

# 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 Kramer*



# CERN was founded 1954: 12 European States

“Science for Peace”

## Today: 23 Member States

- ~ 2600 staff
- ~ 1800 other paid personnel
- ~ 13600 scientific users

**Member States:** Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, Netherlands, Norway, Poland, Portugal, Romania, Slovak Republic, Serbia, 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

## Distribution of All CERN Users by Nationality on 10 April 2019

> 13.000 users with 110 nationalities

### MEMBER STATES

**8066**

Austria	119
Belgium	120
Bulgaria	86
Czech Republic	233
Denmark	62
Finland	96
France	864
Germany	1344
Greece	238
Hungary	79
Israel	65
Italy	2105
Netherlands	180
Norway	70
Poland	356
Portugal	121
Romania	137
Serbia	55
Slovakia	137
Spain	472
Sweden	99
Switzerland	229
United Kingdom	799

### OBSERVERS

**2726**

Japan	310
Russia	1205
USA	1211

### ASSOCIATE MEMBERS

India	387	<b>778</b>
Lithuania	39	
Pakistan	71	
Turkey	165	
Ukraine	116	

### ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP

**59**

Cyprus	26
Slovenia	33

### OTHERS

**1999**

Albania	4	Bolivia	3	Ecuador	10	Iraq	1	Malta	9	Palestine	7	Sudan	1
Algeria	14	Bosnia & Herzegovina	3	Egypt	27	Ireland	13	Mexico	85	Paraguay	1	Syria	1
Argentina	26	Brazil	127	El Salvador	1	Jordan	2	Mongolia	2	Peru	6	Taiwan	56
Armenia	22	Burkina Faso	1	Estonia	15	Kazakhstan	10	Montenegro	11	Philippines	3	Thailand	26
Australia	36	Burundi	1	Georgia	51	Kenya	1	Morocco	24	Saint Kitts and Nevis	1	Tunisia	4
Azerbaijan	10	Cameroon	1	Ghana	1	Korea	183	Myanmar	2	San Marino	1	Uruguay	1
Bahrain	1	Canada	170	Guatemala	1	Kyrgyzstan	1	Nepal	7	San Marino	1	Uzbekistan	3
Bangladesh	8	Chile	21	Hong Kong	1	Latvia	4	New Zealand	5	Saudi Arabia	4	Venezuela	9
Belarus	45	China	576	Honduras	1	Lebanon	27	Nigeria	4	Senegal	1	Viet Nam	11
Benin	1	Colombia	44	Iceland	4	Luxembourg	4	North Korea	4	Singapore	5	Zambia	1
		Croatia	50	Indonesia	11	Madagascar	1	North Macedonia	3	South Africa	56	Zimbabwe	2
		Cuba	16	Iran	58	Malaysia	22	Oman	3	Sri Lanka	10		



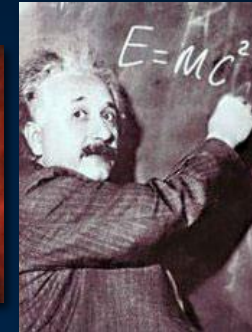
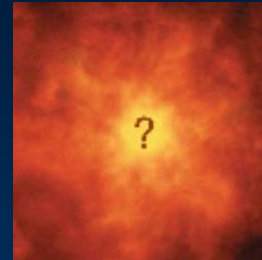




# The Mission of CERN

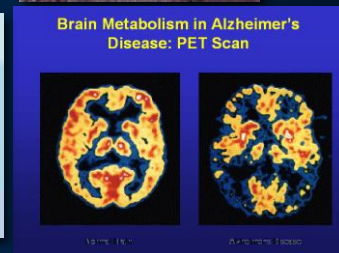
- **Push back** the frontiers of knowledge

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

Director General  
F. Gianotti

Health, Safety and Environment

Legal Service

Internal Audit

Council Support

4 Directors

Accelerator and Technology  
F. Bordry

Finance and Human Resources  
M. Steinacher

International Relations  
Ch. Warakaulle

Research and Computing  
E. Elsen

10 Departments

Beams  
P. Collier

Finance and Administration  
F. Sonnemann

Stakeholder Relations

Experimental Physics  
M. Kramer

Technology  
J.M. Jiménez

Industry, Procurement and Knowledge Transfer  
Th. Lagrange

Education, Communication and Outreach

Theoretical Physics  
G.F. Giudice

Engineering  
R. Losito

Human Resources  
J. Purvis

Information Technology  
F. Hemmer

Site Management and Buildings  
LL. Miralles

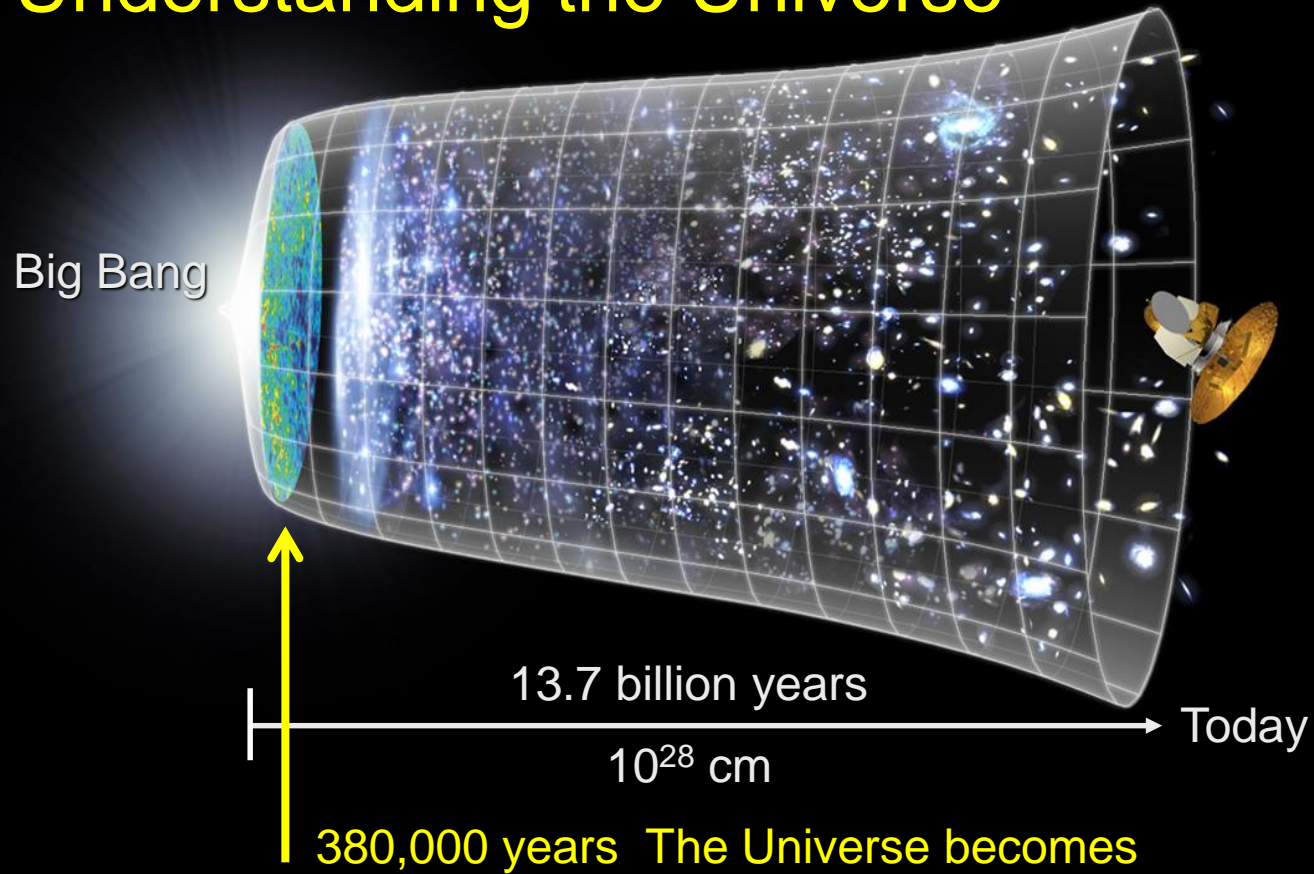
Experimental Physics Department (EP):

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

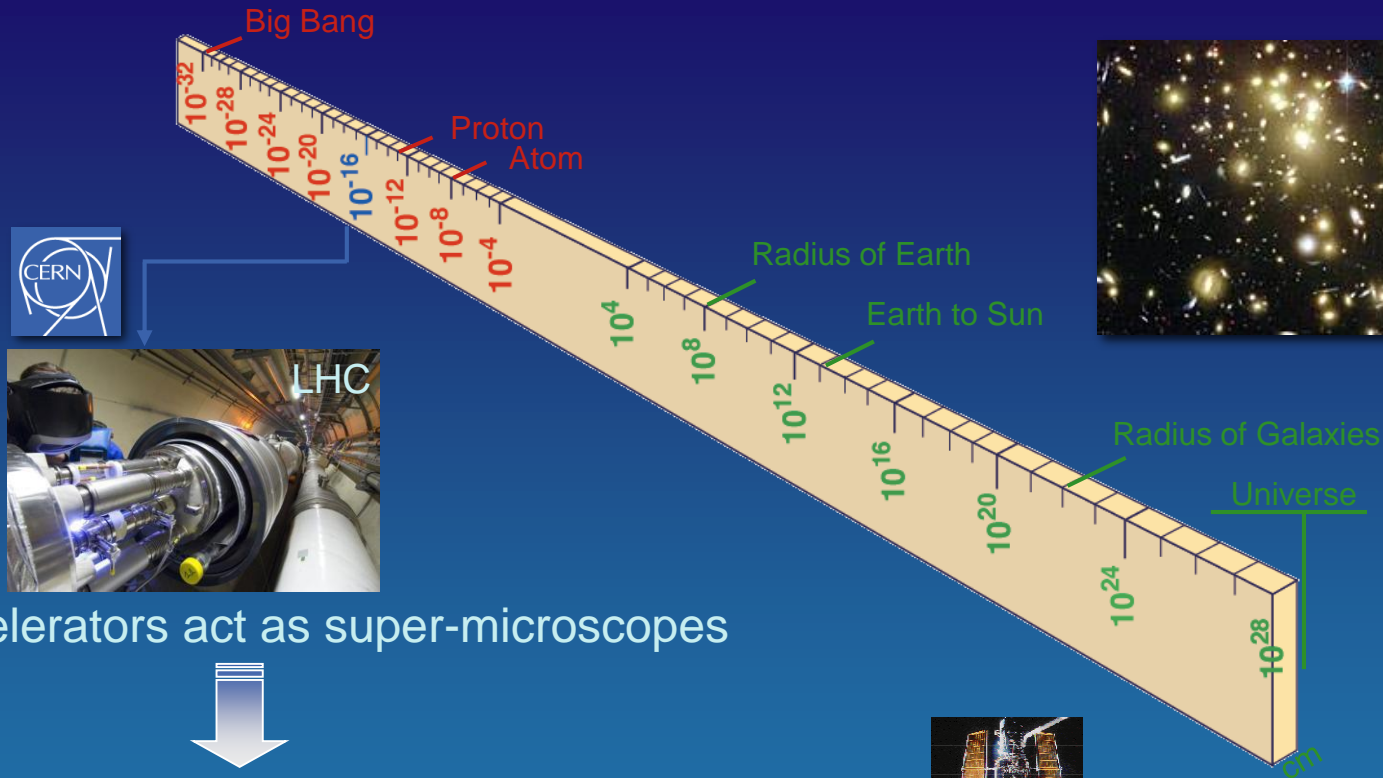
>13000 users assigned to the department!



# Physics at CERN: Understanding the Universe



# From the smallest to the largest Structures



Accelerators act as super-microscopes

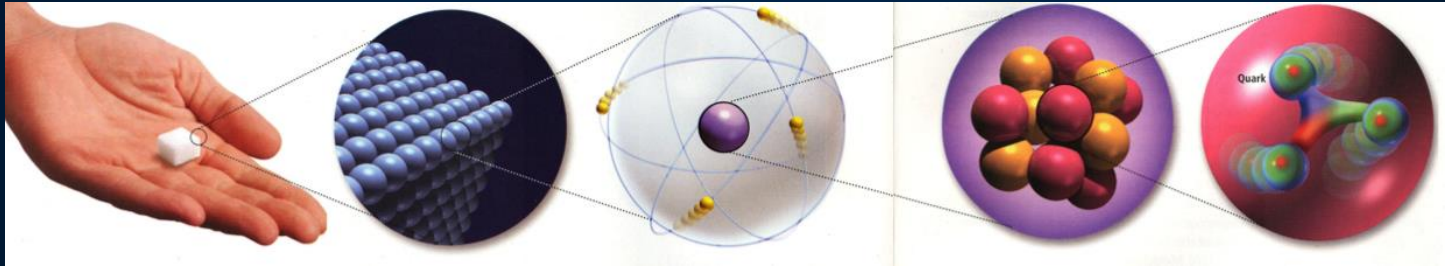


Study laws of physics at first moments after Big Bang

Increasing symbiosis between Particle Physics, Astrophysics and Cosmology



# Composition of Matter

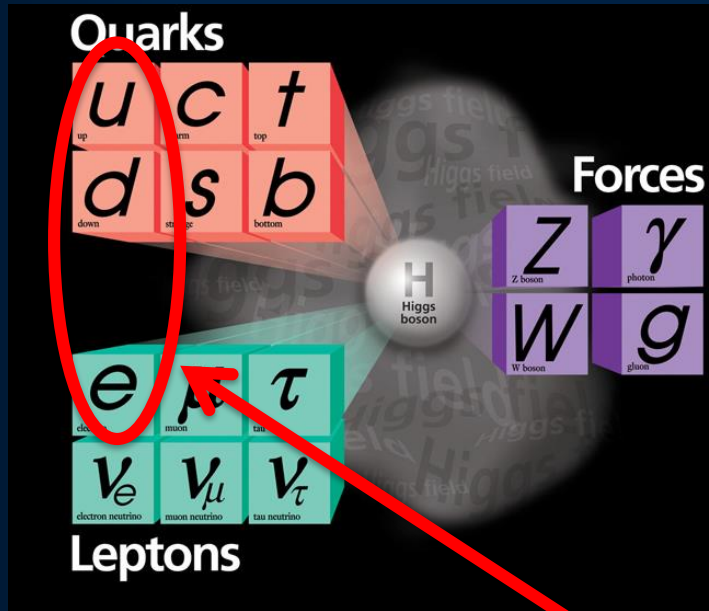


- All matter built from Atoms
- Atoms consist of a Nucleus and **Electrons**
- The Nucleus consist of Neutrons and Protons
- Neutrons and Protons consist of **Up** and **Down Quarks** (and Gluons)

**Fundamental Matter Particles: Electrons, Up Quarks, Down Quarks**



# The Standard Model of Particle Physics



**Fermions** (spin  $\frac{1}{2}$ ) 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**, gives mass to particles

Plus antimatter partners of each particle.

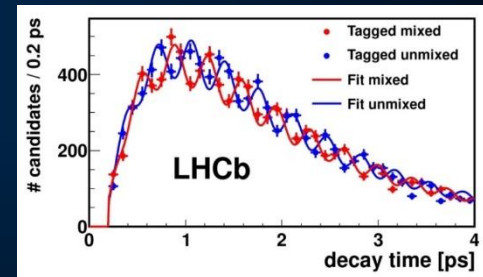
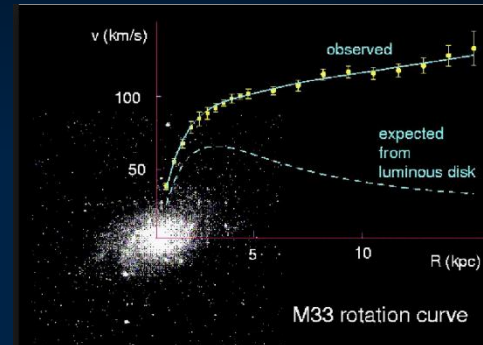
**Sufficient to explain the matter around us**

# 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.

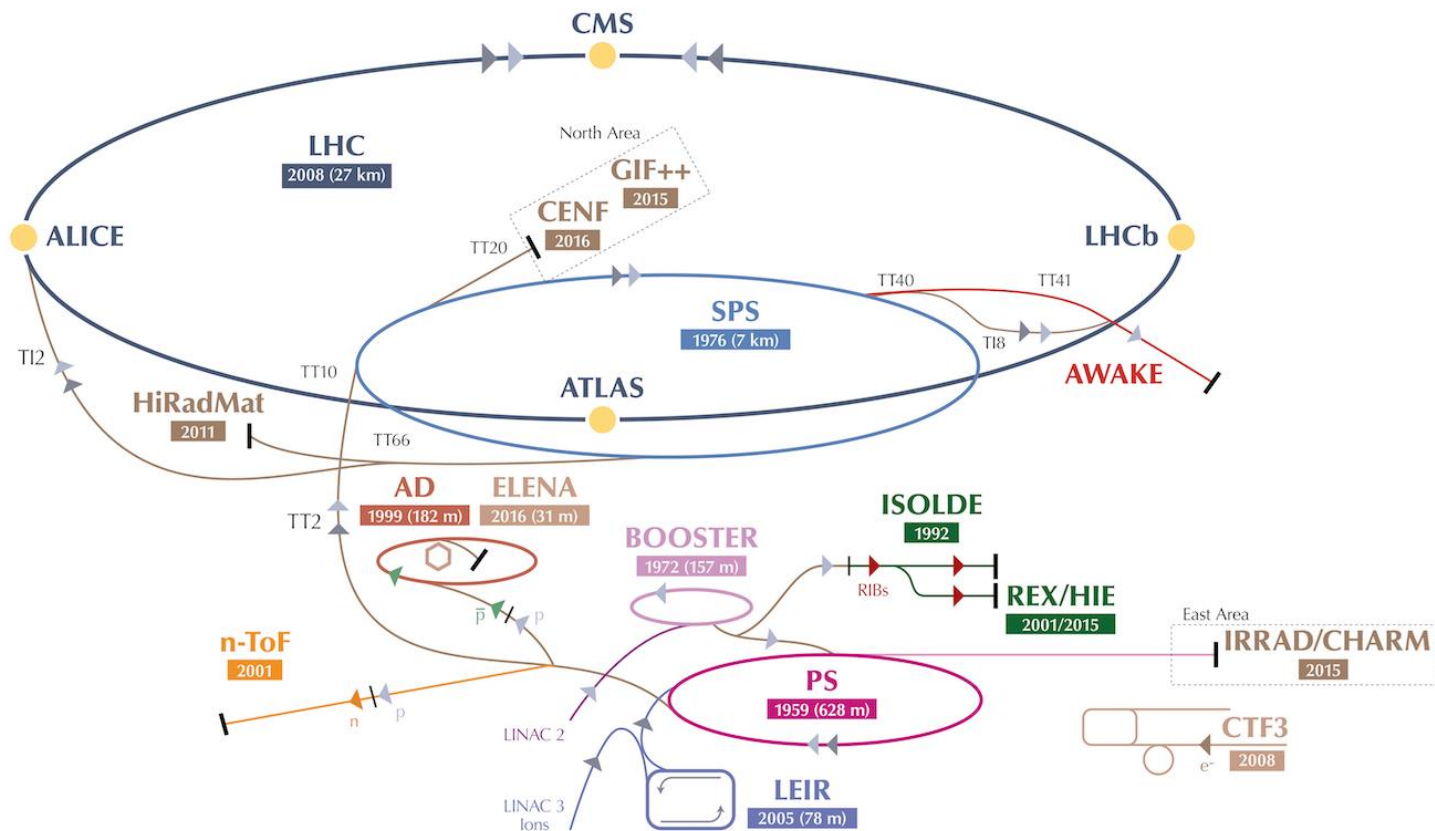
Still a lot to explore, to measure and to collect Nobel prizes!



# Research in Particle Physics needs:

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

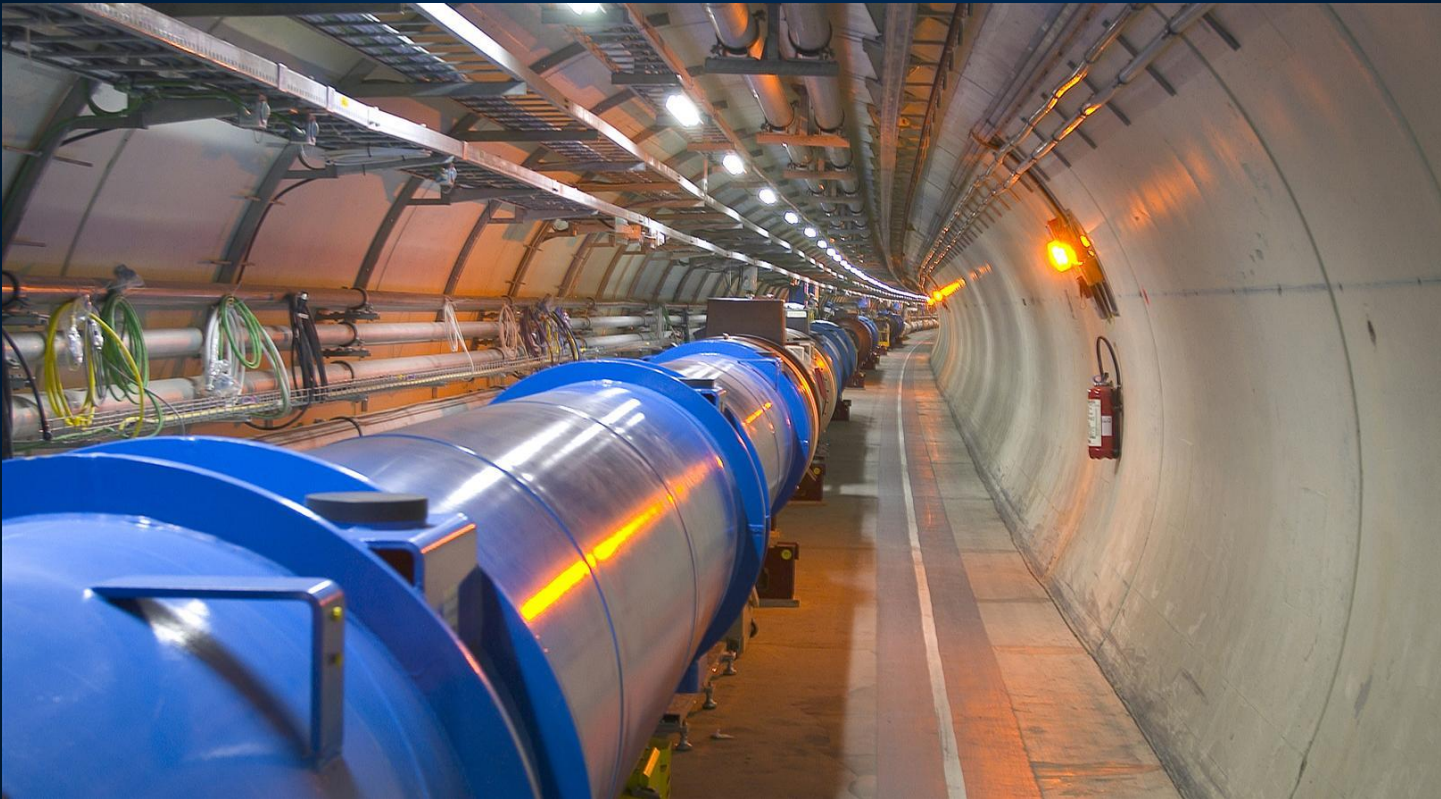
# CERN Accelerators *les accélérateurs*





# The Large Hadron Collider

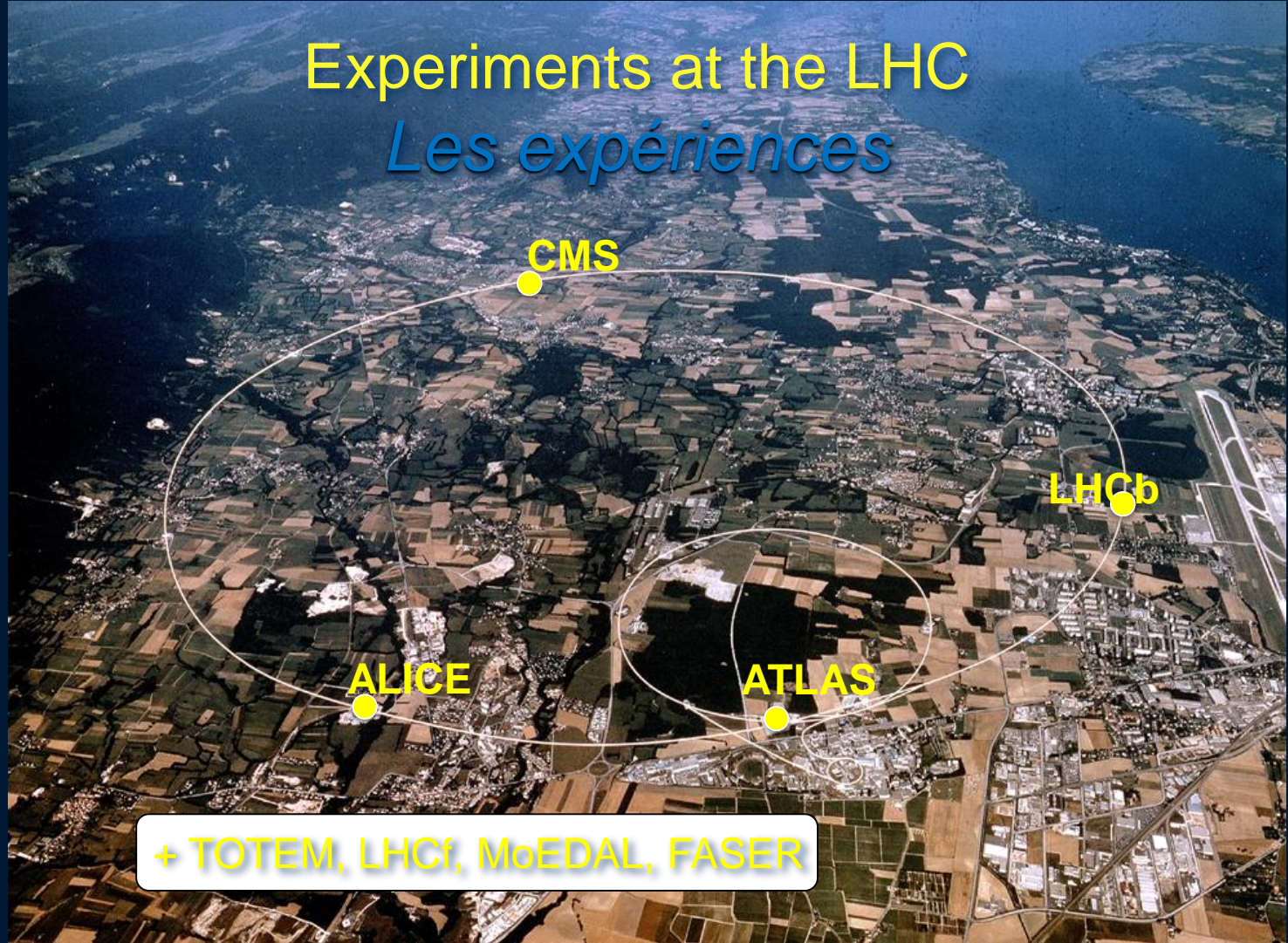
Search for the Higgs Boson, and physics beyond the Standard Model  
Exploration of a new energy frontier in p-p and Pb-Pb collisions





# Experiments at the LHC

## *Les expériences*

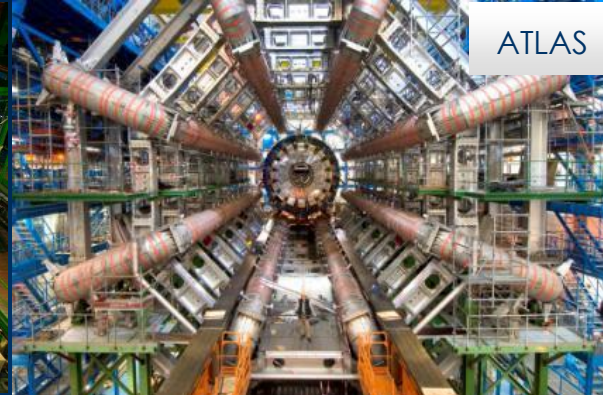
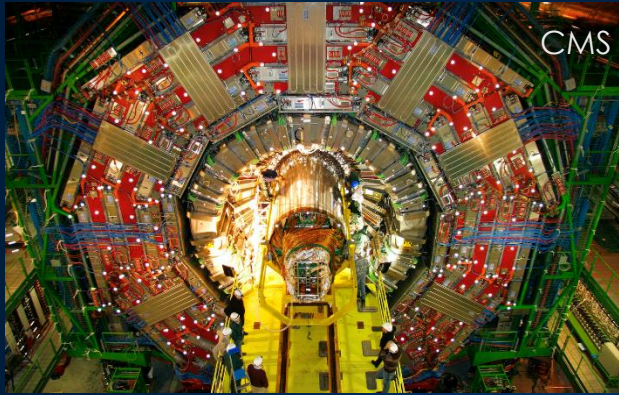


+ TOTEM, LHCf, MoEDAL, FASER



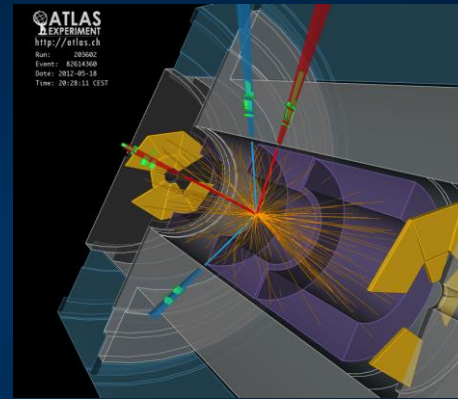
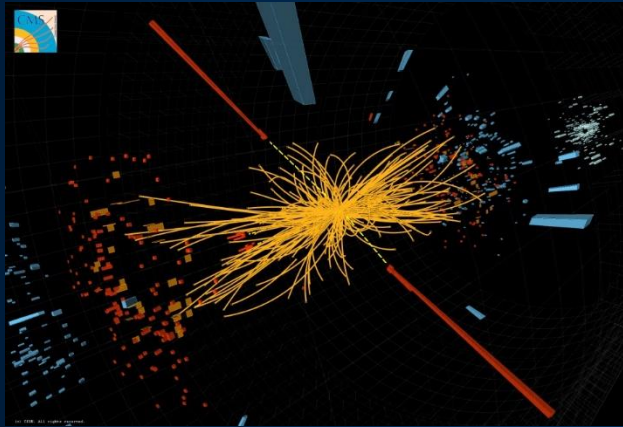
# Experiments at the LHC

Four major experiments



# Experiments at the LHC

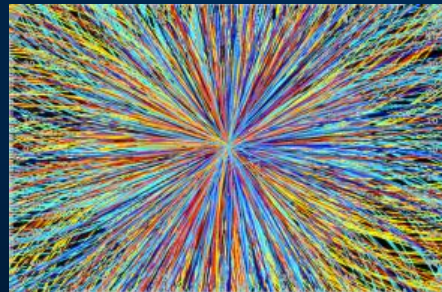
Brilliant performance of the LHC, the experiments and the Grid computing:  
Run1 2011-2012 :  $E_{\text{cm}} = 7-8 \text{ TeV}$     Run2 2015-2018:  $E_{\text{cm}} = 13 \text{ TeV}$



**ALICE**  
Heavy ions  
~ 1 month/year

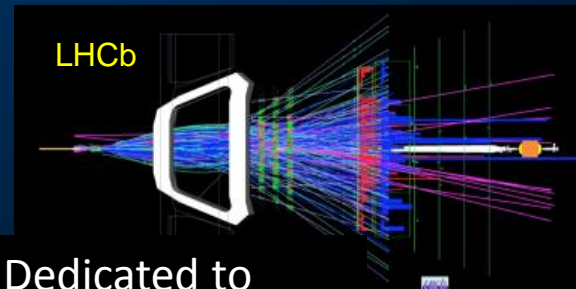
Pb-Pb  
collisions

$E_{\text{cm}} = 5 \text{ TeV}/N$



**LHCb**

Dedicated to  
flavour physics (b  
and c quarks)

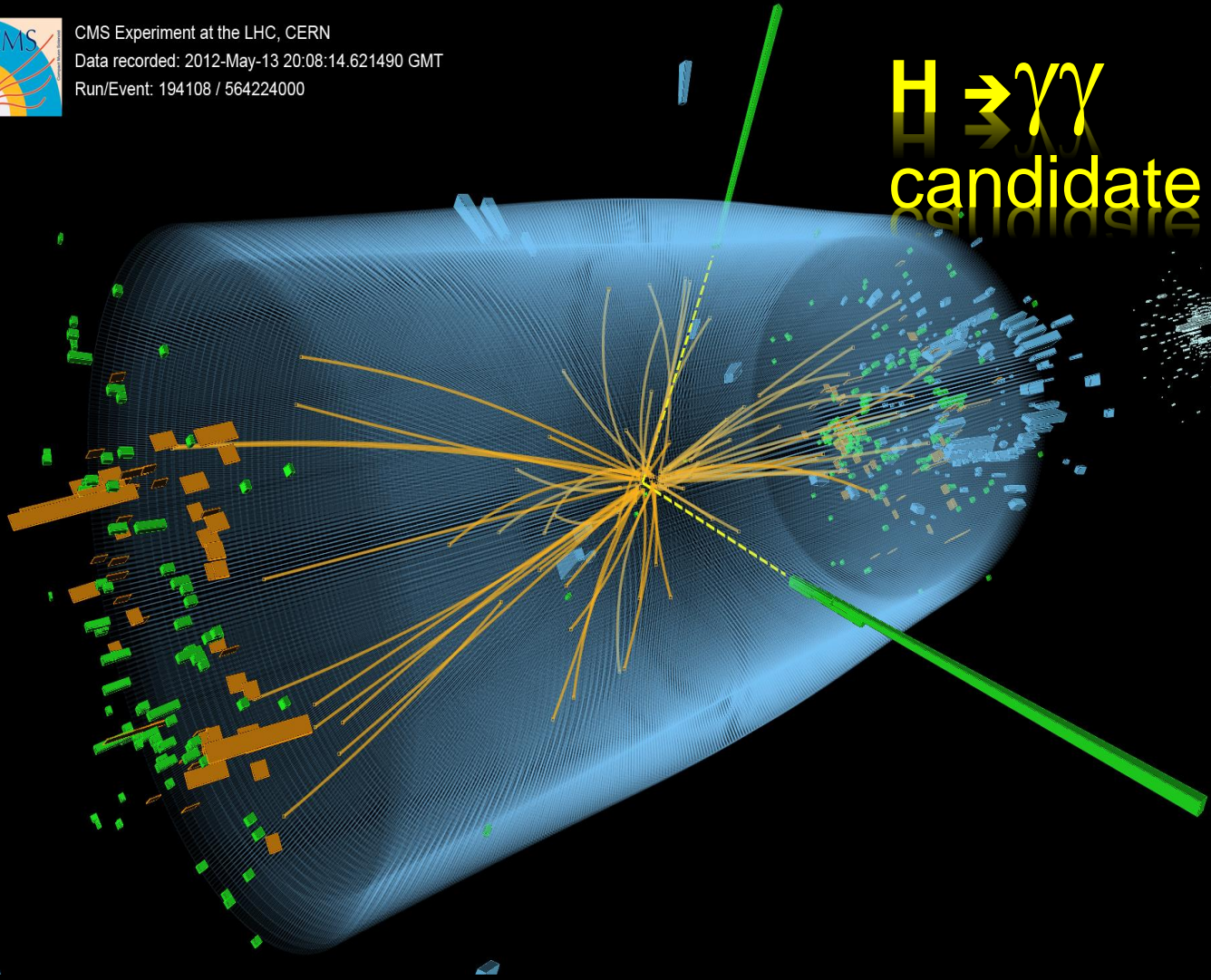




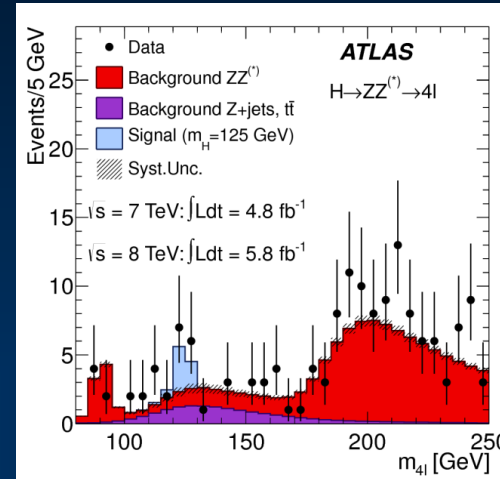
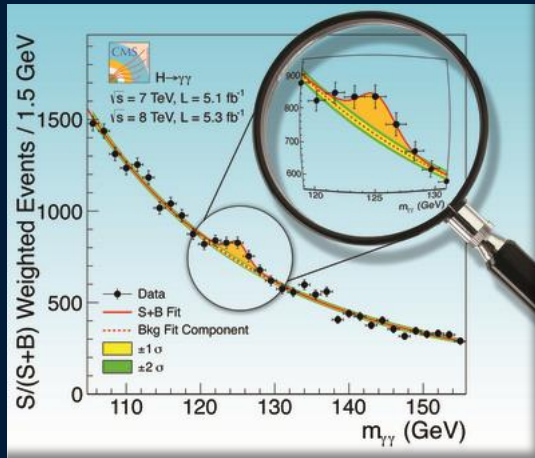


CMS Experiment at the LHC, CERN  
Data recorded: 2012-May-13 20:08:14.621490 GMT  
Run/Event: 194108 / 564224000

$H \rightarrow \gamma\gamma$   
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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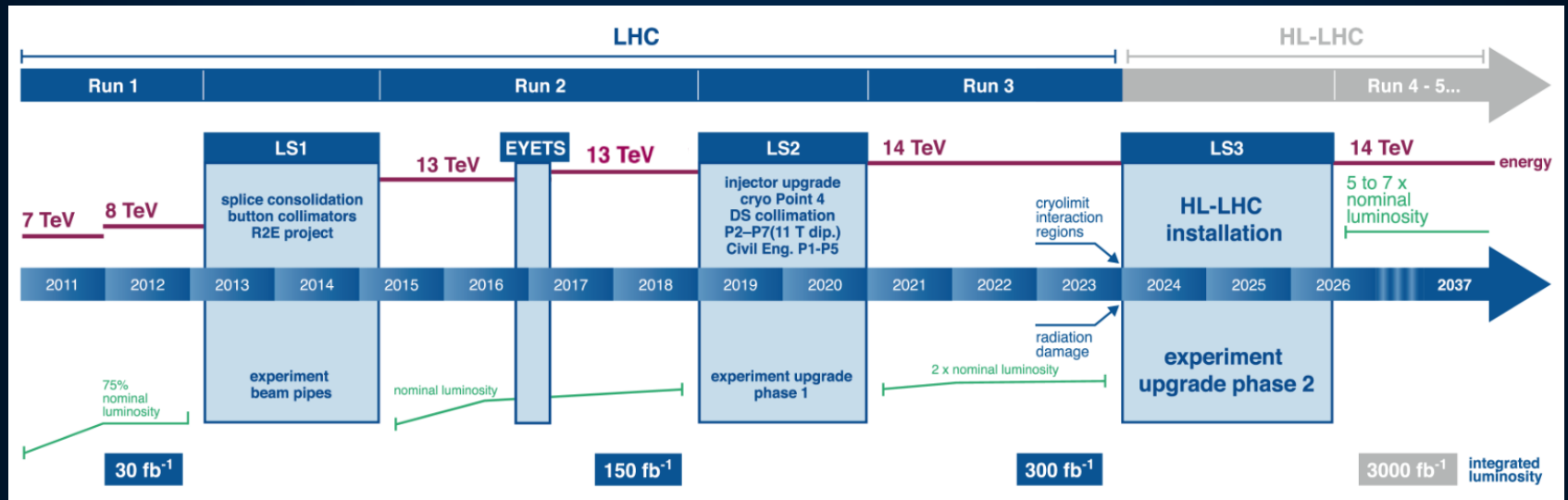


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# LHC and HL-LHC Program until 2037

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

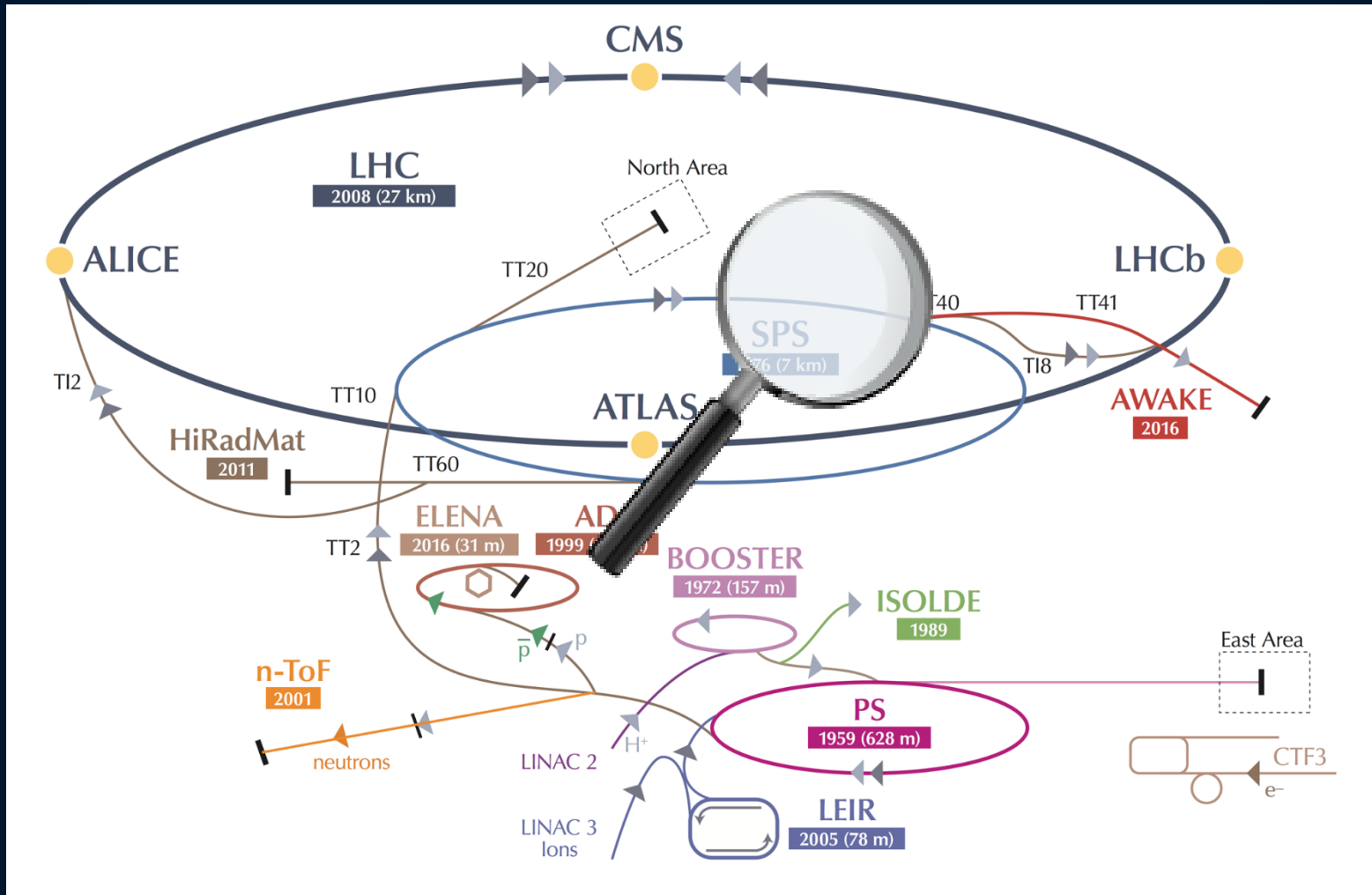


HL-LHC project officially approved by CERN Council in June 2016

Operation of the LHC foreseen until 2037

Until now only ~5 % of LHC/HL-LHC data taken – a lot to come!

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





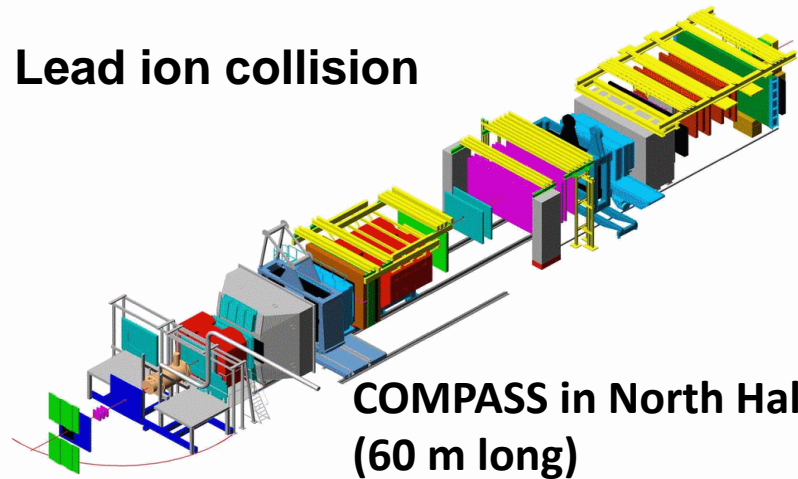
# Fixed Target Physics

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  $BR(K^+ \rightarrow \pi^+ \nu \bar{\nu})$
- NA63: electromagnetic processes in strong crystalline fields
- NA64: search for dark sectors in missing energy events



## Lead ion collision



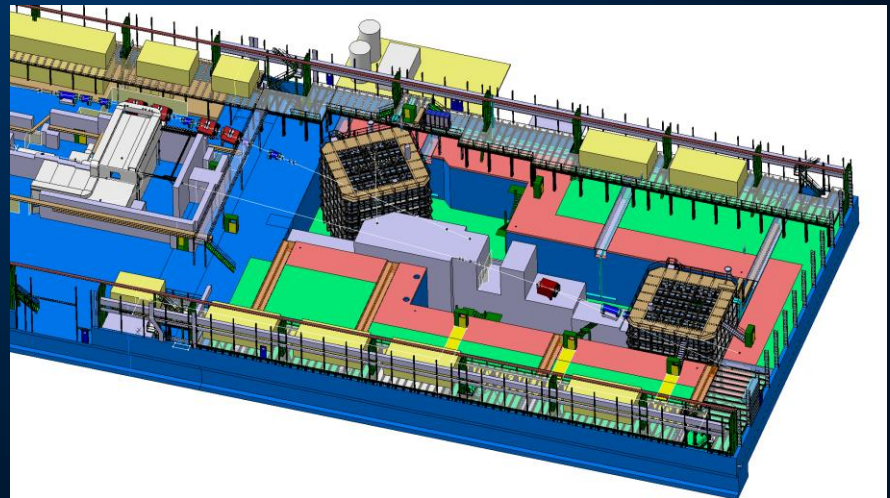
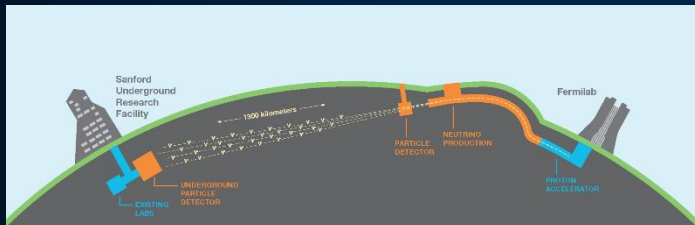
COMPASS in North Hall  
(60 m long)

# Neutrino Platform (new extension of North Area)

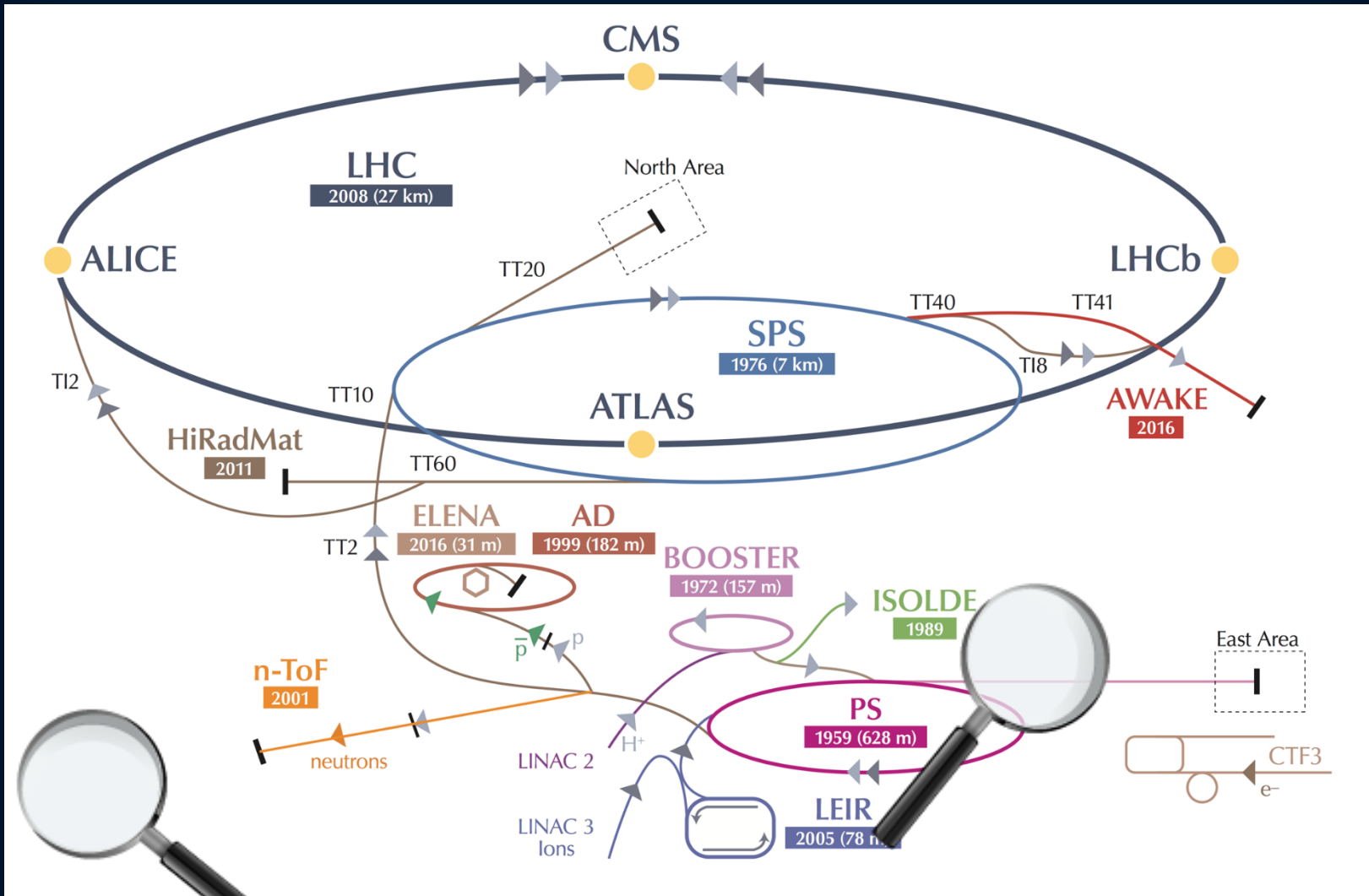
Like quarks, neutrinos exist in different flavors  $\nu_e$   $\nu_\mu$   $\nu_\tau$   
and **their flavour oscillates**  $\nu_\mu \leftrightarrow \nu_\tau$   $\nu_\mu \leftrightarrow \nu_e$   
Has been studied with  $\nu_\mu$  beam sent from CERN to Gran Sasso in Italy (CNGS).

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

Over 20 Target materials:

carbides, oxides, solid metals,  
molten metals and molten salts

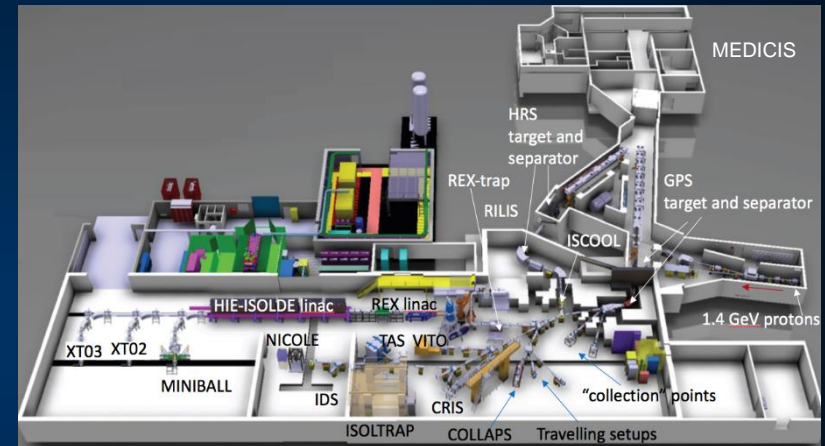
3 types of ion sources: surface, plasma,  
laser

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

## nTOF (neutron time-of-flight)

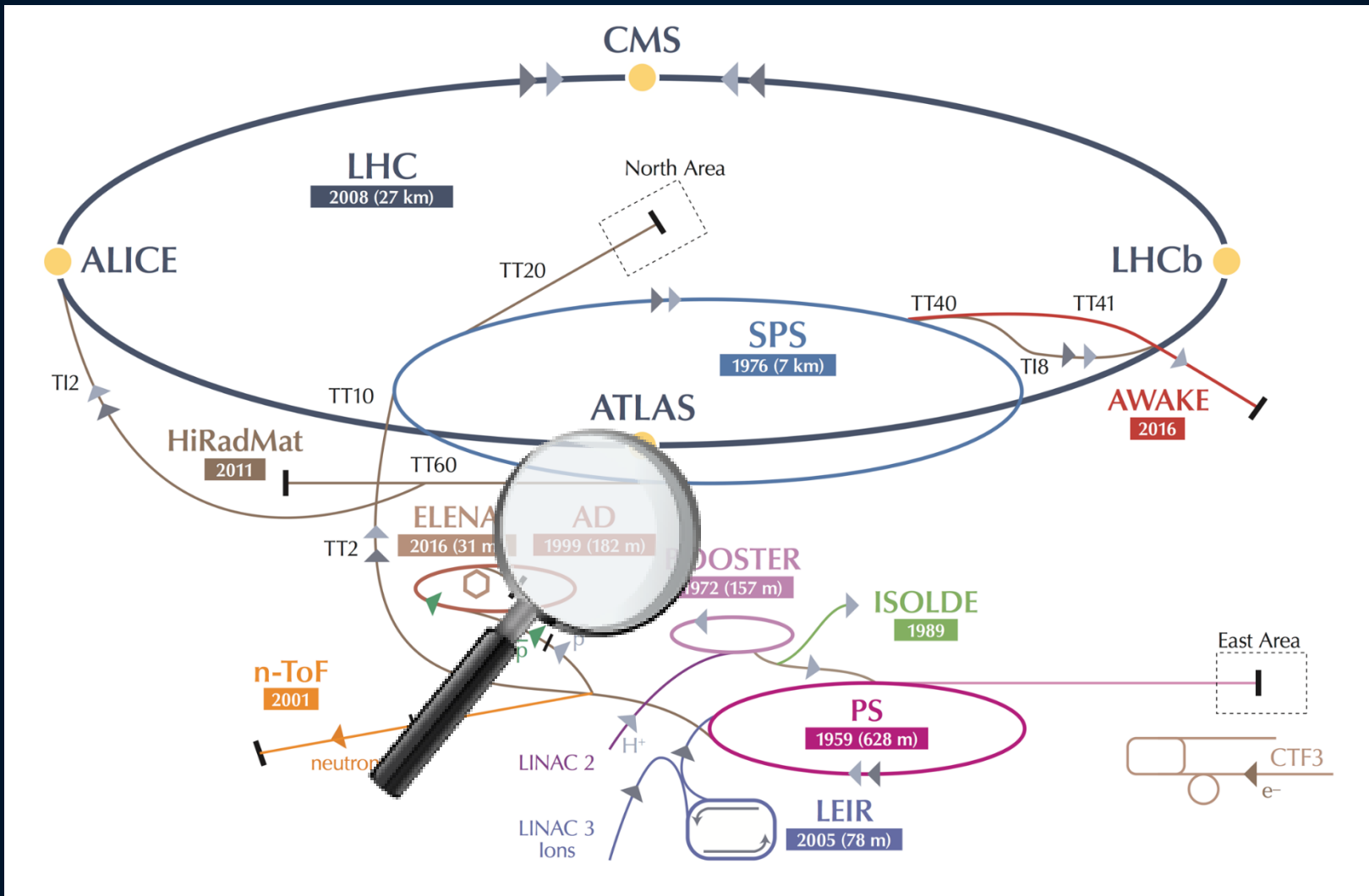
### Neutron cross-section measurements

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





# Antiproton Decelerator



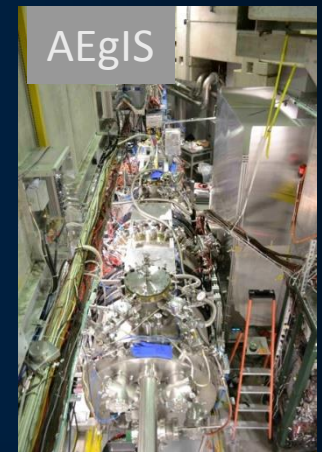
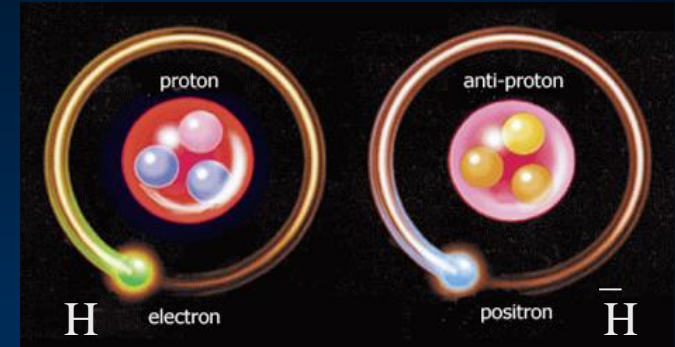
# Antiproton & Antihydrogen Physics

## Matter-Antimatter comparison

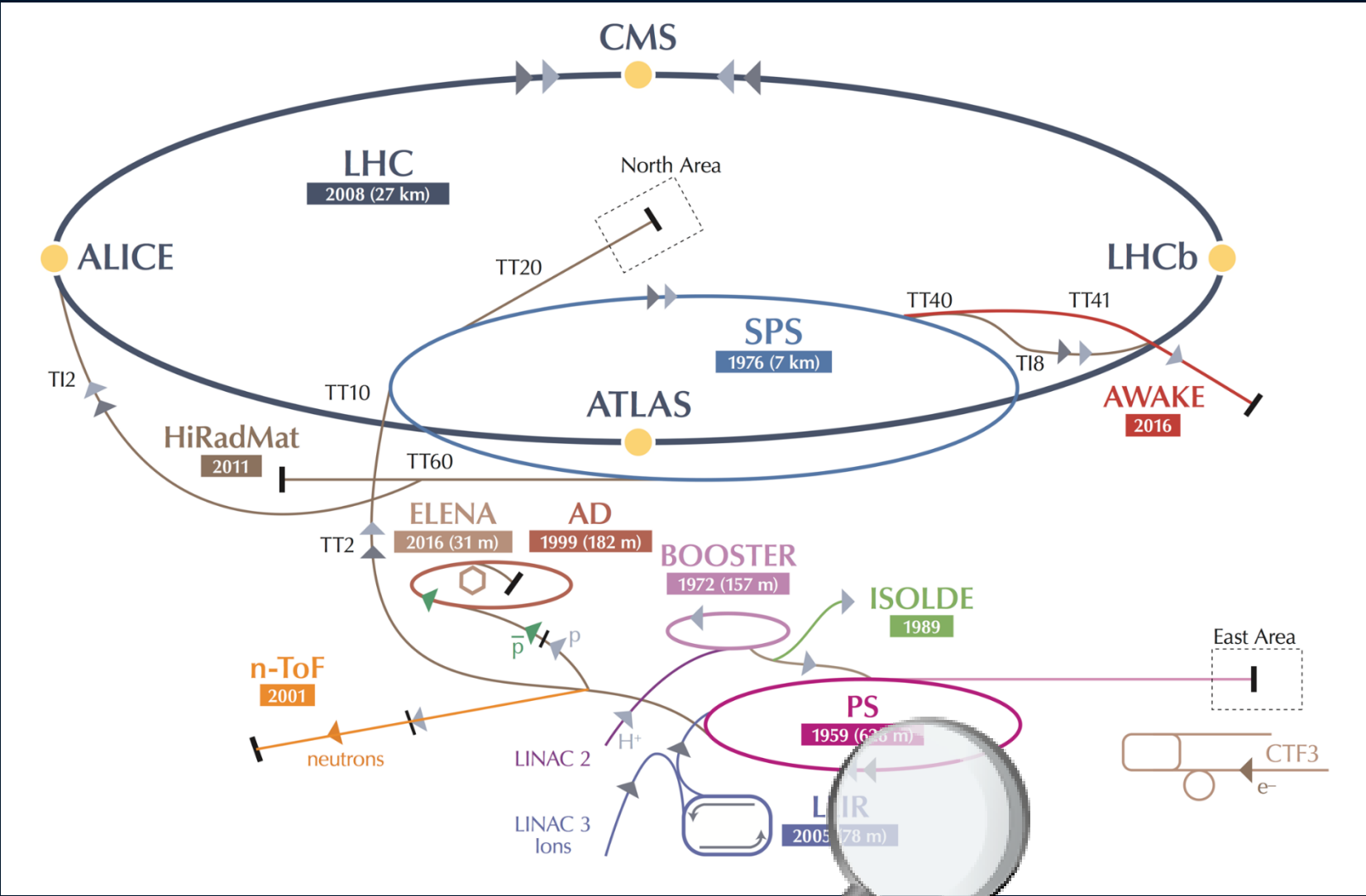
Fundamental in the current theory  
of physics:  $m = \bar{m}$ ,  $g = \bar{g}$

### 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** antimatter gravity experiment



# 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

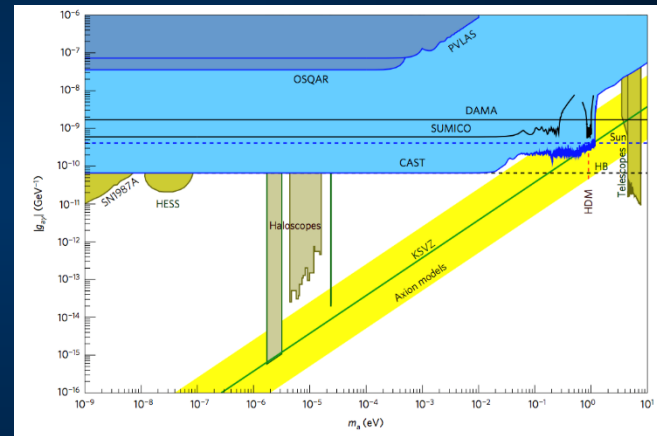
## CAST: The CERN Axion Solar Telescope

- 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

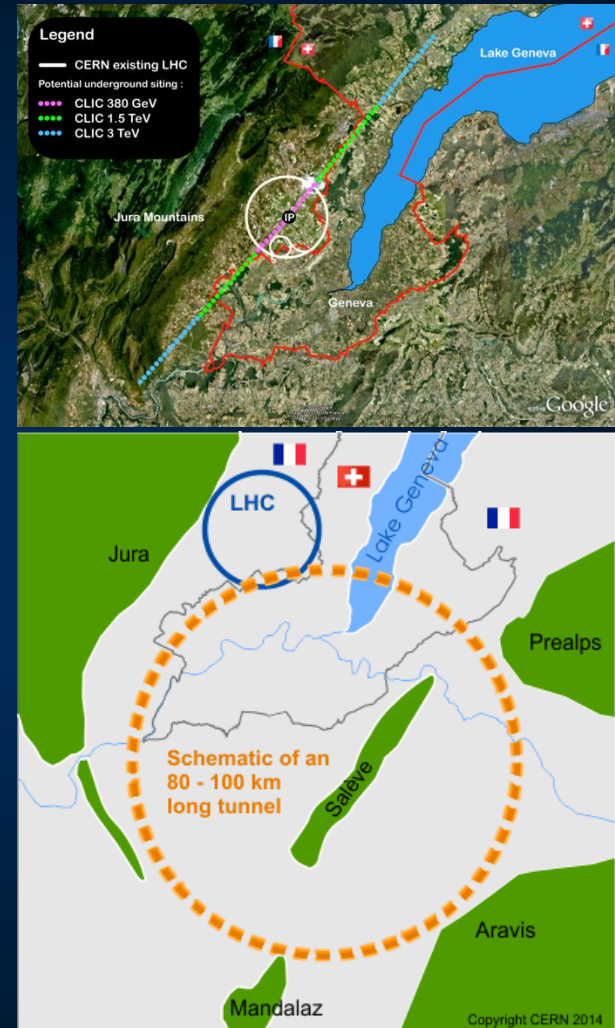


# Future accelerators

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!***

