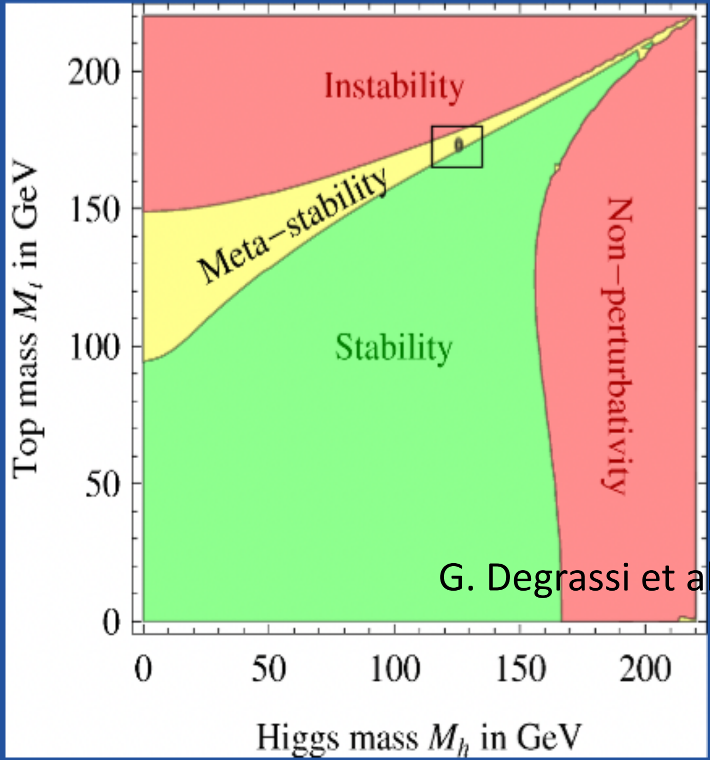


Measurement of the Higgs mass at the 1 ‰ level !
➔Higgs mass measurement: 125.1 +/- 0.14 GeV

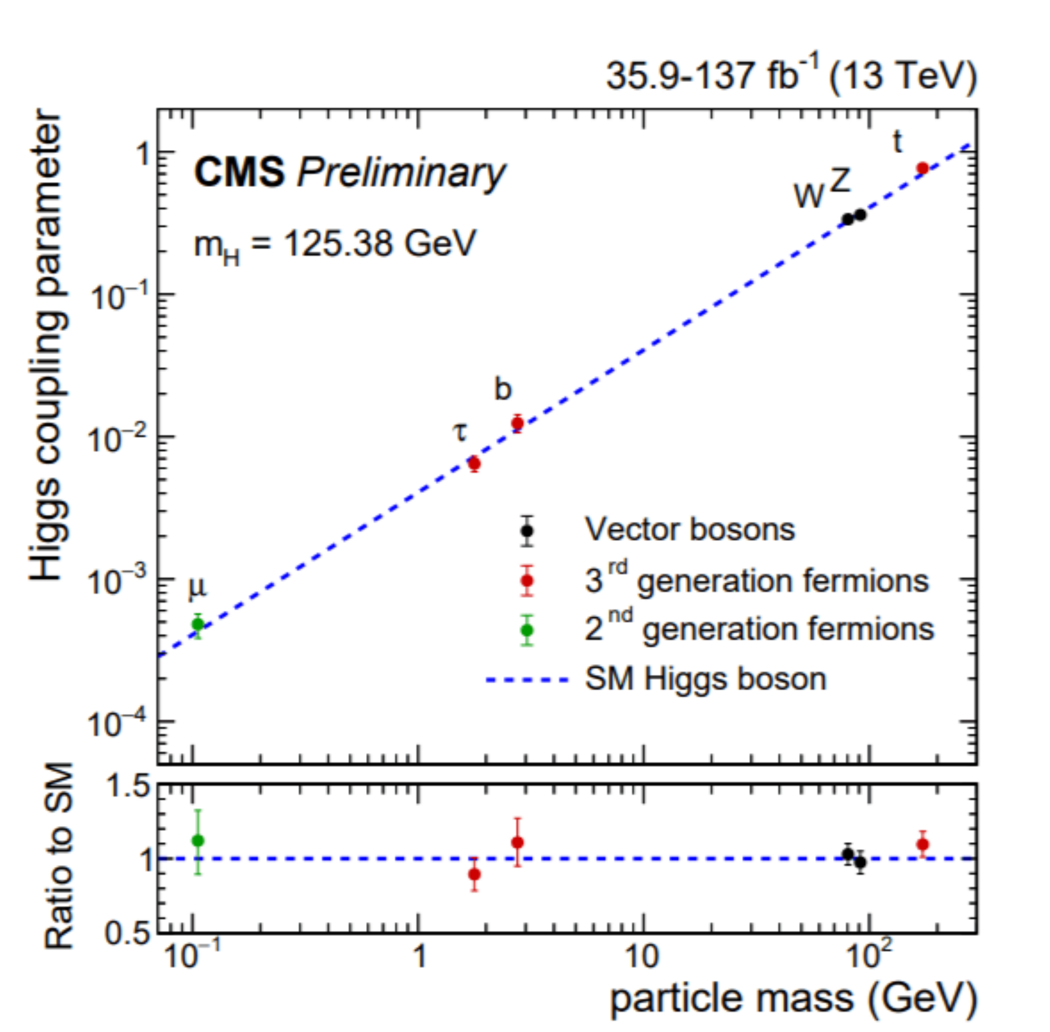
Top mass measurement: 172.8 +/- 0.3 GeV
Top, W and Higgs mass → consistency check

Is the vacuum state of the Universe stable?

Evolution of the vacuum up to the Planck scale:
➔ Calculation based on the Higgs mass and the top mass
Current measurement indicate meta stability
➔More accurate measurement (top mass!) ➔ ee-collider
➔New physics?
➔Or Universe may transit to another vacuum state at some point



Higgs couplings



If the particle discovered at Atlas and CMS is the Higgs boson, the coupling to elementary particles (quarks, leptons, bosons) has to be proportional to their masse !

→The higher the masse, the easier to verify
→ Verification down to the 2nd generation

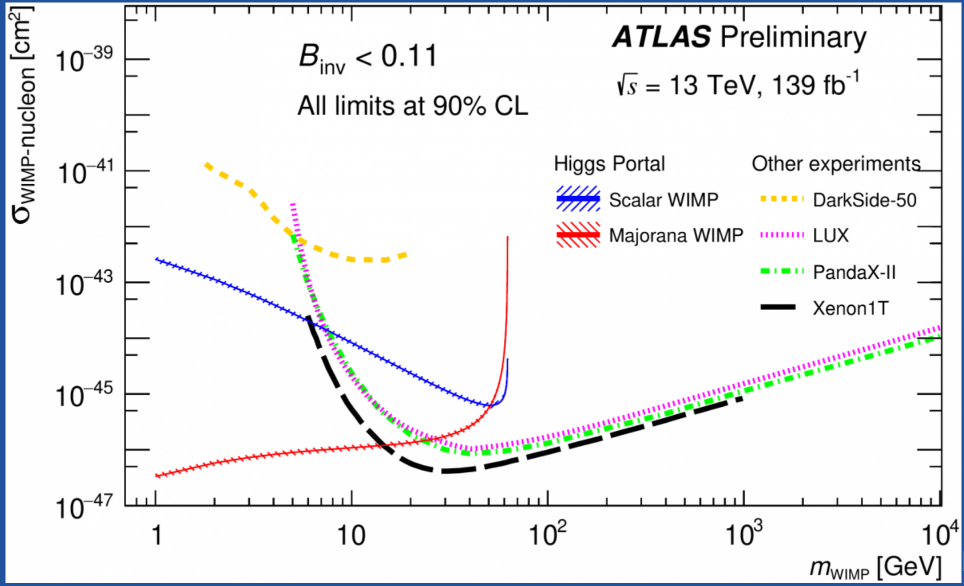
For physics beyond the Standard Model → deviations < 1%

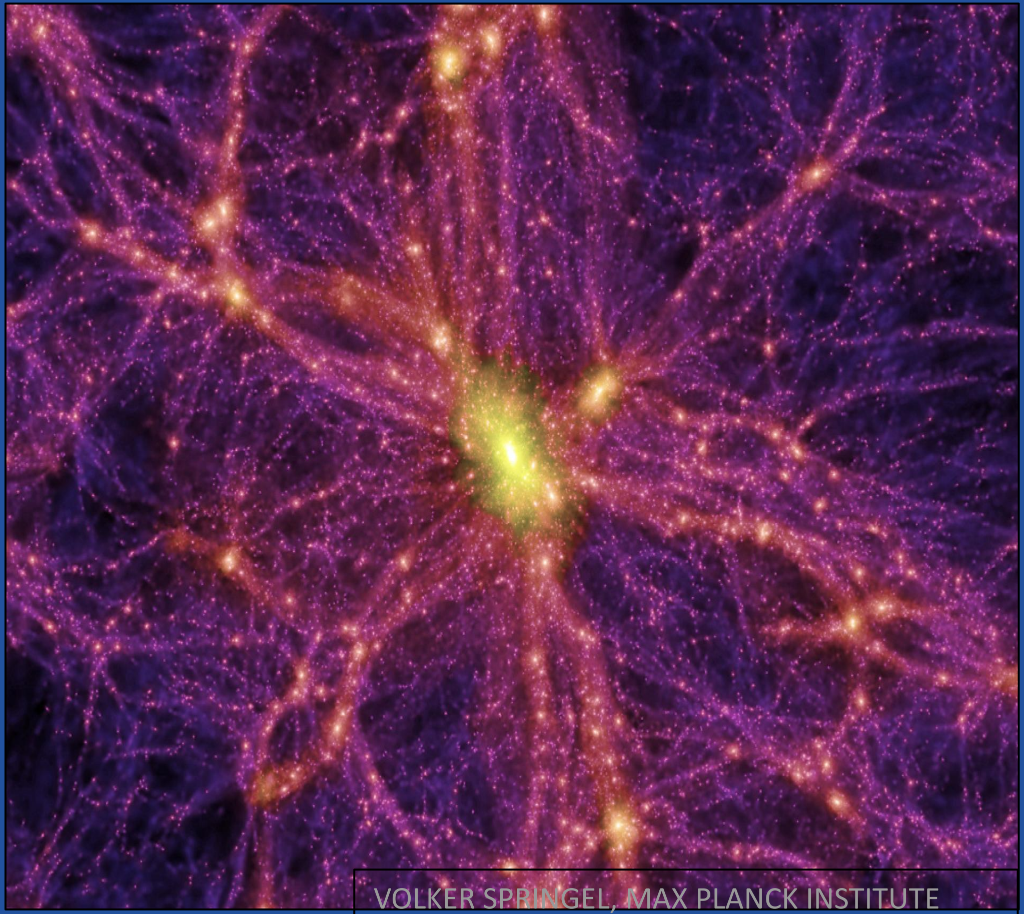
Higgs portal to Dark Matter?

Dark Matter first proposed Fritz Zwicky in the 1930
→ firmly established by Vera Rubin in the 1970s
All massive particles should couple to the Higgs boson:
Could we see Dark Matter particles through the Higgs boson?

1) Higgs mass ➔ life-time of the particle
➔ particle width Γ_H = 4.1MeV
➔ related to the couplings
Current limits: ≈ 3-4 x SM value

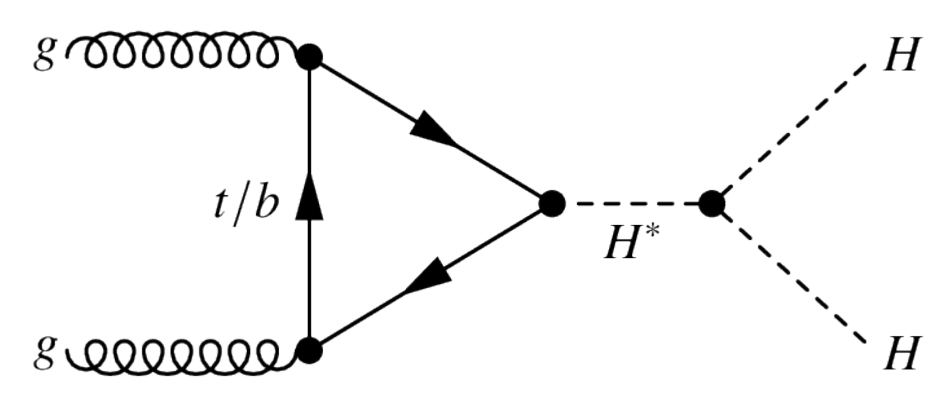
2) Search for invisible particles in Higgs decays

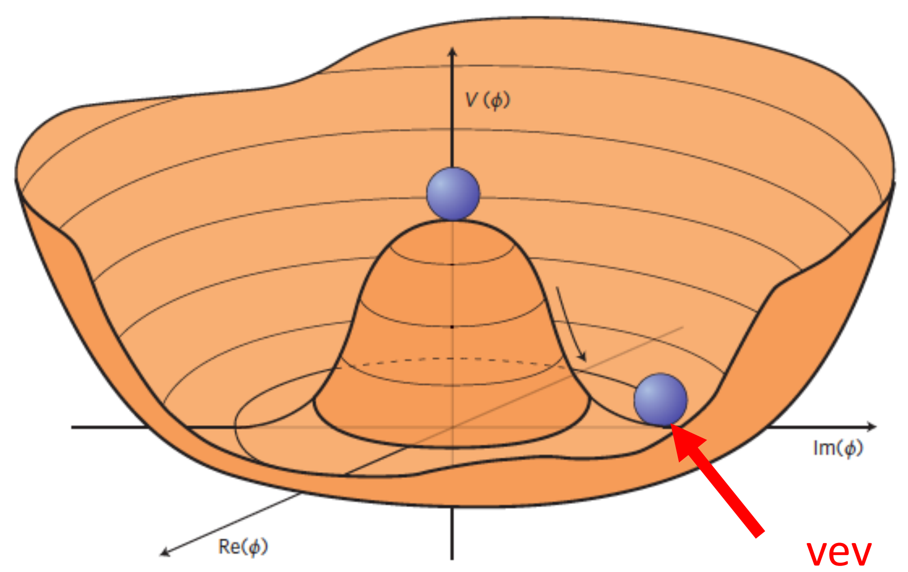




VOLKER SPRINGEL, MAX PLANCK INSTITUTE FOR ASTROPHYSICS, ET AL

Higgs self-coupling





Higgs boson has a mass → it couples to itself!

The Higgs boson in the Standard Model has a potential of:

$$V = -m_H^2\ |\phi|^2 + \lambda|\phi|^4$$

→vev = 246 GeV computed from M_W and the weak coupling g

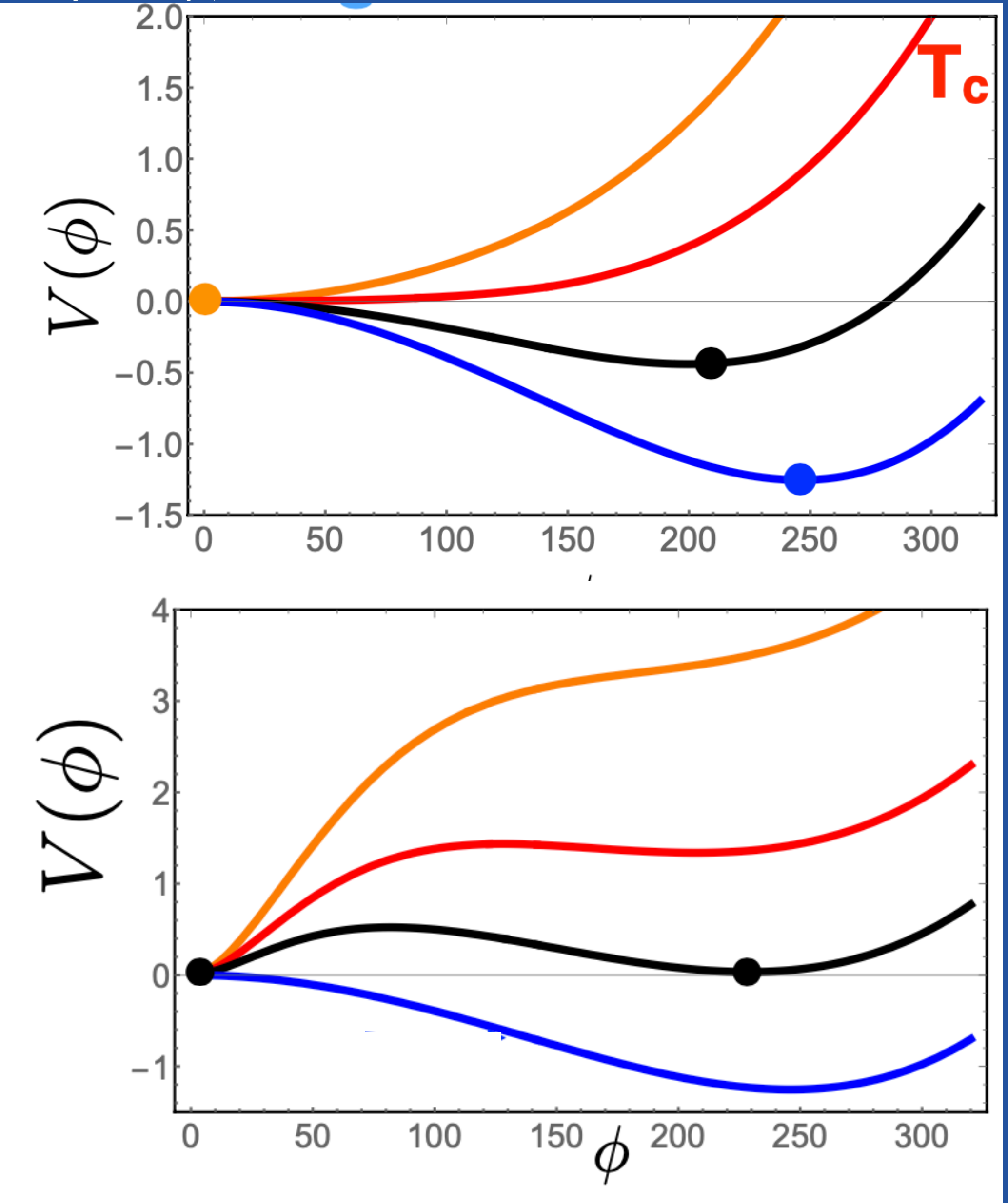
→ Relation vev, m_H and λ (coupling)

$\lambda = m_H^2/2vev^2 \approx 0.13$ → strong prediction

Potential deviations:

- Beyond Standard model physics

Higgs phase transition

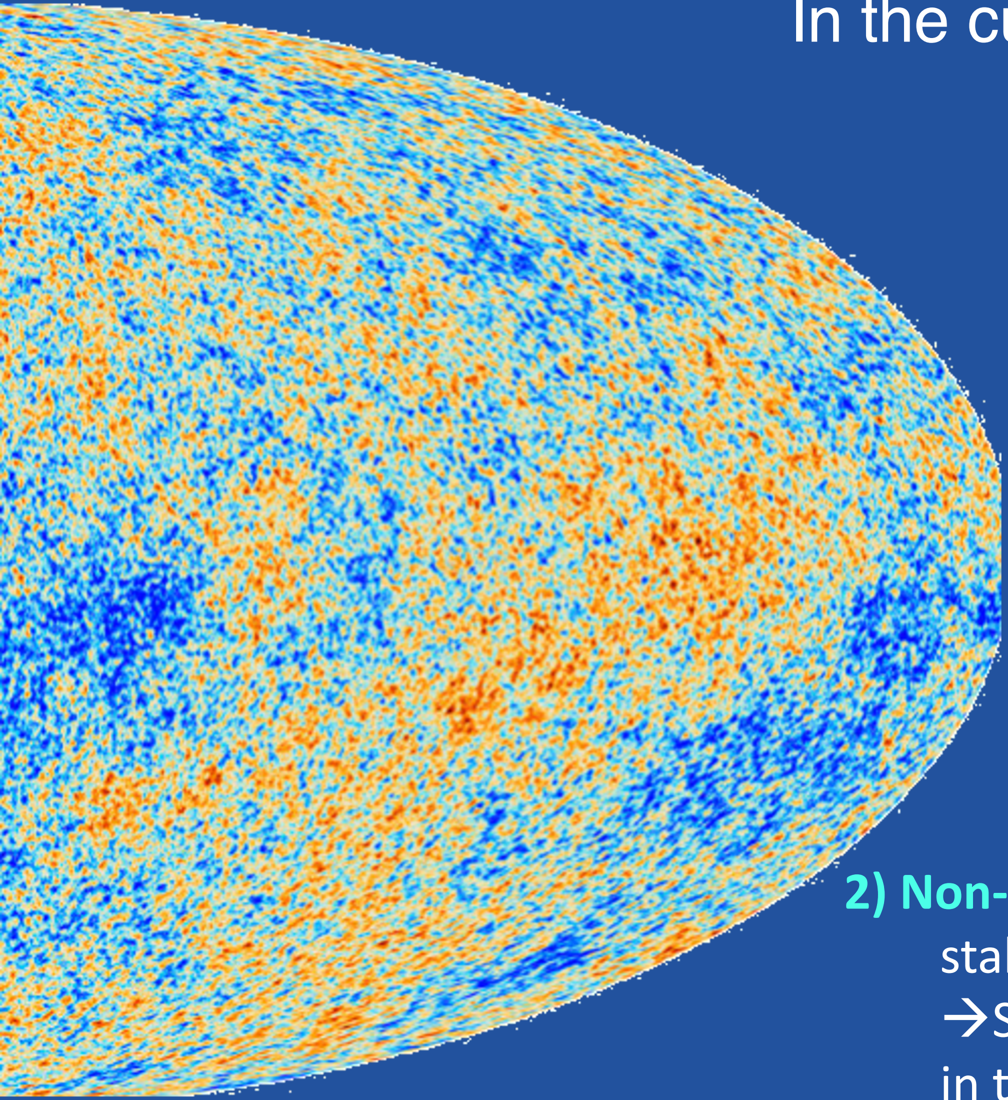


Higgs potential must have evolved during the cool-down of the Universe : How?

2nd order phase transition: Universe stays in thermic equilibrium → favoured by the Higgs mass measurement (m_H<70 GeV): matter creation?

1st order phase transition:
No thermic equilibrium → formation of “bubbles” and tunnelling effects : required for baryogenesis, but physics beyond the Standard Model necessary i.e. additional scaler fields

Where is the antimatter?



In the current Universe: 10^9 photons, 1 proton - 0 antiprotons
Yet, matter and antimatter should have been created in equal amounts!

1 µs after the Big Bang:
500 000 001 quarks and 500 000 000 antiquarks annihilate!

Why does matter exist ?

3 Sakarahov conditions for baryogenesis:

1) No thermal equilibrium:

reaction and backwards reaction not in equilibrium
→ 1st order phase transition → measurement of Higgs potential

2) Non-conservation of the baryon number:

stability of the proton measured to 10^{31}: limit to be reached 10^{39}
→Sphaléron: non-perturbative process at high energy
in the Standard Model → transformation of 3 baryons into 3 anti-leptons
→ could this be observed at a collider?

CP-violation: Anti-matter in the mirror

3) CP violation:

Charge-Parity symmetry is not conserved : matter and anti-matter behaves differently

Indirect CP violation observed by Cronin and Fitch in 1964 in Kaon decays

Direct CP violation observed in 1990 at CERN and Fermilab for Kaons

in the 2000 by BaBar and Belle for B-mesons, today LHCb, Belle-2

Baryogenesis: CP violation from weak interactions in the quark sector too small x 10^9

Other sources of CP violation?

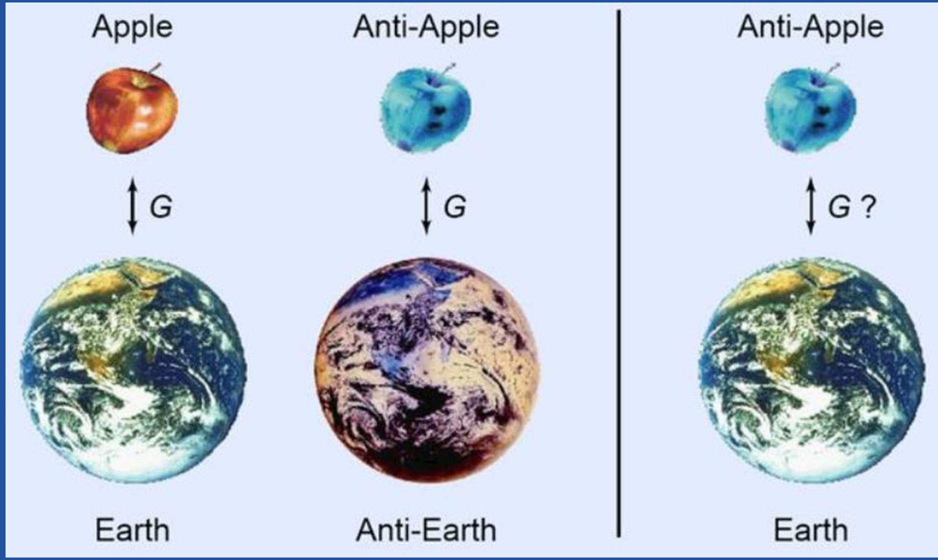
strong CP problem: no CP violation in strong interactions, but theories allows for!

Measurement: electric dipole moment of the neutron ➔ new measurements to come from PSI

Solution proposed in 1970s by Peccei and Quinn ➔ a new particle : the Axion

Axion could also be a Dark Matter candidate: searches at CERN, DESY…

Antimatter - antigravity



Or…

Could anti-matter behave different than matter for gravity?

First ideas in the 1960's form Roland Omnès
Today work on a model of "Dirac-Milne Universe" – to be compatible with current observations from cosmology

And experiments?

- difficulty: produce "cold" antihydrogen in order to achieve sensitivity for gravitational effects

→ several experiments in preparation at CERN
"Antimatter Factory"

Neutrino physics

Neutrinos predicted by Wolfgang Pauli en 1930 ➔ energy conservation in radioactive beta-decays:

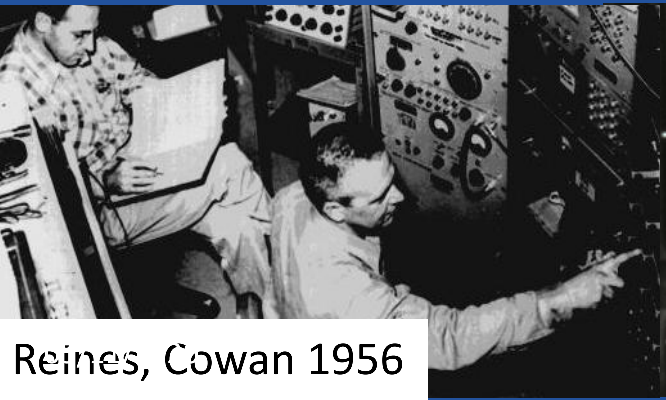
"I have done something very bad today by proposing a particle that cannot be detected; it is something no theorist should ever do."

➔ ν discovered in 1956 by Reines and Cowan close to a nuclear reactor (ν_μ in 1962 and ν_τ in 2000)

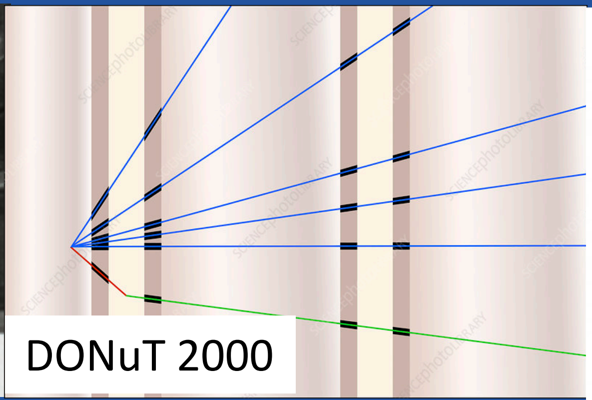
Solar neutrino problem: flux of solar neutrino flux observed by the Homestake experiment (1968 -2000):
shape corresponds to prediction by Behcall but flux only 1/3

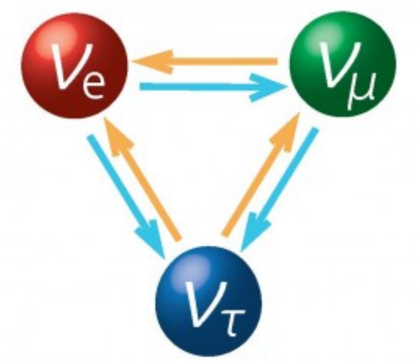
➔ Discovery in 2001 of neutrino oscillations by SNO and Super-Kamiokande
(first ideas on neutrino oscillation: end 1950's by Bruno Pontecorvo)

Implication: only massless, left-handed neutrinos (spin/chirality) exist in the Standard Model!


Reines, Cowan 1956


Lederman, Schwartz, Steinberger 1962


DONuT 2000



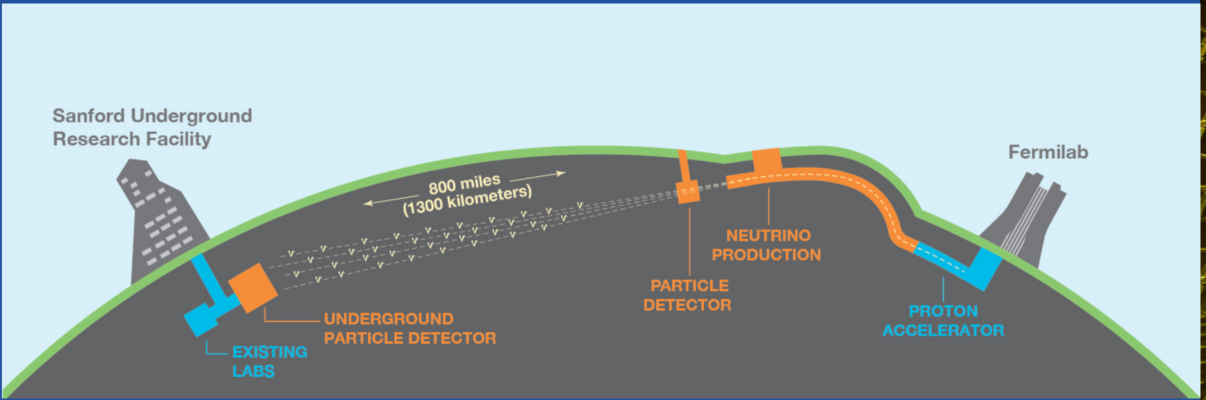
Neutrinos : the unknows

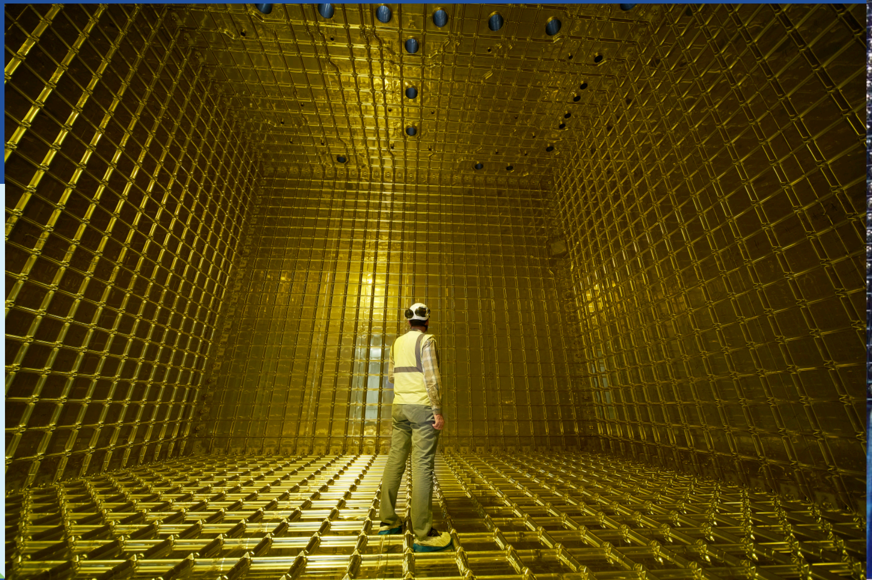
Accelerator based, reactor based and atmospheric/cosmic neutrino experiments ongoing!

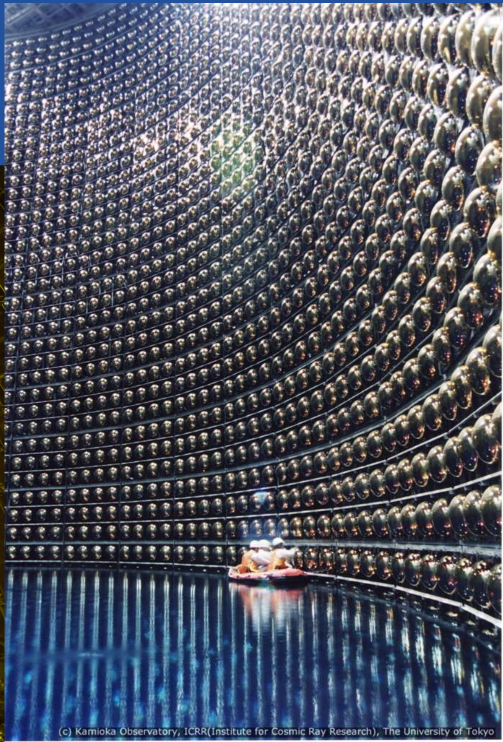
- Measurement on the oscillation parameters: mass hierarchies, mixing angles
- Search for possible CP violation → would be a hint towards "leptogenesis models"
- Search for possible righthanded neutrinos :
  - Could be sterile neutrinos?
  - Could be very heavy neutrinos (see-saw mechanism) ?
  - If so, dark matter candidates?
- Could the neutrino be its propre anti-particle? Dirac or Majorana type neutrinos?

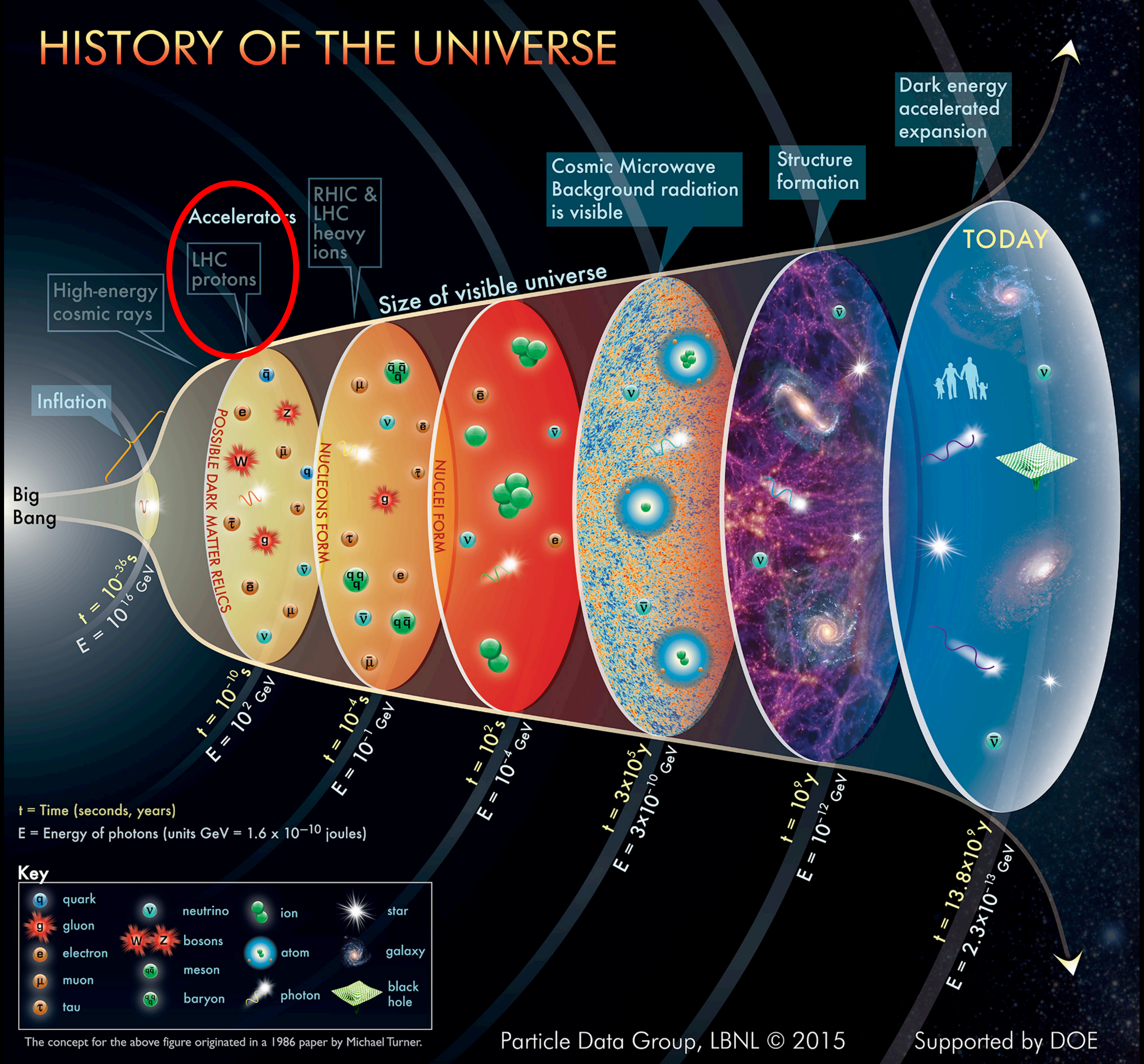
- Absolute Neutrino mass measurements
  - → Katrin experiment, model-dependent constraints from cosmology

- Dream: Cosmic neutrino background !



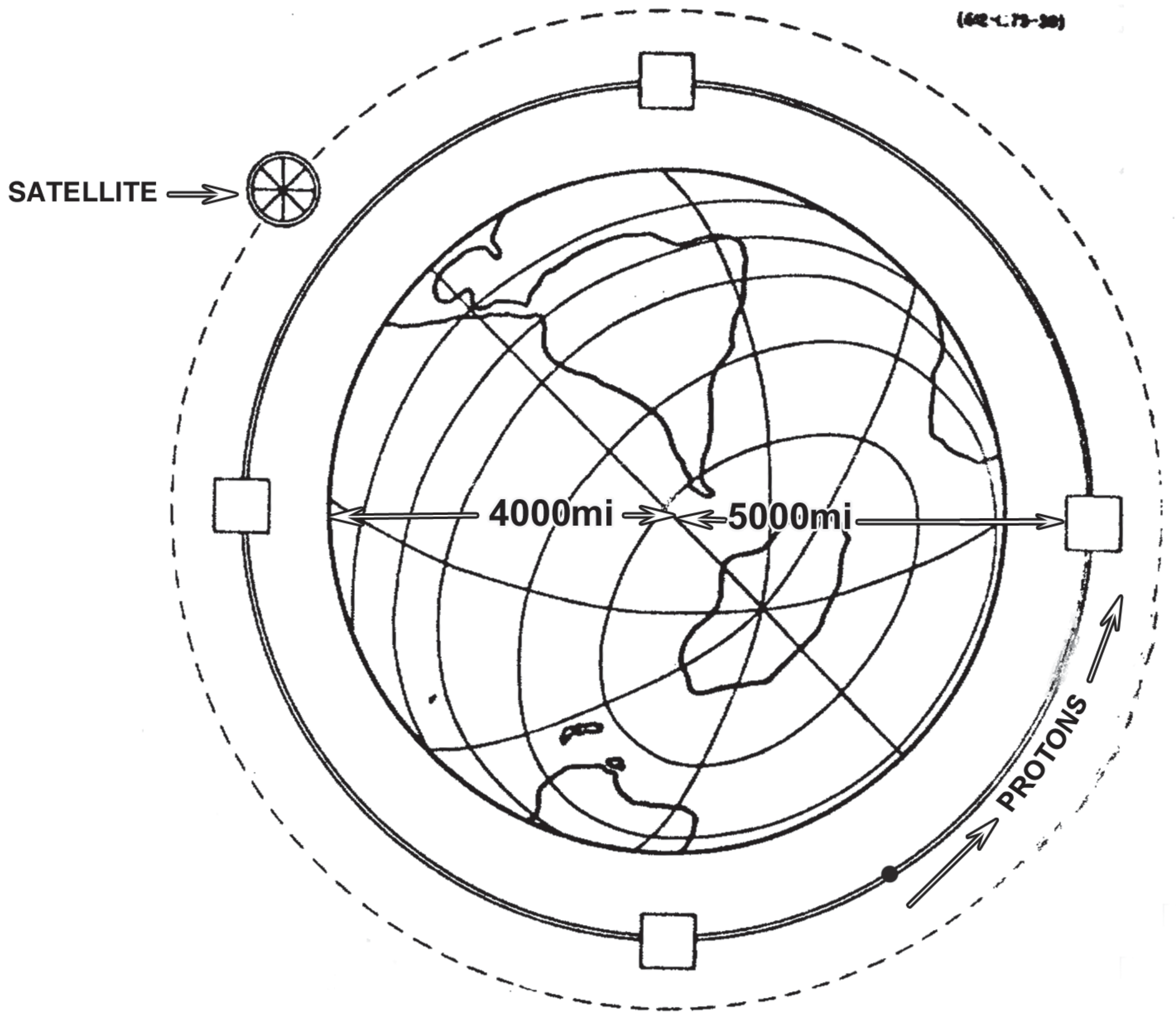






HISTORY OF THE UNIVERSE
Dark energy accelerated expansion
Structure formation
Cosmic Microwave Background radiation is visible
RHIC & LHC heavy ions
Accelerators
LHC protons
High-energy cosmic rays
Size of visible universe
TODAY
Inflation
Big Bang
POSSIBLE DARK MATTER RELICS
NUCLEONS FORM
NUCLEI FORM
$t = 10^{-36}$ s
$E = 10^{16}$ GeV
$t = 10^{-10}$ s
$E = 10^{2}$ GeV
$t = 10^{-4}$ s
$E = 10^{-1}$ GeV
$t = 10^{2}$ s
$E = 10^{-4}$ GeV
$t = 3x10^{5}$ y
$E = 3x10^{-10}$ GeV
$t = 10^{9}$ y
$E = 10^{-12}$ GeV
$t = 13.8x10^{9}$ y
$E = 2.3x10^{-13}$ GeV
t = Time (seconds, years)
E = Energy of photons (units GeV = 1.6×10^{-10} joules)
Key
quark
gluon
electron
muon
tau
neutrino
bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
The concept for the above figure originated in a 1986 paper by Michael Turner.
Particle Data Group, LBNL © 2015
Supported by DOE

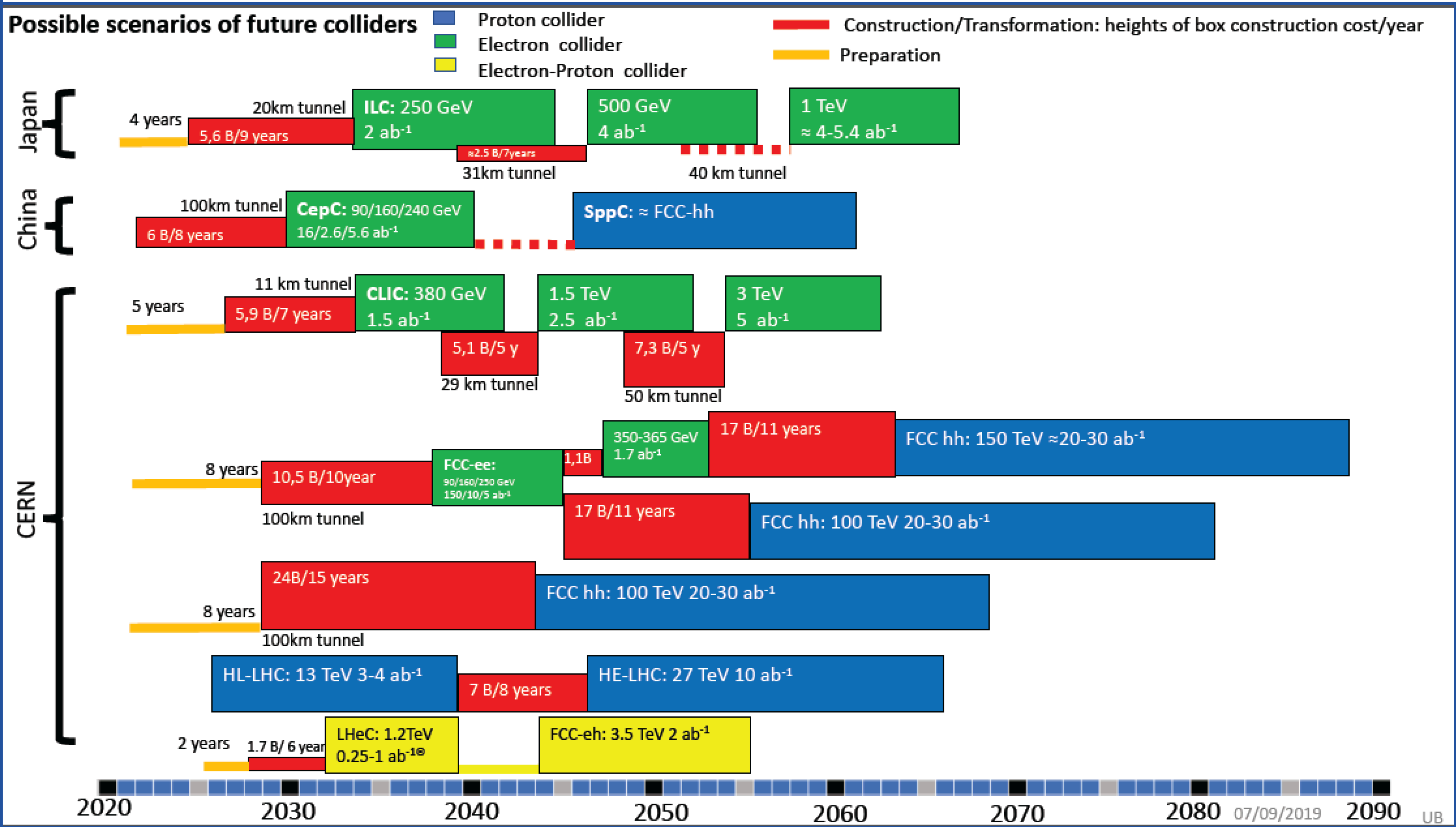
Enrico Fermi's ultime accélérateur



Vision of Enrico Fermi in 1954 : principle of a particle collider was not know → beams were only shot on targets :

- Accelerator of ≈100 TeV
- Should be built by 1994
- Price: 170 Md$
- Preliminary concept:
  - 8000 km
  - magnets of 2 T

What we think of today…



ESPP conclusions

European strategy for particle physics est. **2005**:

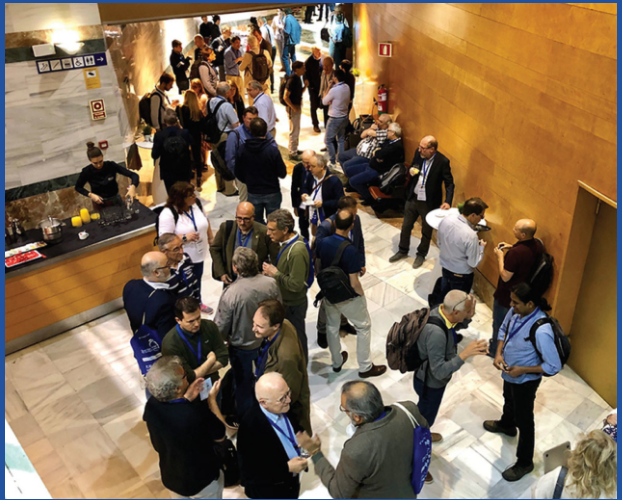
- updated every 5-7 years by the CERN Council

- **bottom-up** process with about 160 contributions received and discussed during an Open Symposium

→ Produced a 200 page briefing book

→ Transvers working groups: early careers and diversity, global governance, relations with other fields, technology transfer, communication and outreach, environmental impact

- “**topish-down”:** delegates from all European Member States of CERN formulate the strategy



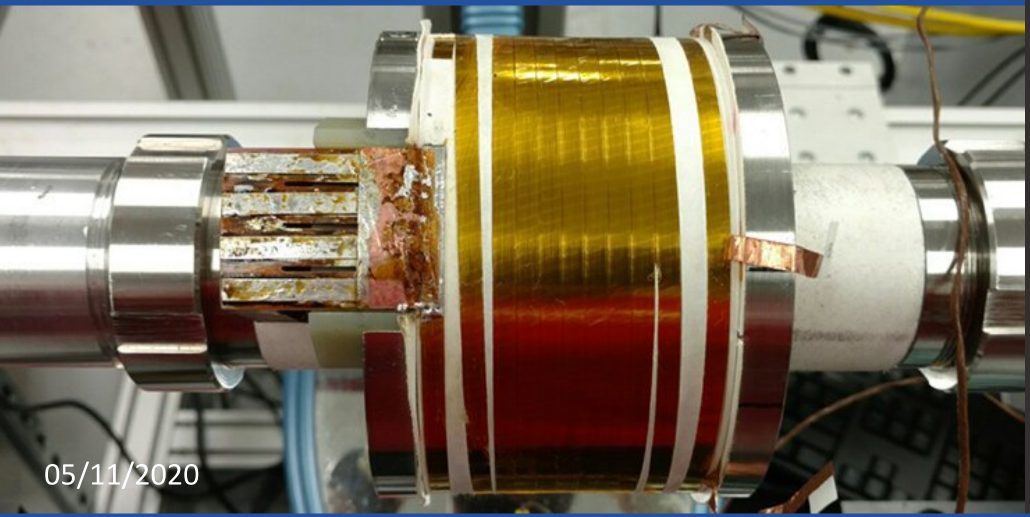
High priority future initiatives

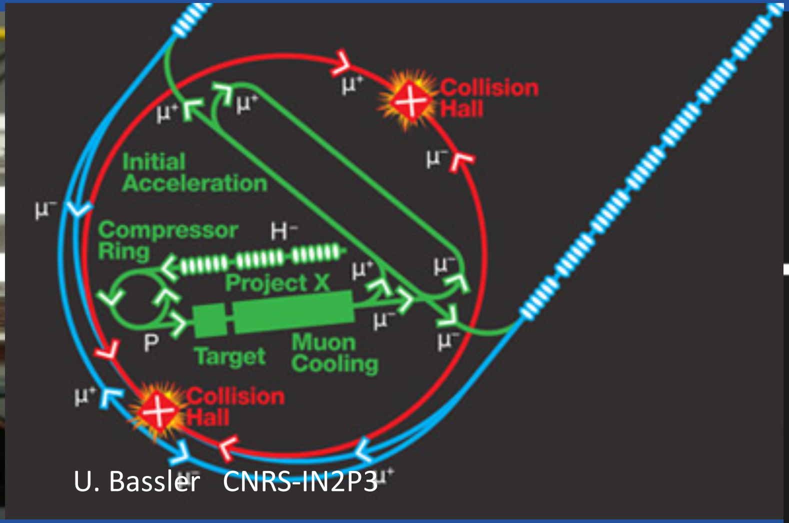
- An electron-positron Higgs factory is the highest priority
- Ambition at the longer term to operate a hadron collider at the highest achievable energies
- Development of innovative accelerator technologies : muon-collider, plasma acceleration, two-beam acceleration

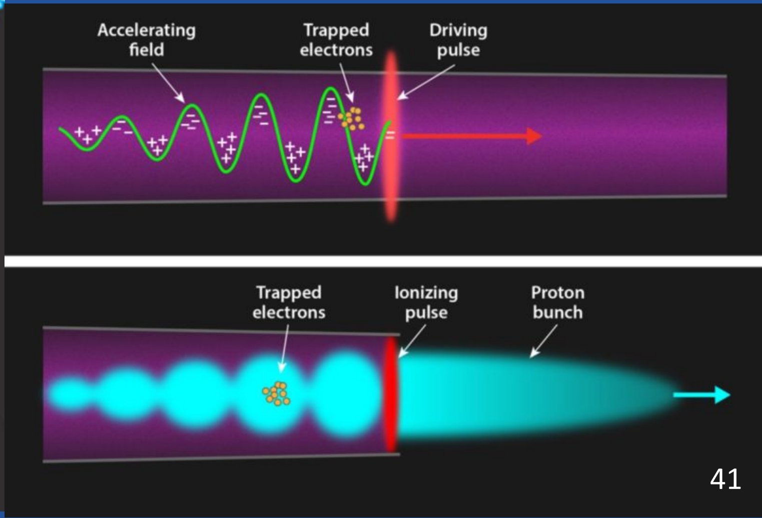
What is needed:

➔ Development of high field superconductive magnets, if possible at high critical temperature

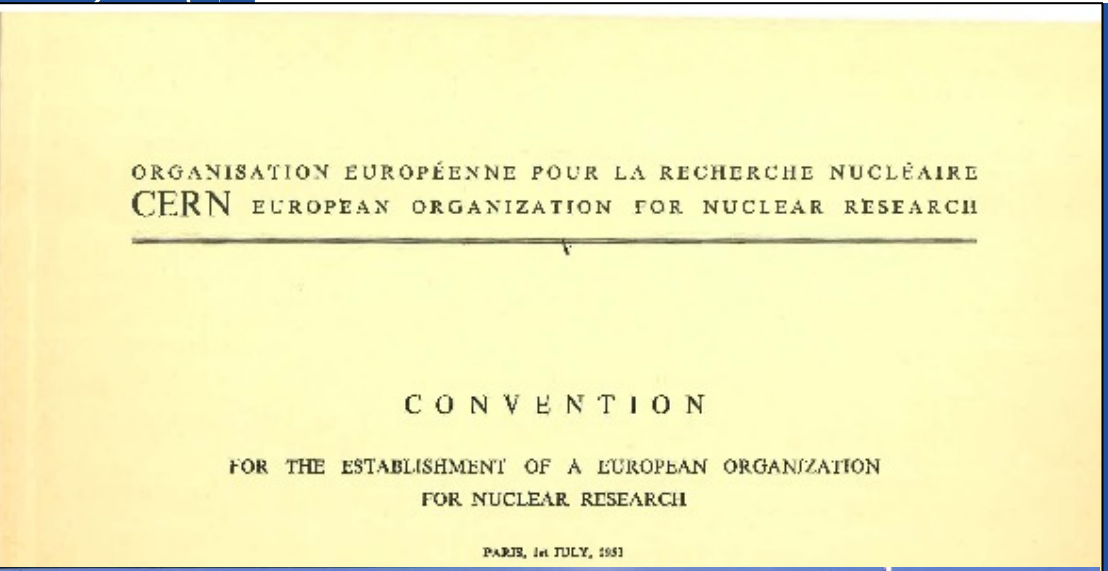
➔ Technical and Financial feasibility study, including environmental impact







Challenges


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

- **Cost of a new collider needs additional resources than current CERN budget**
  - First global infrastructure?
  - Contributions from the private sector?
- **Scientific research is motivated by scientific questions**
  - Innovation is essential but not the first goal
- **Particle Physics requires long term engagement**
  Coordination structures and orgnisations such as CERN are essential
- **Reducing environmental impact**
  - Primordial, but possible field for innovation

Quests in particle physics

- Particle physics aims to understand the basic properties of particles, and to describe the evolution of the universe at a fundamental level

→ Strong link to cosmology and quantum physics

- Fundamental questions: is the Standard Model valid up to the Planck Scale?
  - Can we built and test a theory of quantum gravity?
  - How to explain matter-anti-matter asymmetry?
  - Does dark energy and dark matter have a microscopic explanation?

- Two fold way: precision measurements and exploration of high energy frontier
- How to go there?
  → Explore the feasibility of colliders we know in principle how to built
  → Explore the possibility of colliders we don’t know how to built

What I like about working in particle physics

Particle physics is collaborative !

- No one can obtain a result by themselves: thinking of the common good in a collaboration is mandatory
- Contributions of everyone are recognized through authorship
- Possibility to experience a large variety of activities:
  Hardware, software, analysis, phenomenology, management, communication…
- Flat hierarchies and open to initiatives and ideas, autonomy
- International coordination to avoid duplications
- Promotion of Open Science