The CERN Scientific Program

Le programme scientifique du CERN

A tour around the laboratory

CERN is the largest laboratory in the world for particle physics

CERN has the world's highest energy accelerator (the LHC)

CERN has a very broad scientific program

Experimental Physics Department (EP)

Manfred Krammer

CERN was founded 1954: 12 European States

"Science for Peace"

Today: 22 Member States

~ 2500 staff
~ 2300 other paid personnel
~ 13000 scientific users

Member States: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, Netherlands, Norway, Poland, Portugal, Romania, Slovak Republic, Spain, Sweden, Switzerland and United Kingdom

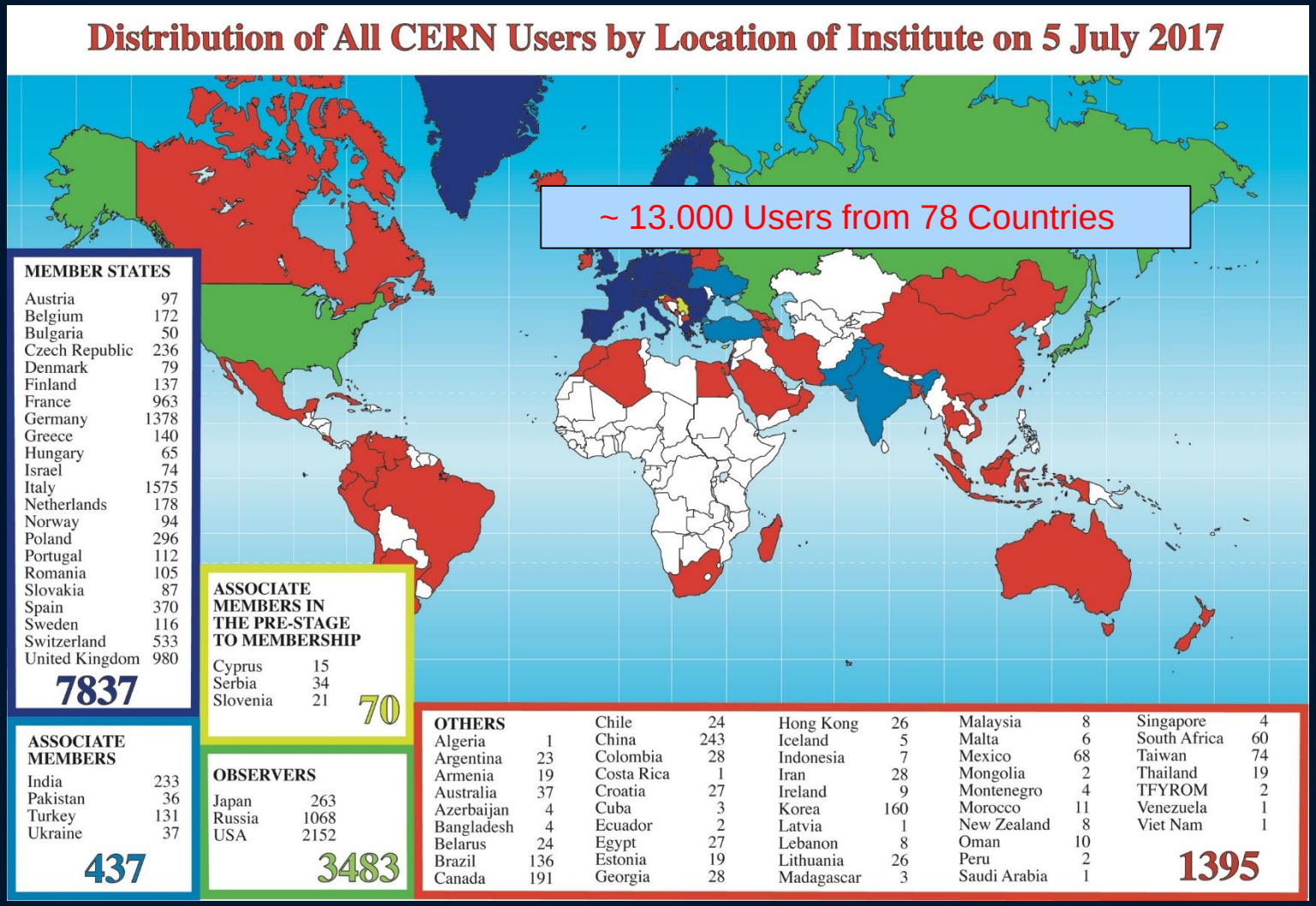
Associate Members in the Pre-Stage to Membership: Cyprus, Serbia, Slovenia

Associate Member States: India, Lithuania, Pakistan, Turkey, Ukraine

Applications for Membership or Associate Membership:
Brazil, Croatia

Observers to Council: Japan, Russia, United States of America;
European Union, JINR and UNESCO

CERN attracts scientists from all over the world



The Mission of CERN

- Push back the frontiers of knowledge

  Studying the structure of matter on the smallest distances/highest energies… what was the matter like in the first moments of the Universe's existence?

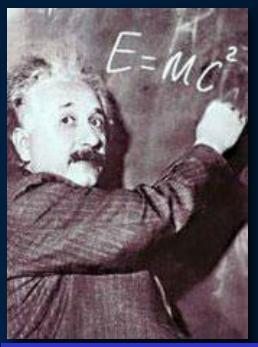
- Develop new technologies for accelerators and detectors

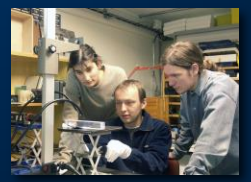
  Information technology - the Web and the GRID

  Medicine - diagnosis and therapy

- Train scientists and engineers of tomorrow

- Unite people from different countries and cultures



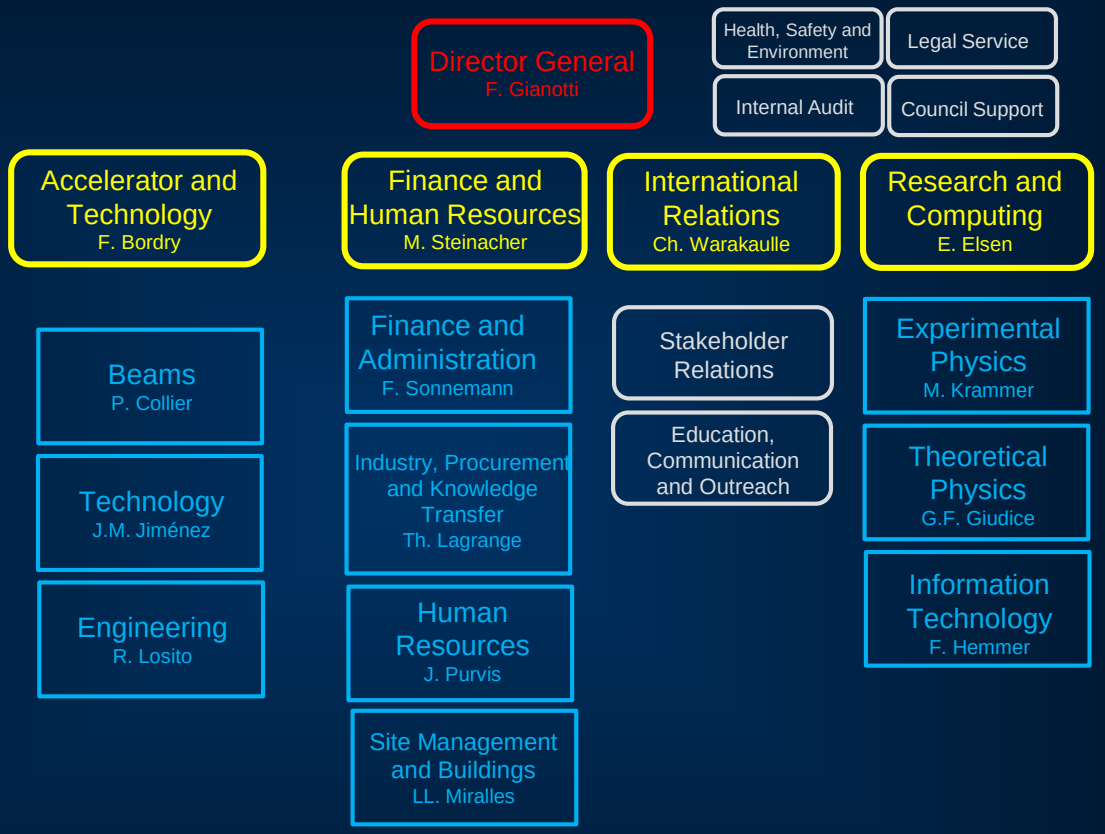


CERN structure

Director General

4 Directors

10 Departments

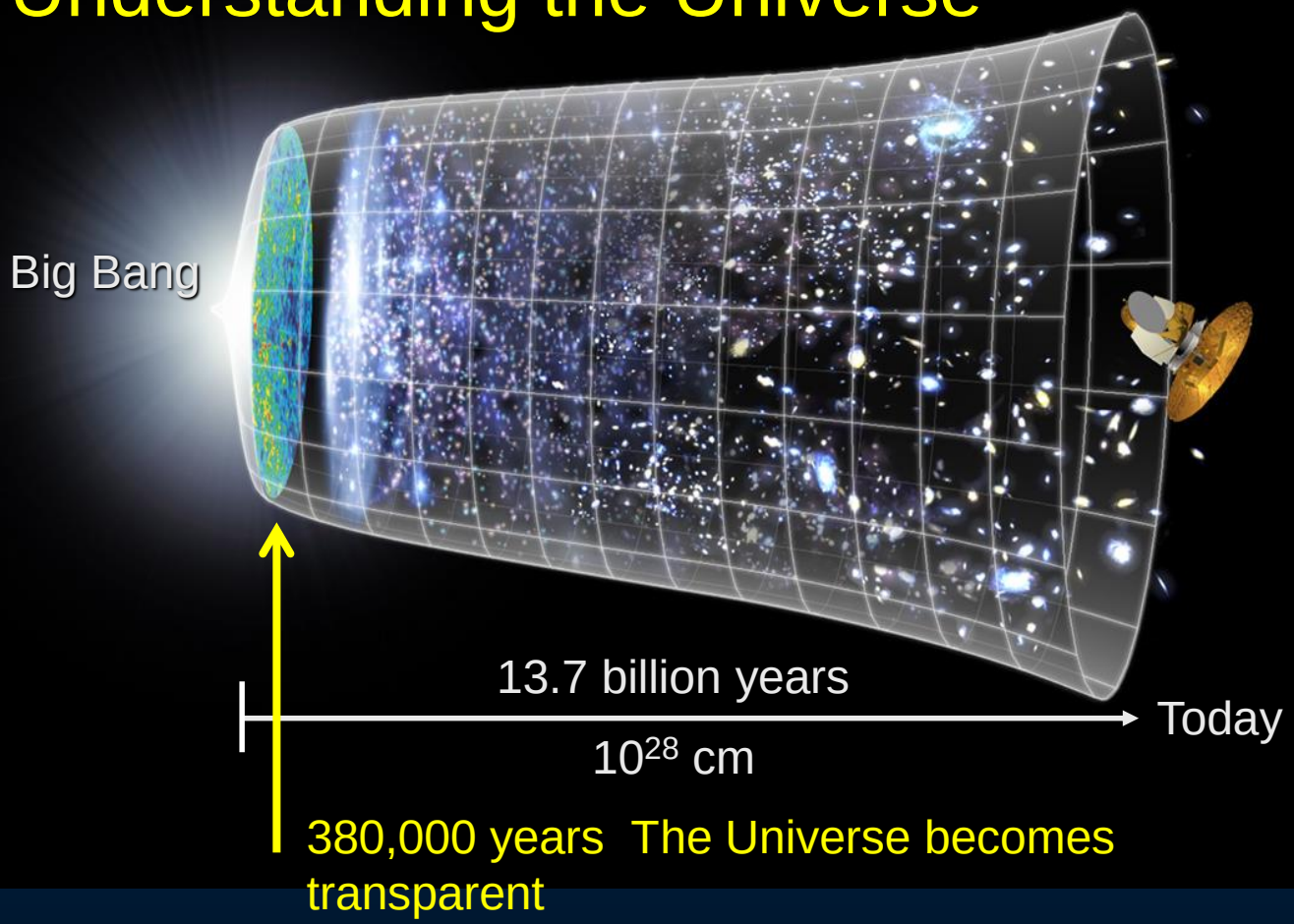


Experimental Physics Department (EP):

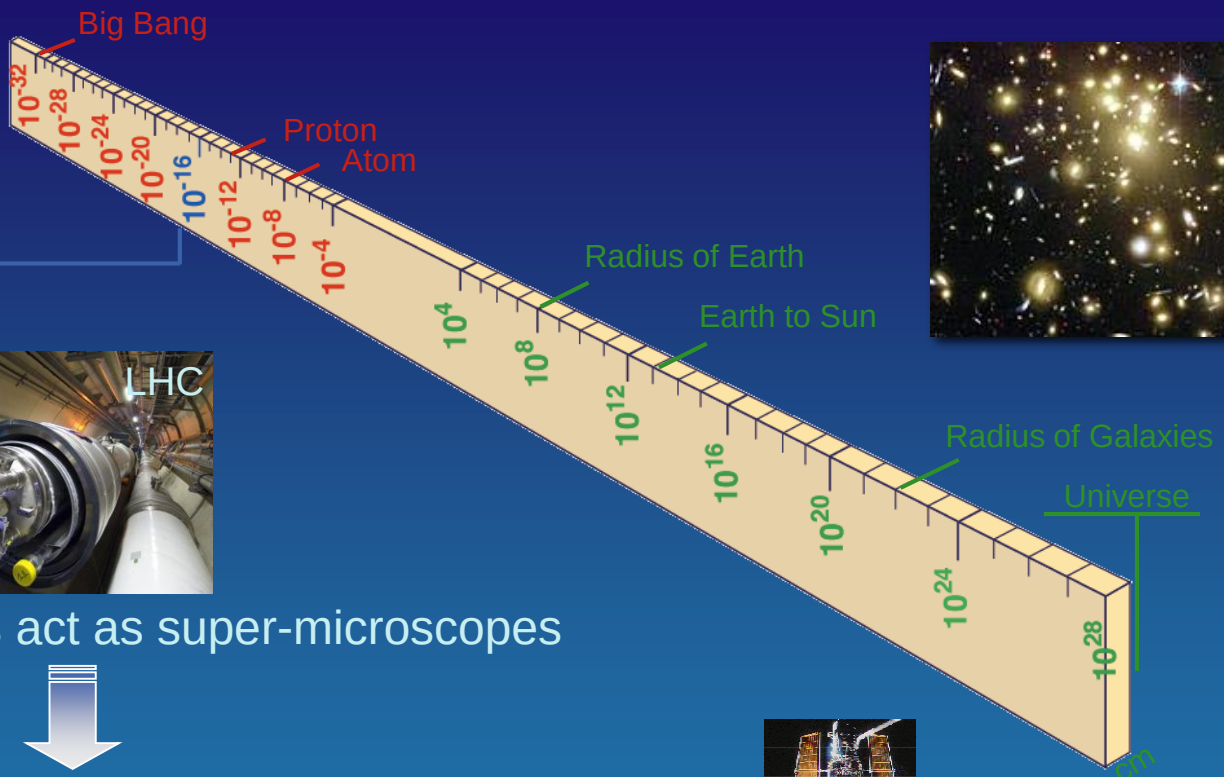
~ 500 staff (~ 20% of CERN total), ~ 500 students/fellows/associates/…

>13000 users assigned to the department!

Physics at CERN: Understanding the Universe



From the smallest to the largest Structures

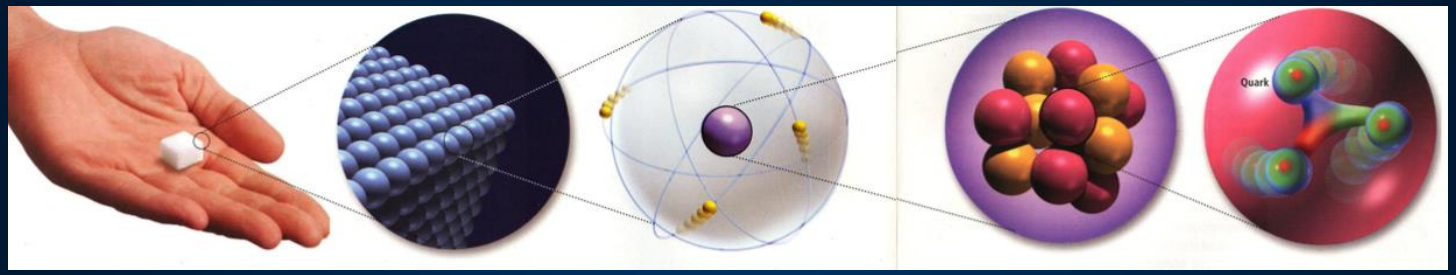


Accelerators act as super-microscopes

Study laws of physics at first moments after Big Bang

Increasing symbiosis between Particle Physics, Astrophysics and Cosmology

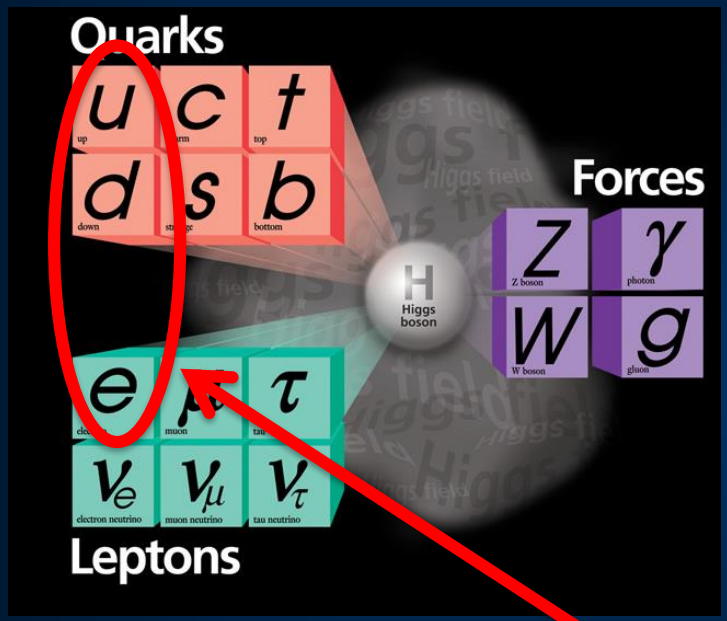
Composition of Matter



- All matter built from Atoms
- Atoms consist of a Nucleus and Electrons
- The Nucleus consist of Neutrons and Protons
- Neutrons and Protons consist of Up and Down Quarks (and Gluons)

Fundamental Matter Particles: Electrons, Up Quarks, Down Quarks

The Standard Model of Particle Physics



Fermions (spin ½) quarks and leptons: the building blocks of matter

Bosons (integer spin) carry the forces: electromagnetic (Photon), weak force (W, Z) and strong force (Gluons)

Higgs Boson, gives mass to particles

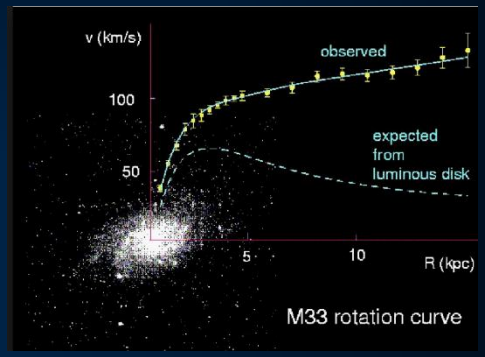
Plus antimatter partners of each particle.

Sufficient to explain the matter around us

What's next?

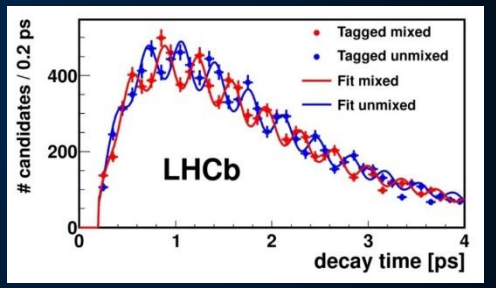
Several observations and mysteries point to the fact that the Standard Model is not the final theory:

- Dark matter (as "seen" in Astrophysics) not explained: need new particles? 5x more dark matter than "standard" matter.



- Matter Antimatter asymmetry: Why is the Universe made of matter, when matter and antimatter would be equally produced in the Big Bang?

- Mass of the neutrinos not explained by the SM: 3 different "flavour" of neutrinos – changing flavour, hence have to have mass.
- …



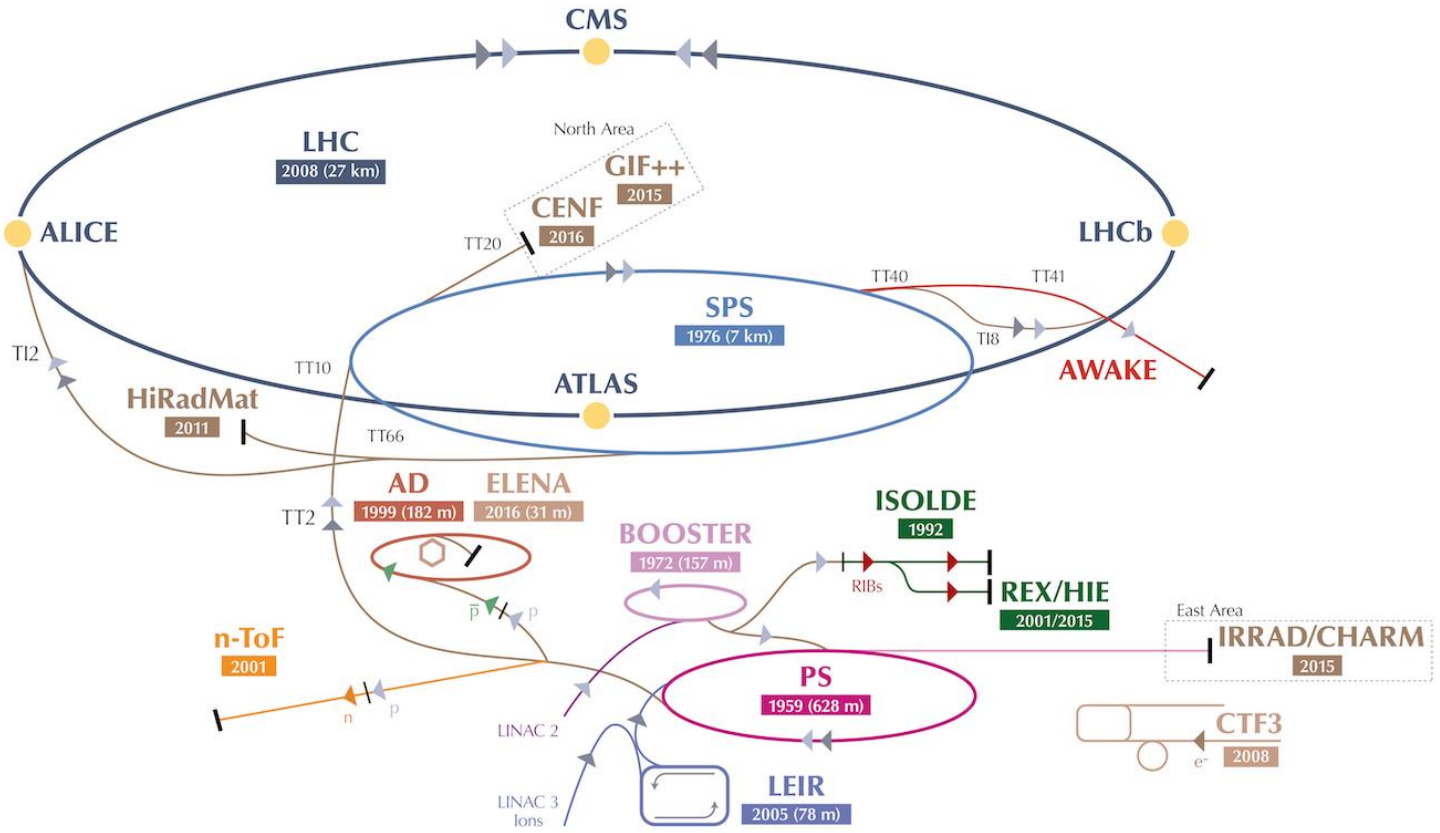
- And finally, inclusion of Gravity in the final theory.

Still a lot to explore, to measure and to collect Nobel prizes!

Research in Particle Physics needs:

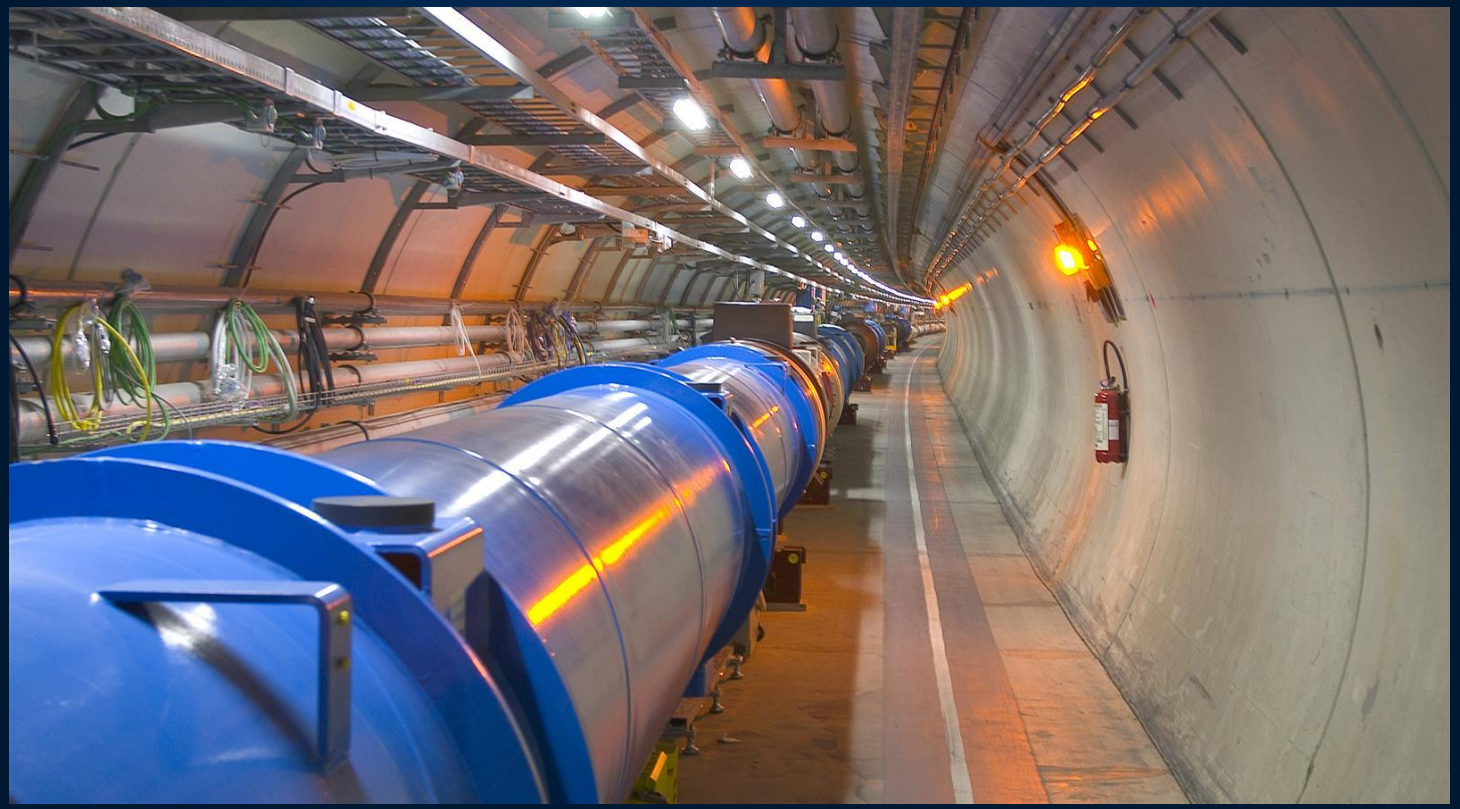
- **Theories**
- **Accelerators - Engineering**
- **Experiments - Computing**
- **People**
- **People**
- **People**
- **People**

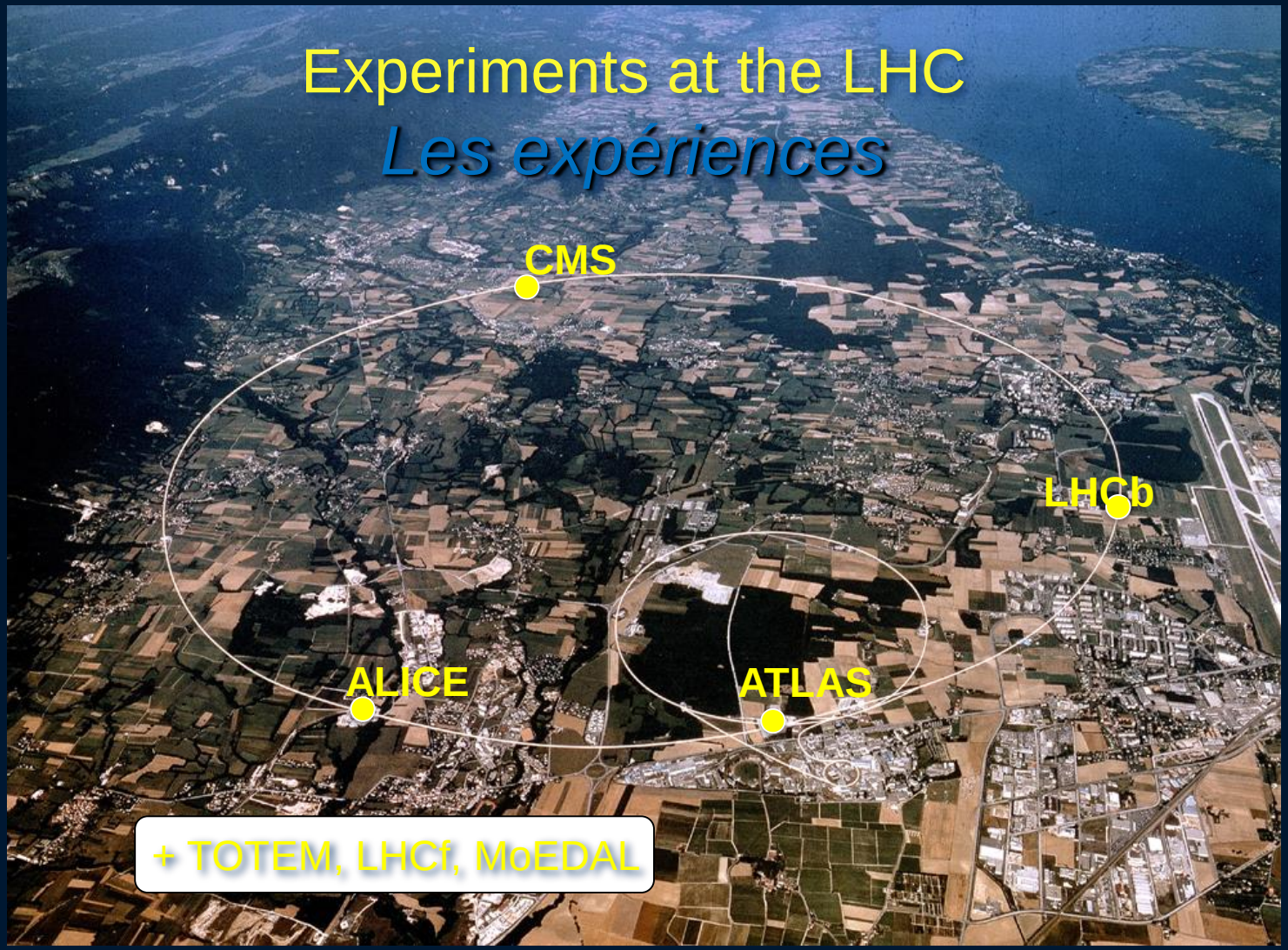
CERN Accelerators *les accélérateurs*



The Large Hadron Collider

Search for the Higgs Boson, and physics beyond the Standard Model
Exploration of a new energy frontier in p-p and Pb-Pb collisions



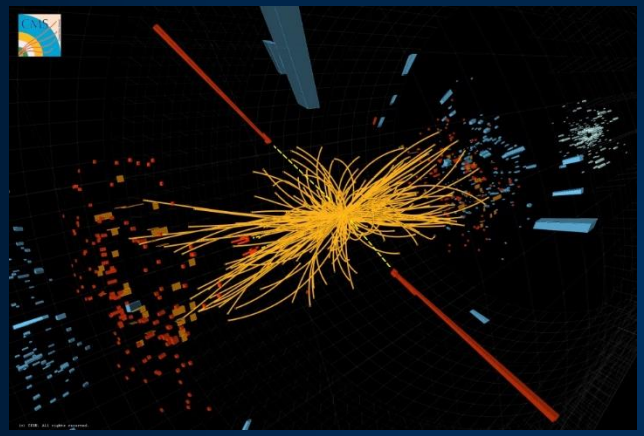

Experiments at the LHC
Les expériences
CMS
LHCb
ALICE
ATLAS
+ TOTEM, LHCf, MoEDAL

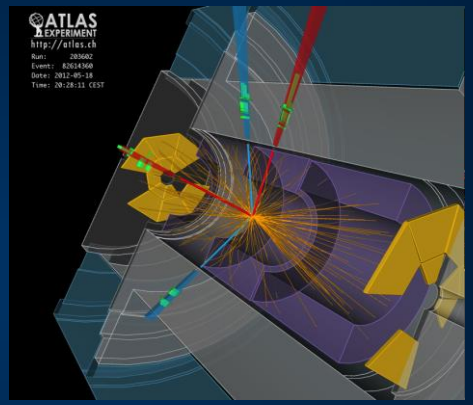
Experiments at the LHC

Four major experiments

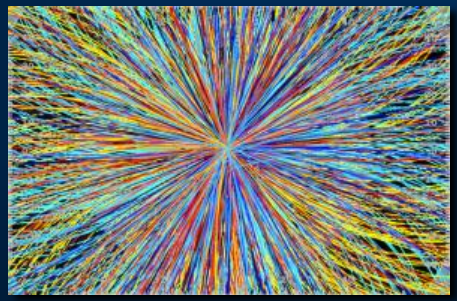
Experiments at the LHC

Brilliant performance of the LHC, the experiments and the Grid computing:
Run1 2011-2012 : E_{cm} = 7– 8 TeV Run2 2015-2018: E_{cm} = 13 TeV

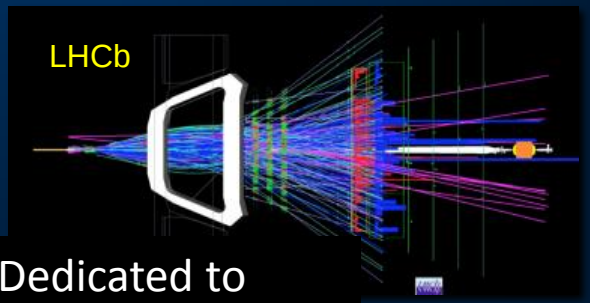




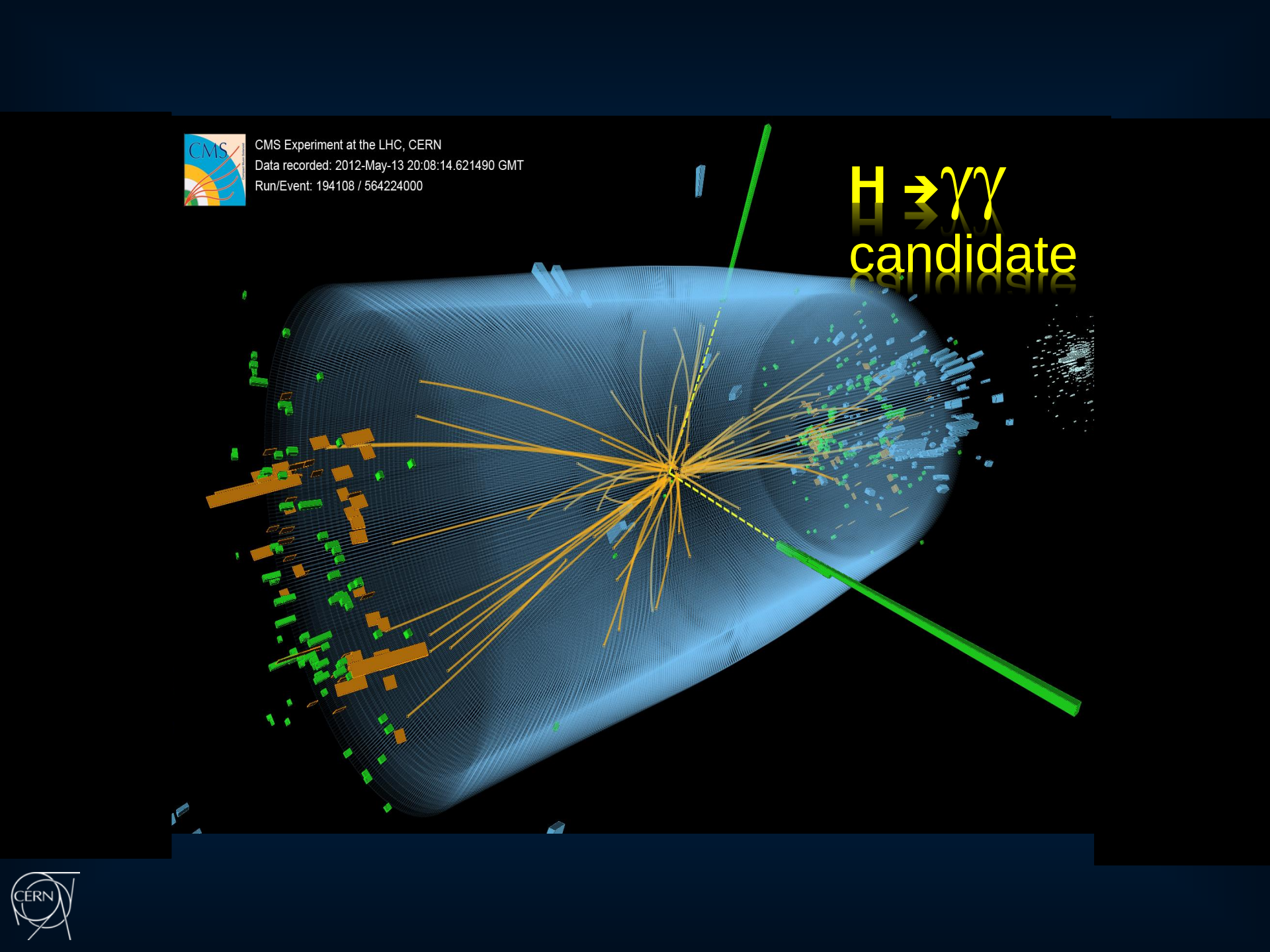
ALICE
Heavy ions
~ 1 month/year



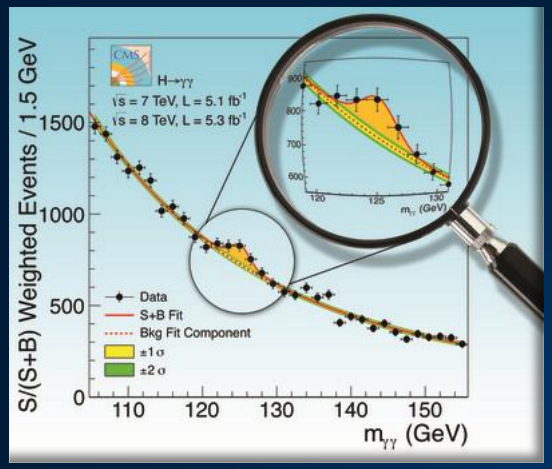
Pb-Pb collisions
E_{cm} = 5 TeV/N

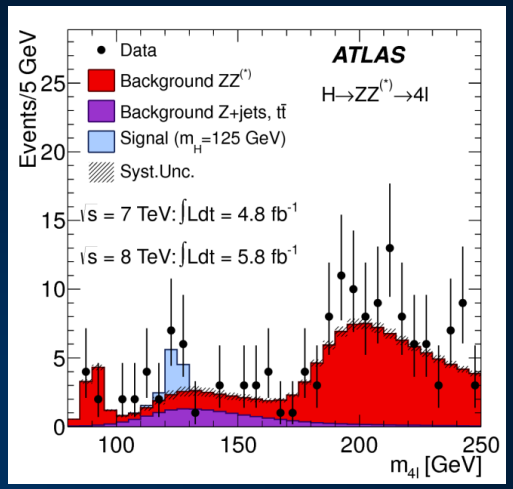


Dedicated to flavour physics (b and c quarks)


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
H → γγ
candidate

July 2012: “ATLAS and CMS observe a new particle compatible with the Higgs Boson”





François Englert

Photo: A. Mahmoud

Peter W. Higgs

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

Photos

To cite

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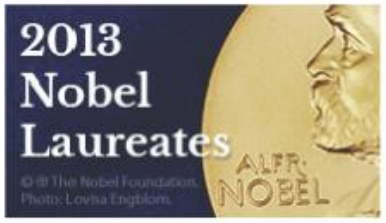
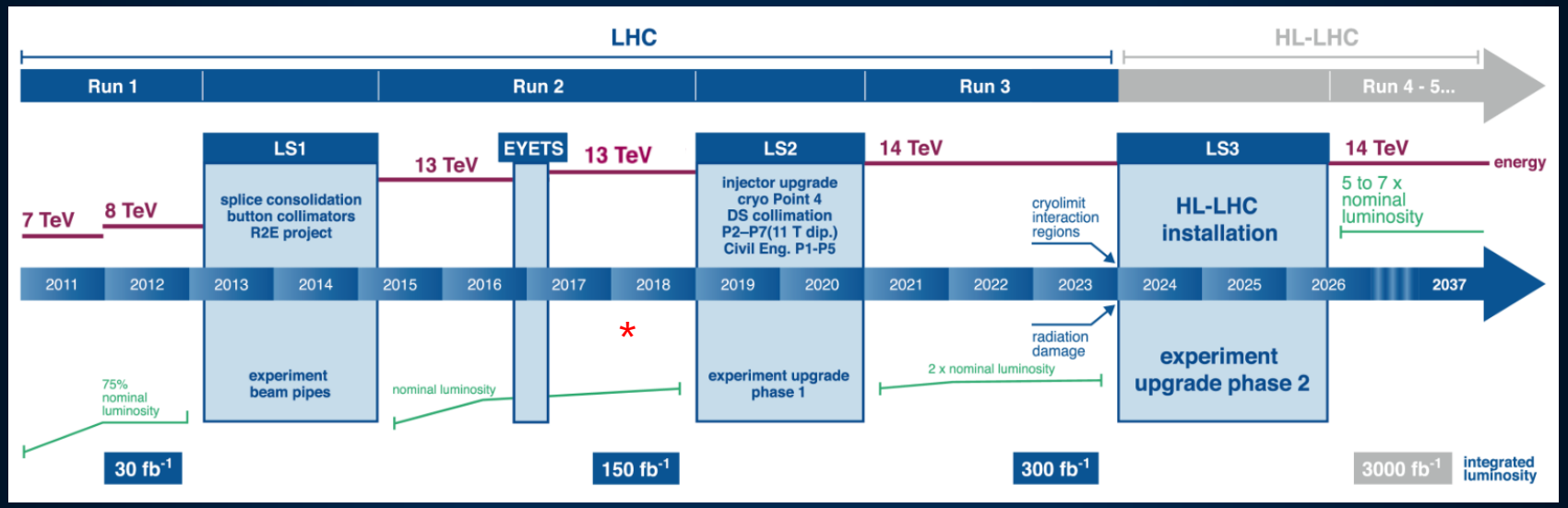


LHC and HL-LHC Program until 2037

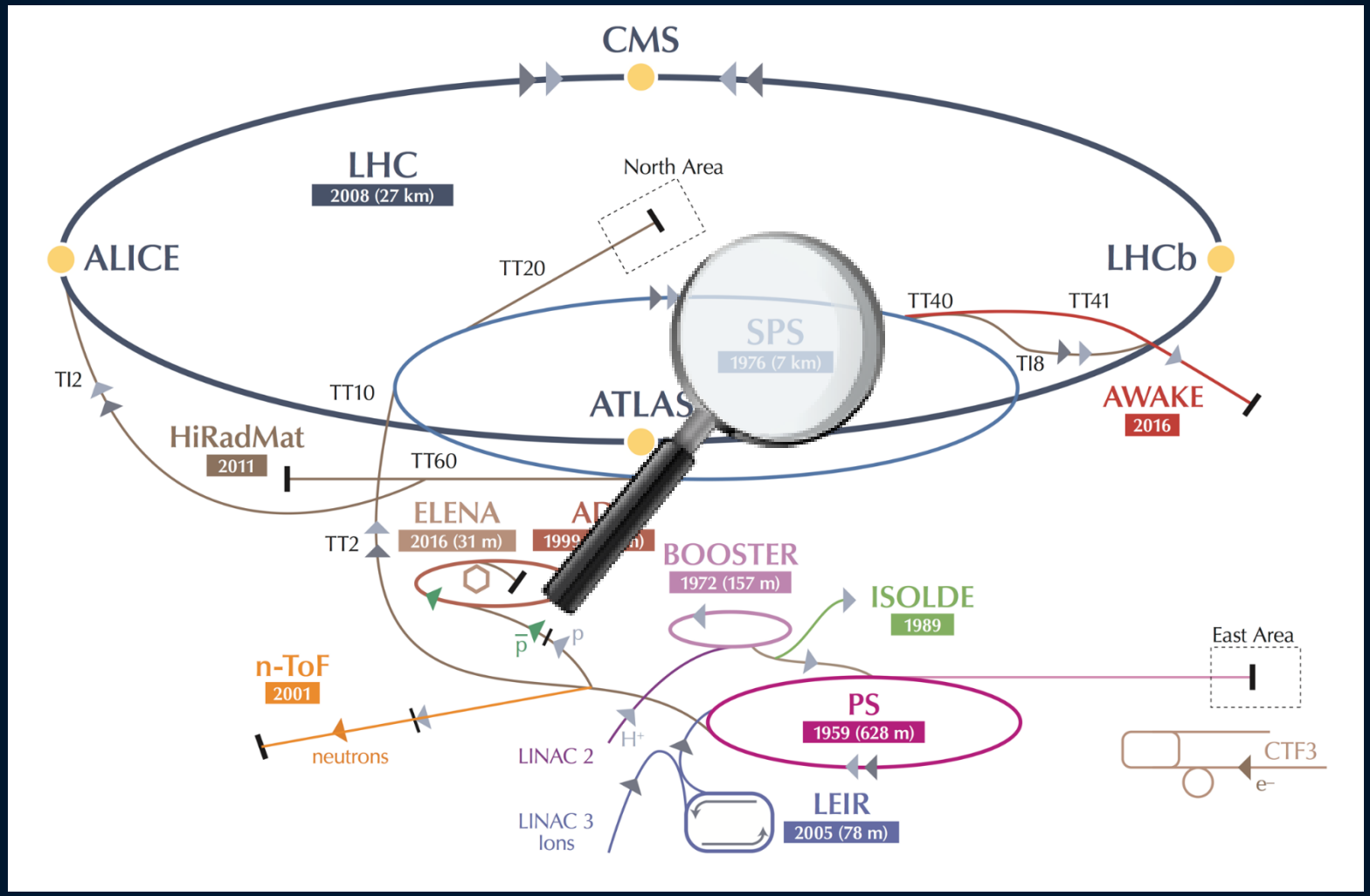
Present planning: operation at 13 TeV during run 2,
increase energy to 14 TeV for run 3



HL-LHC project officially approved by CERN Council in June 2016
Operation of the LHC foreseen until 2037

Until now only ~4% of LHC/HL-LHC data taken – a lot to come!

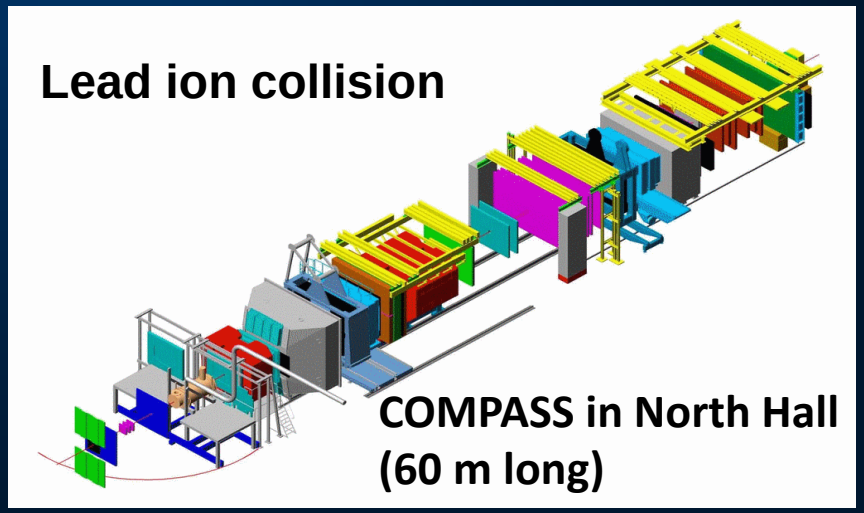
SPS: Injector for the LHC and accelerator for experiments in the North Area



Fixed Target Physics

Lower energy experiments at PS or SPS (in 1-100 GeV range)
allow precision measurements and comparison with theory
Deviations can be sign of new physics at higher energies

- NA58 (COMPASS): muon spin physics, hadron spectroscopy
- NA61 (SHINE): strong interaction, quark gluon plasma, neutrino and cosmic ray programm
- NA62: rare K decays BR($K^+ \rightarrow \pi^+ \nu\nu$)
- NA63: electromagnetic processes in strong crystalline fields
- NA64: search for dark sectors in missing energy events

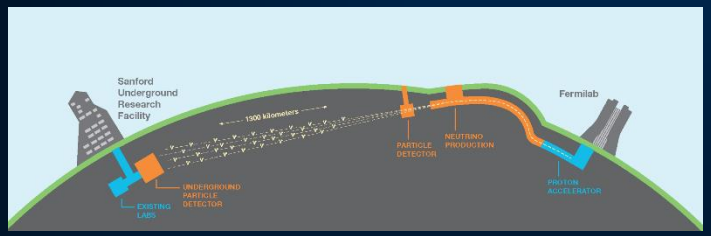


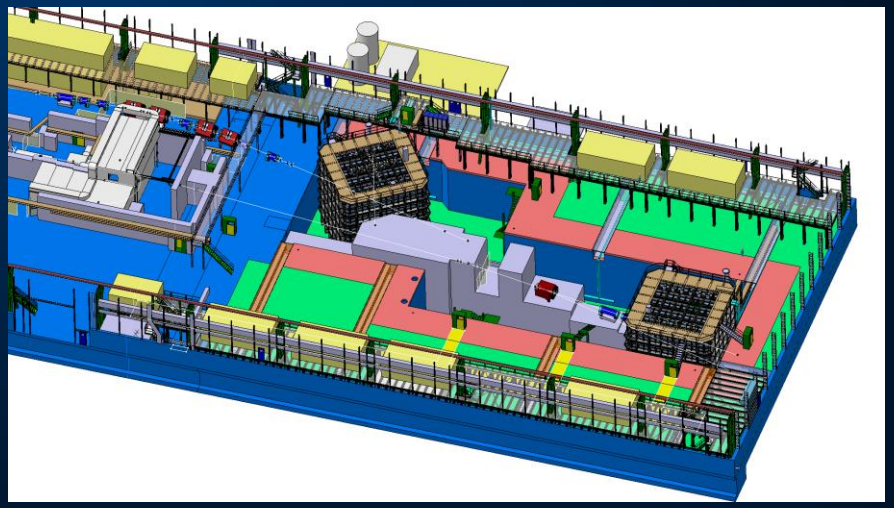
Neutrino Platform (new extension of North Area)

Like quarks, neutrinos exist in different flavors ν_e ν_μ ν_τ
and **their flavour oscillates** $\nu_\mu \Leftrightarrow \nu_\tau$ $\nu_\mu \Leftrightarrow \nu_e$
Has been studied with ν_μ beam sent from CERN to Gran Sasso in Italy (CNGS).

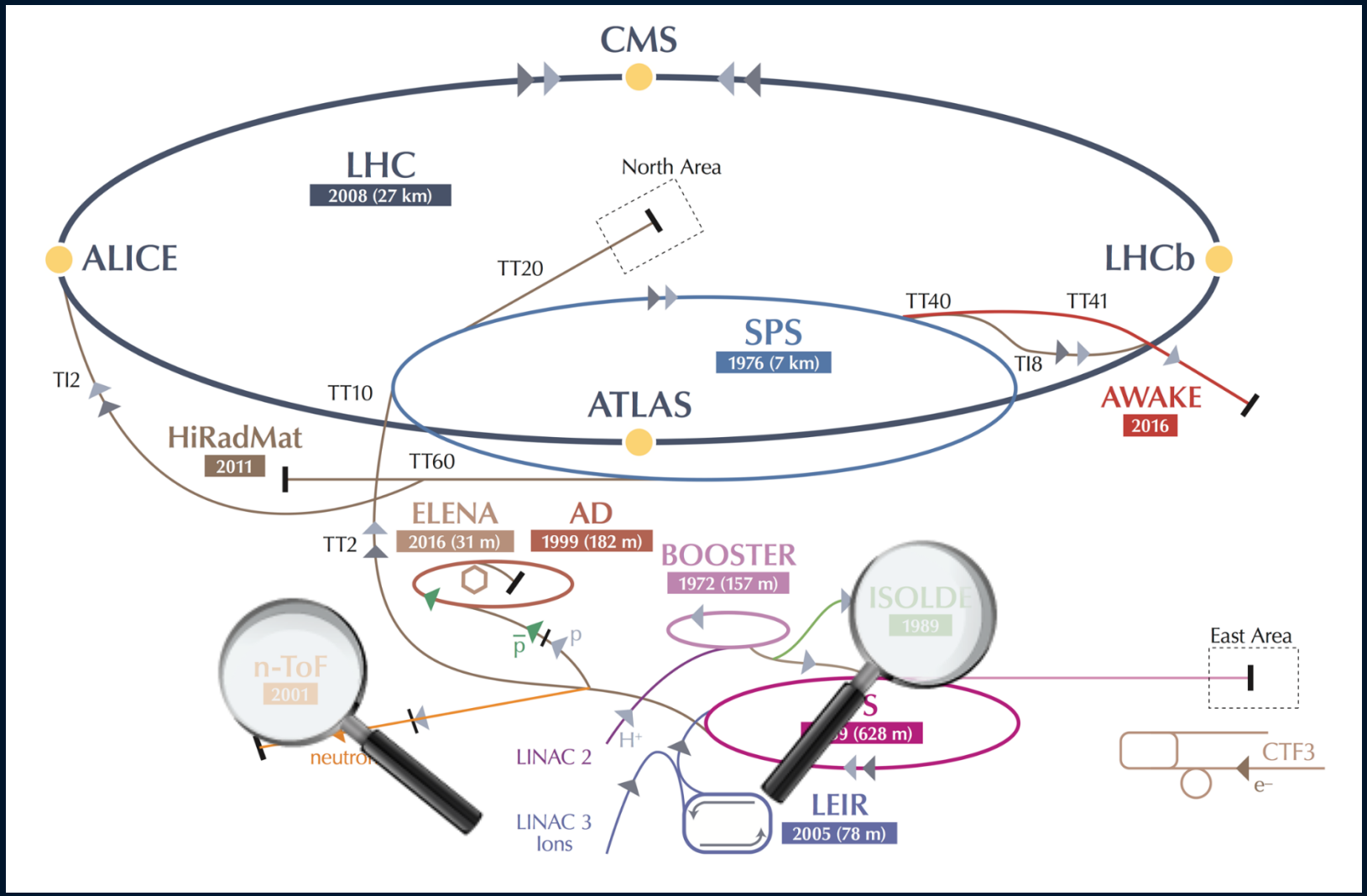
Neutrino platform as a test area with charged beams for neutrino detectors (e.g. R&D for large liquid argon detectors).
The experiments will take place in the US and Japan.

LBNF/DUNE in the US:





ISOLDE and nTOF



Nuclear Physics: ISOLDE & nTOF

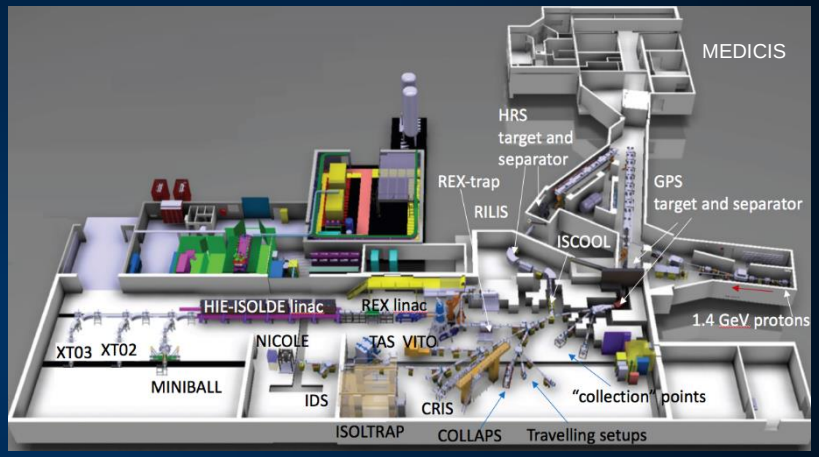
ISOLDE: radioactive ion beams

(1000 nuclides of over 75 elements produced, about 50 experiments every year)

- *Nuclear and Atomic physics*
- *Astrophysics*
- *Solid state physics*
- *Life Sciences*

Over 20 Target materials:
carbides, oxides, solid metals, molten metals and molten salts
3 types of ion sources: surface, plasma, laser

HIE-ISOLDE (post acceleration up to 10 MeV/nucleon), to be completed in 2018

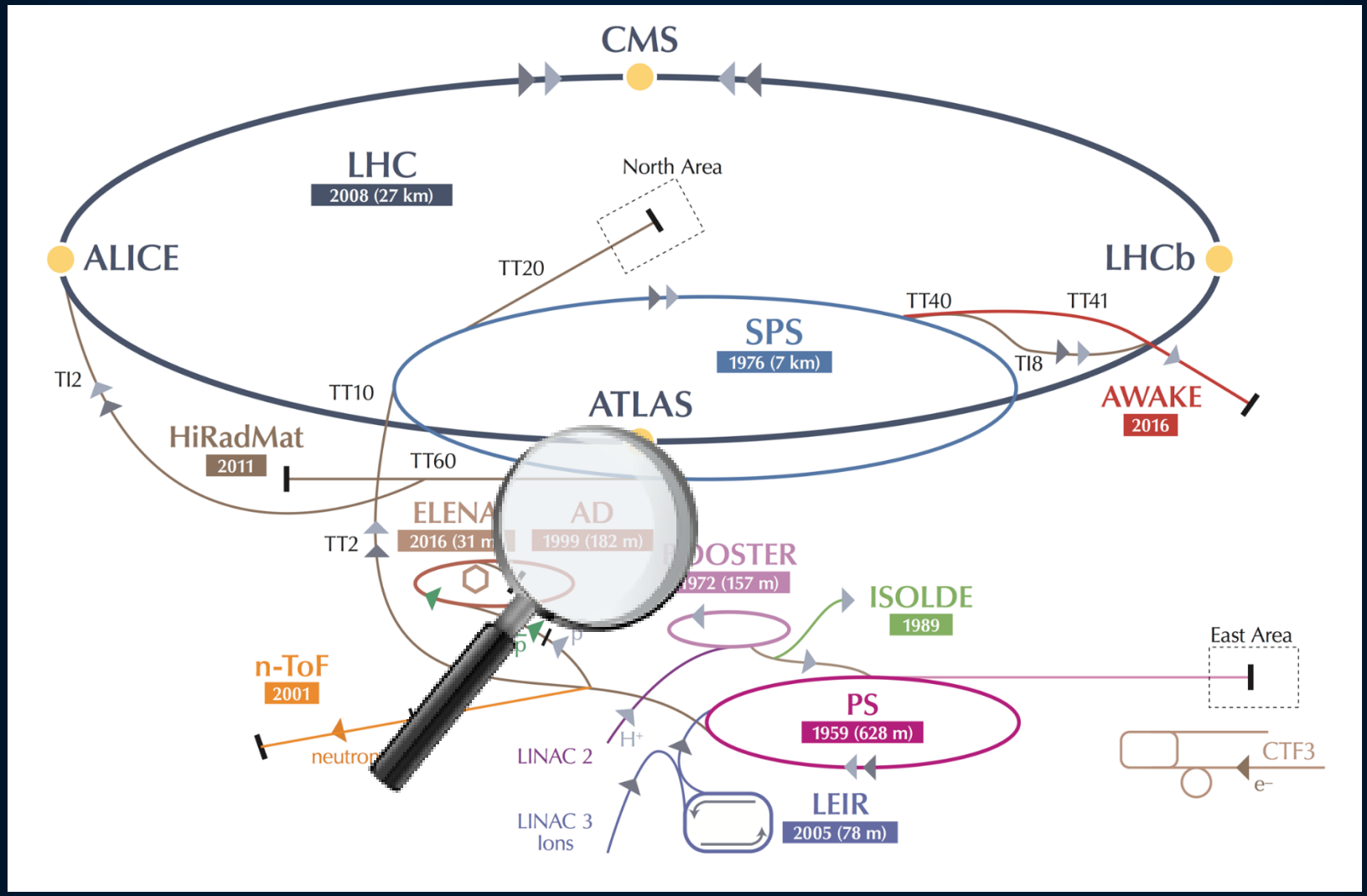


nTOF (neutron time-of-flight)

Neutron cross-section measurements

- *Astrophysics*
- *Nuclear Physics*
- *Medical Applications*
- *Nuclear Waste Transmutation*

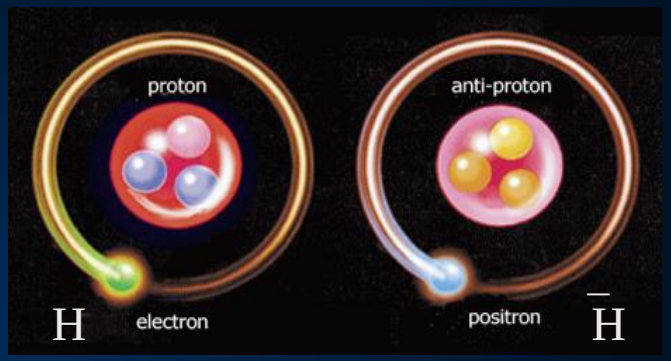
Antiproton Decelerator



Antiproton & Antihydrogen Physics

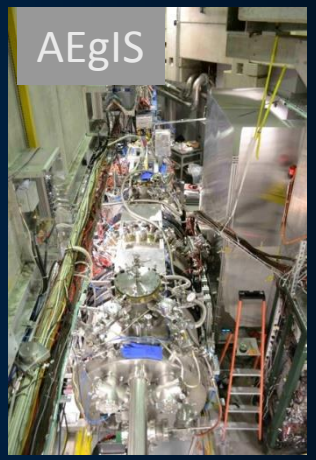
Matter-Antimatter comparison

Fundamental in the current theory of physics: $m = \bar{m}$, $g = g^{-}$

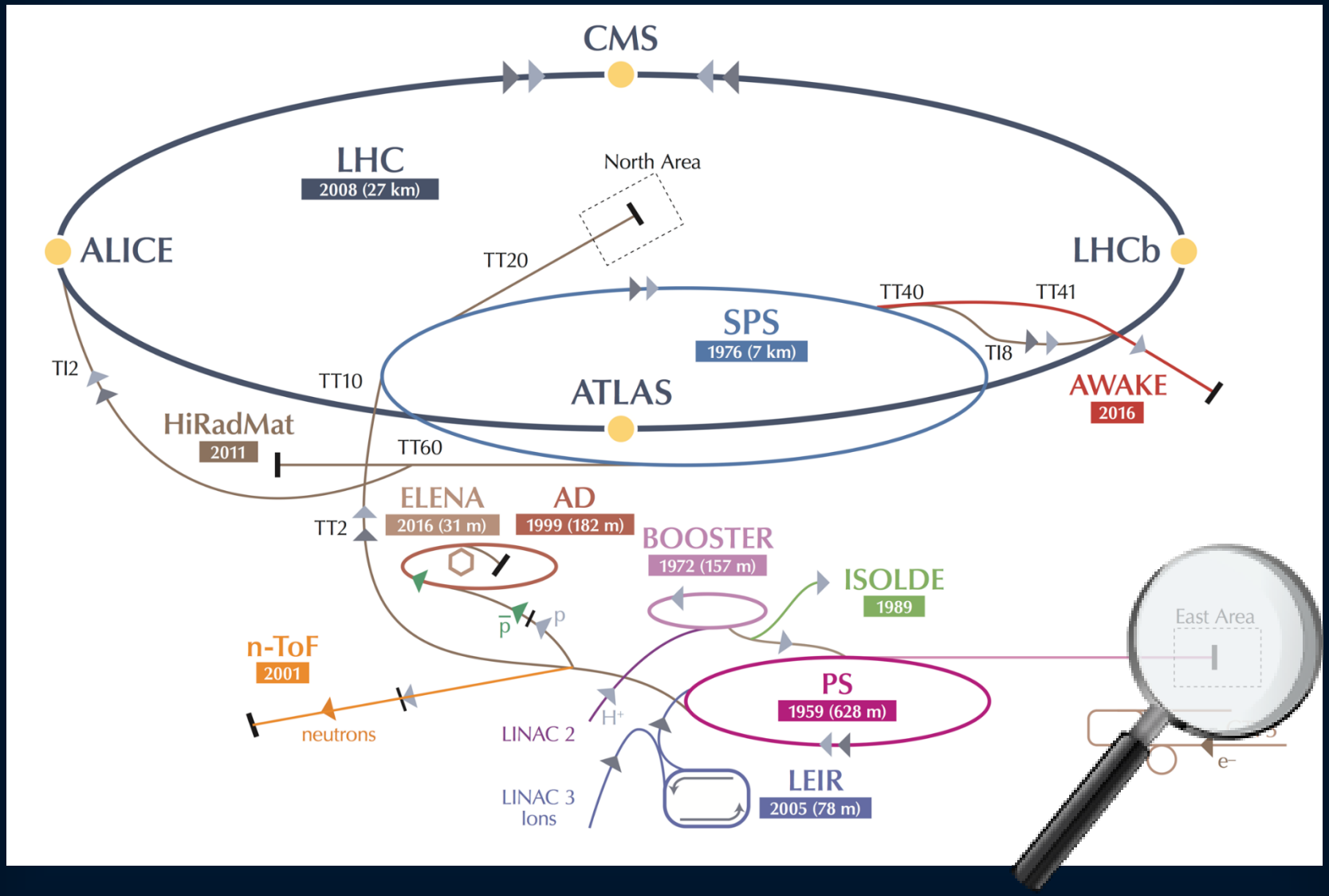


6 experiments:

- **ATRAP** spectroscopy and magnetic moment of the antiproton
- **ALPHA/ALPHA-g** spectroscopy and gravity
- **ASACUSA** spectroscopy of exotic atoms (antiprotonic Helium), and nuclear collision cross section
- **BASE** magnetic moment of the antiproton
- **AEgIS** spectroscopy, antimatter gravity experiment
- **GBAR** (will start in 2018 connected to ELENA) antimatter gravity experiment



PS East Hall


CMS
LHC
2008 (27 km)
North Area
ALICE
LHCb
TT20
TT40
TT41
SPS
1976 (7 km)
TI8
TI2
TT10
ATLAS
AWAKE
2016
HiRadMat
2011
TT60
ELENA
2016 (31 m)
AD
1999 (182 m)
TT2
BOOSTER
1972 (157 m)
ISOLDE
1989
East Area
n-ToF
2001
PS
1959 (628 m)
neutrons
LINAC 2
LINAC 3
Ions
LEIR
2005 (78 m)

Environmental Physics

CLOUD - Study effect of cosmic rays on cloud formation

Clouds created in a large climatic chamber

Study influence of natural and man made aerosols on the development of clouds, cosmic rays “simulated” by PS beam,

CLOUD breakthrough:

Cloud formation was higher
than expected in pre-industrial times and influenced by cosmic rays.
Result important to reduce uncertainties in current climate model.

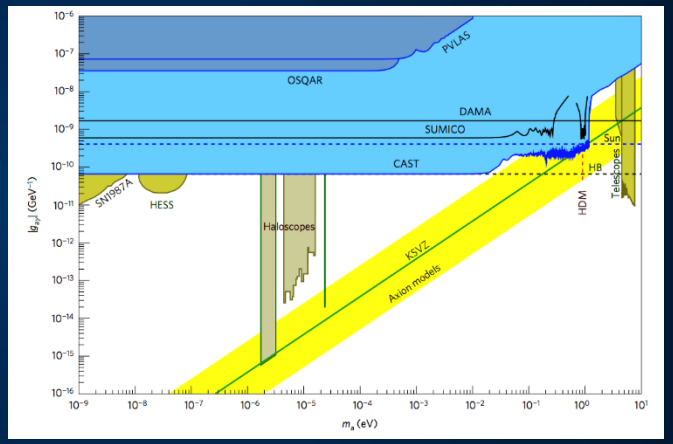
Non Accelerator Experiments

CAST: The CERN Axion Solar Telescope

- Search for solar axions completed in 2015
- New search for dark matter axions
- New search for solar chameleons

Using a LHC test magnet

Constraints on Axion-Photon coupling:



Nature Physics 13, 584-590 (2017)

OSQAR: Search for Axions through “Light shining through wall experiments”

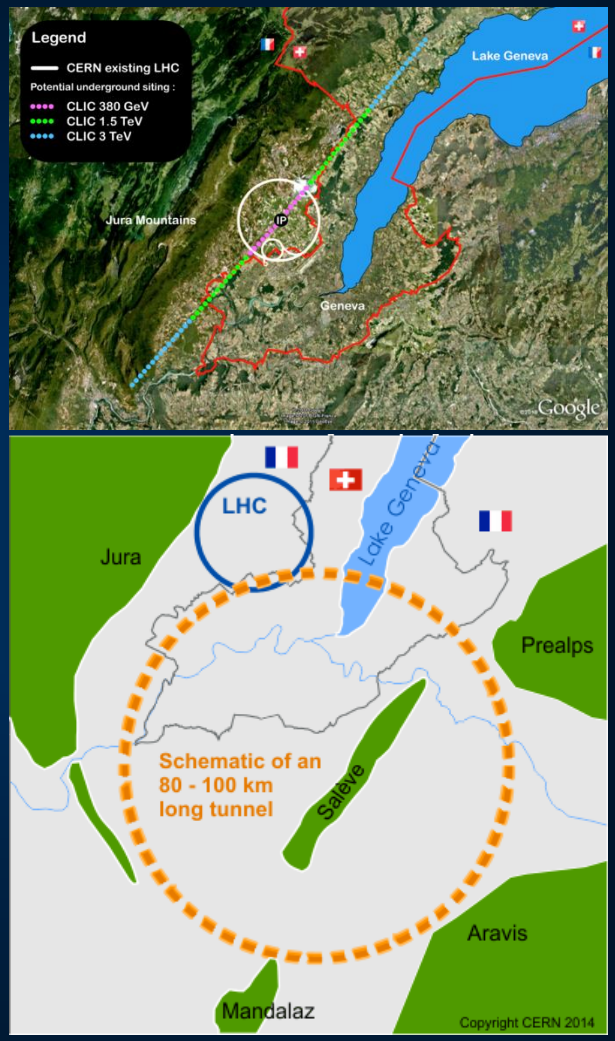
Using LHC prototyp dipol magnet

Future accelerators

LHC, and its upgrade to higher luminosity,
is central to CERN program for next decade(s)
But need to prepare for what will come after,
so future accelerators are under study:

- CLIC – Compact Linear Collider
  Study of the design for a possible
  future e^+e^- linear collider up to 3 TeV
- FCC – Future Circular Collider
  Study of a 100 km circumference machine
  for pp collisions at 100 TeV, as well as e^+e^-
- Physics beyond Colliders
  Study to explore possibilities using the non-collider part of the CERN accelerator complex

Time schedule for next update of the European Strategy define: Conclusion in May 2020.



Summary

The CERN scientific program is:

- Rich and diverse
- Covers a wide range of energies from atomic physics to the highest energy frontier
- Strong in transfer of technology, education and relevance to issues in wider society (information, health, climate, energy, …)

CERN's success is built on its personnel

Welcome, to join the adventure! *Bienvenu!*