The CERN Scientific Program

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: 23 Member States

~ 2600 staff
~ 1800 other paid personnel
~ 12500 scientific users

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

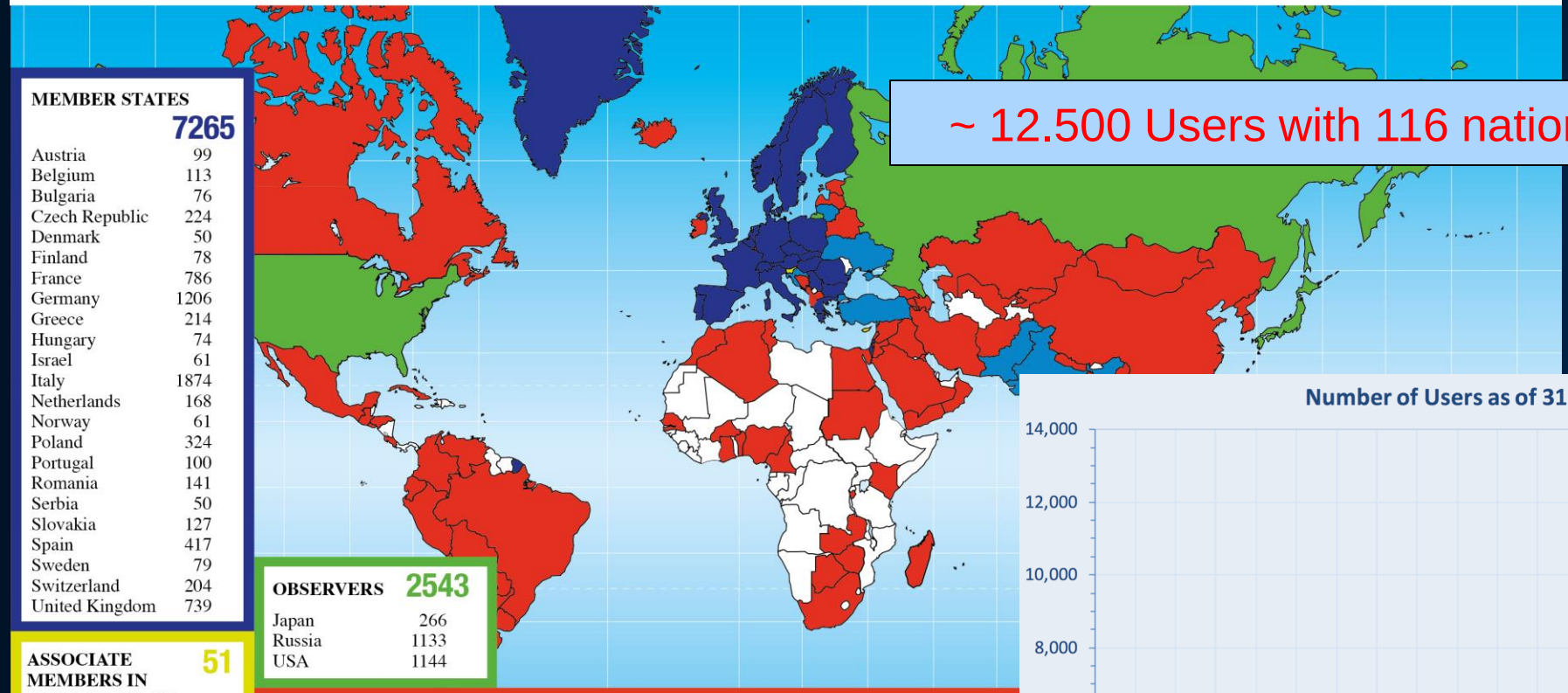
Associate Member: Cyprus, India, Lithuania, Pakistan, Slovenia, Turkey, Ukraine

Applicant States for Membership or Associate Membership:
Brazil, Croatia

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

CERN attracts scientists from all over the world

Distribution of All CERN Users by Nationality on 10 October 2019



~ 12.500 Users with 116 nationalities

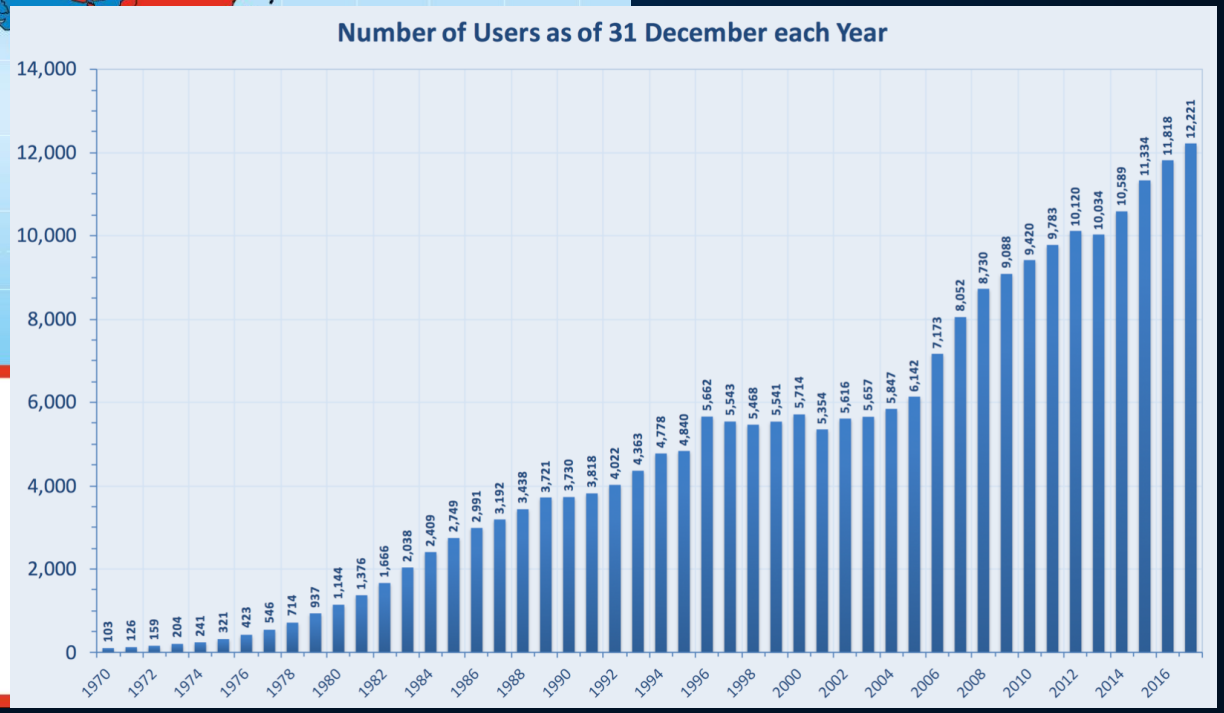
MEMBER STATES	7265
Austria	99
Belgium	113
Bulgaria	76
Czech Republic	224
Denmark	50
Finland	78
France	786
Germany	1206
Greece	214
Hungary	74
Israel	61
Italy	1874
Netherlands	168
Norway	61
Poland	324
Portugal	100
Romania	141
Serbia	50
Slovakia	127
Spain	417
Sweden	79
Switzerland	204
United Kingdom	739

OBSERVERS	2543
Japan	266
Russia	1133
USA	1144

ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP	51
Cyprus	22
Slovenia	29

ASSOCIATE MEMBERS	785
Croatia	44
India	374
Lithuania	33
Pakistan	65
Turkey	165
Ukraine	104

OTHERS							
Albania	4	Bolivia	2	Ecuador	11	Ireland	14
Algeria	11	Bosnia & Herzegovina	3	Egypt	26	Jordan	1
Argentina	22	Bostwana	1	El Salvador	1	Kazakhstan	10
Armenia	18	Brazil	123	Estonia	15	Kenya	1
Australia	29	Burkina Faso	1	Georgia	50	Korea	171
Azerbaijan	8	Burundi	1	Ghana	1	Kyrgyzstan	1
Bahrain	3	Cameroon	1	Guatemala	1	Latvia	4
Bangladesh	7	Canada	163	Hong Kong	1	Lebanon	27
Belarus	49	Chile	19	Honduras	1	Lesotho	1
Benin	1	China	575	Iceland	4	Luxembourg	4
		Colombia	39	Indonesia	10	Madagascar	1
		Costa Rica	1	Iran	47	Malaysia	23
		Cuba	16	Iraq	1	Malta	5



The mission of CERN

- **Push back** the frontiers of knowledge

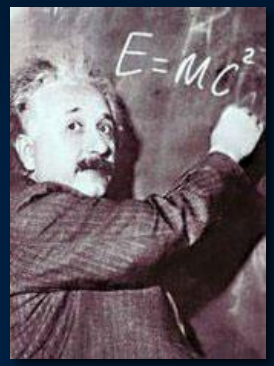
  Studying the structure of matter on the smallest distances/highest energies… what was the matter like in the first moments of the Universe's existence?

- **Develop** new technologies for accelerators and detectors

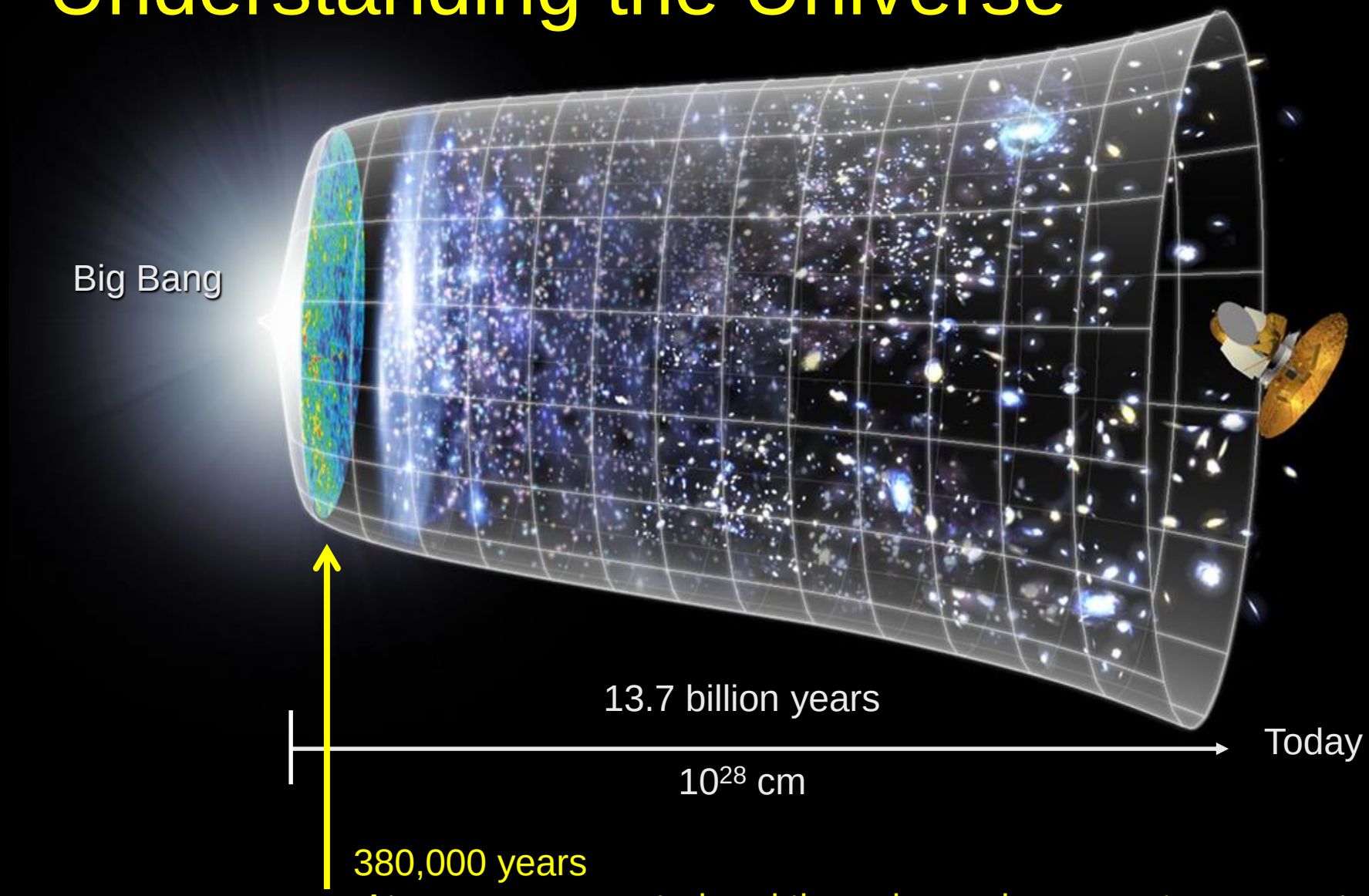
  Benefits for society: e.g. accelerator technology, detectors for medicine, the WWW and the GRID

- **Train** scientists and engineers of tomorrow

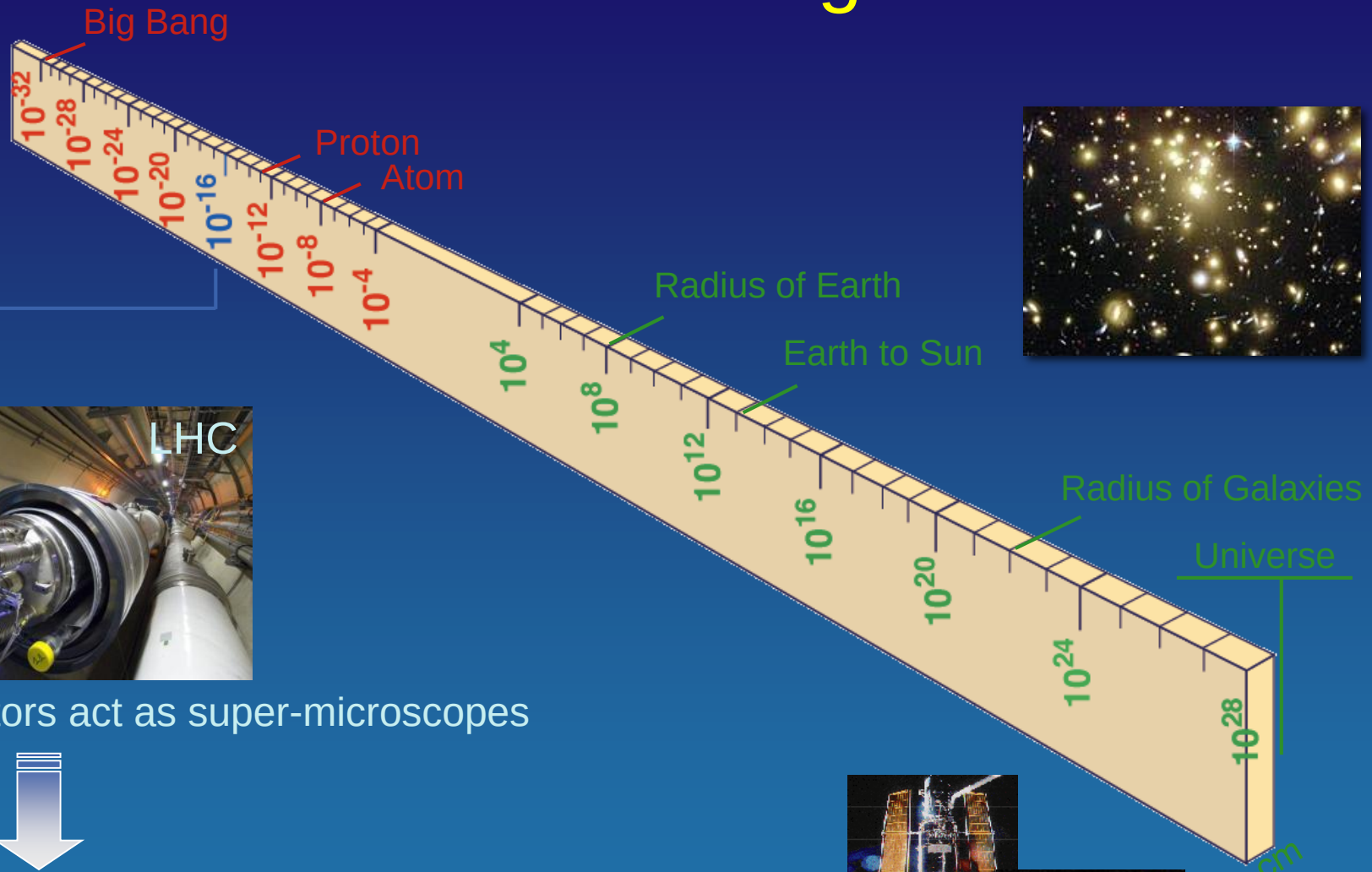
- **Unite** people from different countries and cultures



Physics at CERN: Understanding the Universe



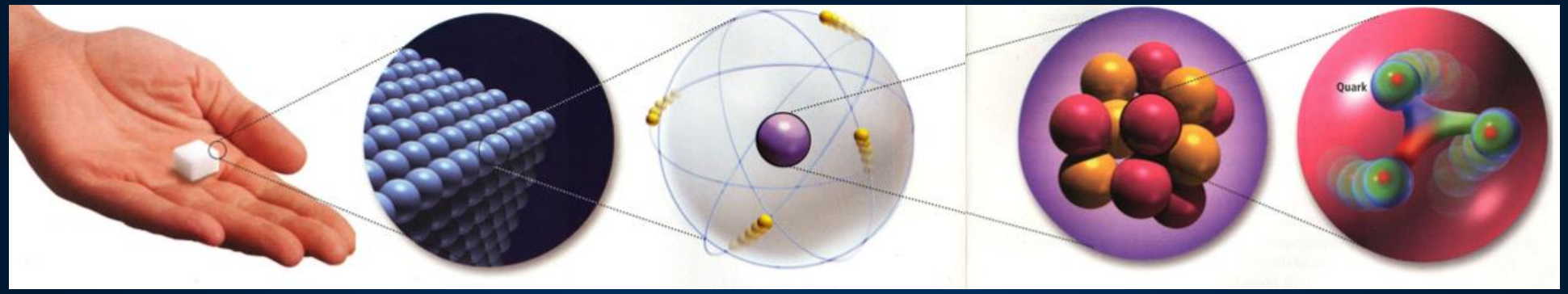
From the smallest to the largest Structures



Accelerators act as super-microscopes

Study laws of physics at first moments after Big Bang
Increasing symbiosis between Particle Physics,
Astrophysics and Cosmology

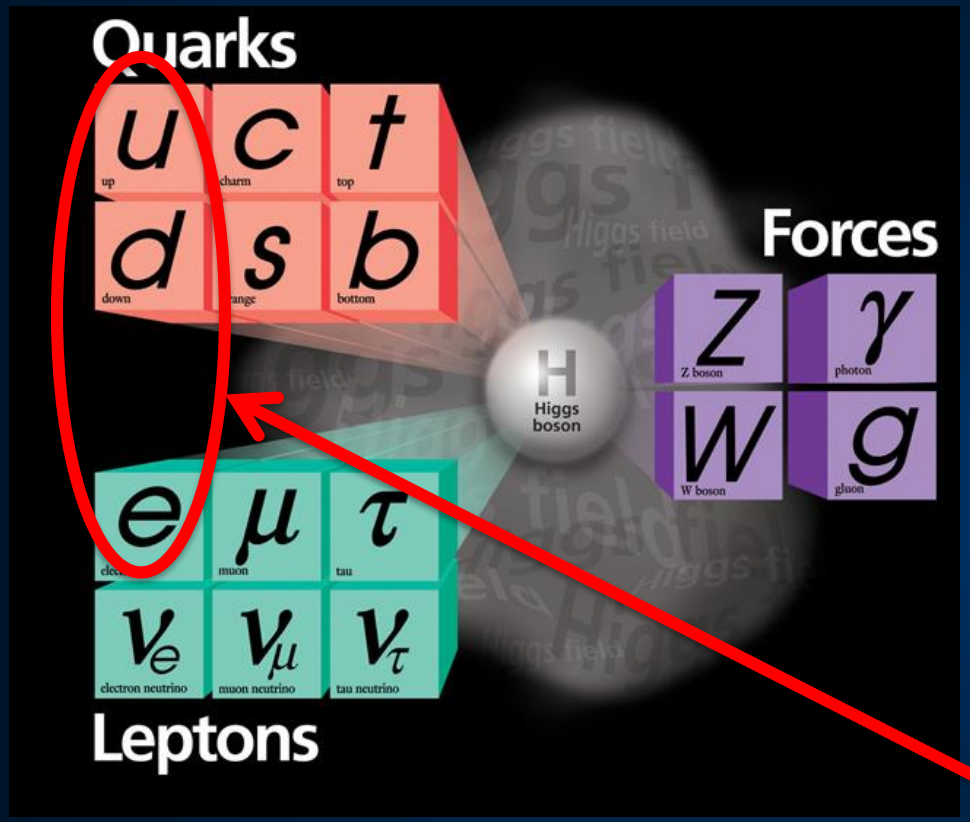
Composition of Matter



- 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

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 (spin 0), gives mass to particles

Sufficient to explain the matter around us

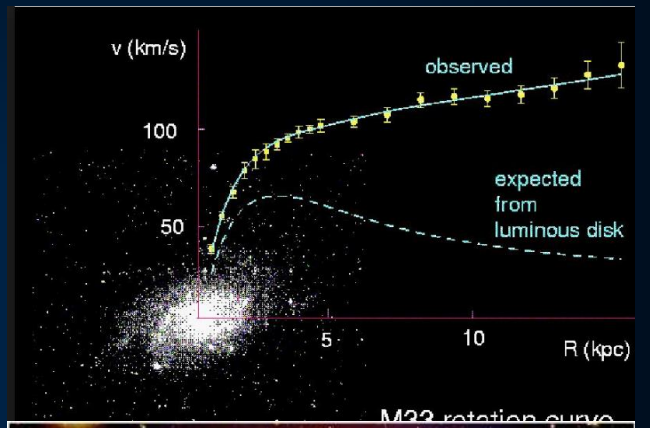
Plus antimatter partners of each particle.

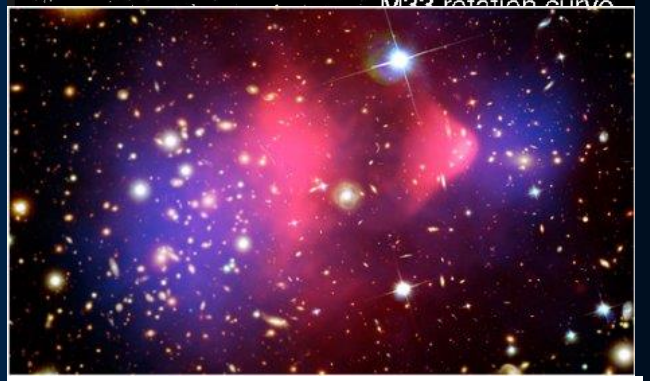
What is missing?

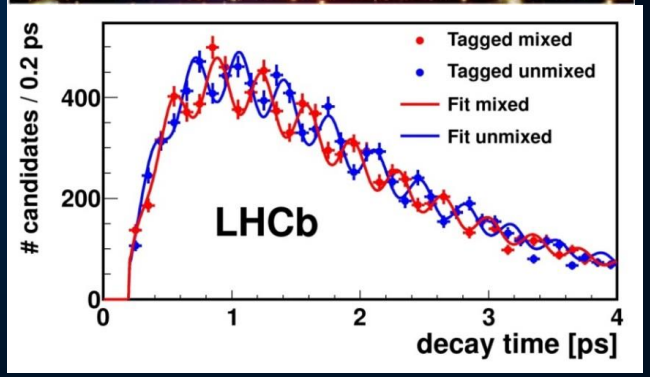
Several observations and mysteries point to the fact that the Standard Model is not the final theory:

- 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!



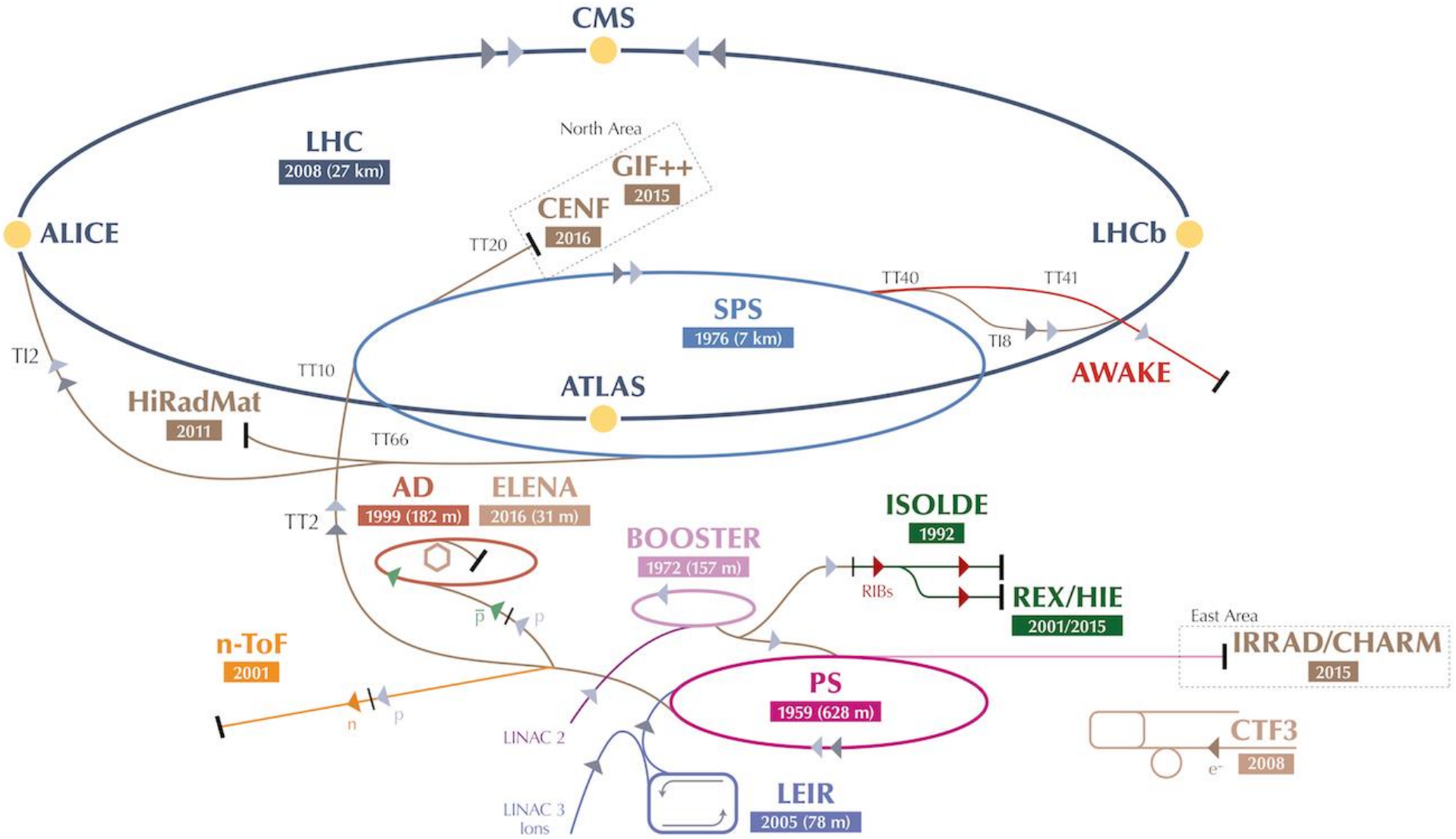




Research in Particle Physics needs:

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

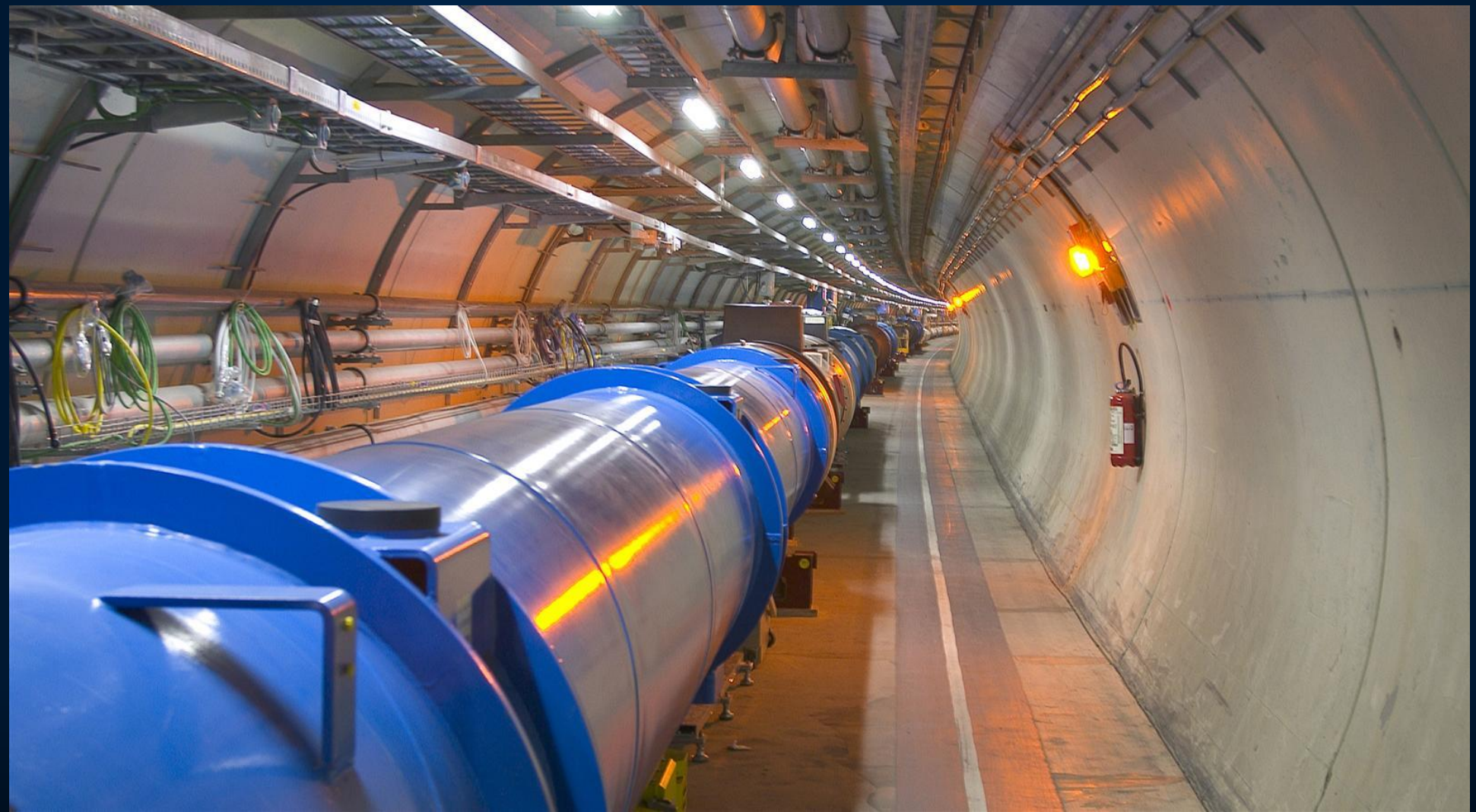
CERN Accelerators



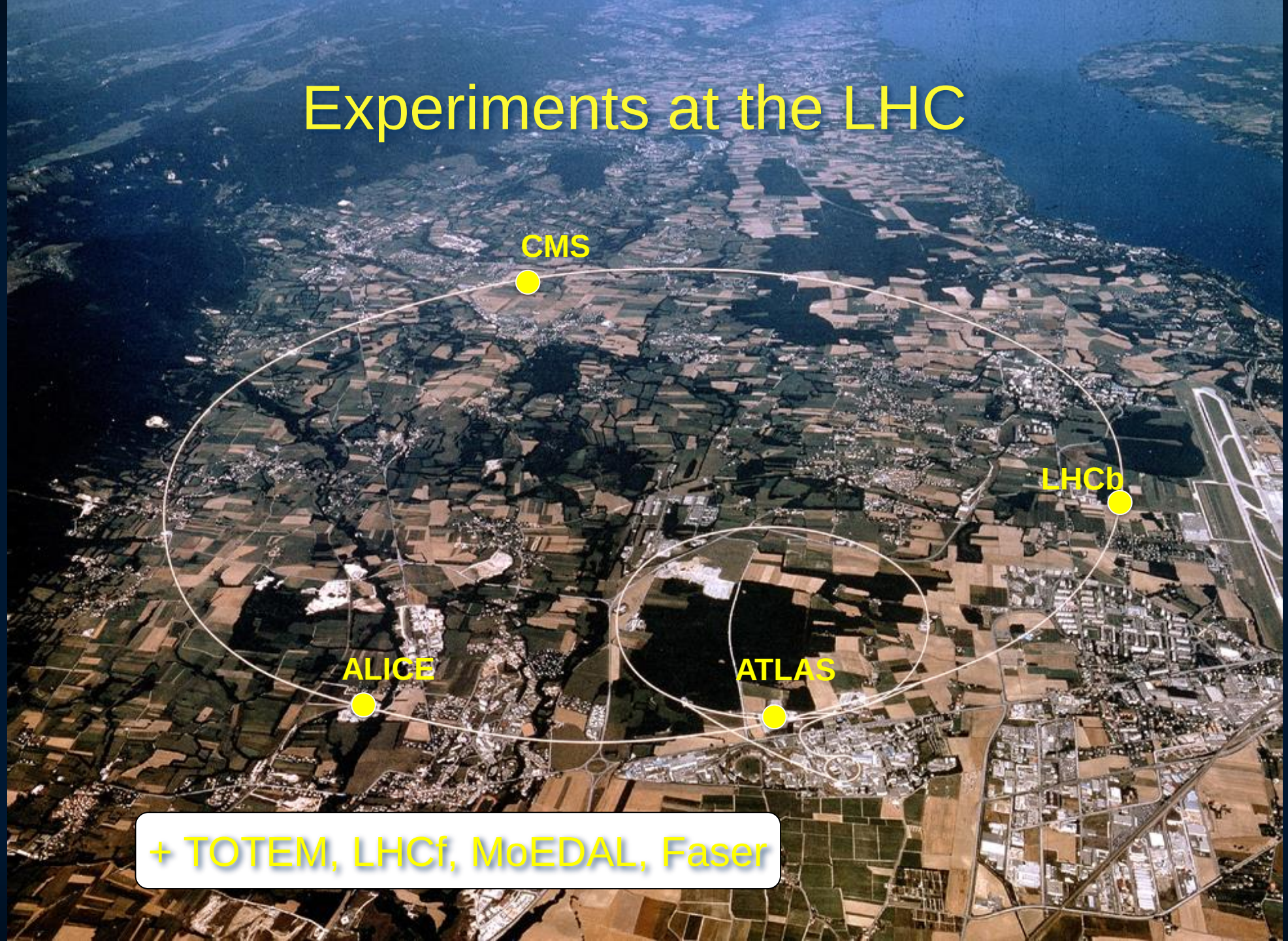
The Large Hadron Collider

Search for the Higgs Boson, study Standard Model particles and search for physics beyond the Standard Model

Exploration of a new energy frontier in p-p and Pb-Pb collisions



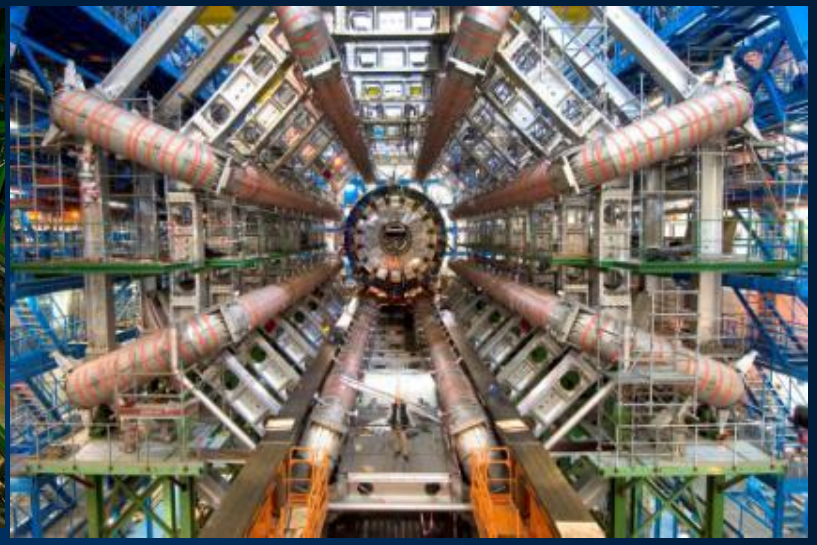
Experiments at the LHC



Experiments at the LHC

Four major experiments

CMS



ATLAS

ALICE

Dedicated to heavy ion physics
~ 1 month/year
Pb-Pb collisions

LHCb

Dedicated to flavour physics (b and c quarks)

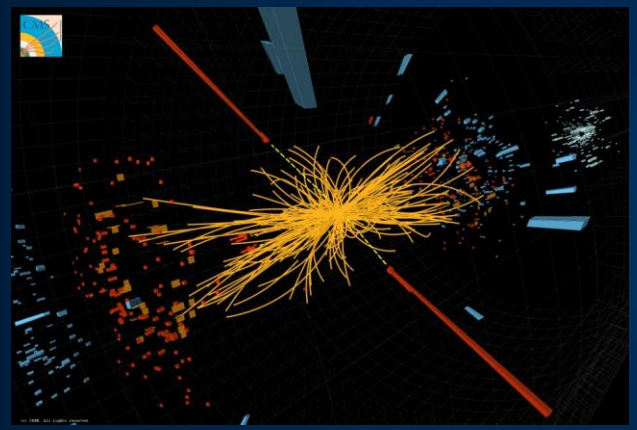
Experiments at the LHC

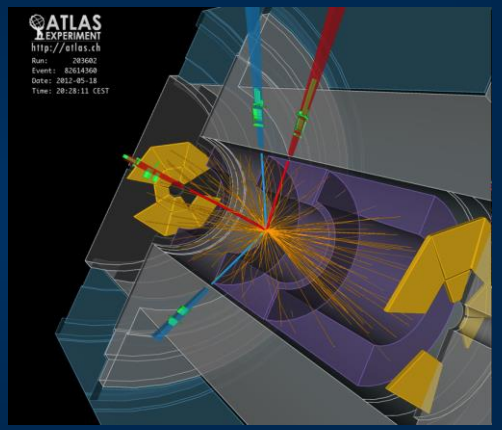
Brilliant performance of the LHC, the experiments and the Grid computing:
Run1 2011-2012: E_{cm} = 7– 8 TeV Run2 2015-2018: E_{cm} = 13 TeV

Preparing for Run3 2022-2024: E_{cm} = 13 -14 TeV (to be determined)

LHC operation approved until 2037

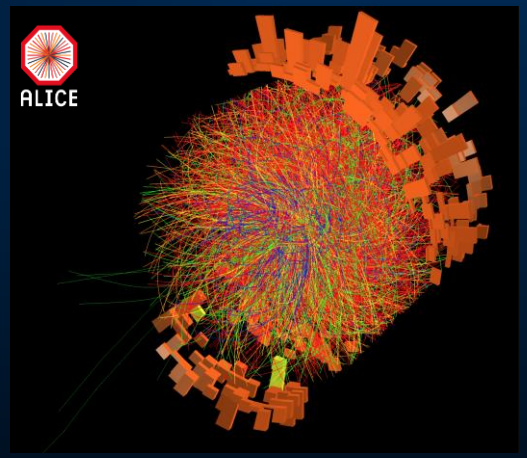
CMS

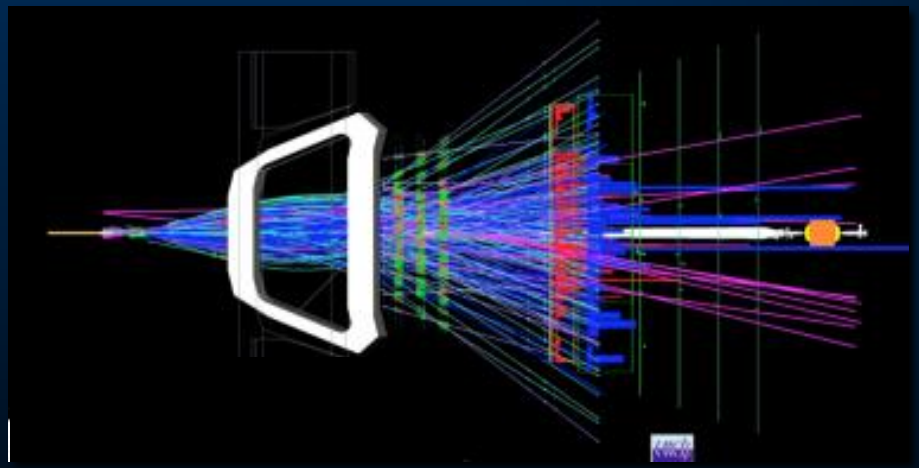




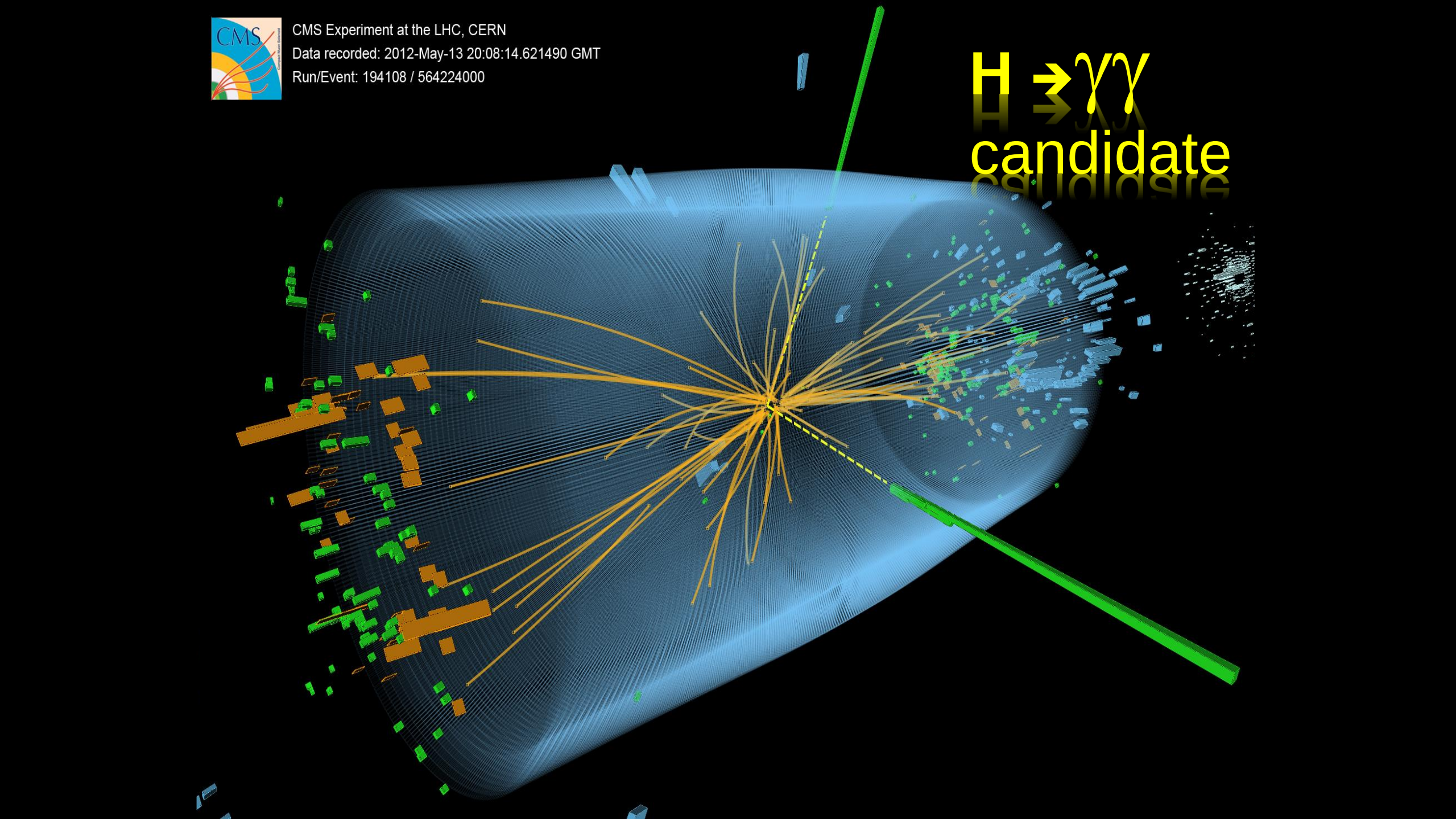
ATLAS

ALICE

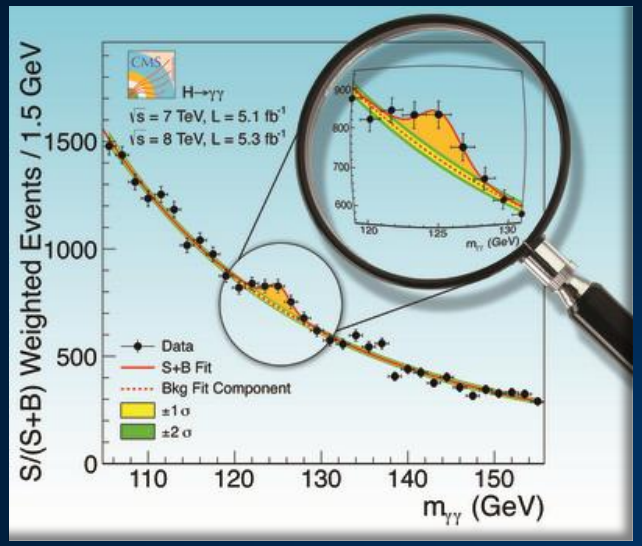


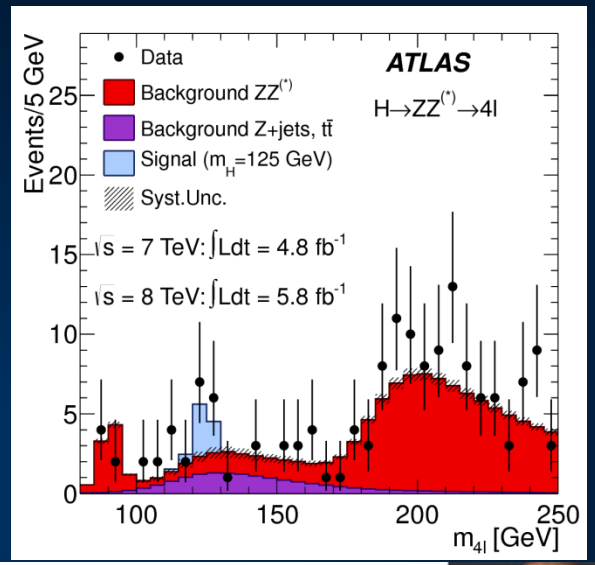


LHCb


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

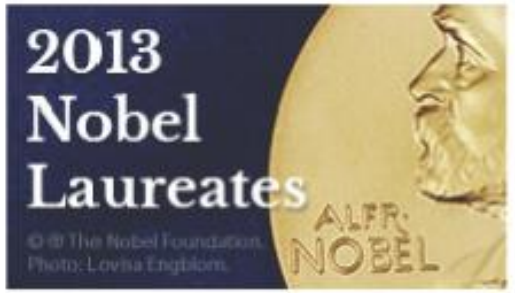
The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental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

Photos

To cite

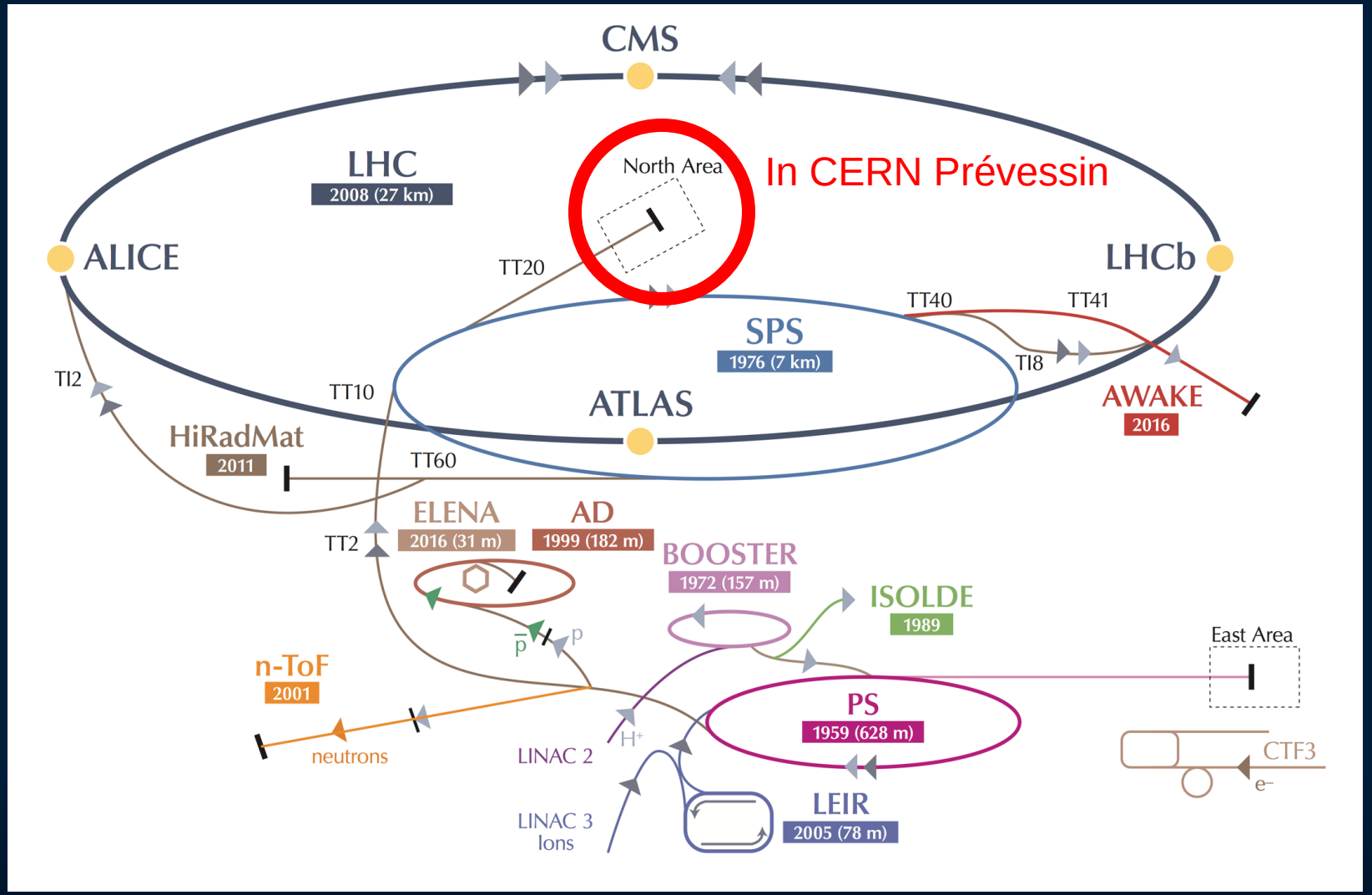
MLA st

Web. 1



CERN is not only the LHC !

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 - 400 GeV range) allow precision measurements and comparison with theory
Deviations can be sign of new physics at higher energies

Super Proton Synchrotron (1976)
Protons up to 400 GeV, max. 9.5×10^9 p per bunch

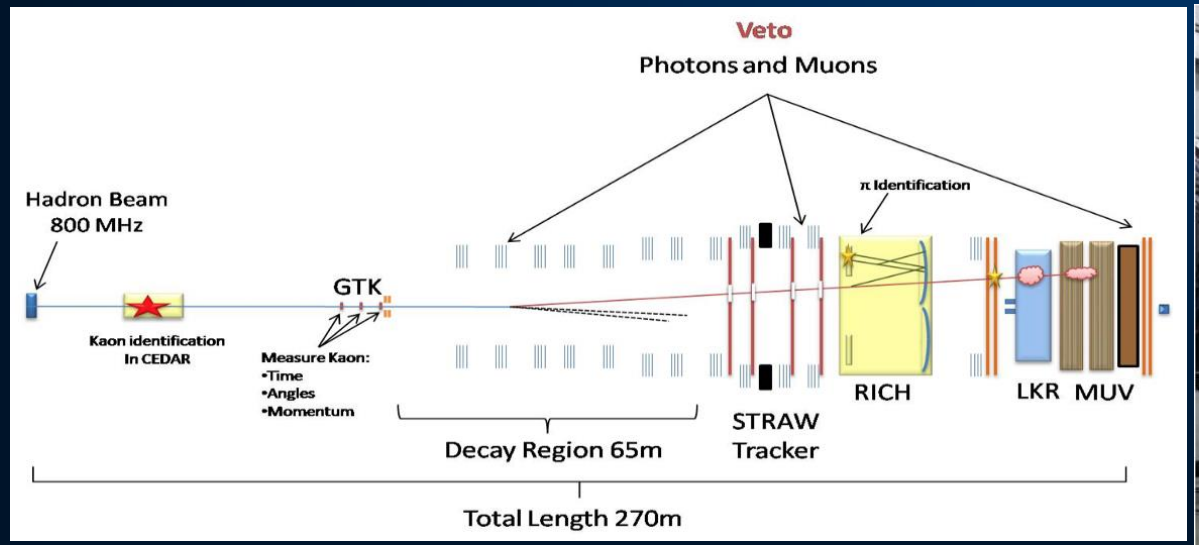
COMPASS in North Hall (60 m long)

Fixed Target Physics

6 approved experiments:

- NA58 (COMPASS): muon spin physics, hadron spectroscopy
- NA61 (SHINE): strong interaction, quark gluon plasma, neutrino and cosmic ray program
- 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
- NA65 (DsTau): study of ν_τ production

Example NA62:



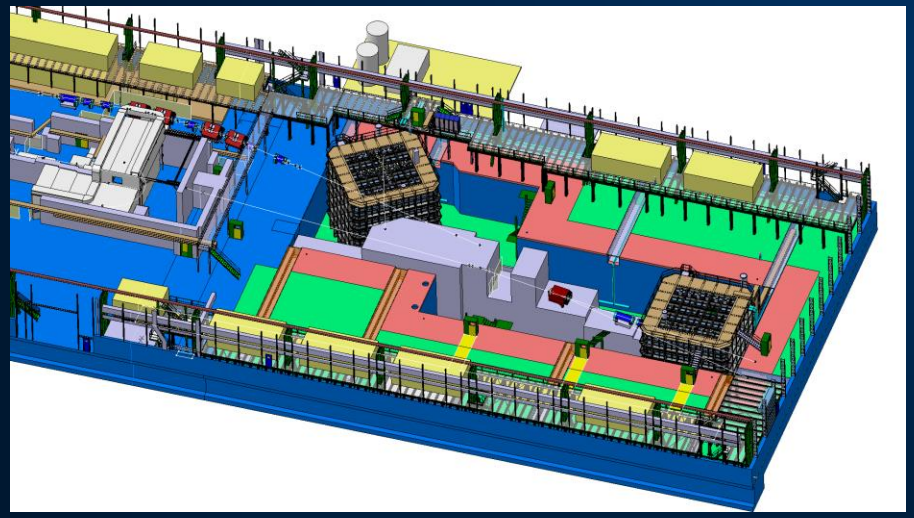
Neutrino Platform (new extension of North Area)

Like quarks, neutrinos exist in different flavors ν_e ν_μ ν_τ

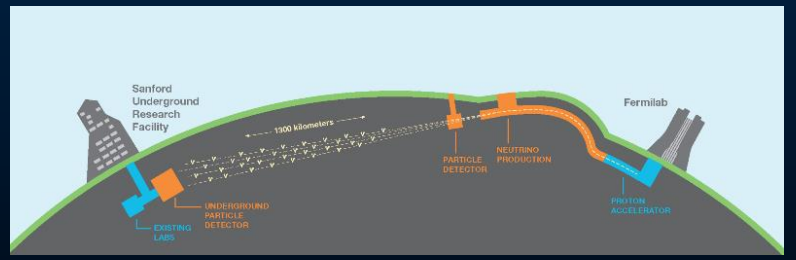
but their flavour oscillates $\nu_\mu \Leftrightarrow \nu_\tau$ $\nu_\mu \Leftrightarrow \nu_e$

Has been studied with ν_μ beam sent from CERN to Gran Sasso in Italy (CNGS).

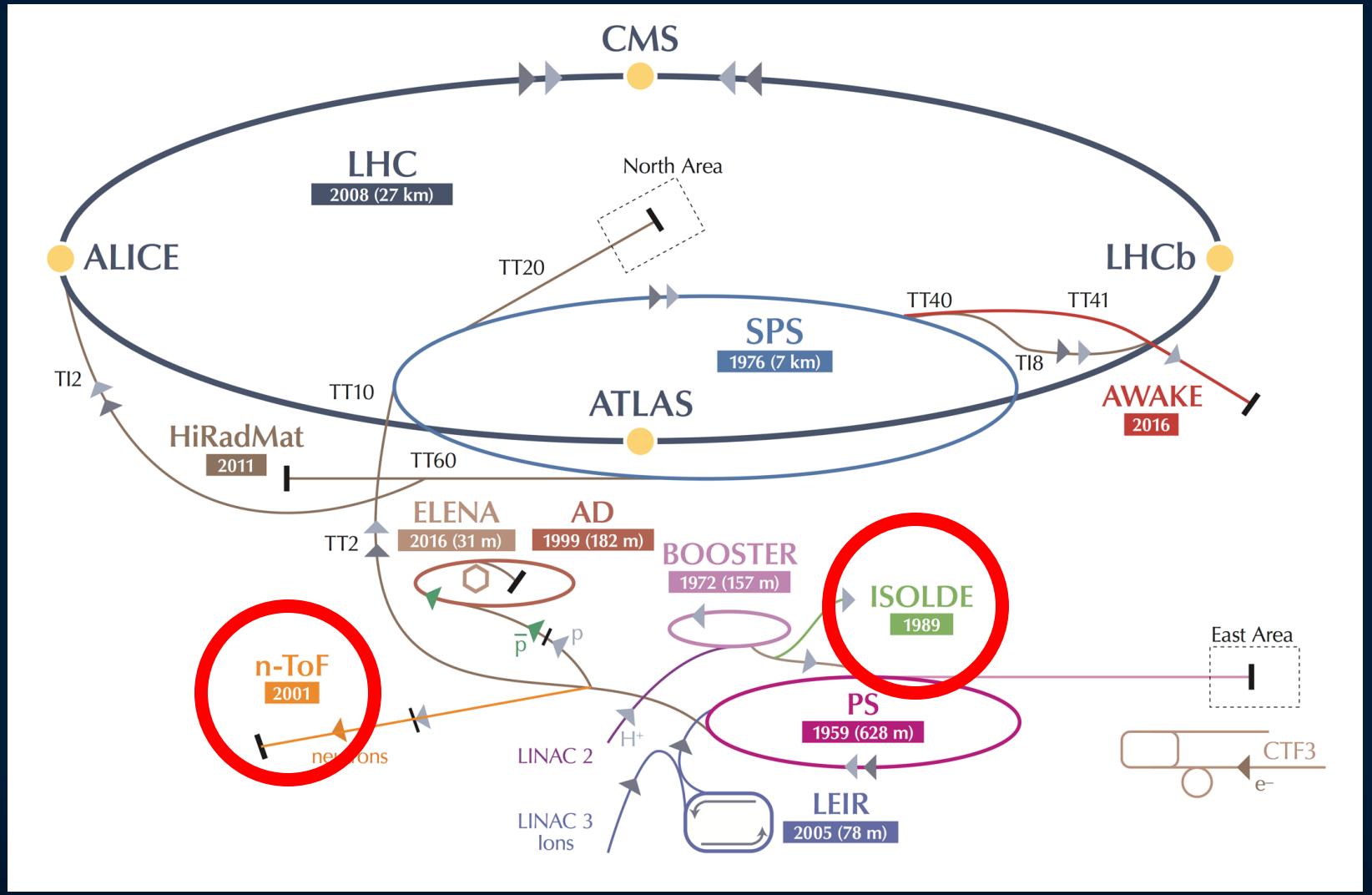
Neutrino platform as a test area with charged beams for neutrino detectors (e.g. R&D for large liquid argon detectors). The experiments will take place in the US and Japan.



LBNF/DUNE in the US:



ISOLDE and nTOF



Nuclear Physics: ISOLDE & nTOF

ISOLDE: radioactive ion beams

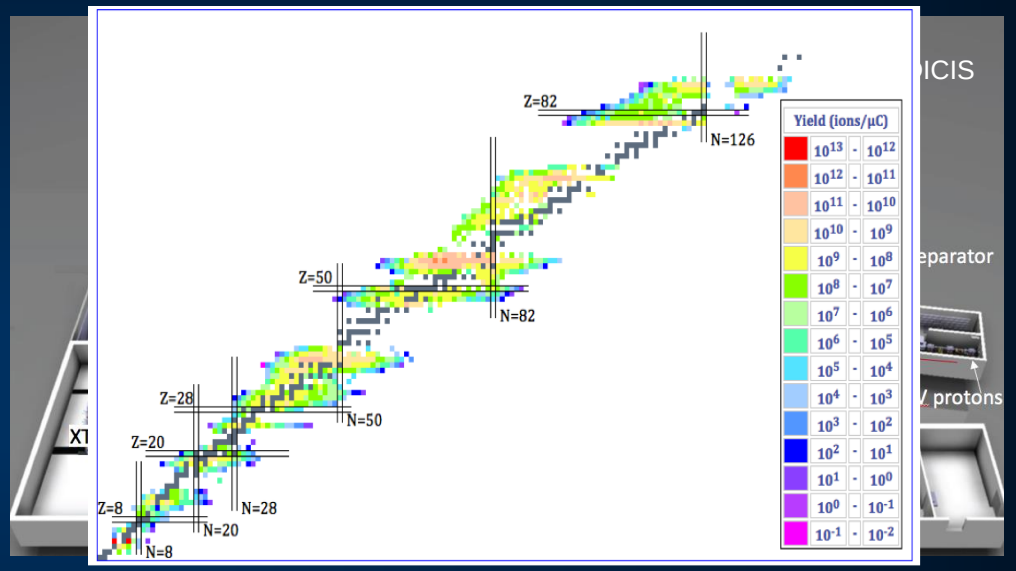
1000 nuclides of over 75 elements produced, about 50 experiments every year

- *Nuclear physics*
- *Fundamental interactions*
- *Nuclear Astrophysics*
- *Applications (Medicine, Material Science)*

Over 20 Target materials:
carbides, oxides, solid metals, molten metals and molten salts (U, Ta, Zr, Y, Ti, Si, …)

3 types of ion sources: surface, plasma, laser

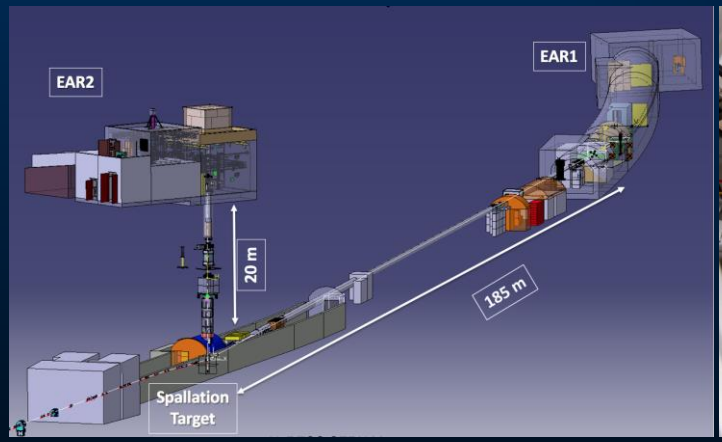
HIE-ISOLDE (post acceleration up to 10 MeV/nucleon)



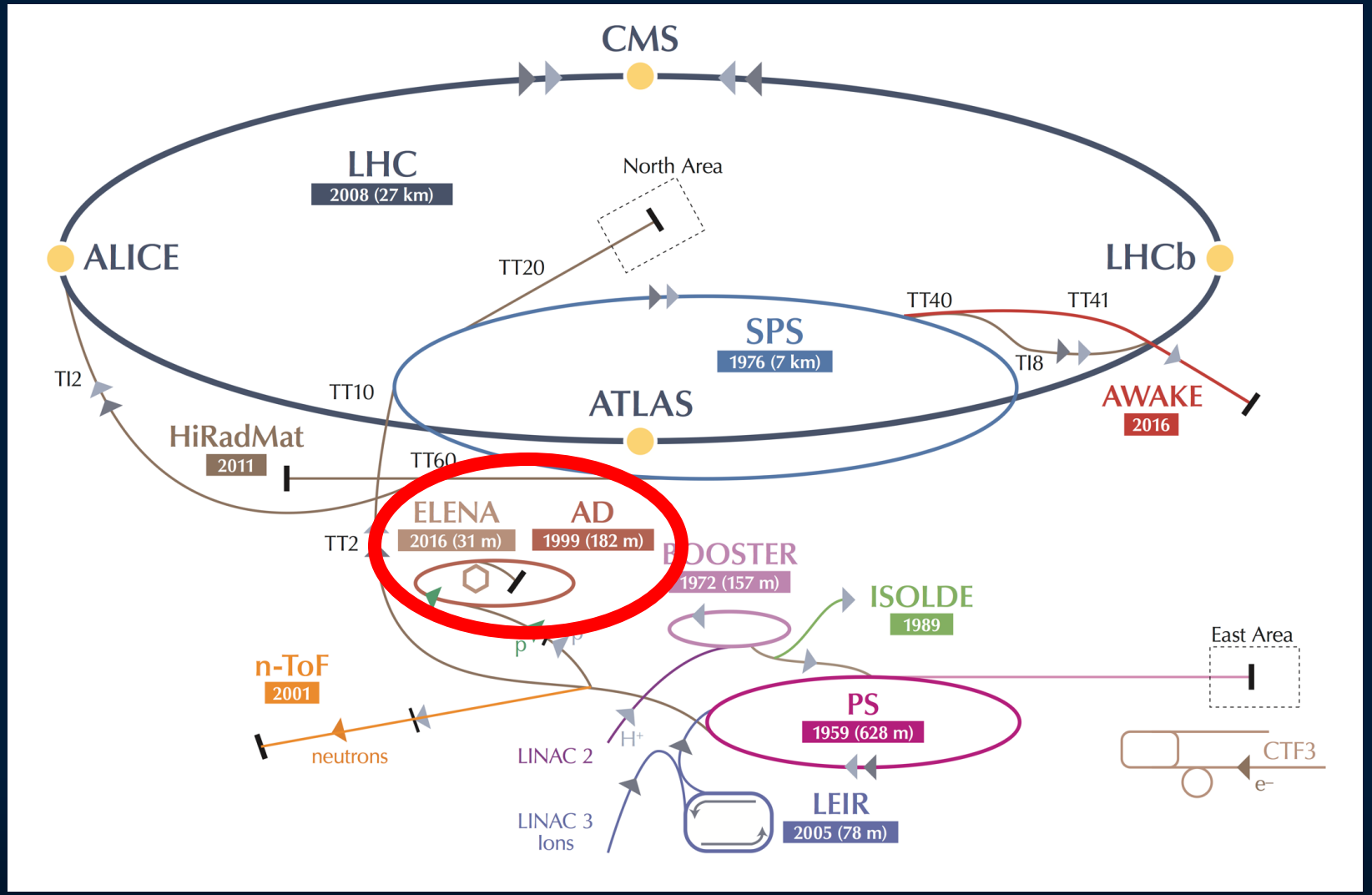
nTOF (neutron time-of-flight)

Neutron cross-section measurements

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



Antiproton & Antihydrogen Physics

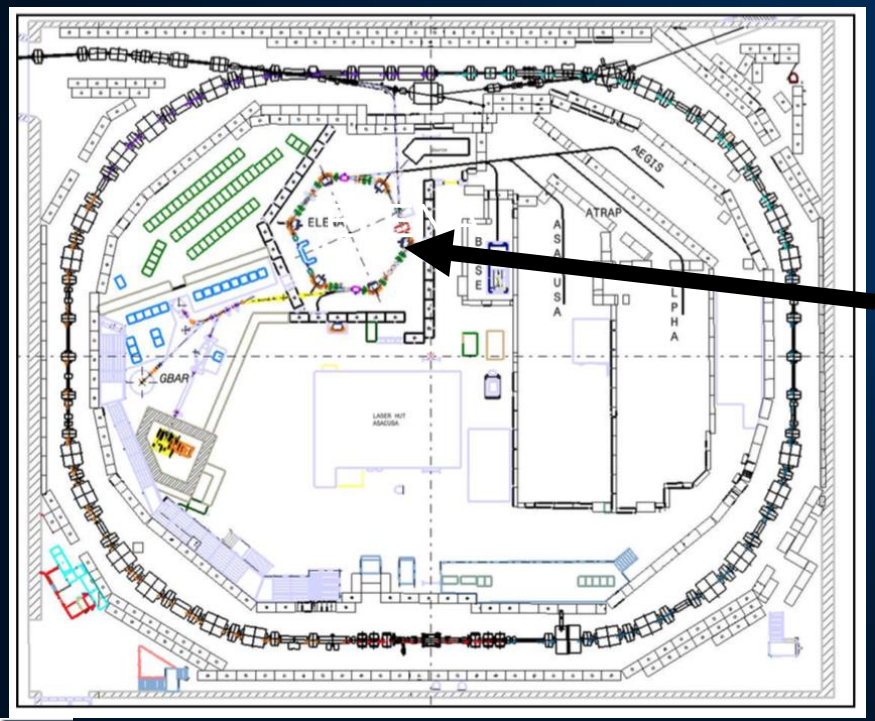


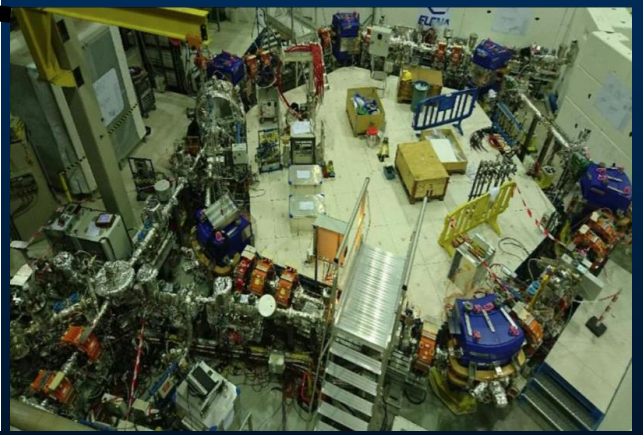
Antiproton & Antihydrogen Physics

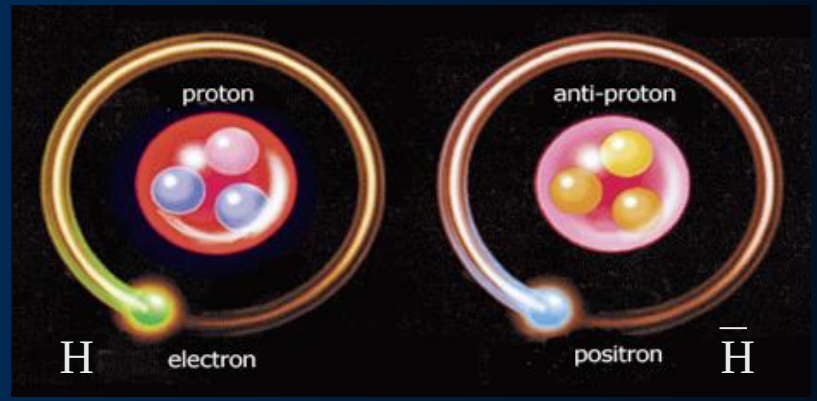
Matter-Antimatter comparison

- Test CPT invariance, the most fundamental Symmetry in relativistic quantum field theory
- Test of the Weak Equivalence Principle by measuring the gravitational behavior of antimatter
- Measurements of “antihydrogen”-like systems: antiprotonic helium, positronium, protonium

The Antiproton Decelerator (AD): antiprotons at 5.3 MeV







In commissioning ELENA
Extra Low Energy Antiprotons
at 100 keV
→10-100 x larger trapping efficiency
→ Parallel running of experiments

Antiproton & Antihydrogen Physics

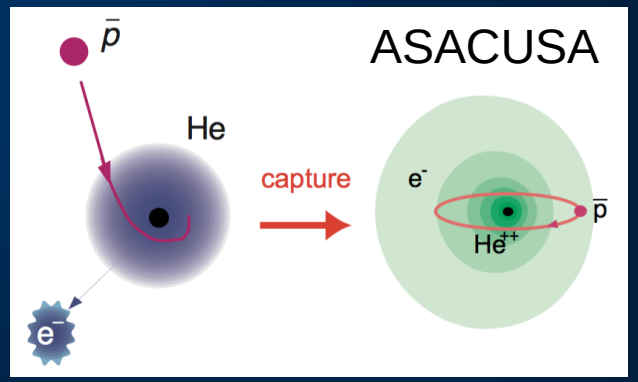
Matter-Antimatter comparison

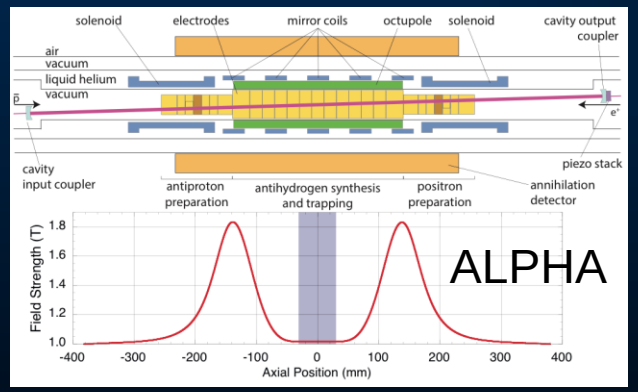
Fundamental in the current theory of physics: $m = \bar{m}$, $g = \bar{g}$

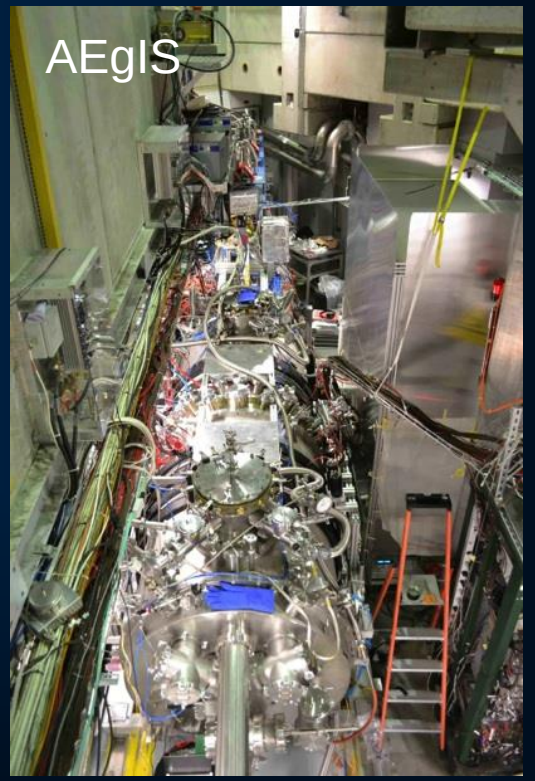
5 experiments:

- **ASACUSA** spectroscopy of exotic atoms (antiprotonic Helium), and nuclear collision cross section
- **BASE** magnetic moment of the antiproton
- **ALPHA/ALPHA-g** spectroscopy and gravity
- **AEgIS** spectroscopy, antimatter gravity experiment
- **GBAR** antimatter gravity experiment

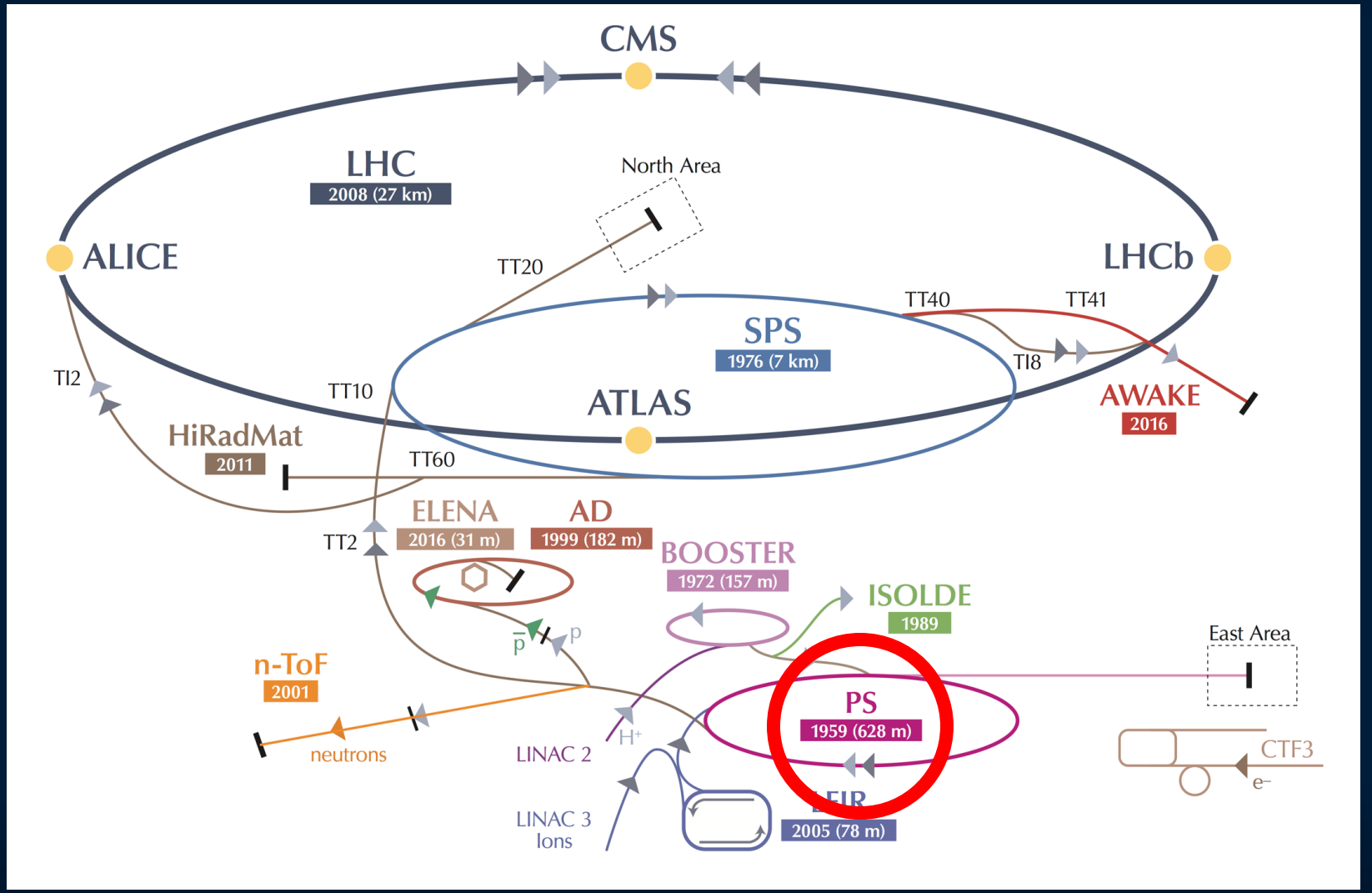
New experiments under discussion







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
2005 (78 m)
CTF3

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.

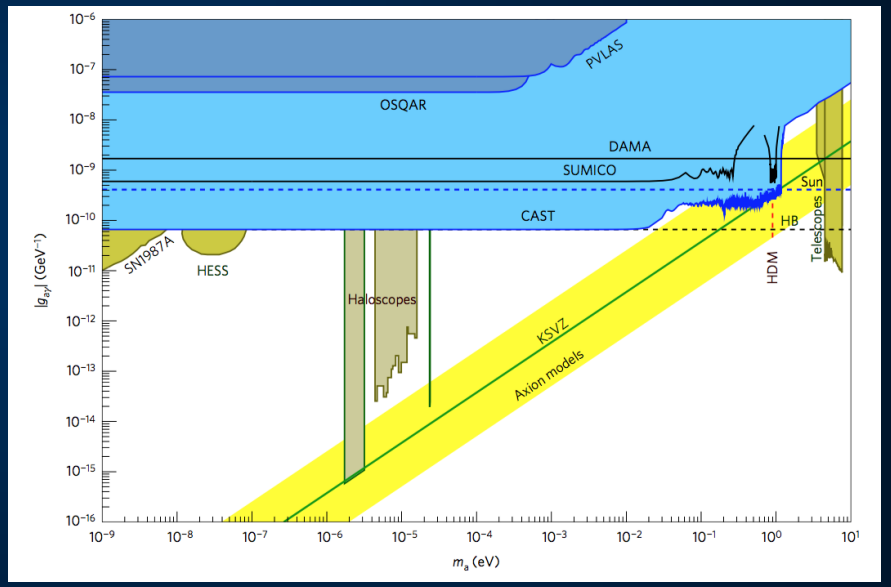
Non Accelerator Experiments

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:

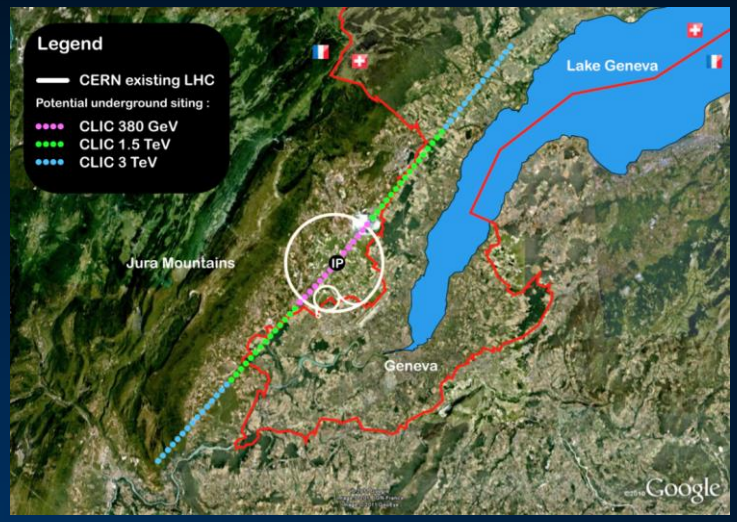
- CLIC – Compact Linear Collider
  Study of the design for a possible
  future e^+e^- linear collider up to 3 TeV

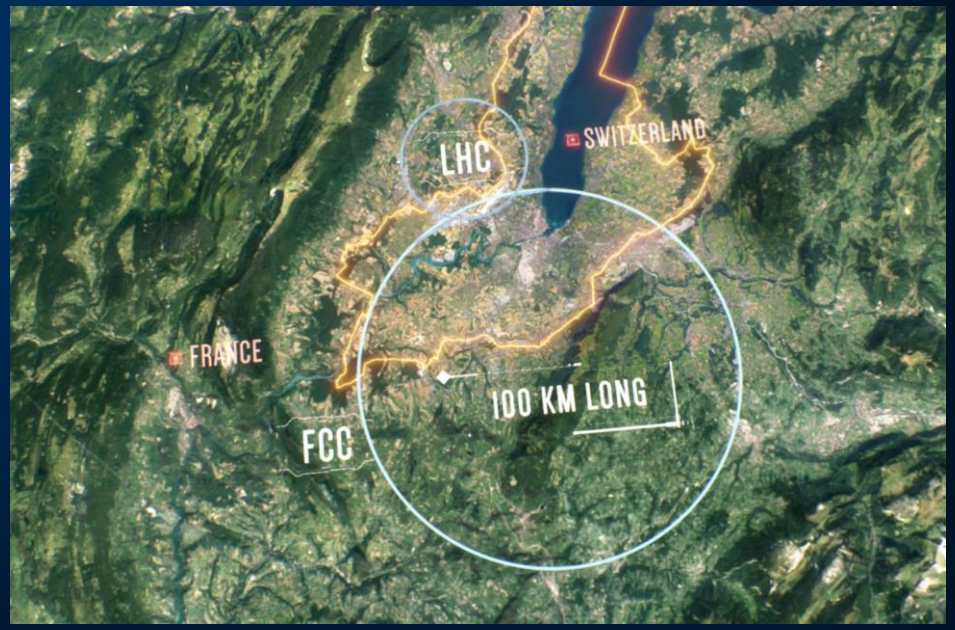
- FCC – Future Circular Collider
  Study of a 100 km circumference machine
  for pp collisions at 100 TeV, as well as e^+e^-

- Physics beyond Colliders
  Study to explore possibilities using the non-collider
  part of the CERN accelerator complex

Direction will be given by the Update of the European Strategy for Particle Physics.

Expected by CERN Council during June 2020 Session.





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!*

Thank you for your attention !