

# 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:** Croatia, Cyprus, India, Lithuania, Pakistan, Slovenia, Turkey, Ukraine

**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

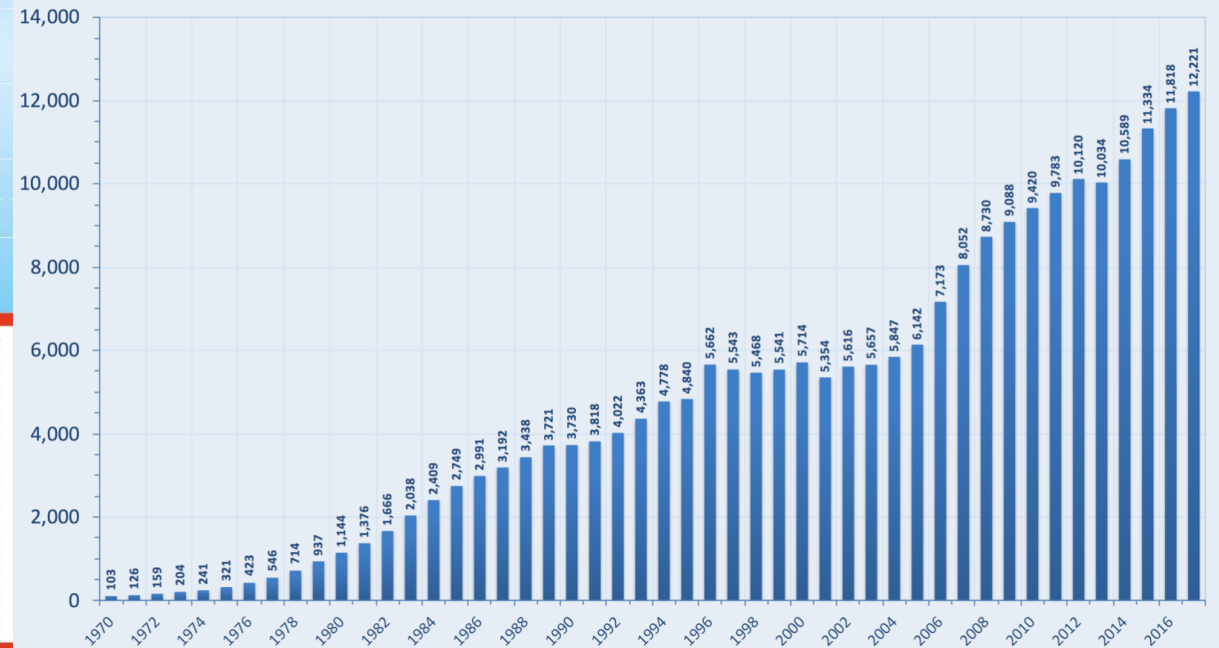
**785**

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

### OTHERS

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

Number of Users as of 31 December each Year

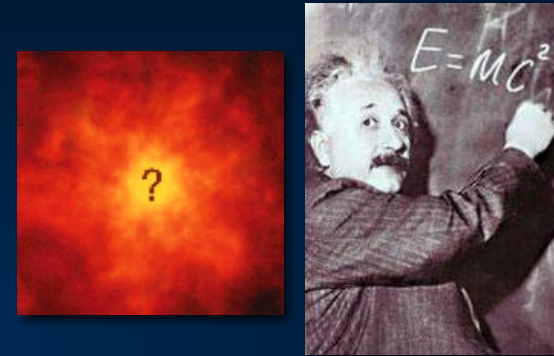




# The mission of CERN

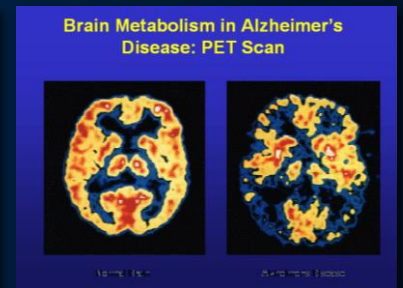
- ❑ **Push back** the frontiers of knowledge

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



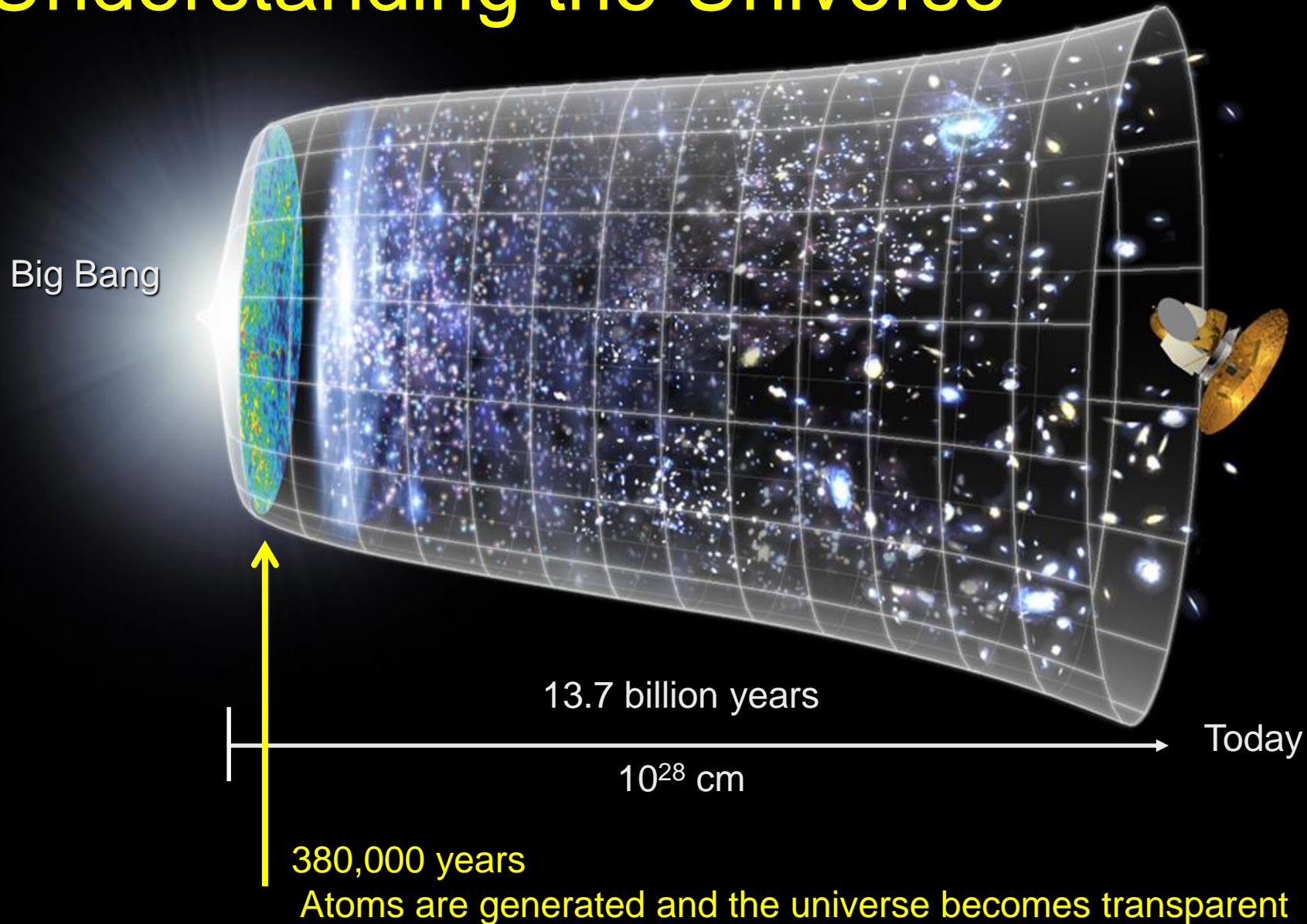
- ❑ **Train** scientists and engineers of tomorrow



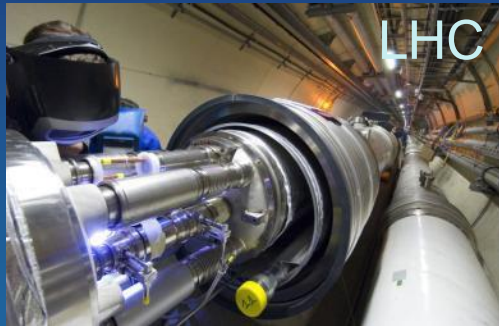
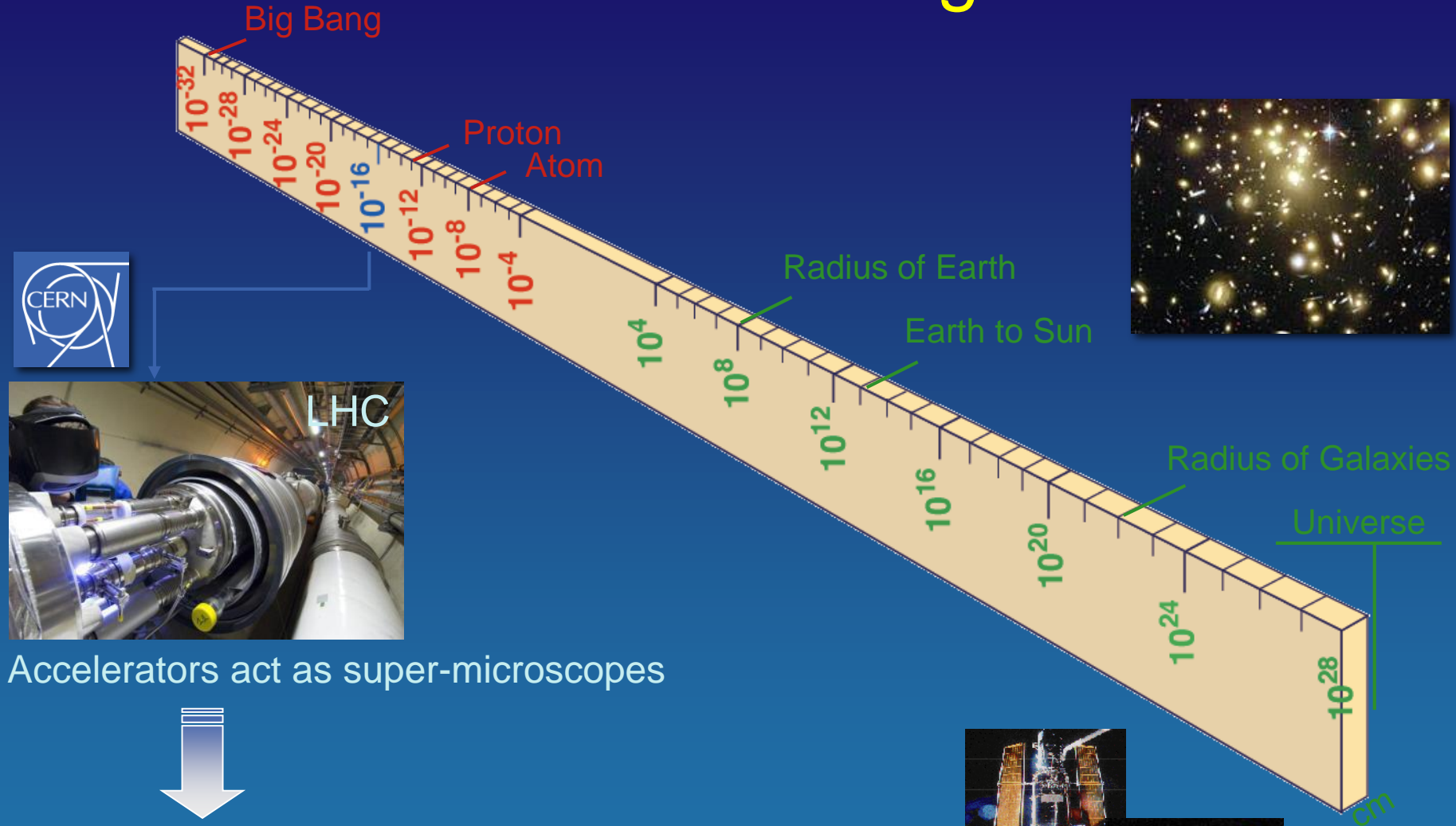
- ❑ **Unite** people from different countries and cultures



# Physics at CERN: Understanding the Universe



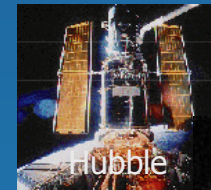
# From the smallest to the largest Structures



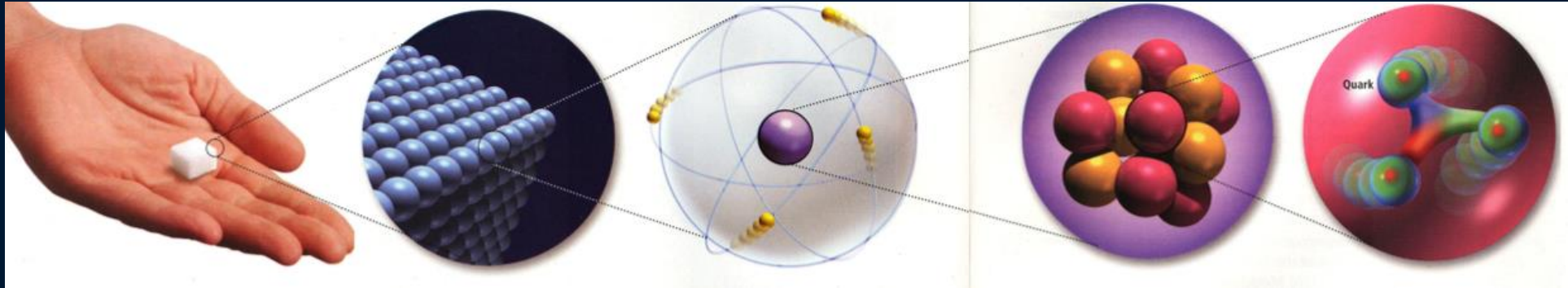
Accelerators act as super-microscopes



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



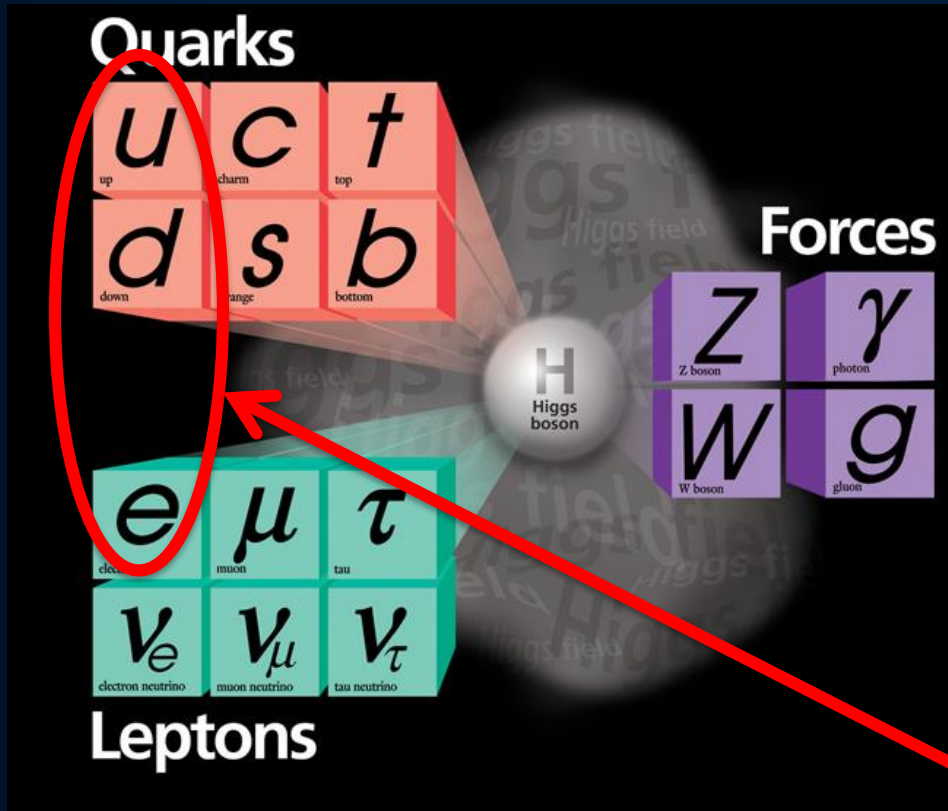
# Composition of Matter



- 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  $\frac{1}{2}$ ) 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.

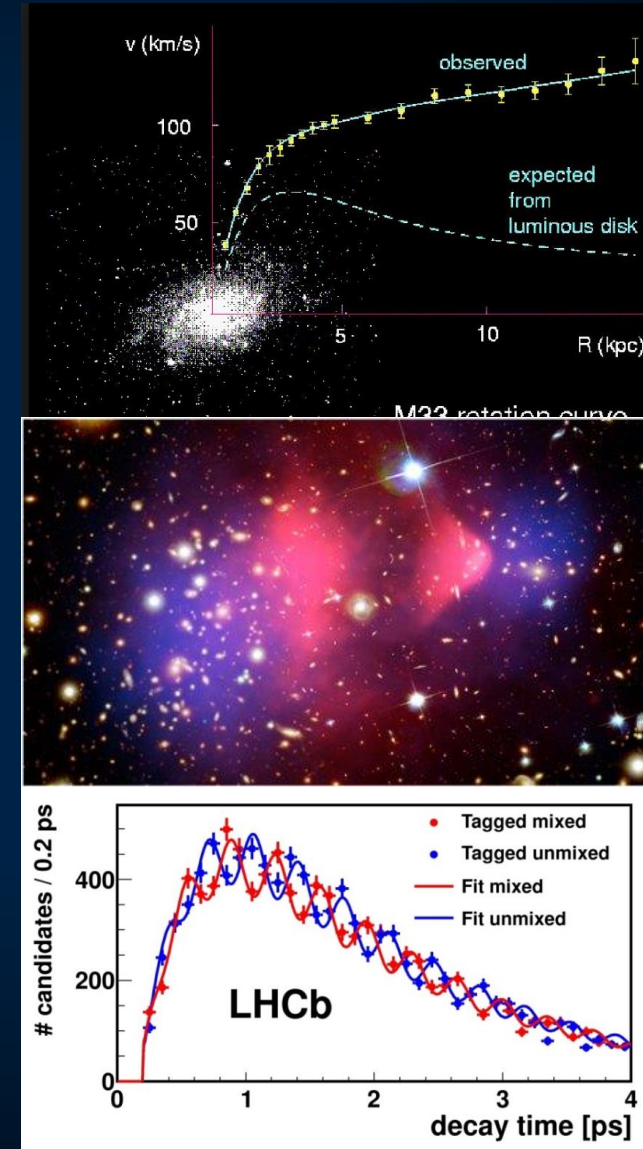


# What is missing?

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.

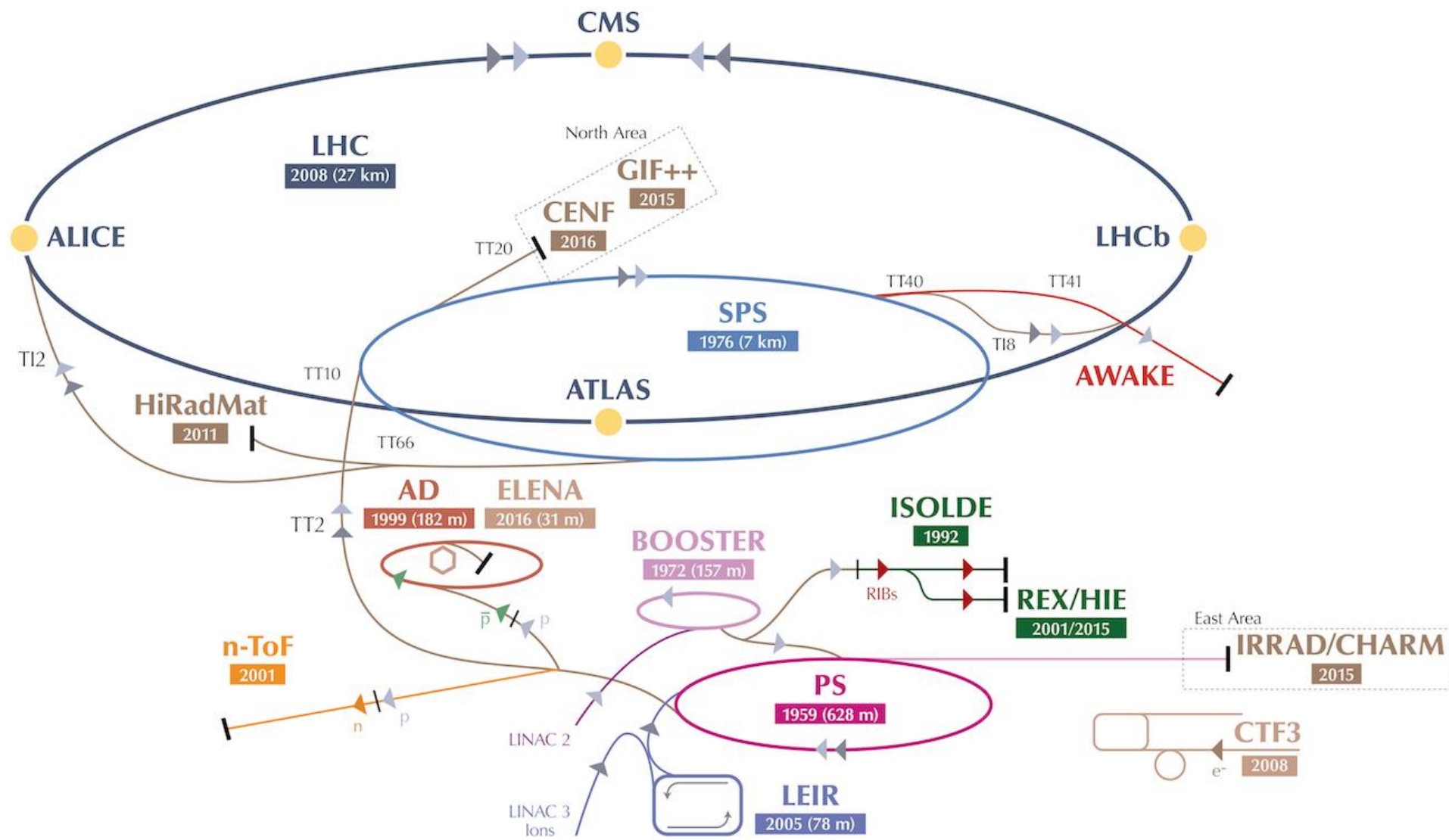
Still a lot to explore, to measure and to collect Nobel prizes!



# 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

CMS

LHCb

ALICE

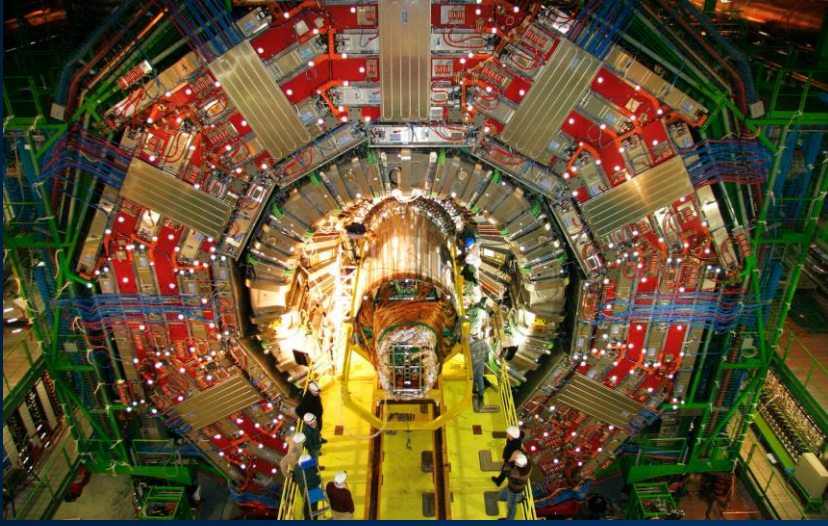
ATLAS

+ TOTEM, LHCf, MoEDAL, Faser

# Experiments at the LHC

Four major experiments

CMS



ATLAS



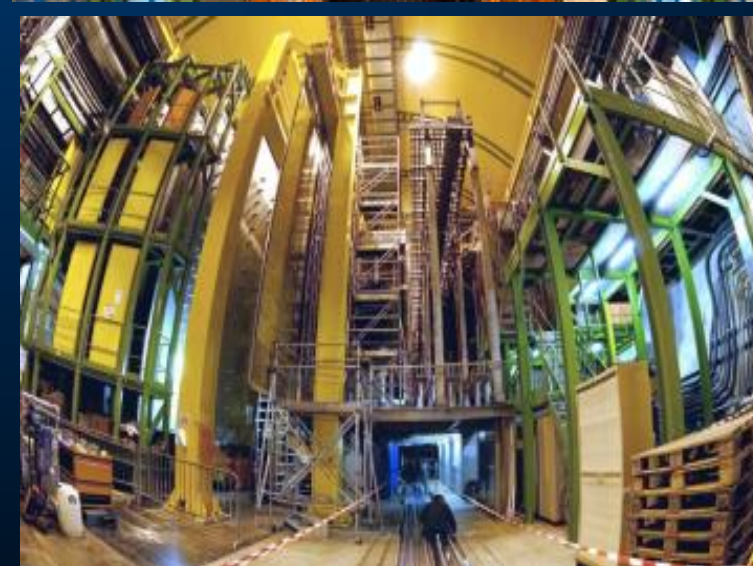
ALICE

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



LHCb

Dedicated to flavour physics (b and c quarks)



# Experiments at the LHC

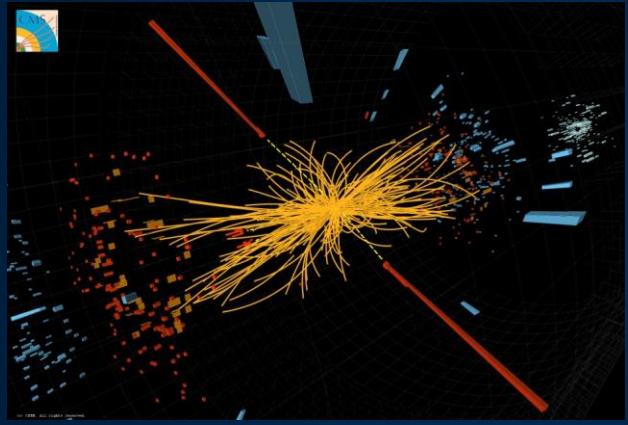
Brilliant performance of the LHC, the experiments and the Grid computing:

Run1 2011-2012:  $E_{cm} = 7-8$  TeV      Run2 2015-2018:  $E_{cm} = 13$  TeV

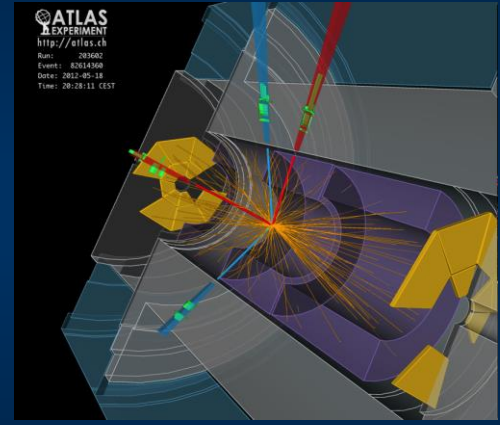
Preparing for Run3 2022-2024:  $E_{cm} = 13-14$  TeV (to be determined)

LHC operation approved until 2037

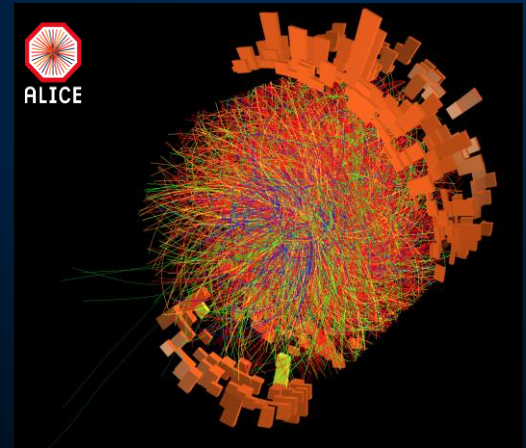
CMS



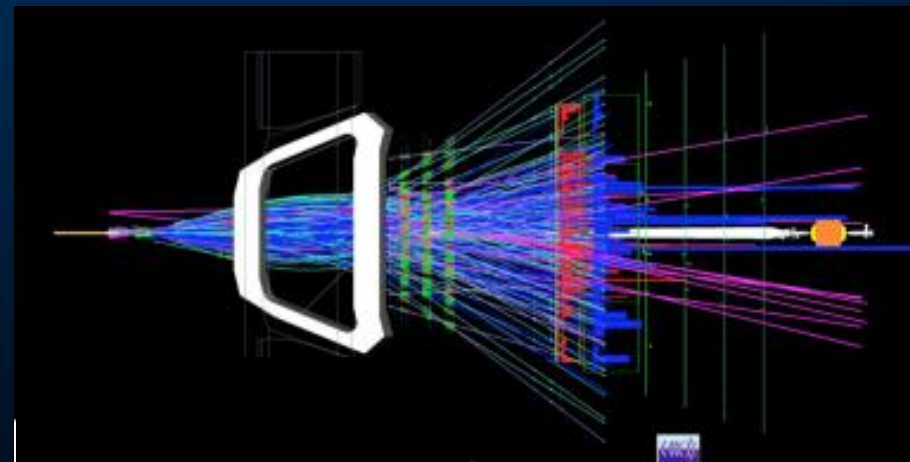
ATLAS

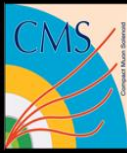


ALICE



LHCb



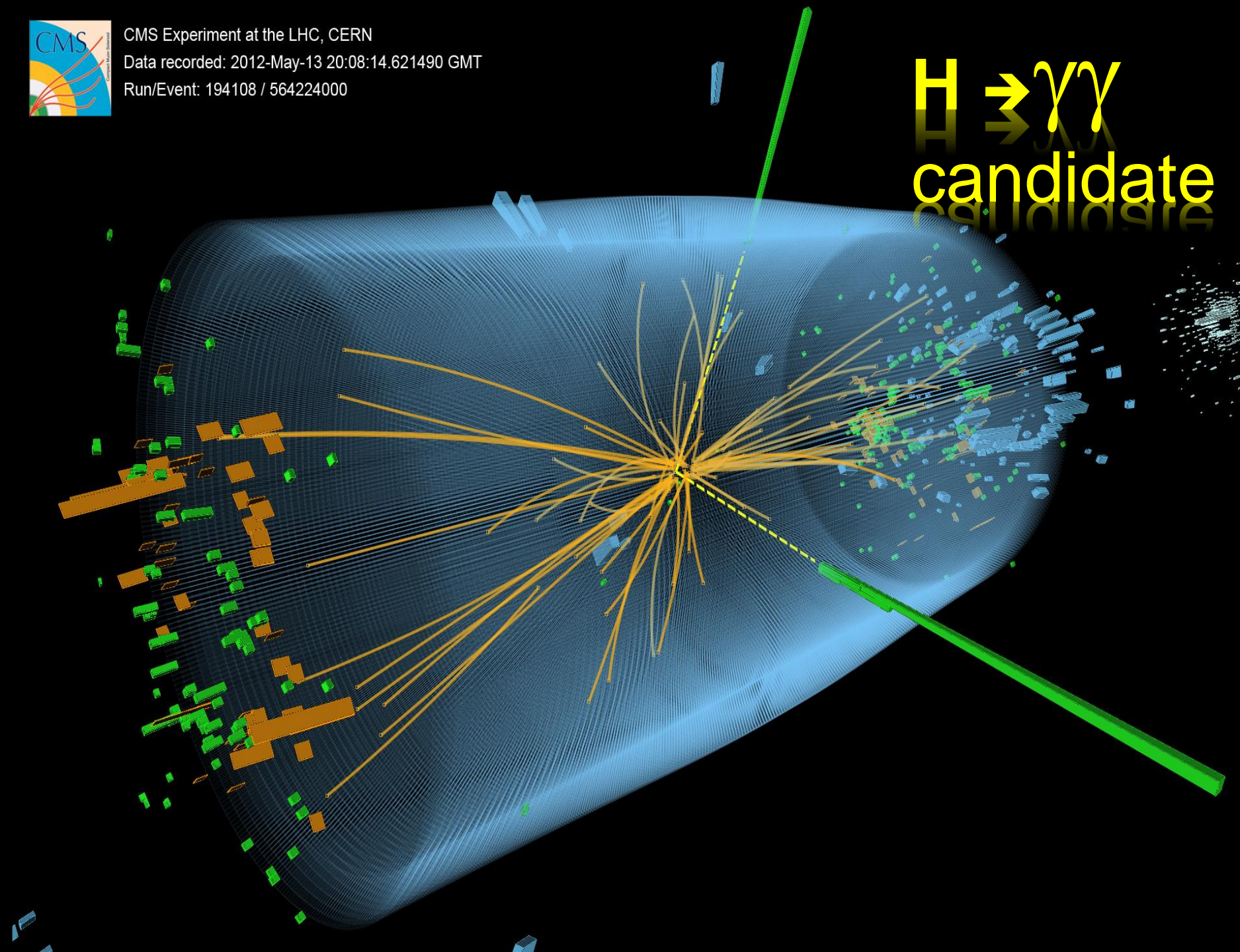


CMS Experiment at the LHC, CERN

Data recorded: 2012-May-13 20:08:14.621490 GMT

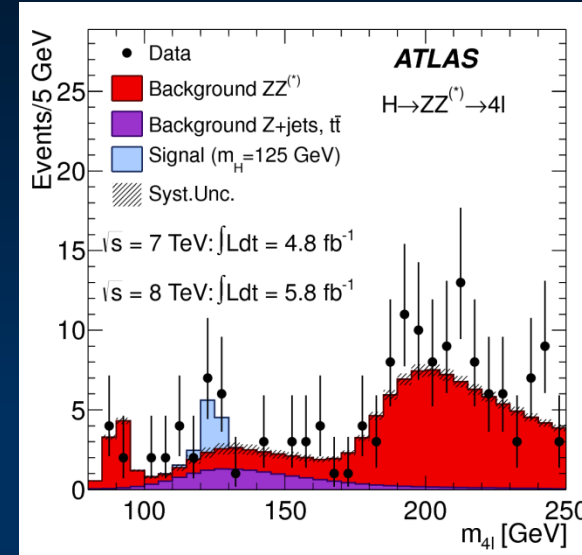
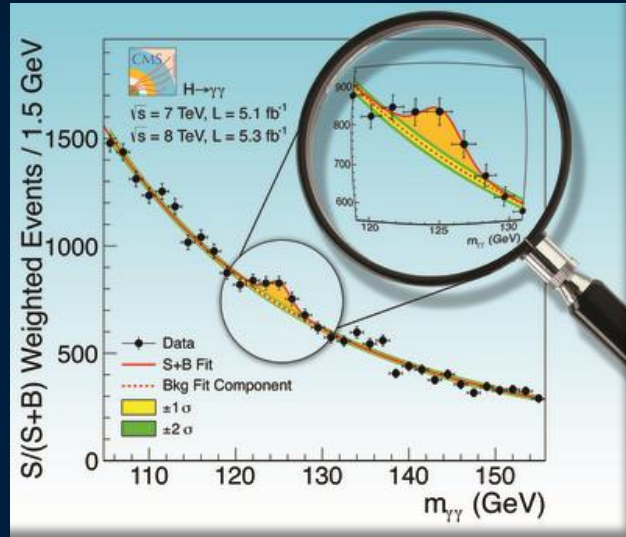
Run/Event: 194108 / 564224000

$H \rightarrow \gamma\gamma$   
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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2013.  
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CERN is not only the LHC !





# 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.  $9.5 \times 10^9$  p per bunch



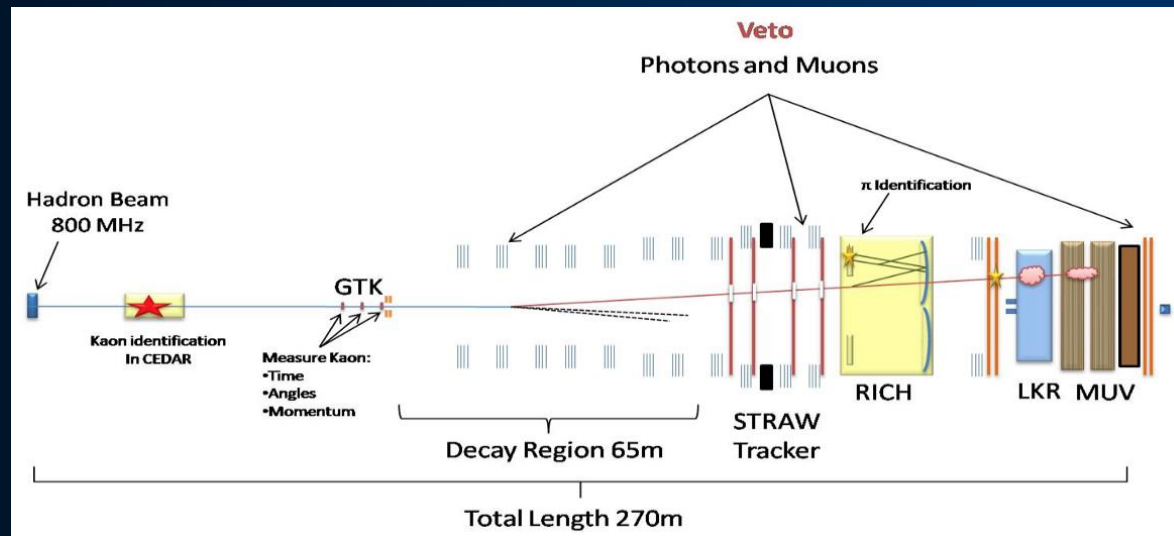
COMPASS in North Hall  
(60 m long)

# 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  $\nu_\tau$  production

Example NA62:



# Neutrino Platform (new extension of North Area)

Like quarks, neutrinos exist in different flavors  $\nu_e \nu_\mu \nu_\tau$

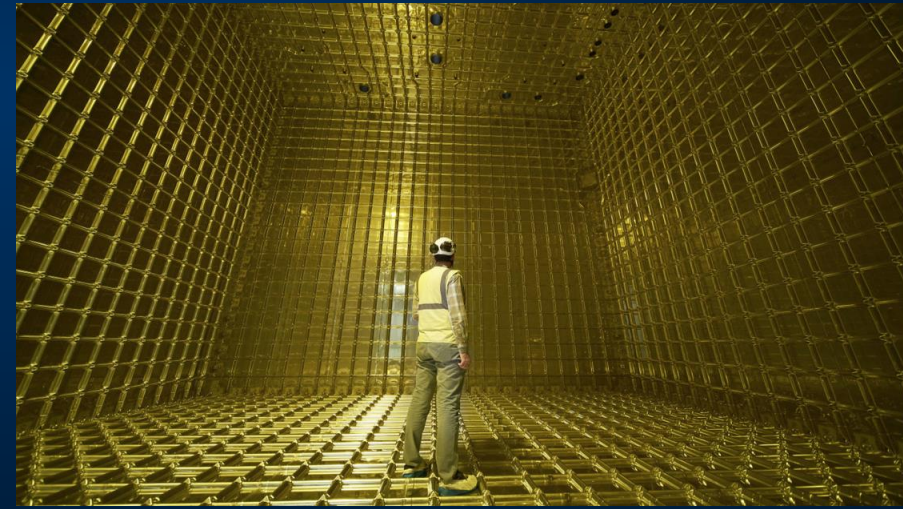
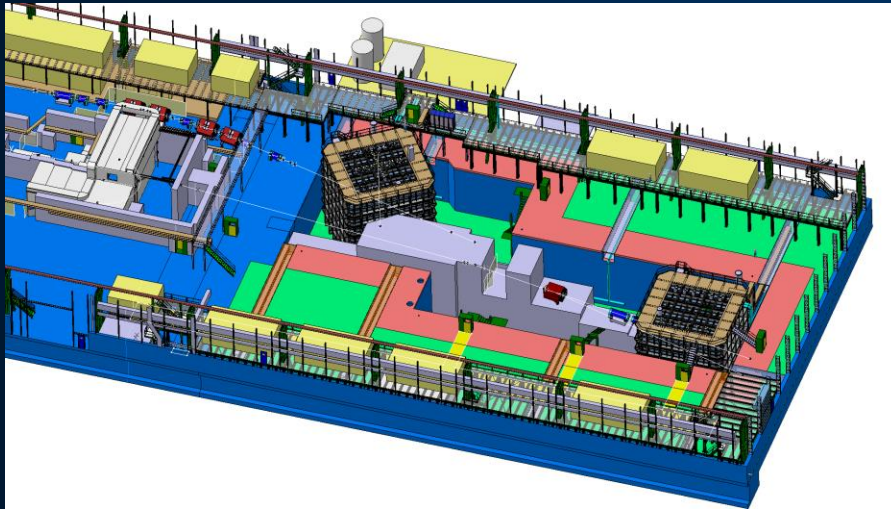
but their flavour oscillates

$$\nu_\mu \leftrightarrow \nu_\tau$$

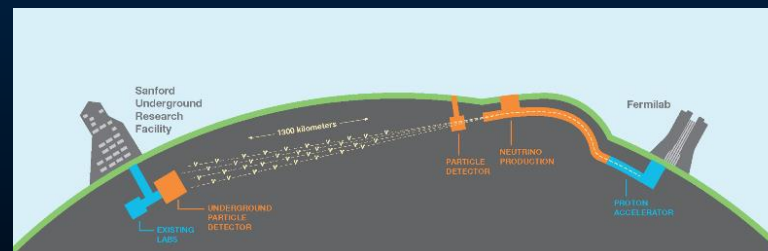
$$\nu_\mu \leftrightarrow \nu_e$$

Has been studied with  $\nu_\mu$  beam sent from CERN to Gran Sasso in Italy (CNGS).

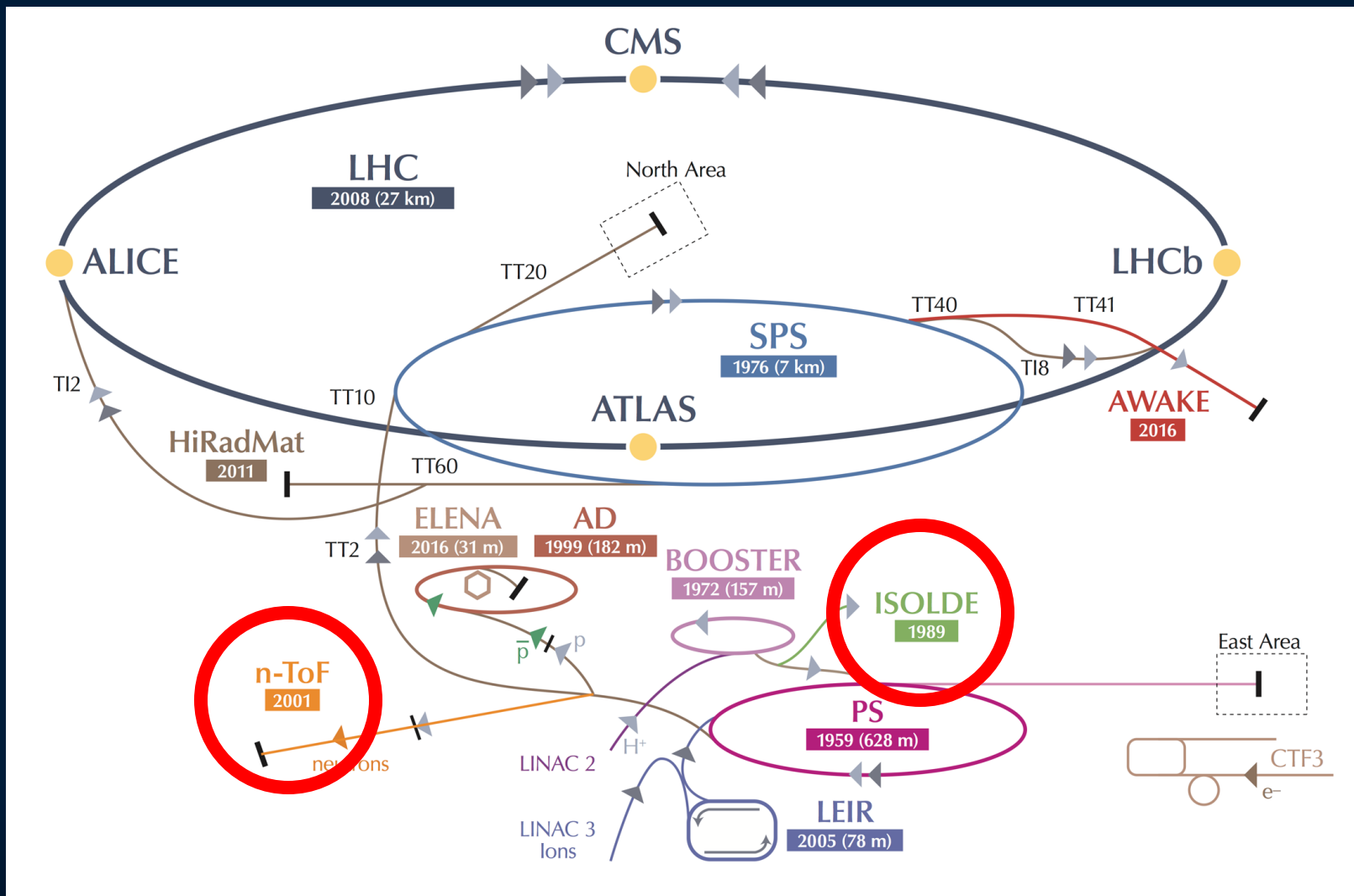
Neutrino platform as a test area with charged beams for neutrino detectors (e.g. R&D for large liquid argon detectors). The experiments will take place in the US and Japan.



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

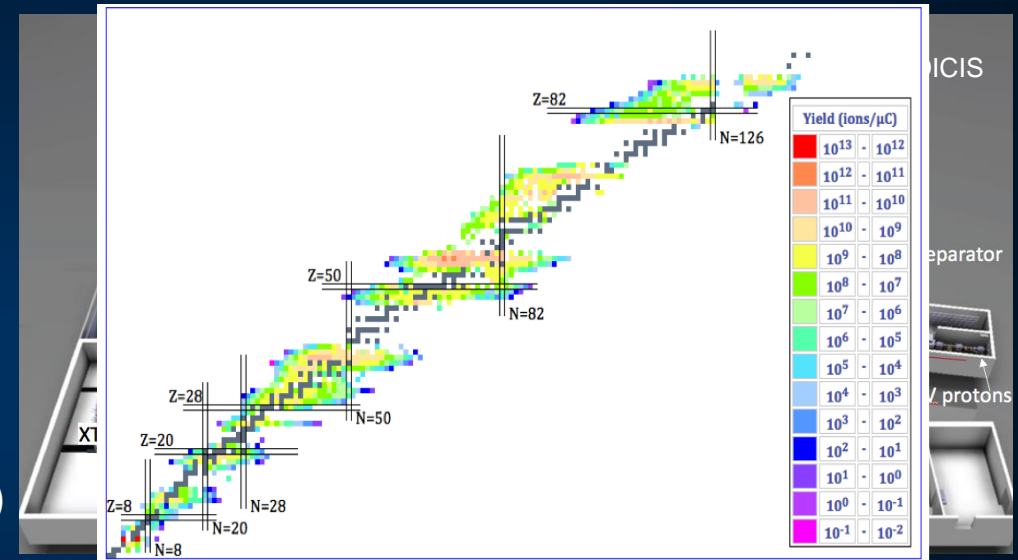
- Nuclear physics
- Fundamental interactions
- Nuclear Astrophysics
- Applications (Medicine, Material Science)

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

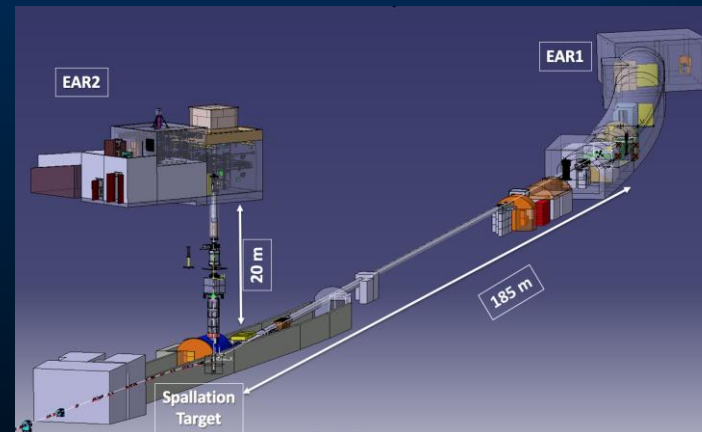
HIE-ISOLDE (post acceleration up to 10 MeV/nucleon)



## nTOF (neutron time-of-flight)

Neutron cross-section measurements

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





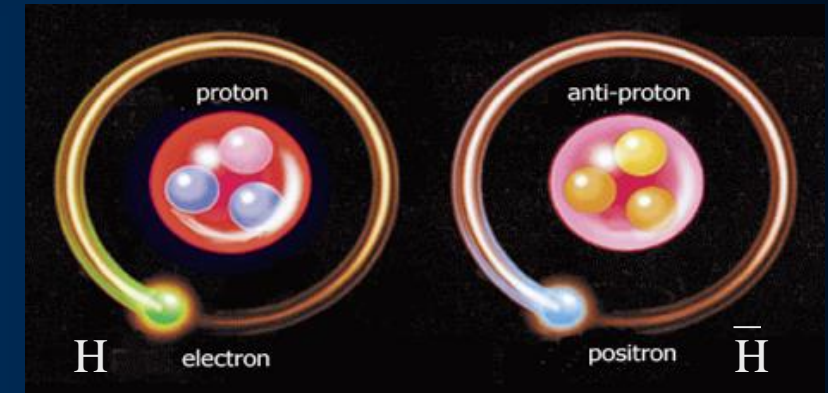
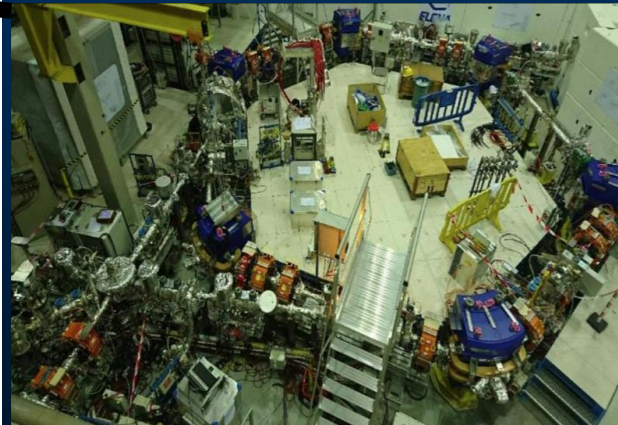
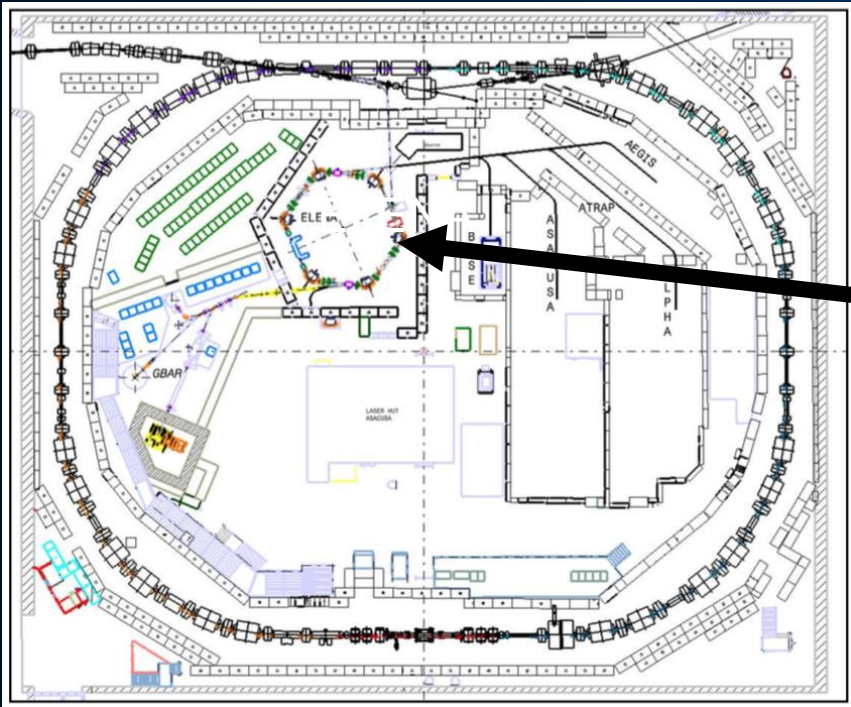


# Antiproton & Antihydrogen Physics

## 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

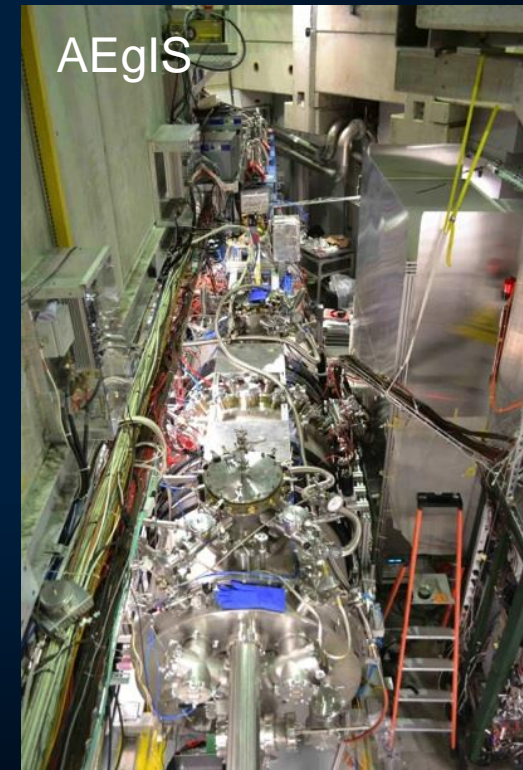
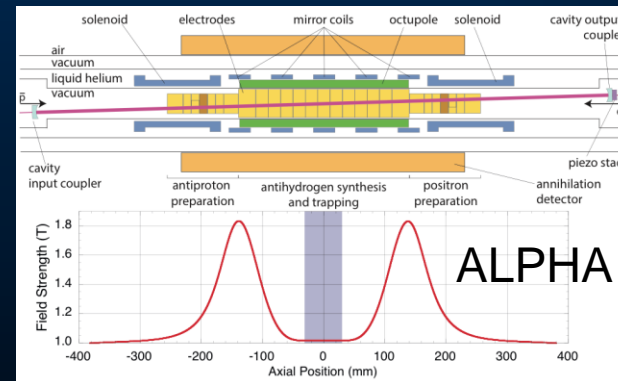
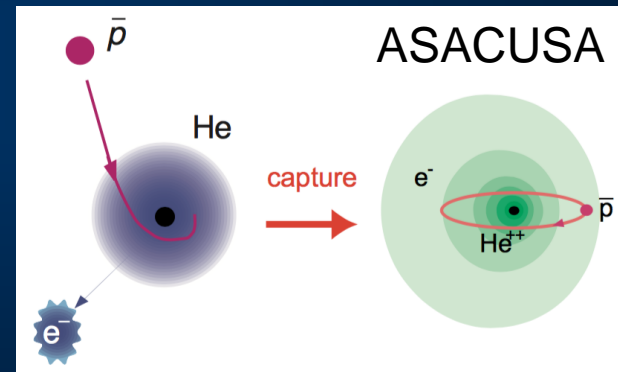
Matter-Antimatter comparison

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

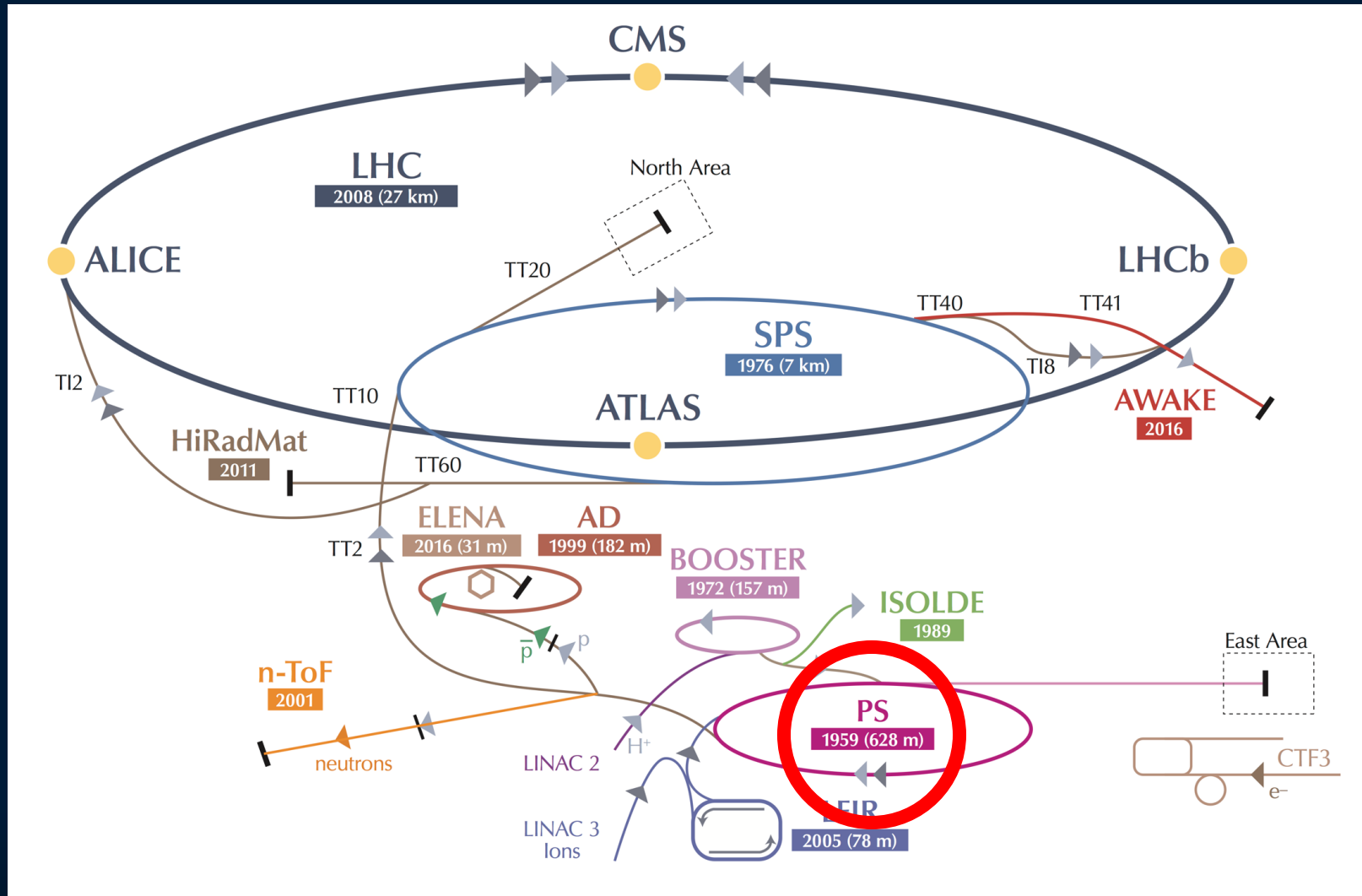
5 experiments:

- **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



# 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

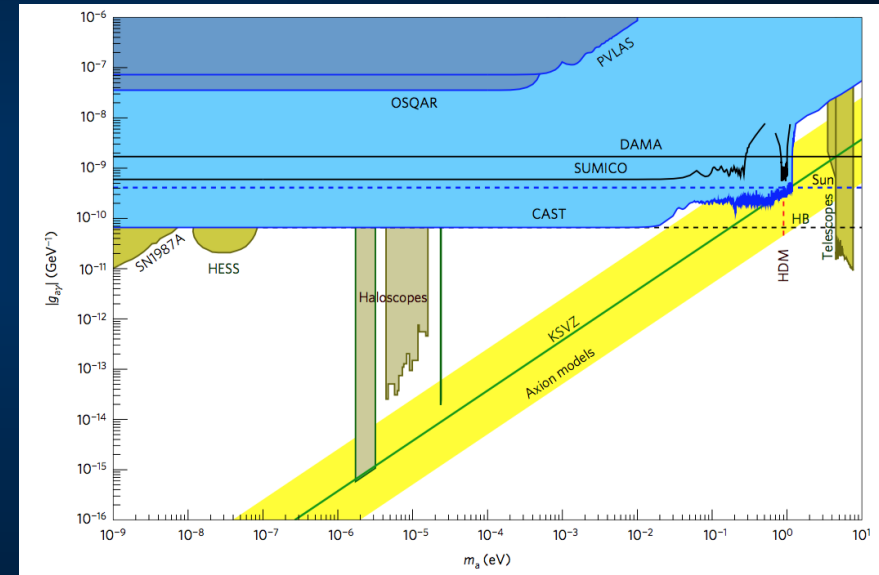
**CAST:** The CERN Axion Solar Telescope

- 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)

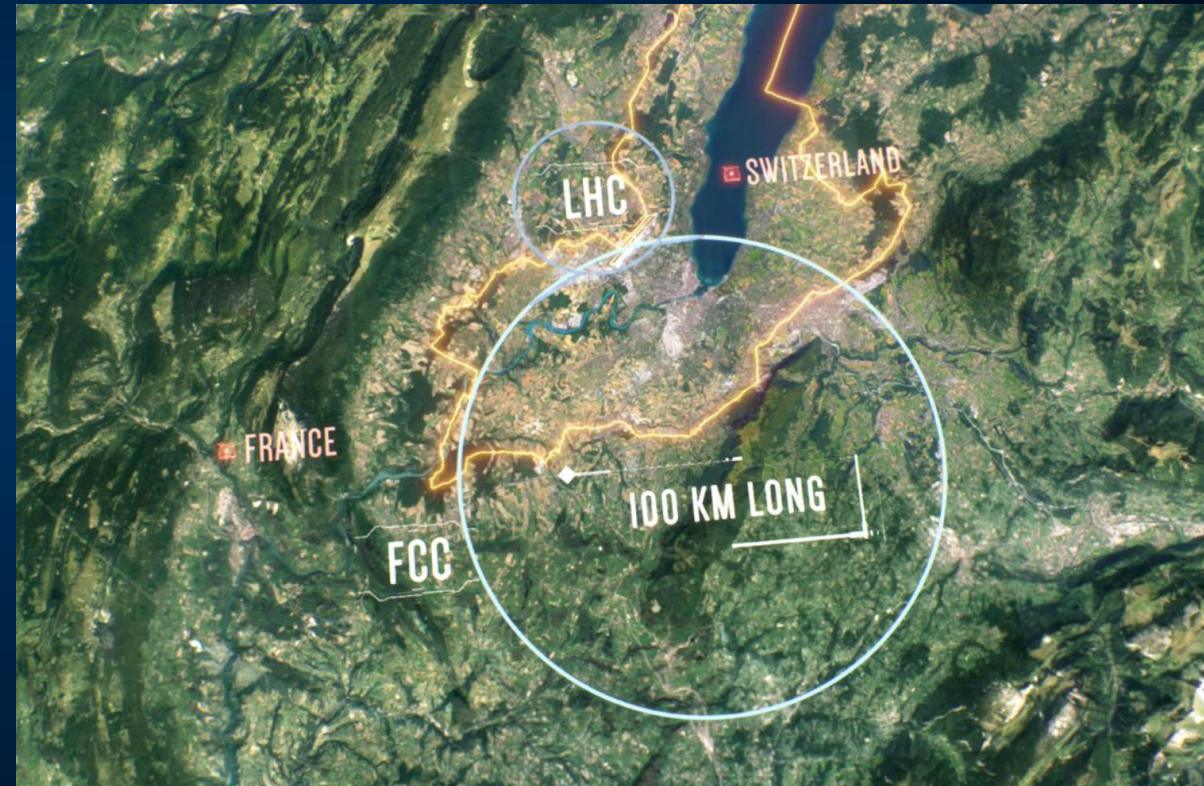
**OSQAR:** Search for Axions through “Light shining through wall experiments”  
Using LHC prototyp dipol magnet

# Future accelerators and experiments at CERN

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.

Following the Update of the European Strategy for Particle Physics in June 2020, continue with two studies:

- **FCC – Future Circular Collider**  
Study of a 100 km circumference machine for pp collisions at >100 TeV, and possible first stage  $e^+e^-$  collider (90-365 GeV, Higgs factory)
- **Physics beyond Colliders**  
Study to explore possibilities using the non-collider part of the CERN accelerator complex



# 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 !