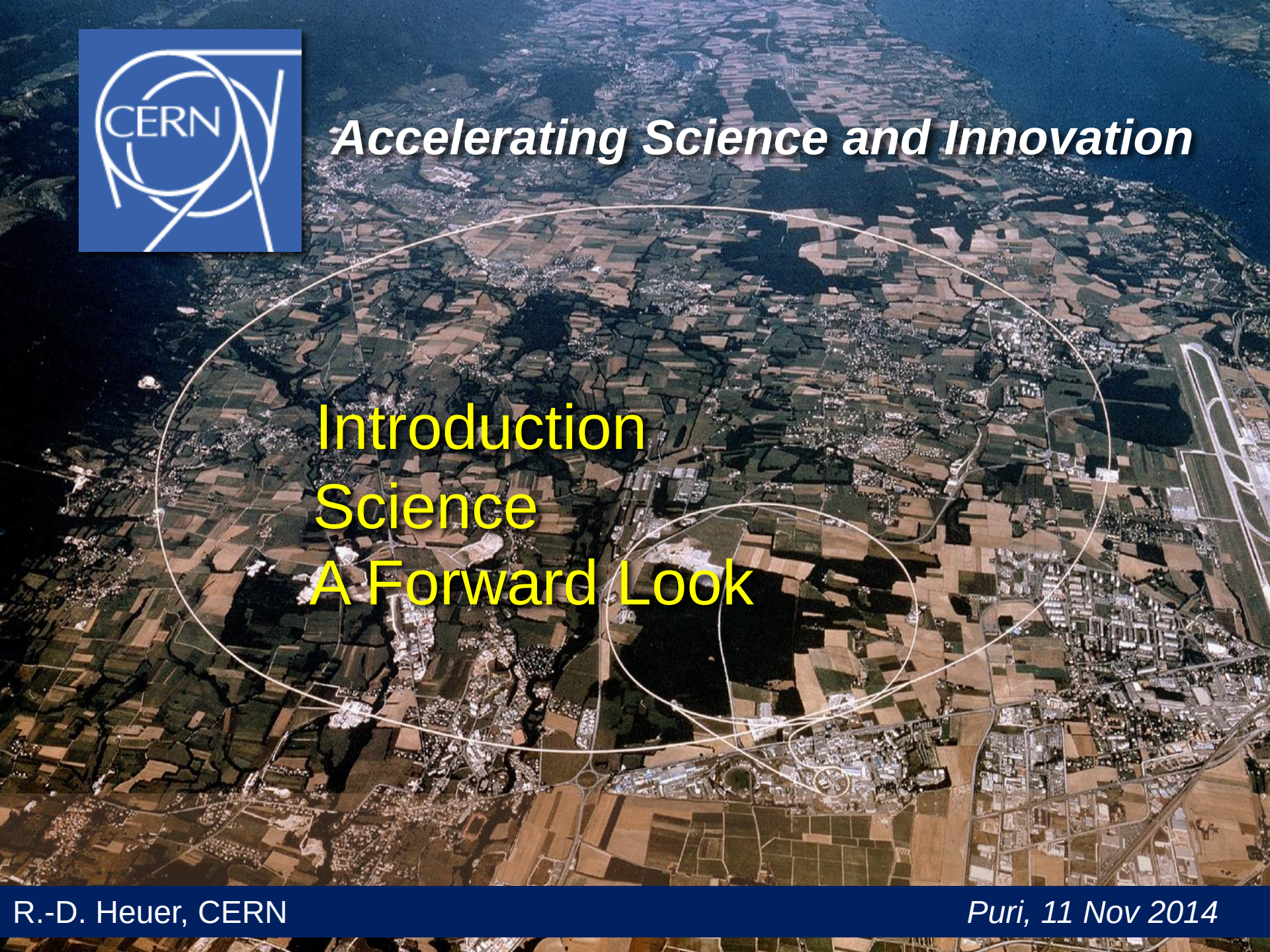
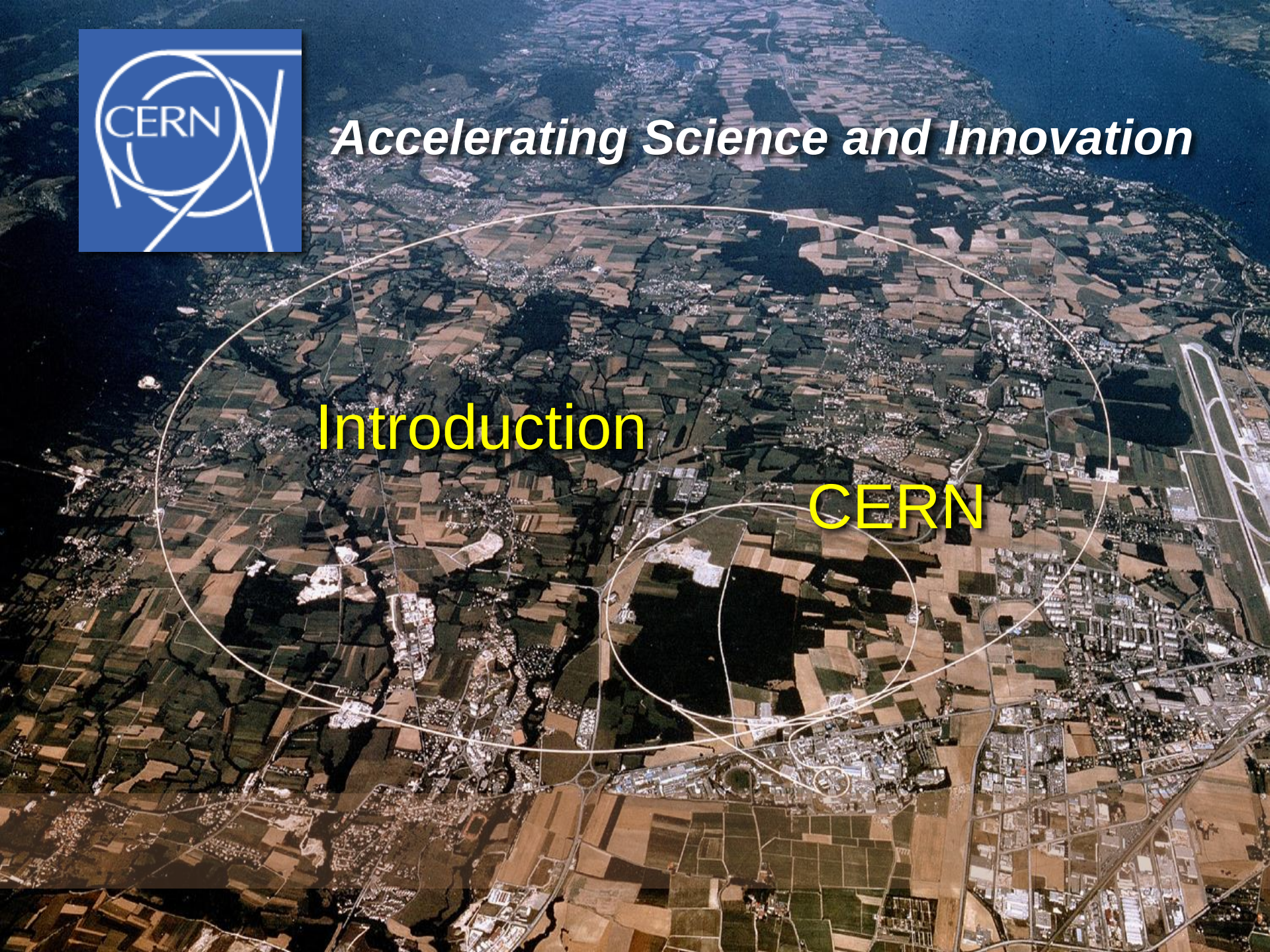
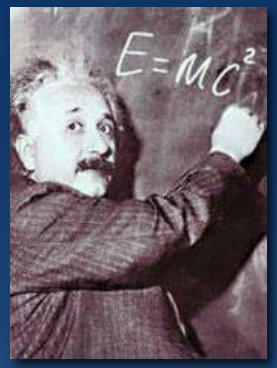

CERN
Accelerating Science and Innovation
Introduction
Science
A Forward Look


CERN
Accelerating Science and Innovation
Introduction
CERN

The Mission of CERN

- **Push back** the frontiers of knowledge

  E.g. the secrets of the Big Bang …what was the matter like within 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 was founded 1954: 12 European States

"Science for Peace"

Today: 21 Member States

~ 2300 staff
~ 1600 other paid personnel
~ 10500 scientific users

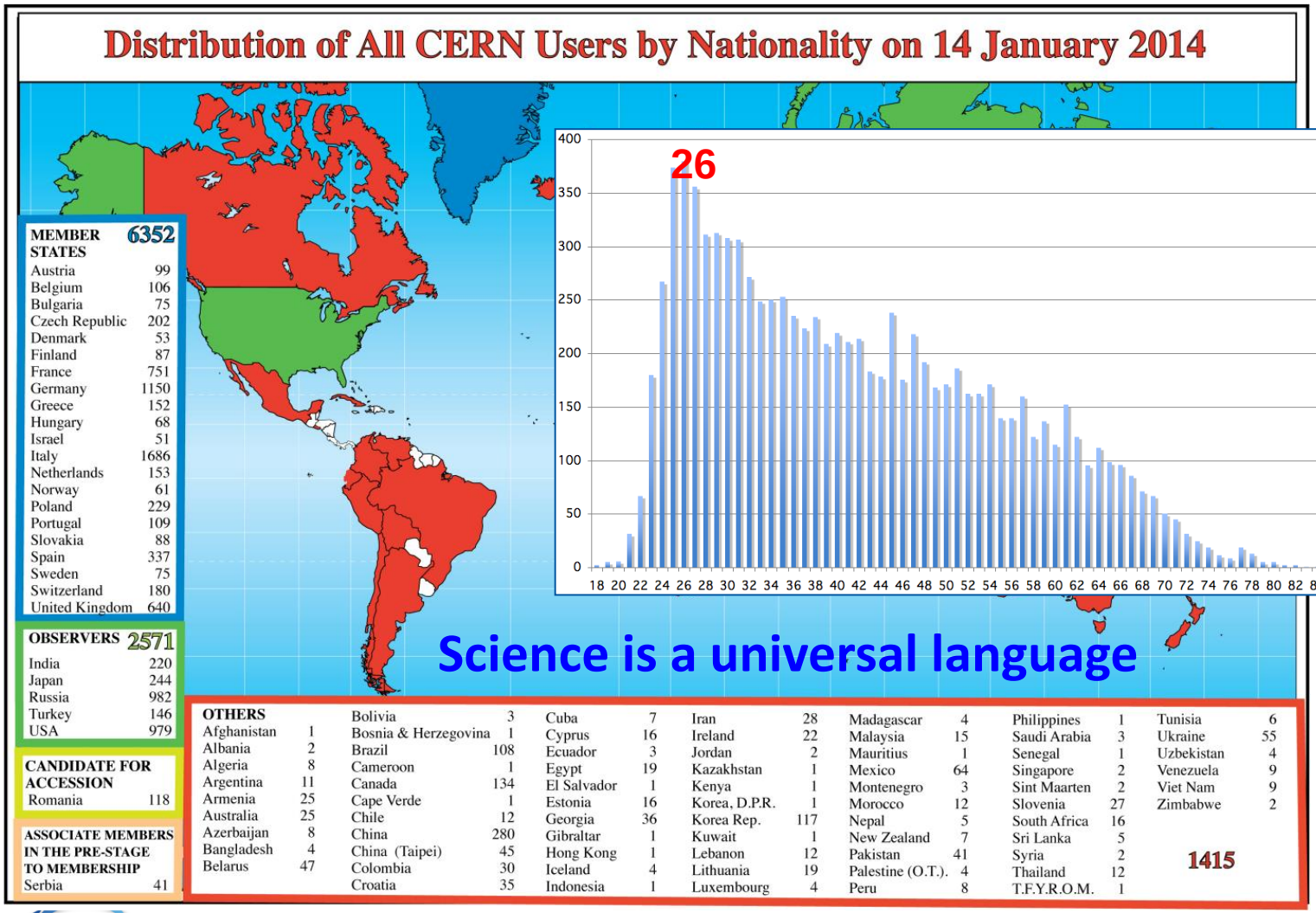
Member States: Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, the Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom

States in accession to Membership: Romania, Serbia

Applicant States for Membership or Associate Membership: Brazil, Croatia, Cyprus, Pakistan, Russia, Slovenia, Turkey, Ukraine

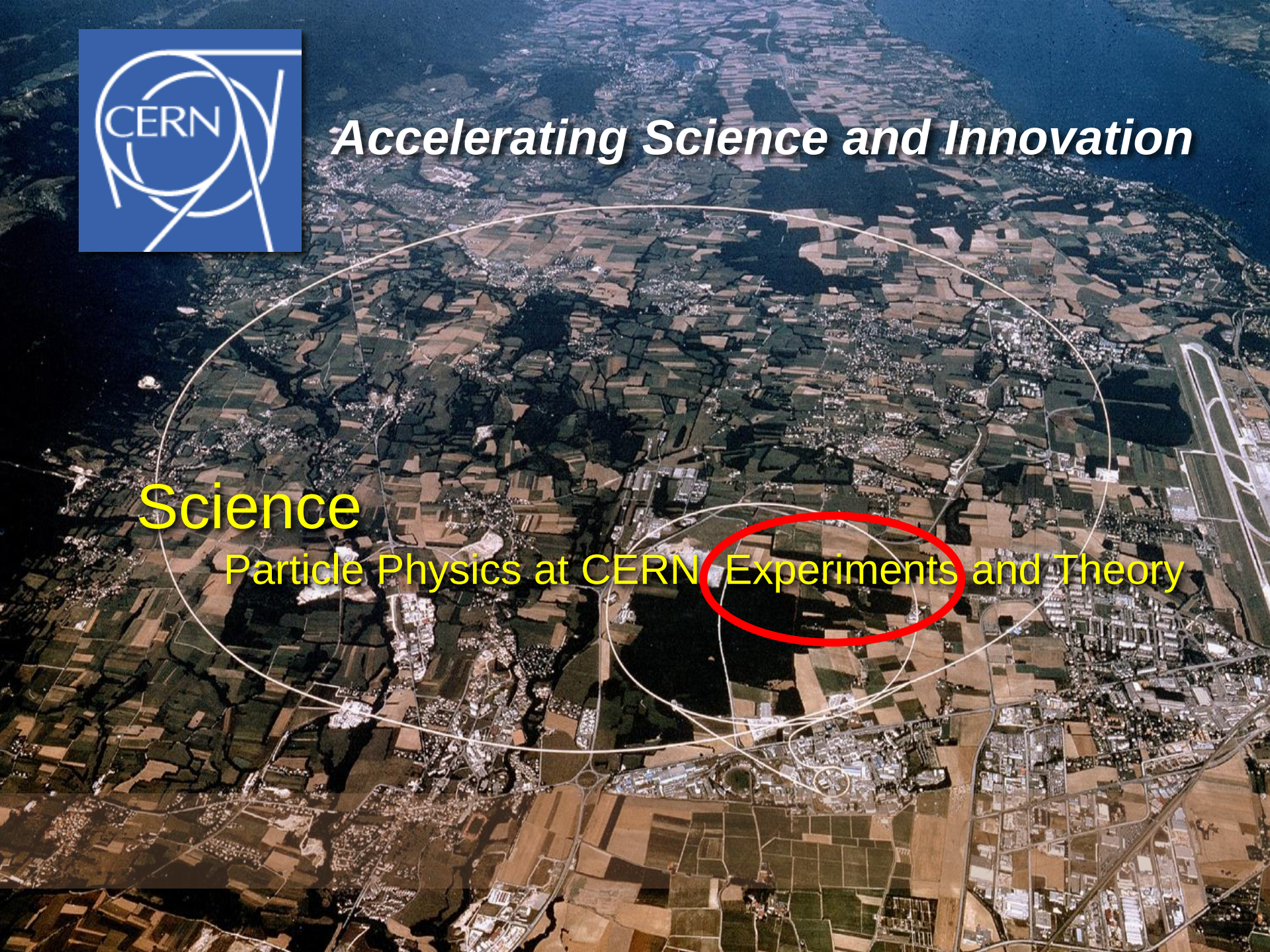
Observers to Council: India, Japan, Russia, Turkey, United States of America; European Commission and UNESCO

Breaking the Walls between Cultures and Nations since 1954



CERN

60 YEARS / ANS CERN

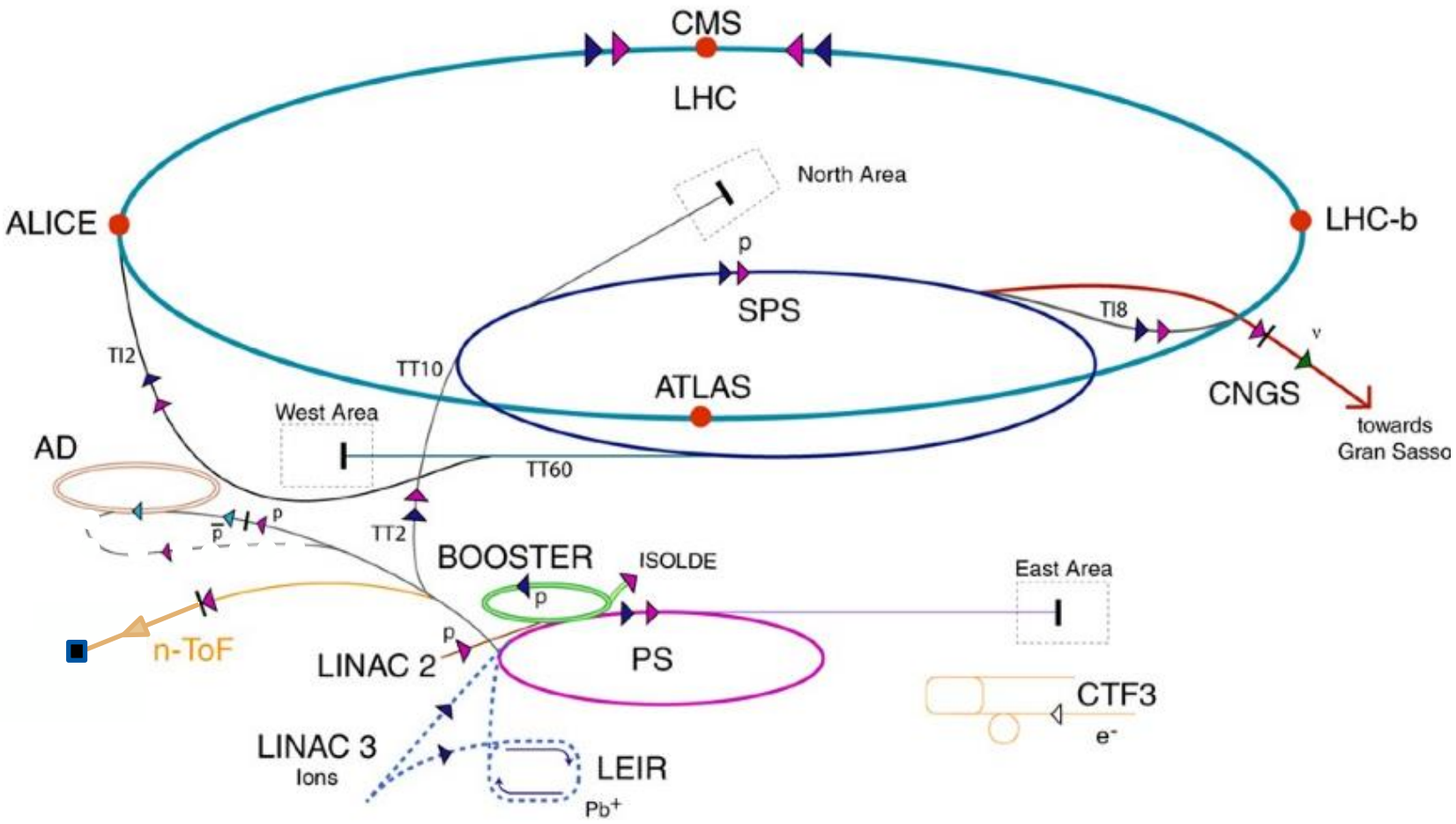

CERN
Accelerating Science and Innovation
Science
Particle Physics at CERN: Experiments and Theory

Starting 1954 …..

Mid 1950's the first accelerator (the synchrocyclotron) arrives . . .

CERN | 60 YEARS / ANS CERN

CERN Accelerator Complex today



CERN

YEARS / ANS CERN

The Particle Physics Landscape at CERN

High Energy Frontier

LHC

Hadronic Matter

deconfinement
non-perturbative QCD
hadron structure

Low Energy

heavy flavours / rare decays
neutrino oscillations
anti-matter

Non-accelerator

dark matter
astroparticles

Multidisciplinary

climate, medicine

Non-LHC Particle Physics = o(1000) physicists / o(20) experiments

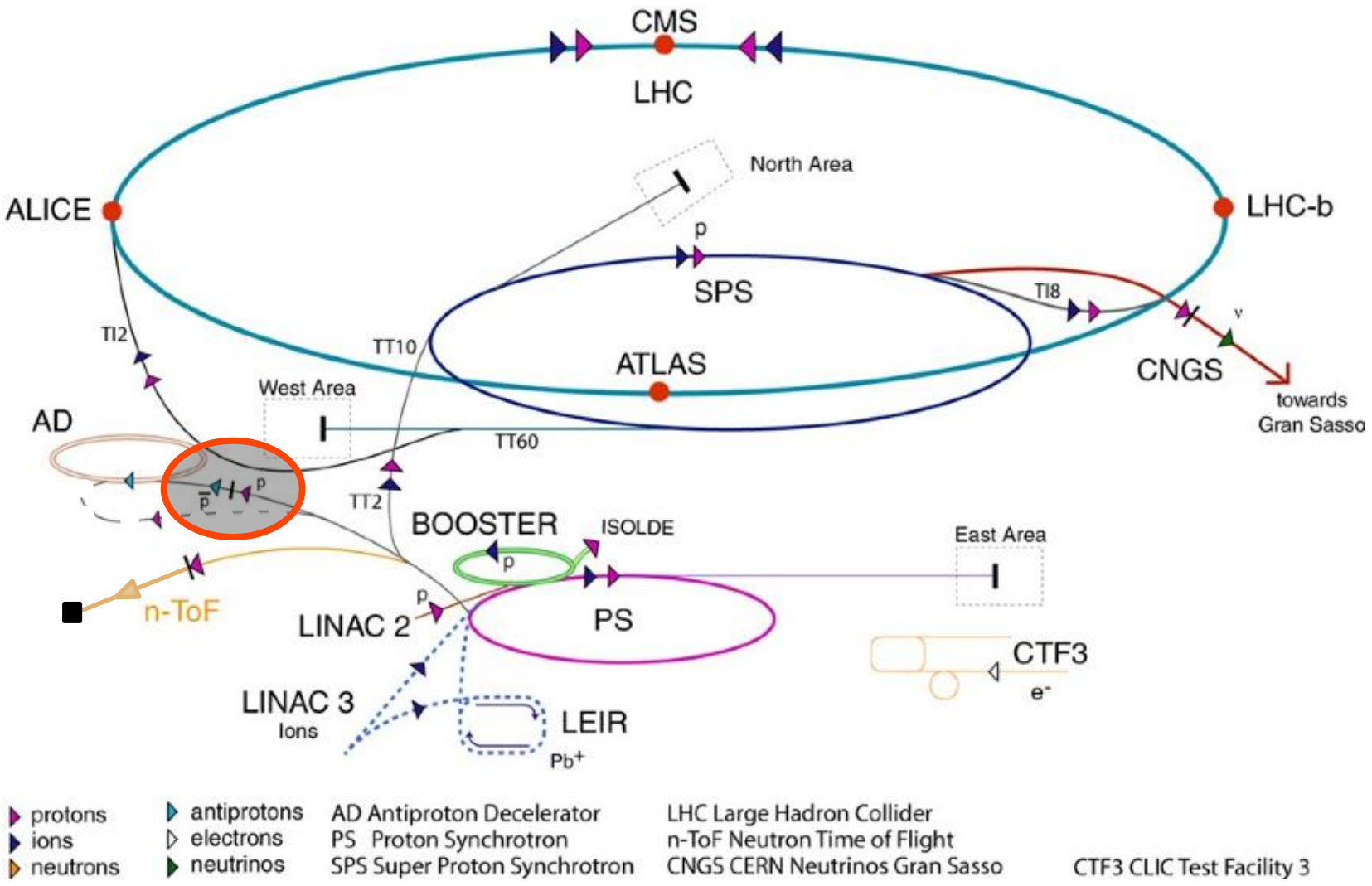
In the past few years

Several breakthroughs !

Steady progress of other programs

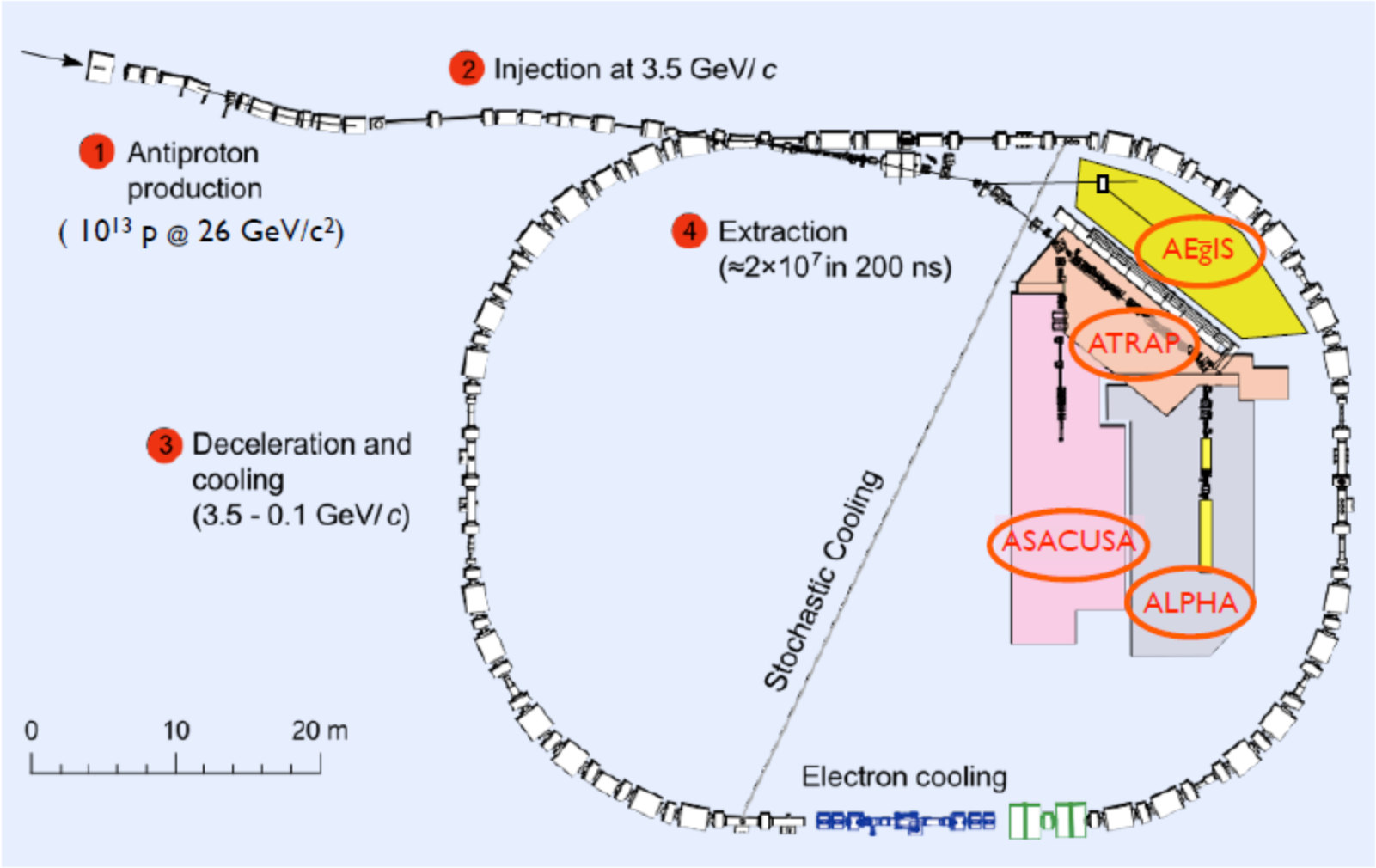
New mid-term and long-term projects started or in discussion

CERN Accelerator Complex



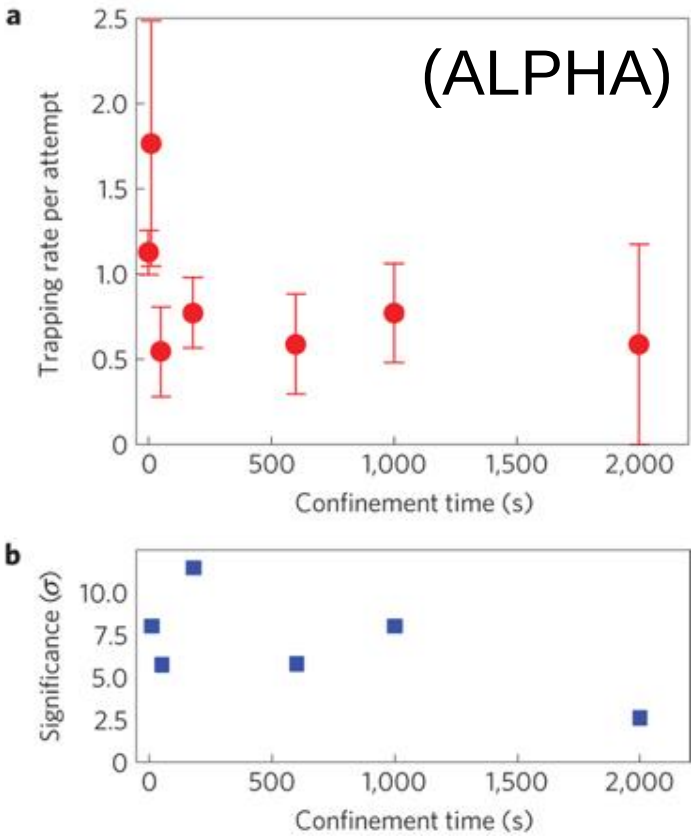
AD (current situation)

Antiproton decelerator

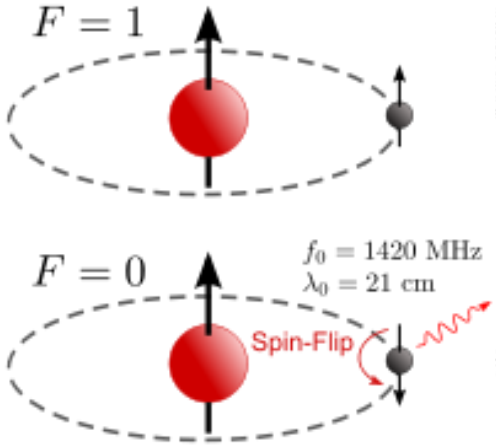


Spectroscopy with trapped antihydrogen?

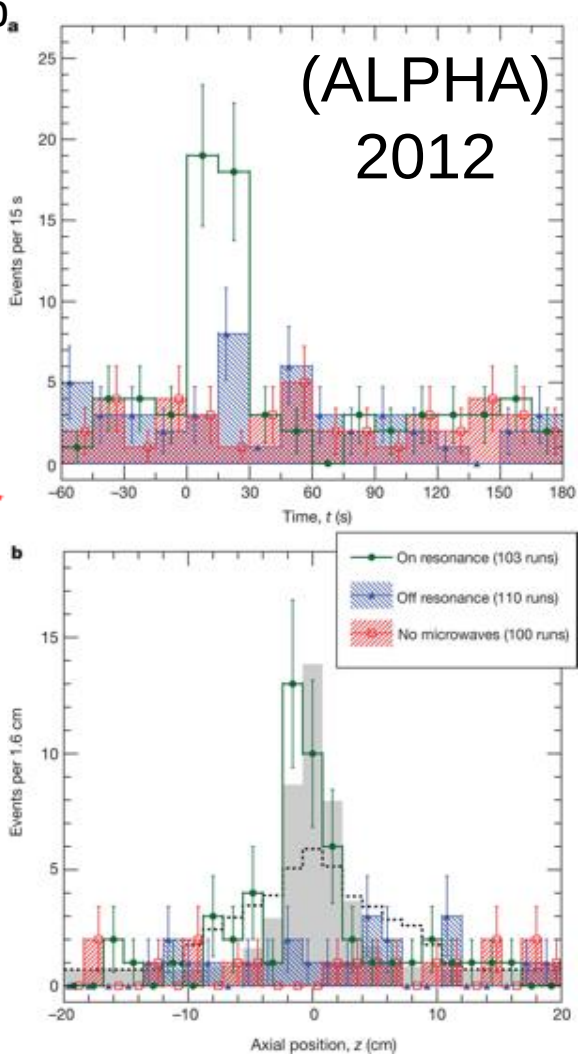
Antihydrogen atom trapping time



Spectroscopy:
HFS
via microwave



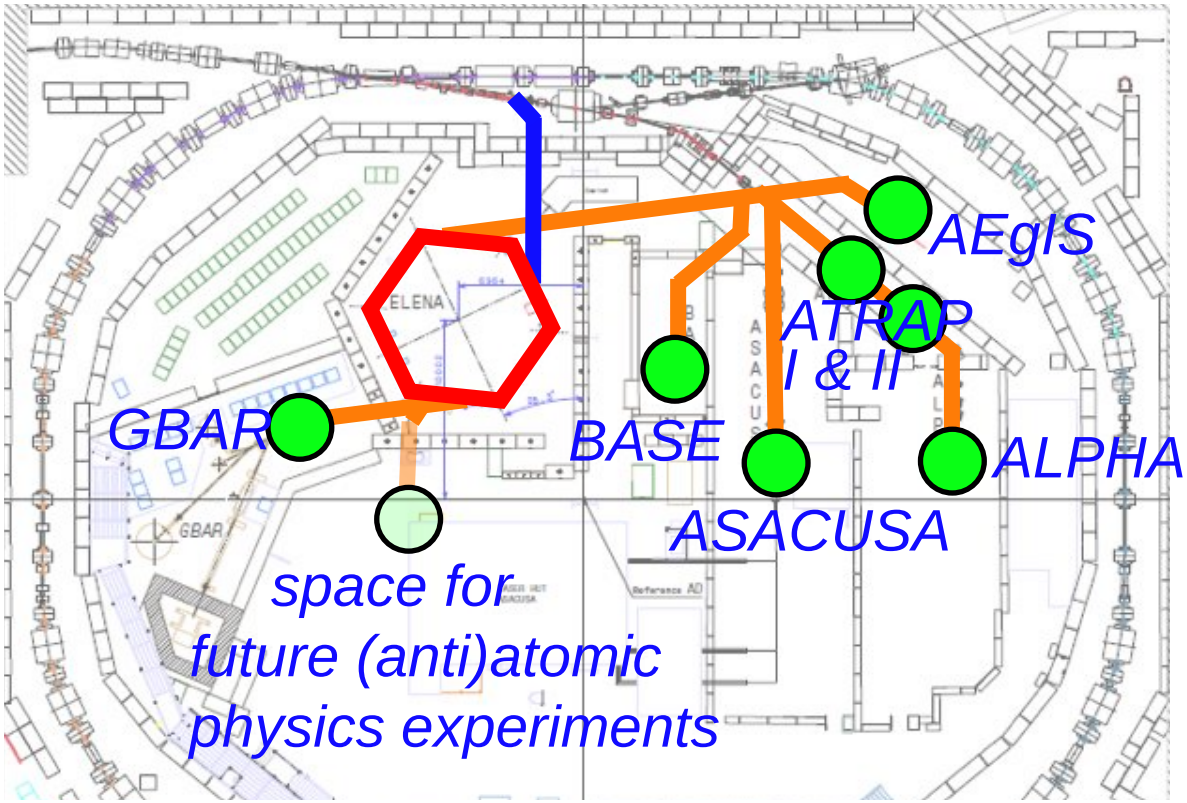
but: B-field varies strongly over trap



Next steps: better cooling, more atoms, laser spectroscopy

increasing & continuous demand for antiprotons,
current methods for trapping them are very inefficient

➔ELENA (will start 2017)



- dramatically slows down the antiprotons from the AD
- increases the trapping efficiency x 100
- allows 4 experiments to run in parallel

The Particle Physics Landscape at CERN

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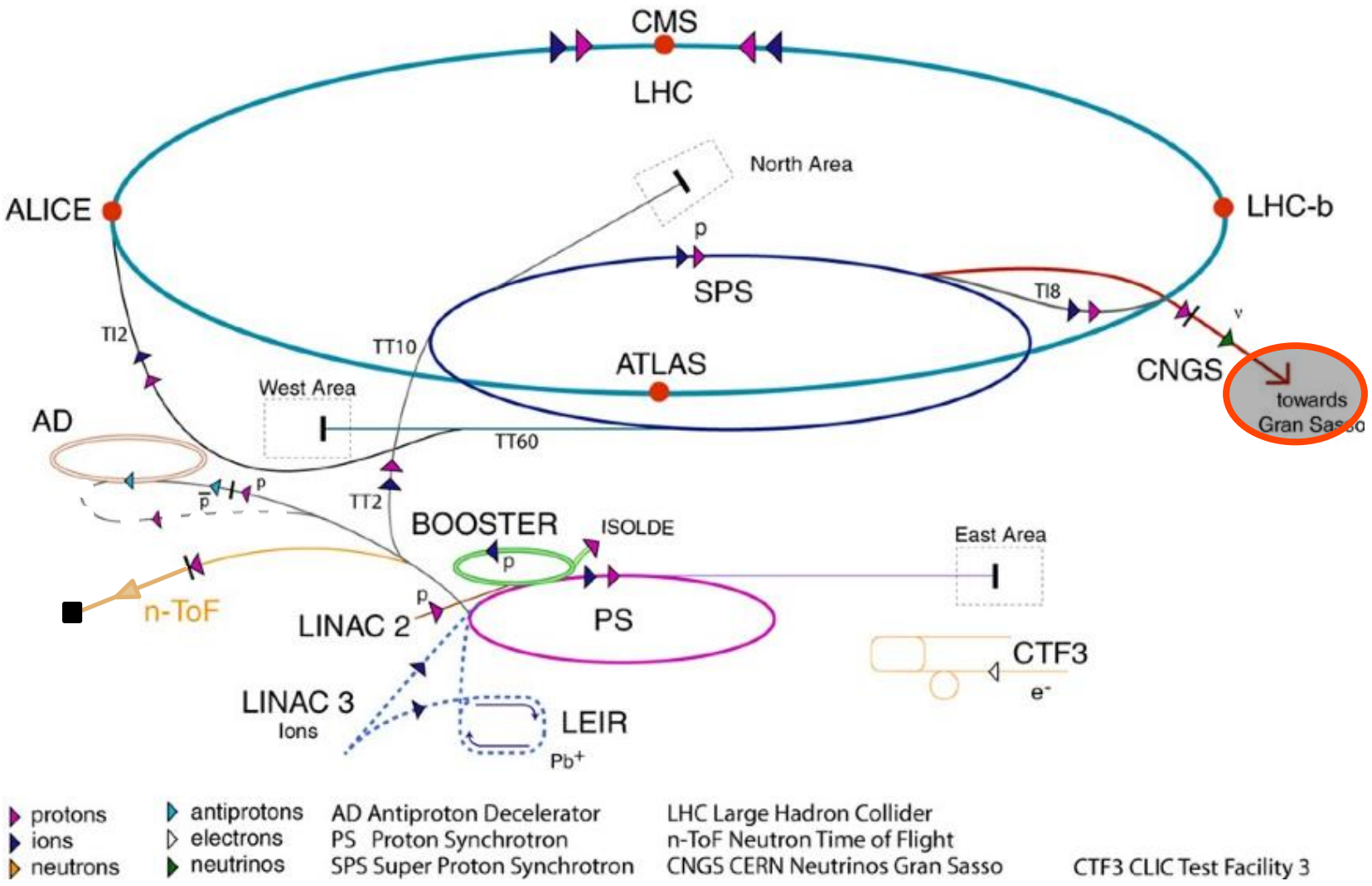
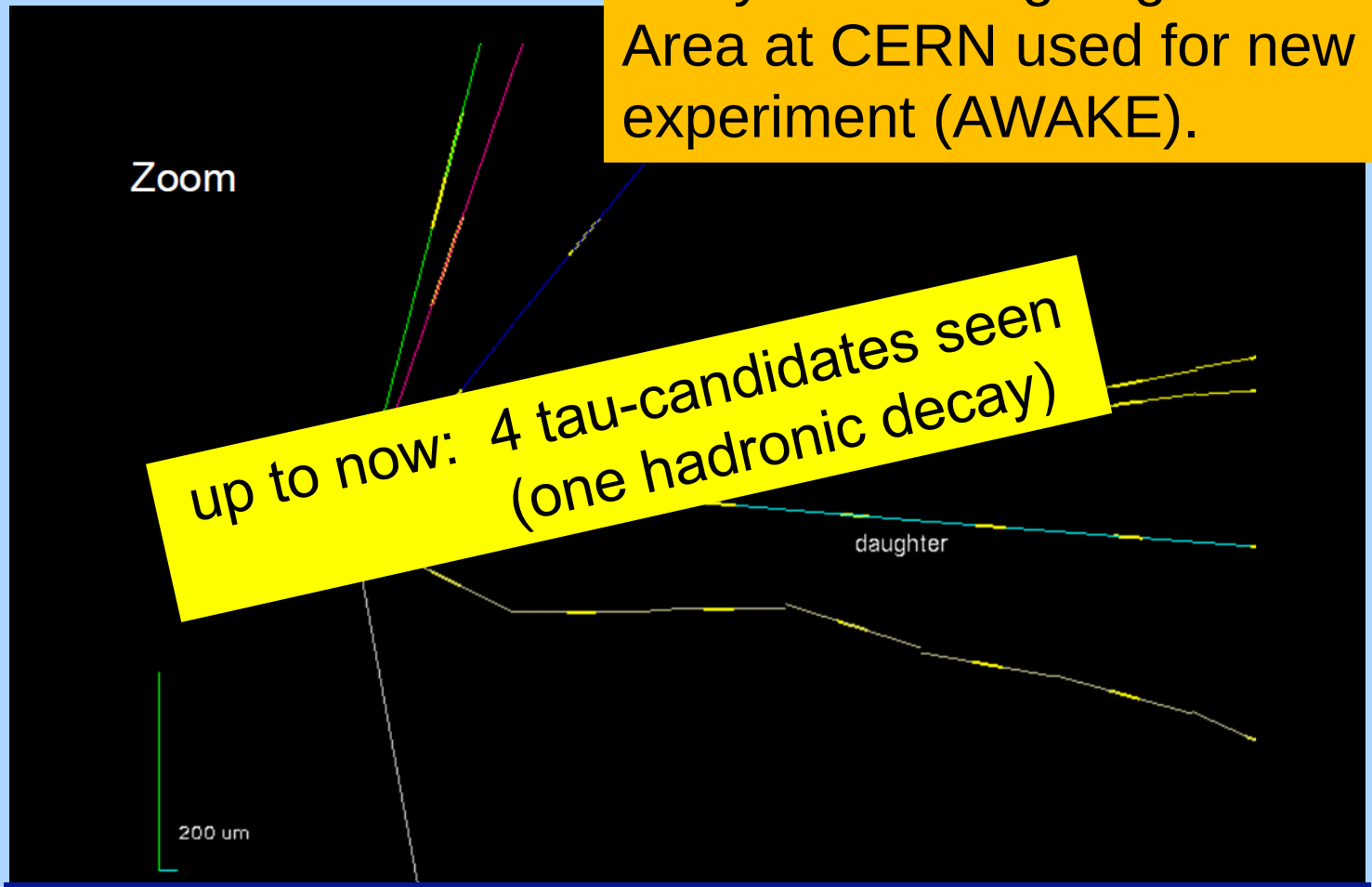
CERN Accelerator Complex



CNGS - OPERA

Data taking now terminated, analysis still ongoing.
Area at CERN used for new experiment (AWAKE).

First υ_τ Candidate



Muonless event 9234119599, taken on 22 August 2009, 19:27 (UTC)
(as seen by the electronic detectors)

The Particle Physics Landscape at CERN

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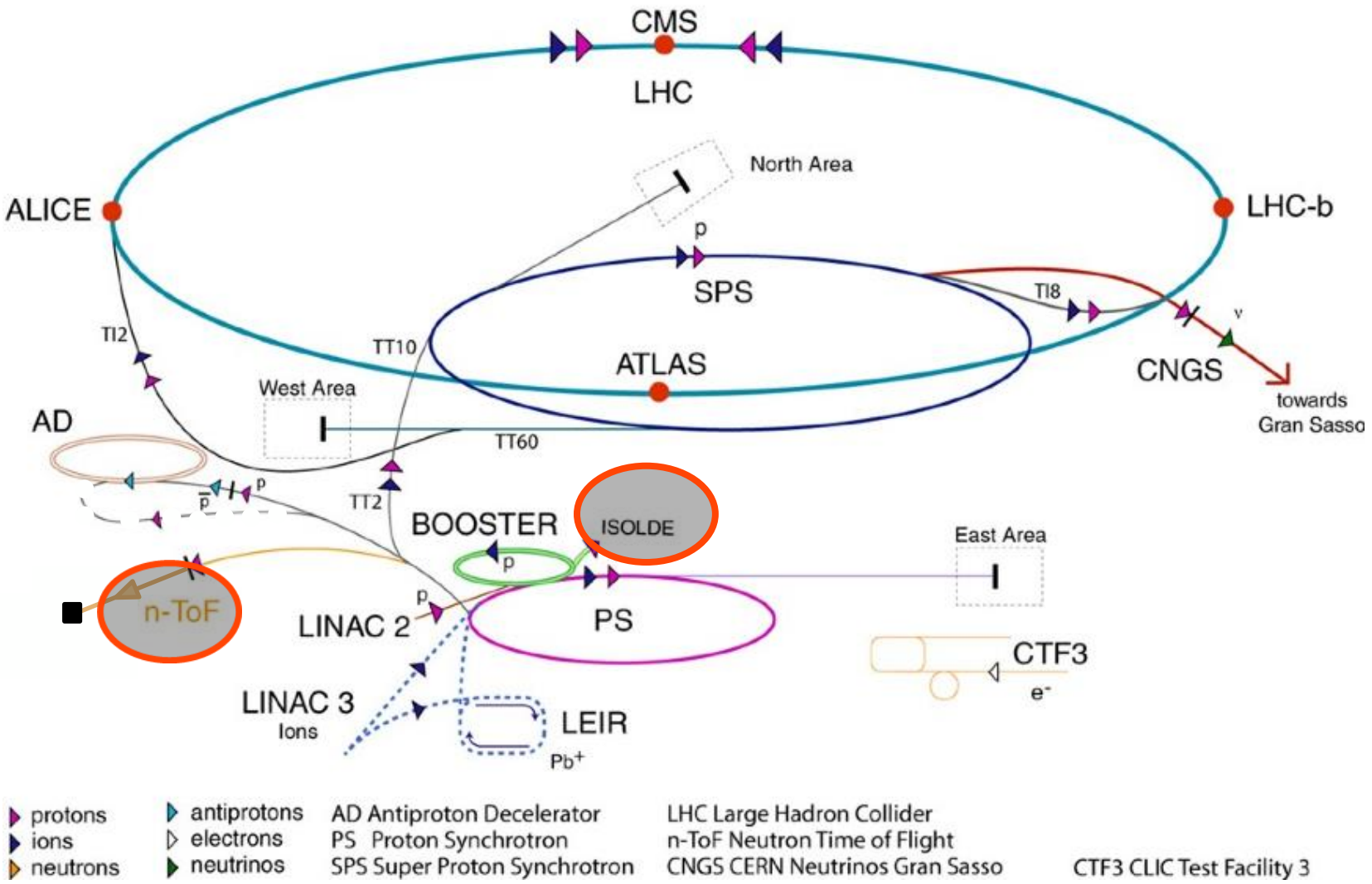
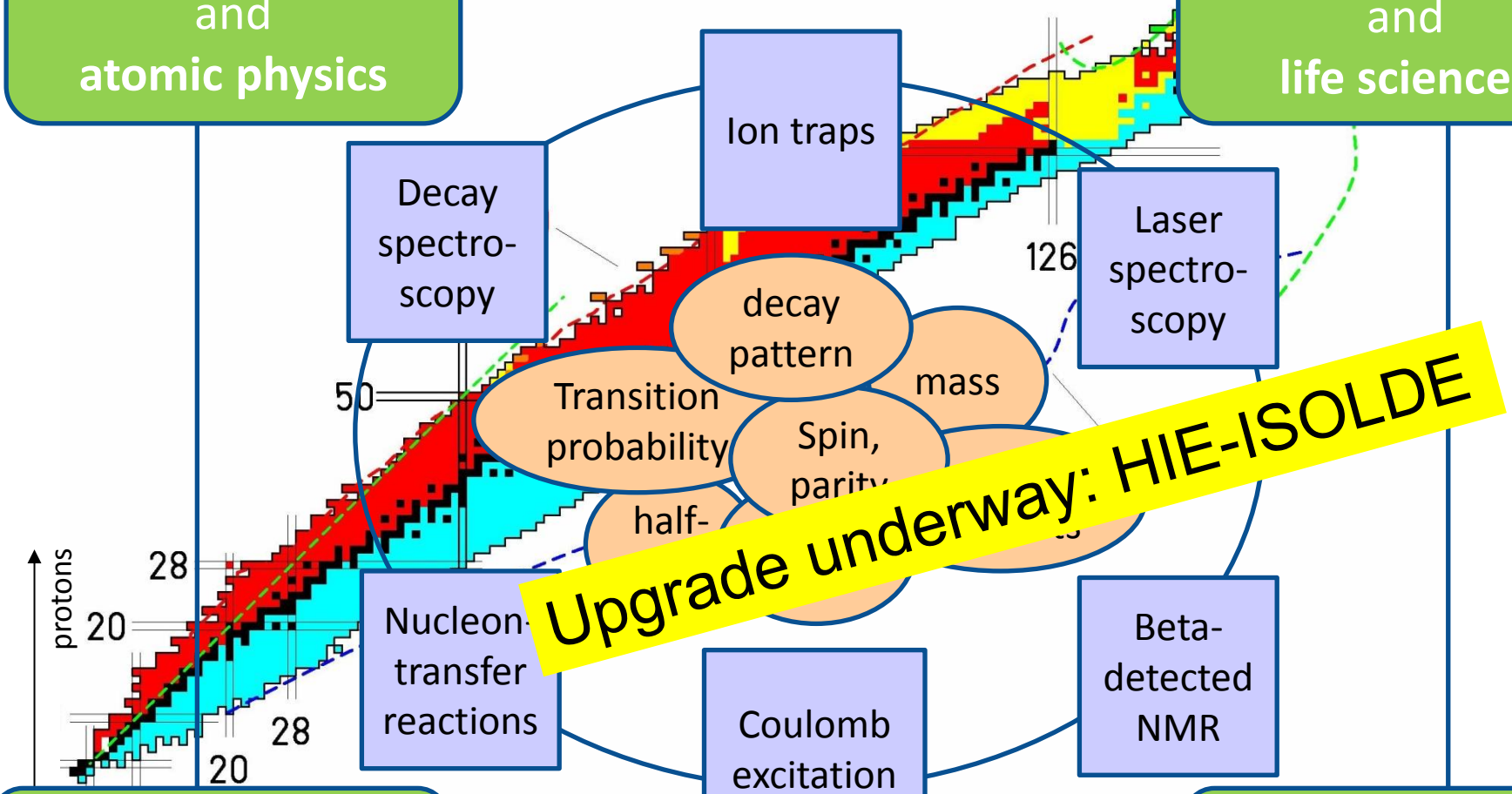


Research with radioactive nuclides

More than 700 nuclides of over 70 chemical elements delivered

Nuclear physics and **atomic physics**

Material science and **life sciences**



Fundamental interactions

Nuclear astrophysics

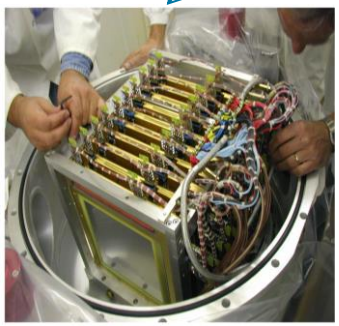
Techniques: all available at ISOLDE

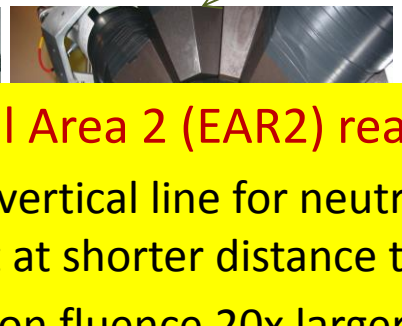
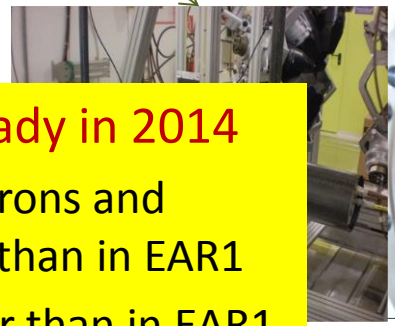
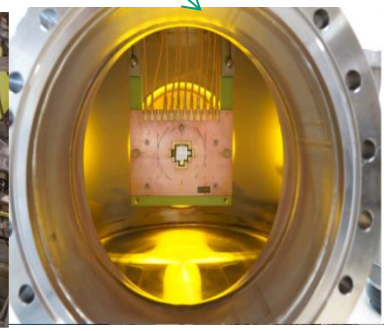
n_TOF physics

100 members, 32 institutions

Nuclear technologies | Nuclear Astrophysics | Medical applications | Basic Nucl. Phys.

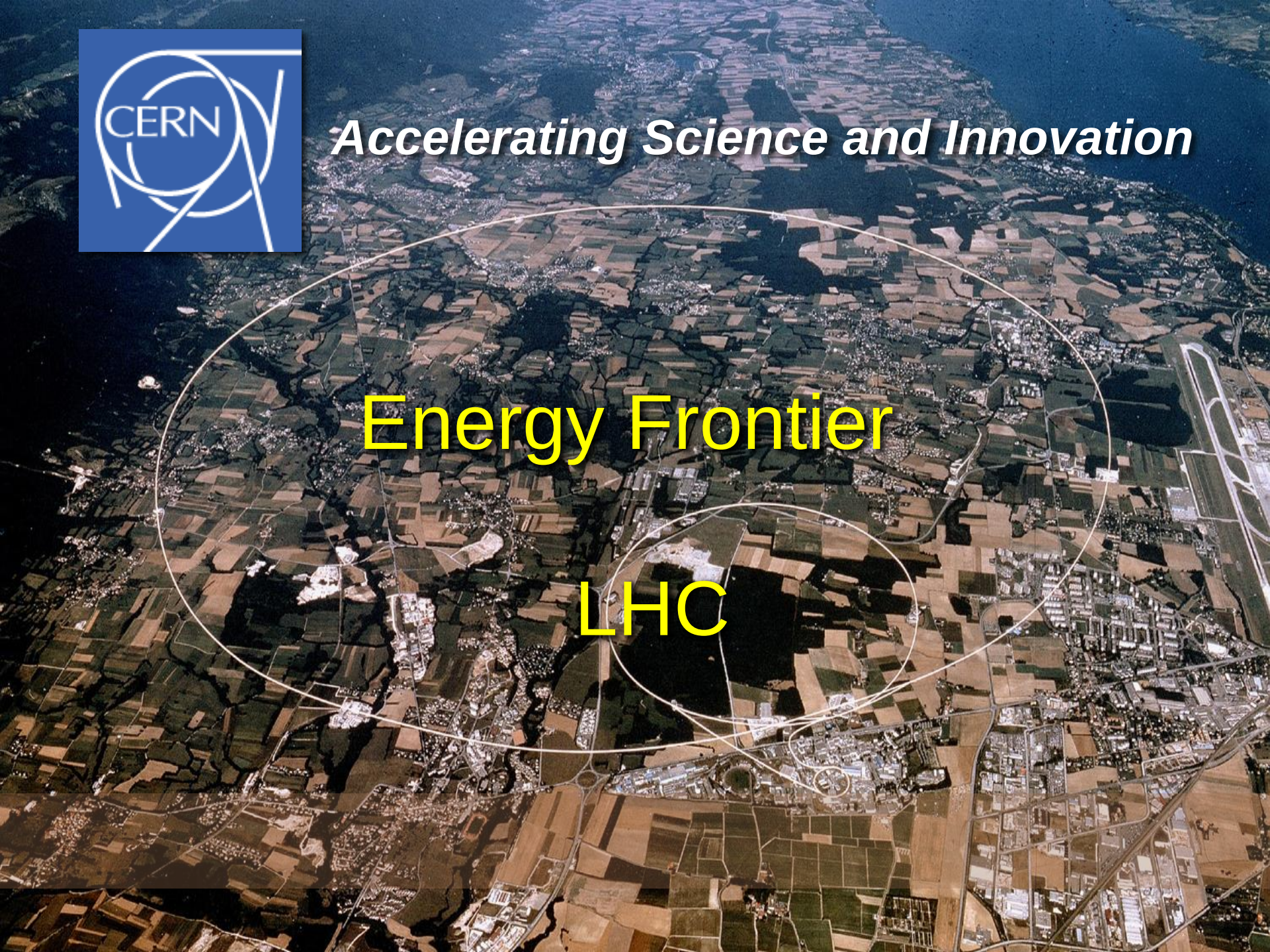
FF Ang. Distribution	Fission	Neutron capture	(n,chp)
^{237}Np, ^{234,235,238}U	^{240,242}Pu, ^{235}U	^{25}Mg, ^{88}Sr, ^{93}Zr, ^{235}U	^{10}B, ^{27}Al, ^{33}S, ^{59}Ni,



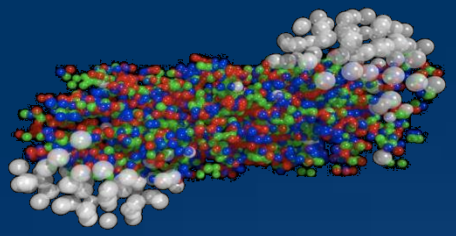
Experimental Area 2 (EAR2) ready in 2014

- New vertical line for neutrons and target at shorter distance than in EAR1
- Neutron fluence 20x larger than in EAR1 but lower resolution due to shorter TOF

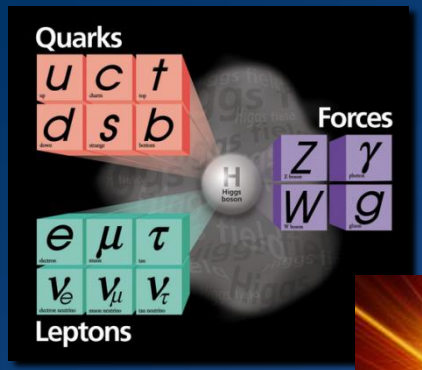

CERN
Accelerating Science and Innovation
Energy Frontier
LHC

The study of LHC data will allow us to answer some of the key questions ...

Will we understand the primordial state of matter after the Big Bang before protons and neutrons formed?



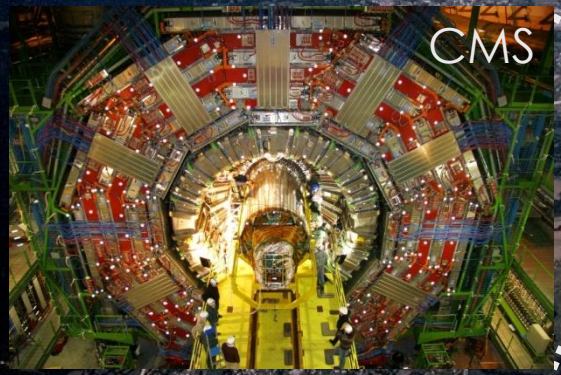
Have we found the Higgs particle that is 'responsible for giving mass' to all particles?



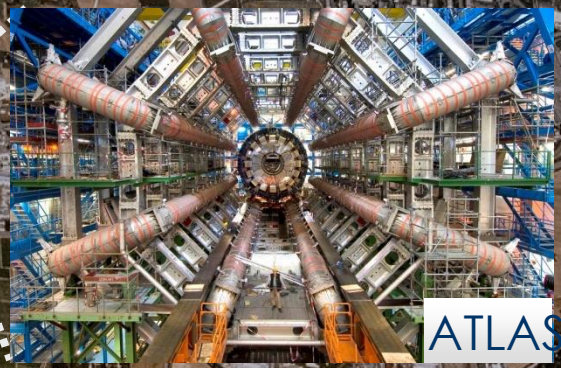
Will we find the reason why antimatter and matter did not completely destroy each other?

Will we find the particle(s) that make up the mysterious 'dark matter' in our Universe? And what's 'dark energy'?

2010: a New Era in Fundamental Science

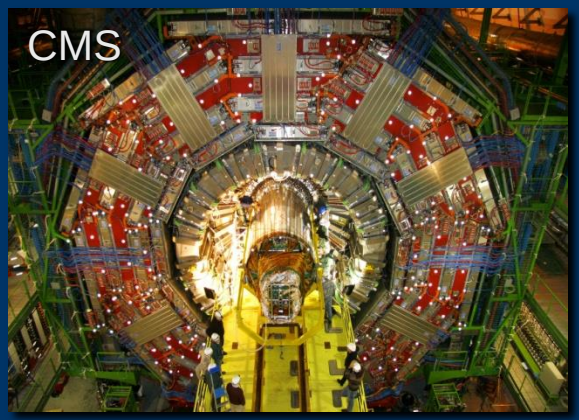


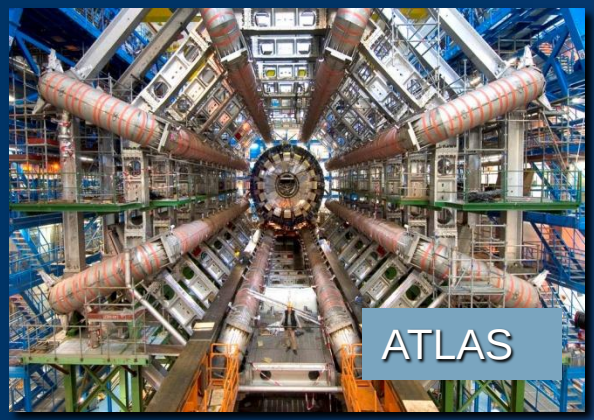
Exploration of a new energy frontier
Proton-proton and Heavy Ion collisions
at E_{CM} up to 14 TeV



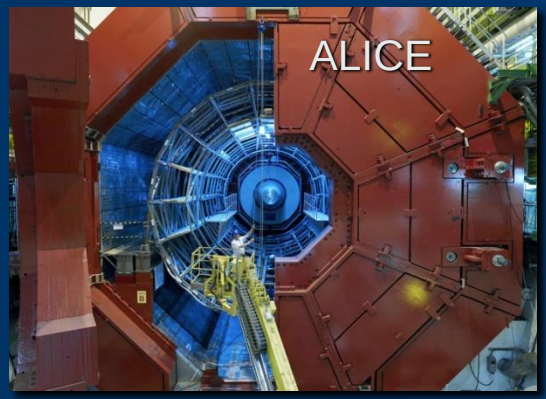
LHC Experiments → complementary

Specialised detector to study b-quarks → CPV





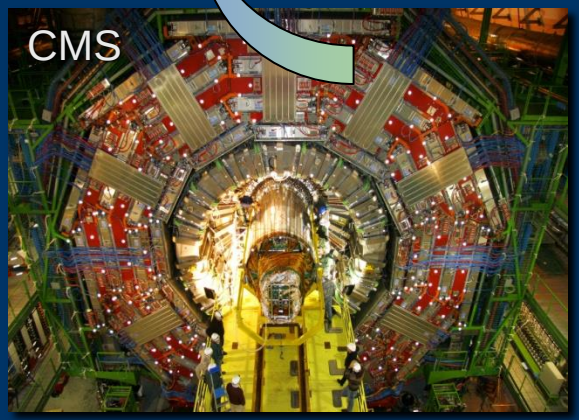
General purpose detectors

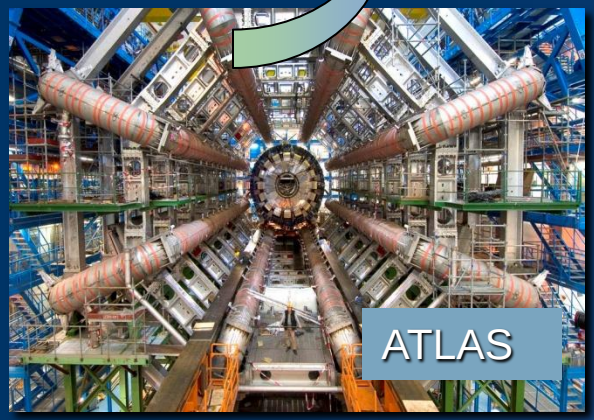


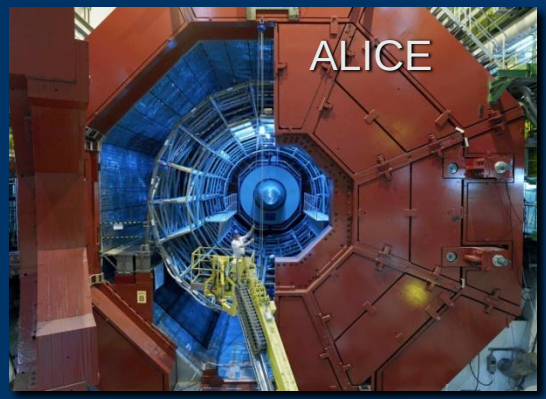
Specialised detector to study heavy ion collisions

LHC Experiments → complementary

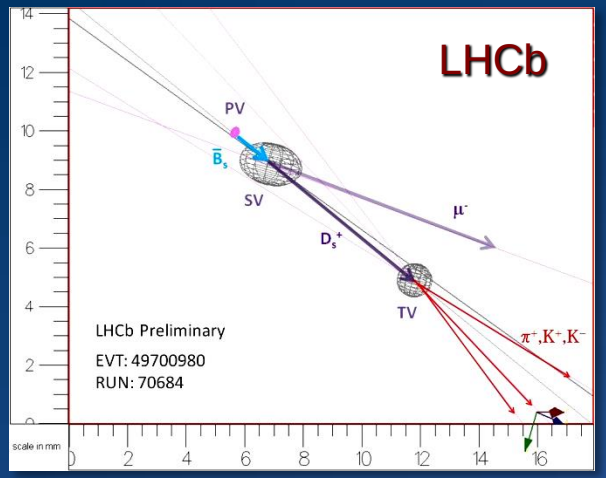
Overlap in physics reach

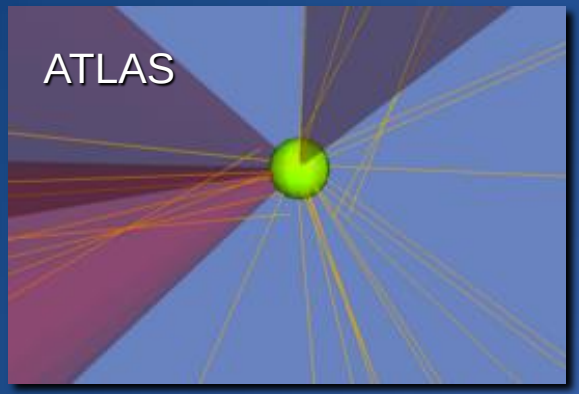






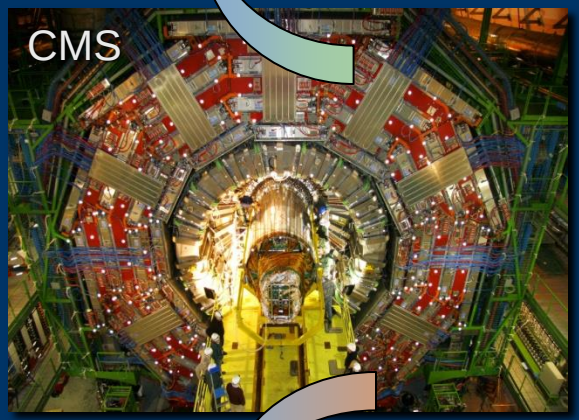
Key feature: reconstruct secondary vertex

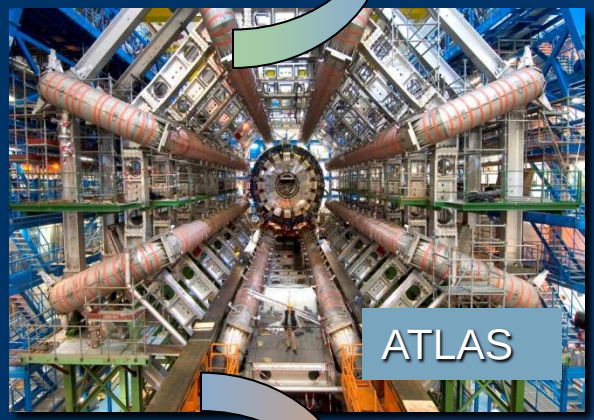




LHC Experiments → complementary

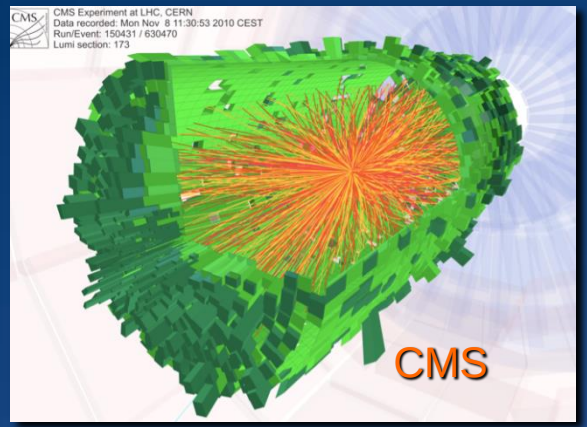
Overlap in physics reach

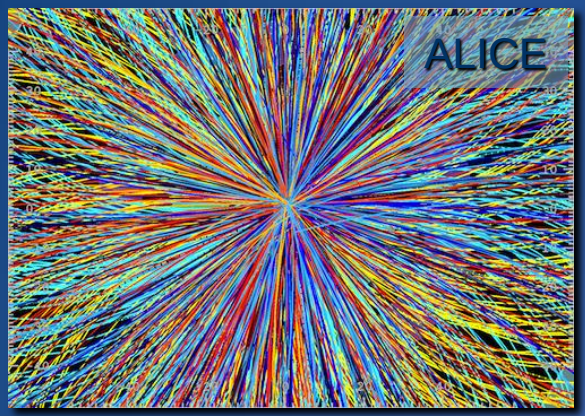


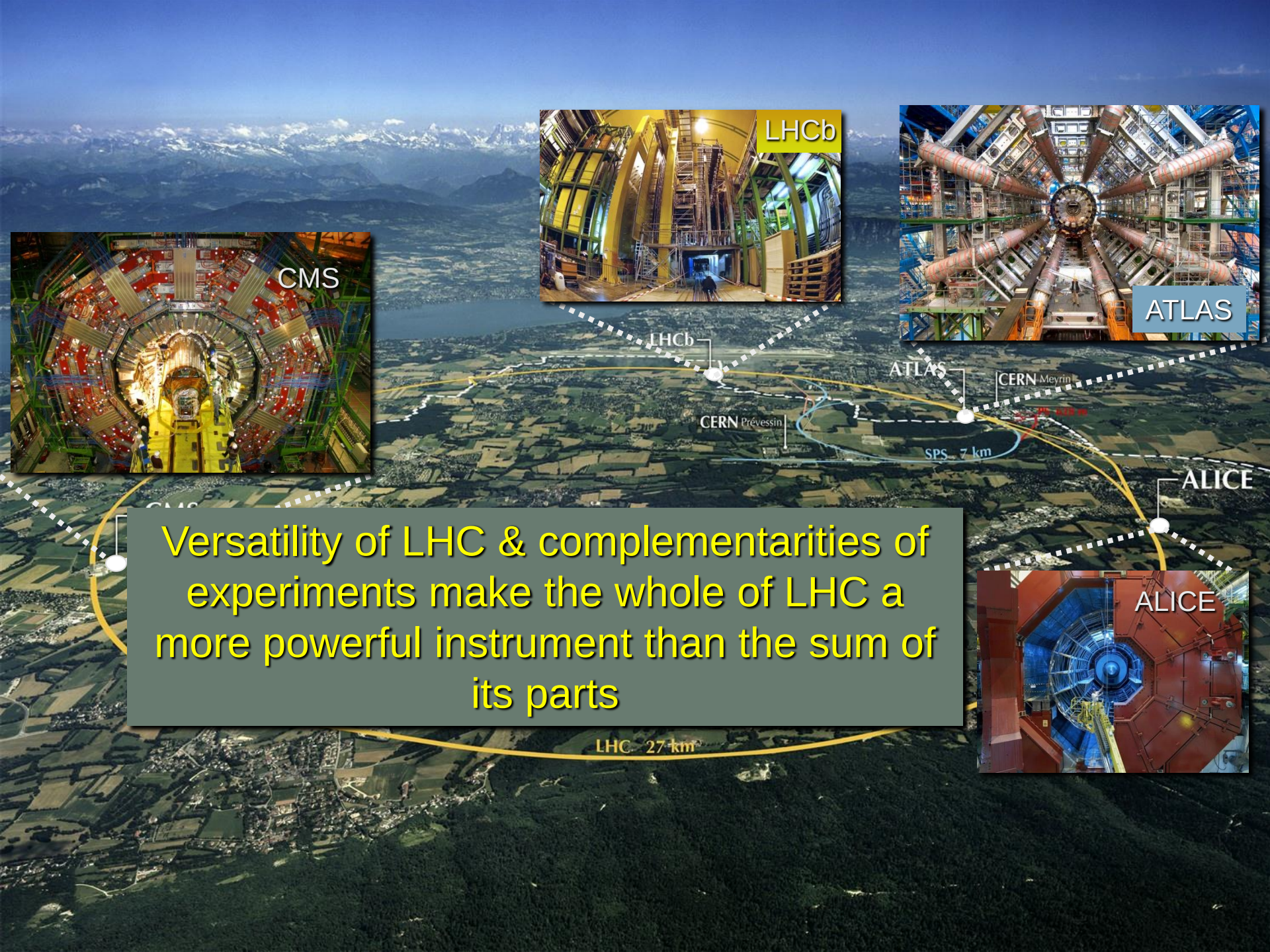


Overlap in physics reach

Key feature: reconstruct > 20’000 charged tracks in one event







Versatility of LHC & complementarities of experiments make the whole of LHC a more powerful instrument than the sum of its parts

LHC run 1
at 7 and 8 TeV

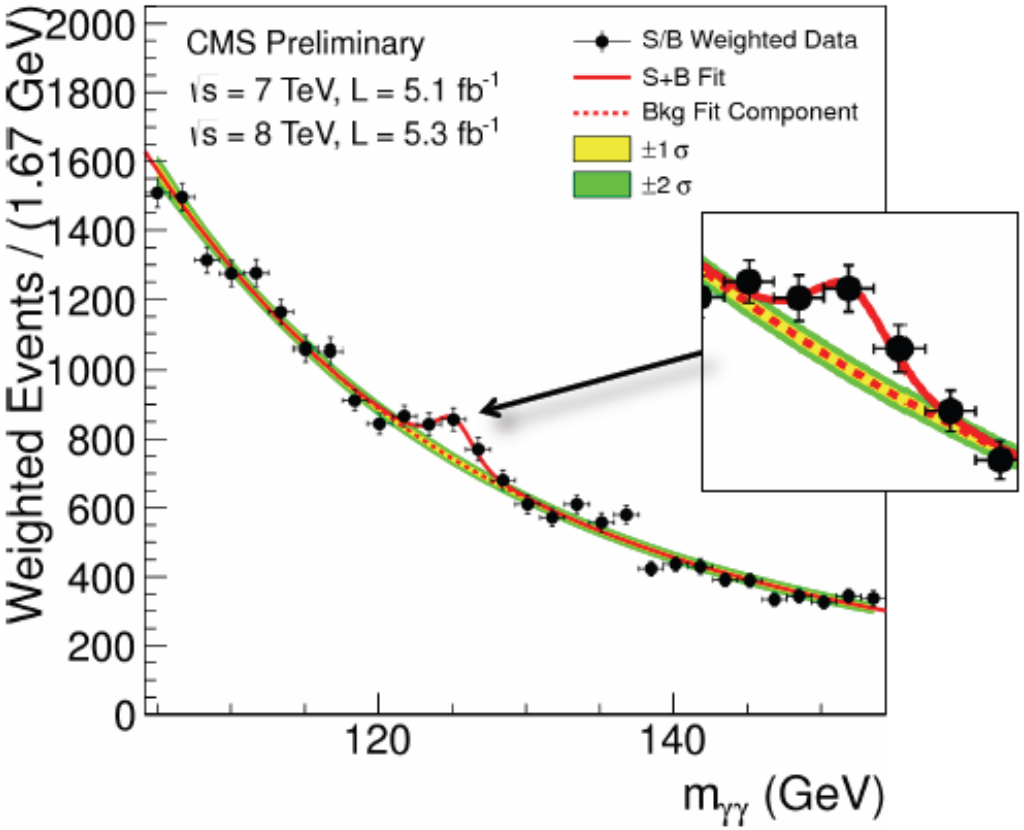
a great success

p-p / Pb-Pb / p-Pb

Discovery of a Higgs-boson,
messenger of the BEH mechanism

S/B Weighted Mass Distribution

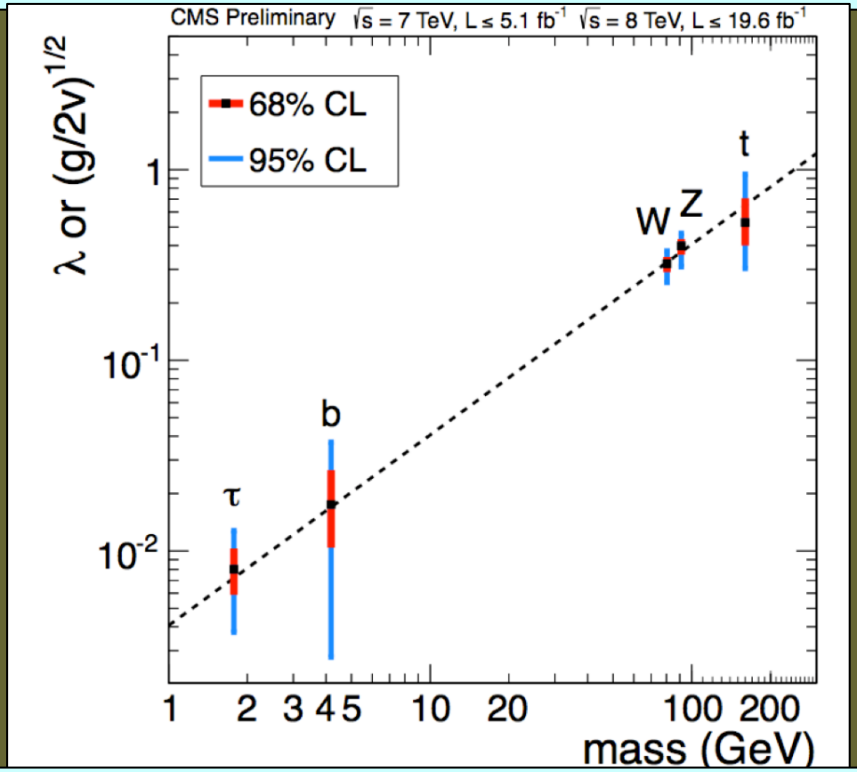
- Sum of mass distributions for each event class, weighted by S/B
  - B is integral of background model over a constant signal fraction interval



The new particle is a Higgs boson

ATLAS and CMS have verified the two “fingerprints”

1) To accomplish its job (providing mass) it interacts with other particles (in particular W, Z) with strength proportional to their masses



2) It has spin 0, it is representing a scalar field

It completes the Standard Model, thus describing ~5% of the Universe

What about the “Dark Universe” ?

The detailed study of the properties of this Higgs Boson could give

… information on Dark Matter
… first hints on Dark Energy

Four main results from LHC Run-1

1) We have **consolidated** the Standard Model
   (wealth of measurements at 7-8 TeV, including the rare B_s → μμ decay, very sensitive to New Physics)
   → it works BEAUTIFULLY …

2) We have **completed** the Standard Model: Discovery of the messenger of the BEH-field, the Higgs boson discovery
   (over 50 years of theoretical and experimental efforts !)

3) We found interesting properties of the hot dense matter

4) We have no evidence of new physics (YET)

What's next ?

post- H(126)-discovery

- Good reasons to expect more
  - We have really just begun the searches
  - Much space has yet to be accessed
  - And there are important new physics models yet-to-be invented
- Precision and rare physics
  - Beyond our direct production reach
    - LHC is a superb intensity frontier machine
- Invest
  - Powe triggers, computing
    - A sustained period of important results
    - And practical applications

The LHC is the only Higgs, (top, Z, W…) factory on the planet for many years to come!

Fabiola:

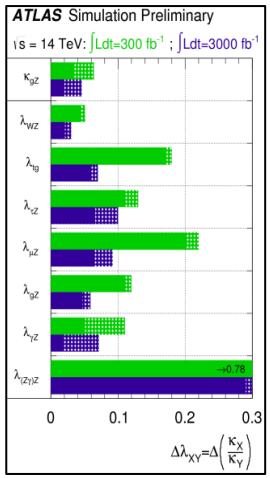
RLIUP summary 07 Nov 2013 AB

LHC --> HL-LHC: *THE* Higgs factory

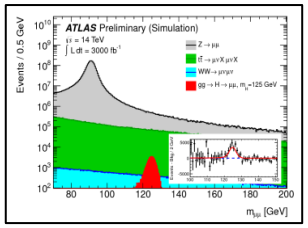
today : ATLAS+CMS have 1400 Higgs events
HL-LHC: (3000fb-1) > 3M/170M useful for precise measurement

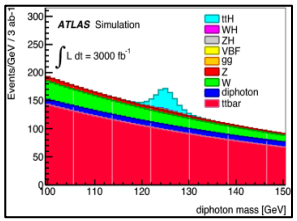
- ❑ Measure as many Higgs couplings to fermions and bosons as precisely as possible
- ❑ Measure Higgs self-couplings (give access to λ)
- ❑ Verify that the Higgs boson fixes the SM problems with W and Z scattering at high E

Couplings



x 1.5 to 2 for 300 --> 3000fb^{-1}



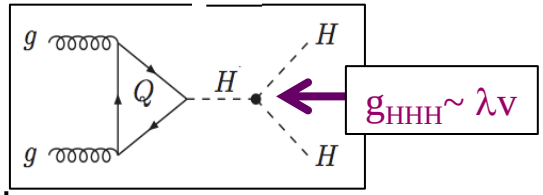


Access to rare processes

Self-coupling

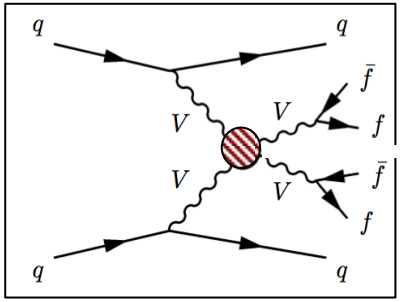
ttH
↳ γγ

H —> μμ



Difficult measurement
precision 30%(?) for 3000fb-1

Vector boson fusion



Check if Higgs does the (whole) job of cancelling divergences

European Strategy for Particle Physics

High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

c) The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme.

Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.

Particle Physics Projects Prioritisation Panel (P5)

Strategic Plan for U.S. Particle Physics

- Charge: A strategic plan, executable over 10 years, in the context of a 20-year global vision
- US community has come together to make a plan
  - Driven by the science
  - Meets fiscal
  - ...iders the global context
  - Resolves key issues for the field
  - Provides a continuous flow of results while making essential investments for the future

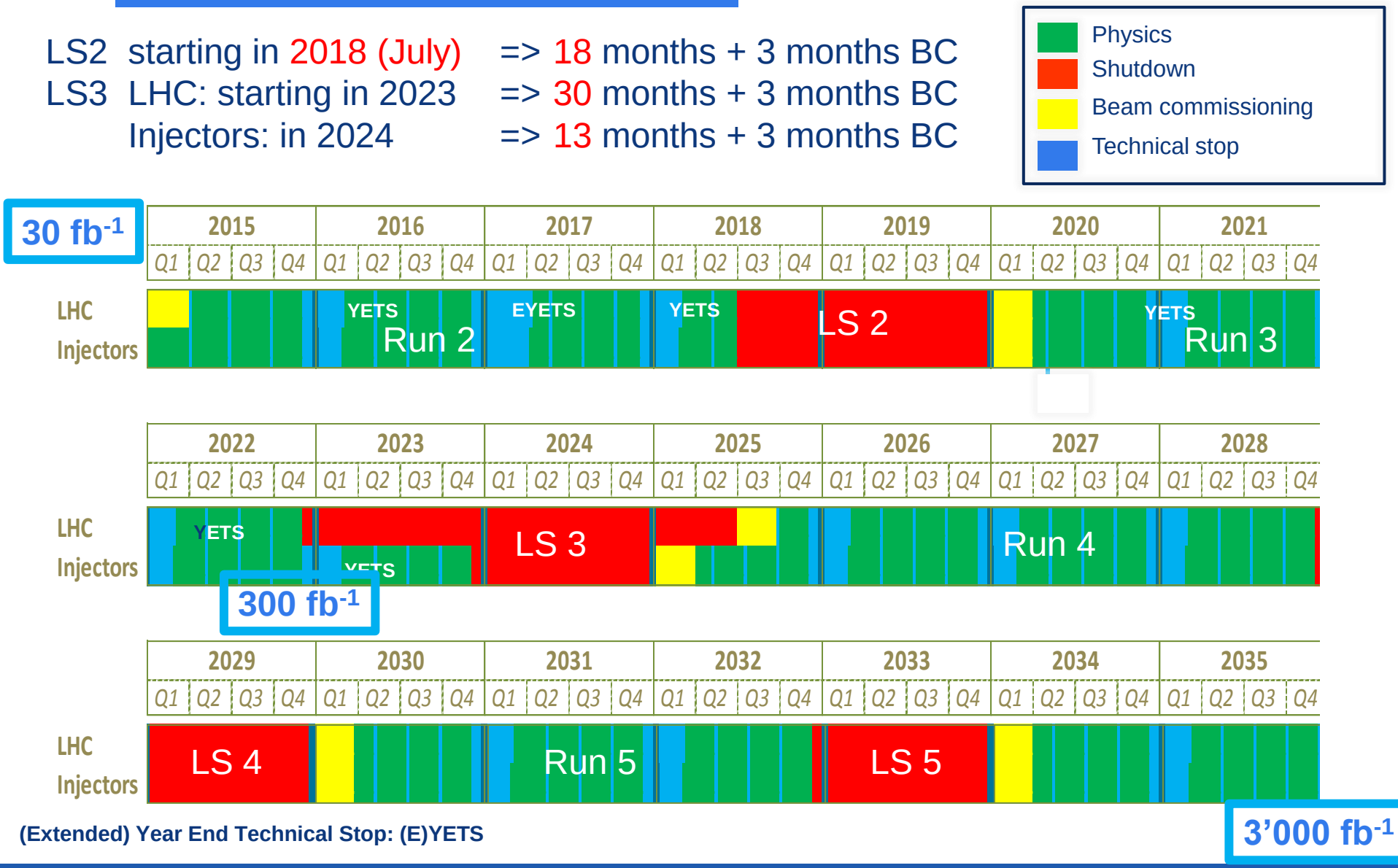
Recommendations in line with the European Strategy

From the P5 report

Recommendation 10: Complete the LHC phase-1 upgrades and continue the strong collaboration in the LHC with the phase-2 (HL-LHC) upgrades of the accelerator and both general-purpose experiments (ATLAS and CMS). **The LHC upgrades constitute our highest-priority near-term large project.**

LHC schedule beyond LS1

LS2 starting in 2018 (July) => 18 months + 3 months BC
LS3 LHC: starting in 2023 => 30 months + 3 months BC
Injectors: in 2024 => 13 months + 3 months BC



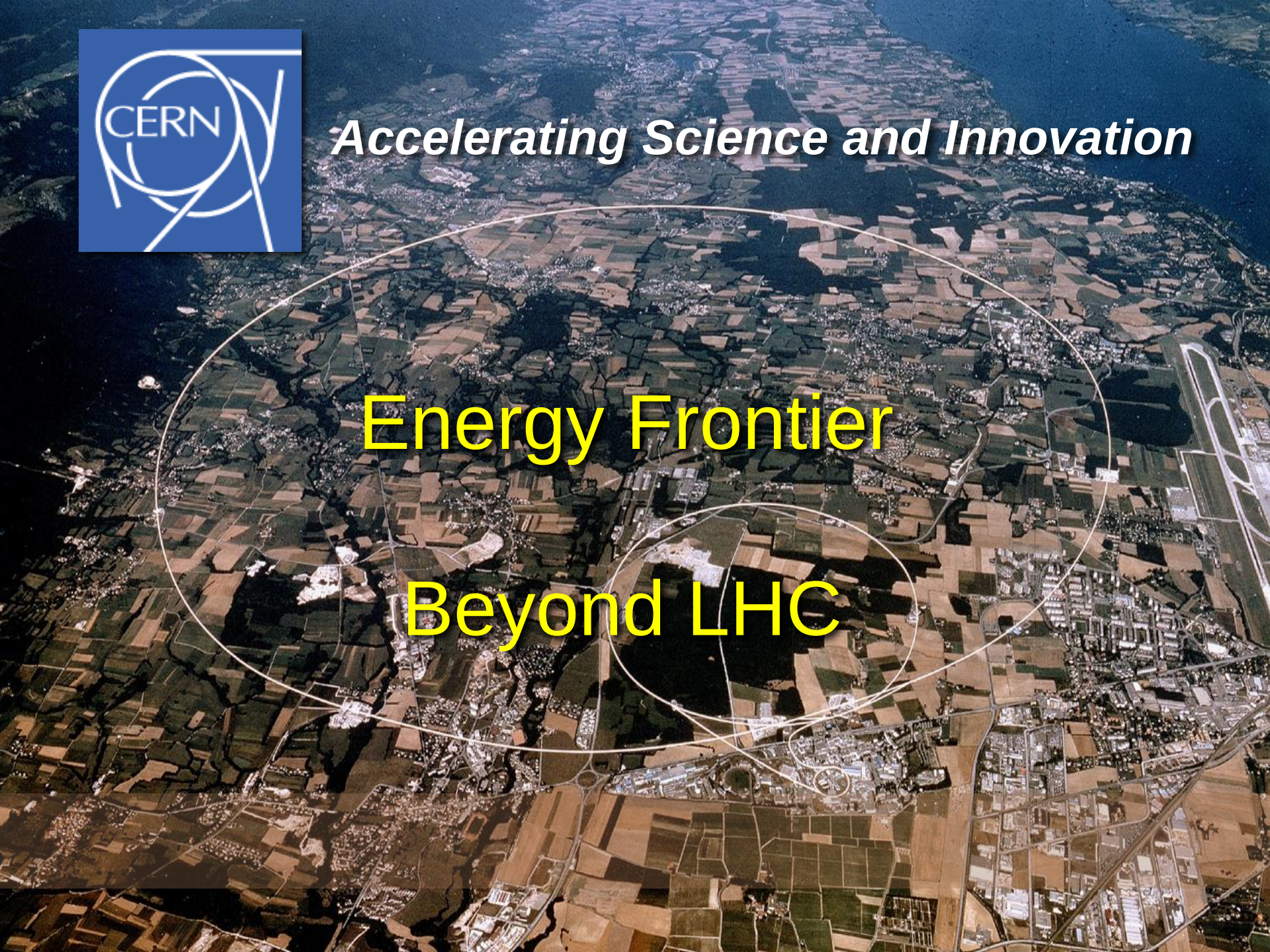
(Extended) Year End Technical Stop: (E)YETS

LHC

Key message

There is a
ntier
TeV (essentially done)
14 TeV design luminosity
14 TeV high luminosity (HL-LHC)

Upgrades to accelerator complex, detectors, and computing Grid are vital to fully exploit the physics potential of LHC


CERN
Accelerating Science and Innovation
Energy Frontier
Beyond LHC

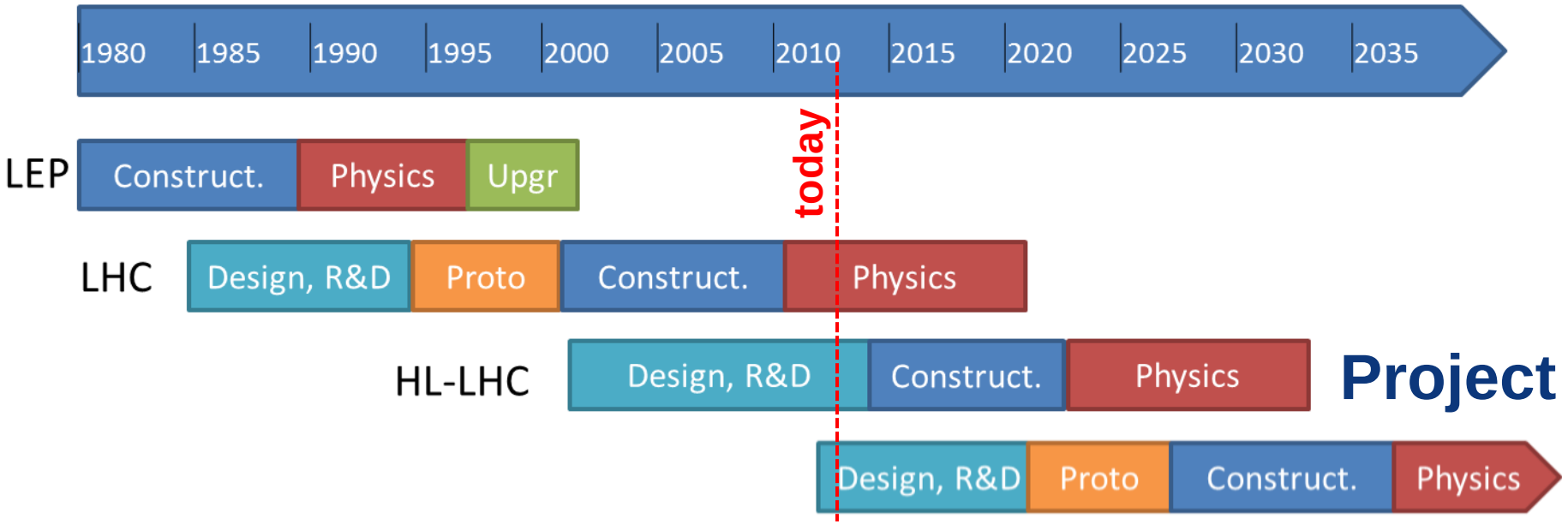
European Strategy for Particle Physics

High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

d) To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available. ***CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.***

European Strategy: "CERN should undertake design studies for accelerator projects in a global context, with emphasis on ***proton-proton*** *and electron- positron* ***high-energy frontier machines****."*



FCC Study : p-p towards 100 TeV

Kick-off meeting: February 2014
(Univ. Geneva)

FCC: Future Circular Colliders

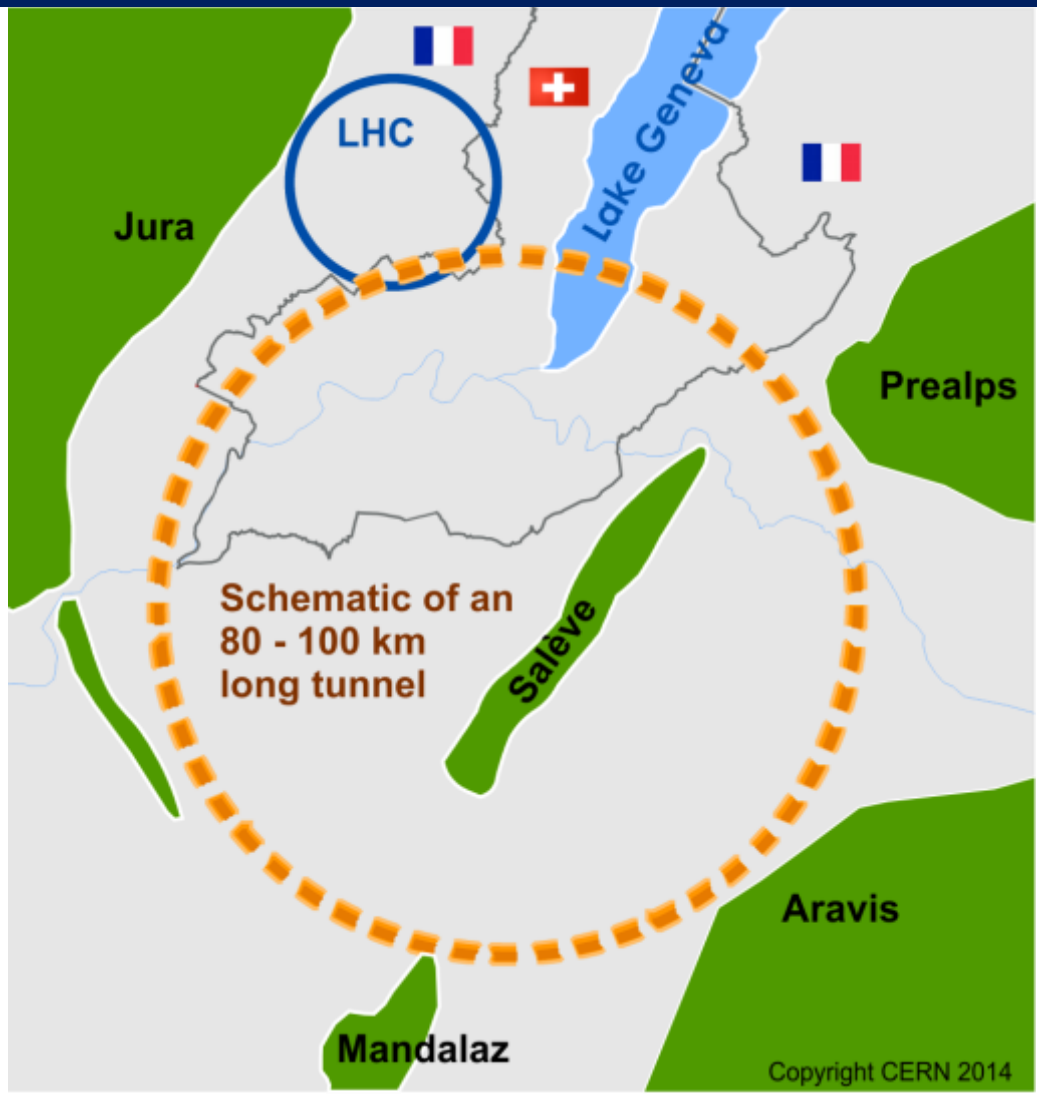
Future Circular Collider Study - SCOPE
CDR and cost review for the next ESU (2018)

Forming an international collaboration to study:

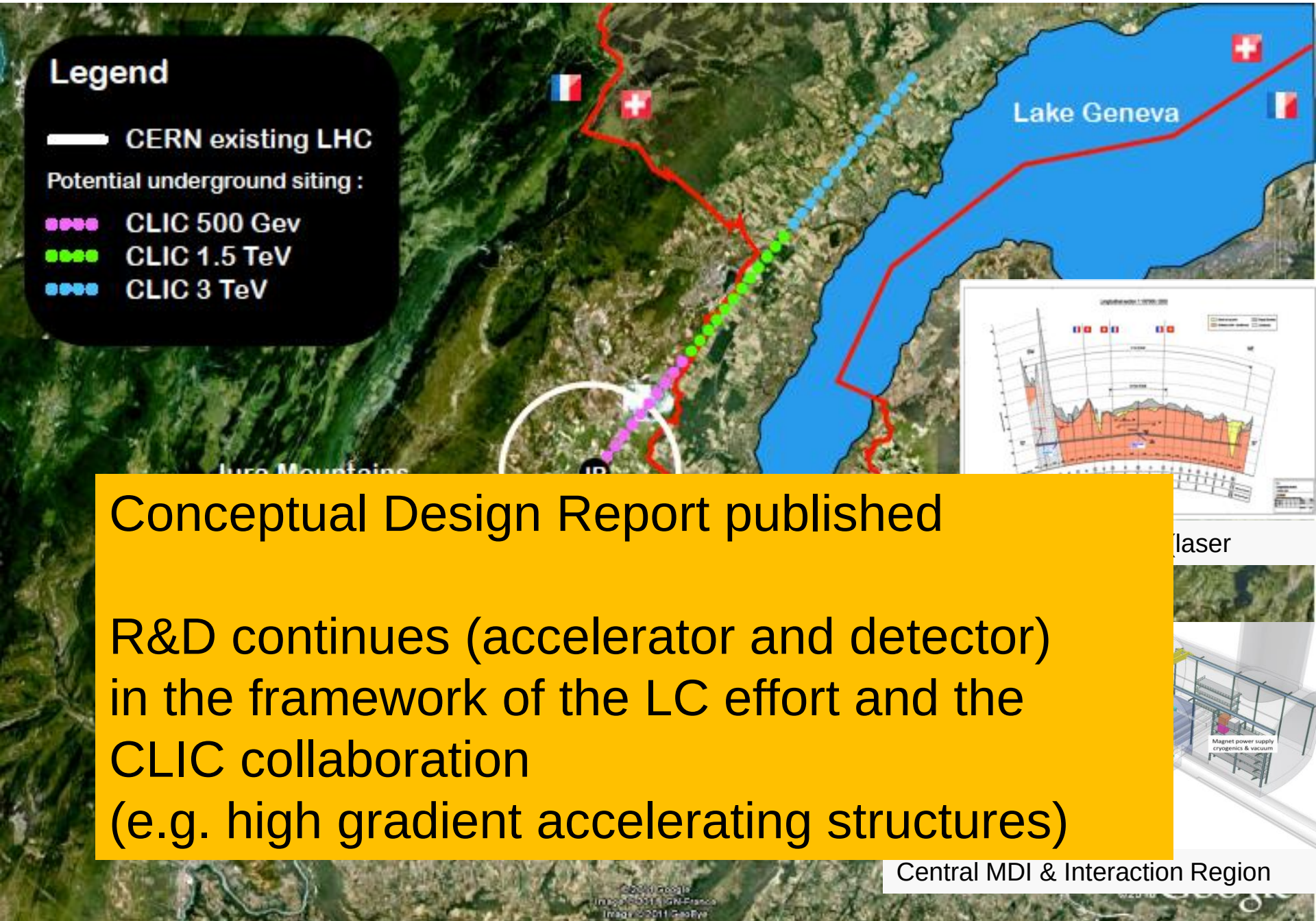
- ***pp*-collider (*FCC-hh*)**
  → defining infrastructure requirements

~16 T ⇒ 100 TeV *pp* in 100 km
~20 T ⇒ 100 TeV *pp* in 80 km

- **e^+e^- collider (*FCC-ee*)** as potential intermediate step
- *p-e* (*FCC-he*) option
- **80-100 km infrastructure** in Geneva area



CLIC near CERN



Conceptual Design Report published

R&D continues (accelerator and detector) in the framework of the LC effort and the CLIC collaboration
(e.g. high gradient accelerating structures)

European Strategy for Particle Physics

High-priority large-scale scientific activities

After careful analysis of many possible la ities requiring significant resources, sizeable co itment, the following four activities h priority.

e) There i positron collider, comple the properties of the Higgs boson and othe ited precision and whose energy can be upgraded Design Report of the International Linear Collider (ILC) has completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. ***Europe looks forward to a proposal from Japan to discuss a possible participation.***

At CERN ILC efforts continue in the framework of the LC efforts. Hosting LCC Director(ate) at CERN

Linear Collider(s)

Continue working on the technical design report for CLIC and common research on ILC (machine and detectors)

P5 Recommendation 11: Motivated by the strong scientific importance of the ILC and the recent initiative in Japan to host it, the U.S. should **engage in modest and appropriate levels of ILC accelerator and detector design** in areas where the U.S. can contribute critical expertise. **Consider higher levels of collaboration if ILC proceeds.**

This parallel research (CLIC and ILC) aims to be ready to decide on the way forward at the time of the next European Strategy update (around 2018)


CERN
Accelerating Science and Innovation
Intensity Frontier

European Strategy for Particle Physics

High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

f) Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector.
CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.

Neutrino Platform

Create a platform to pave the way for a European contribution in a neutrino facility in the US or Asia

Financial scenario with an allocation to allow for

- Extension of the experimental area of the SPS complex (North Area)
- (liquid argon) detector R&D for neutrino experiments
- Preparing detectors at CERN for transport to US

P 5 Recommendation 13: Form a new international collaboration to design and execute a highly capable Long-Baseline Neutrino Facility (LBNF) hosted by the U.S. To proceed, a project plan and identified resources must exist to meet the minimum requirements in the text. **LBNF is the highest-priority large project in its timeframe.**

Final Remark on Science

With the European Strategy, approved by Council May 2013, with the P5 recommendations, approved by HEPAP in the US, with the Japanese roadmap

we have (for the first time) a global vision for our field going beyond regional boundaries

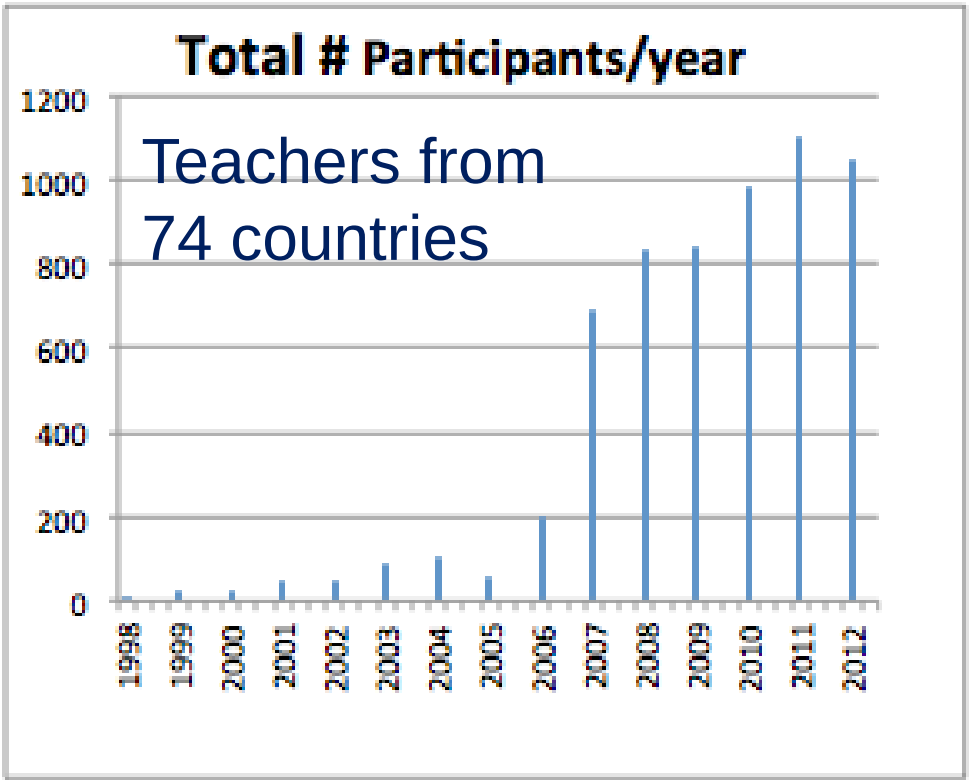
CERN is playing a major role in this global endeavour


CERN
Accelerating Science and Innovation
Beyond Science

Education and Capacity Building at CERN

- Teachers Programs
  - international and ‘national’ programs at CERN and remotely

Education and Capacity Building

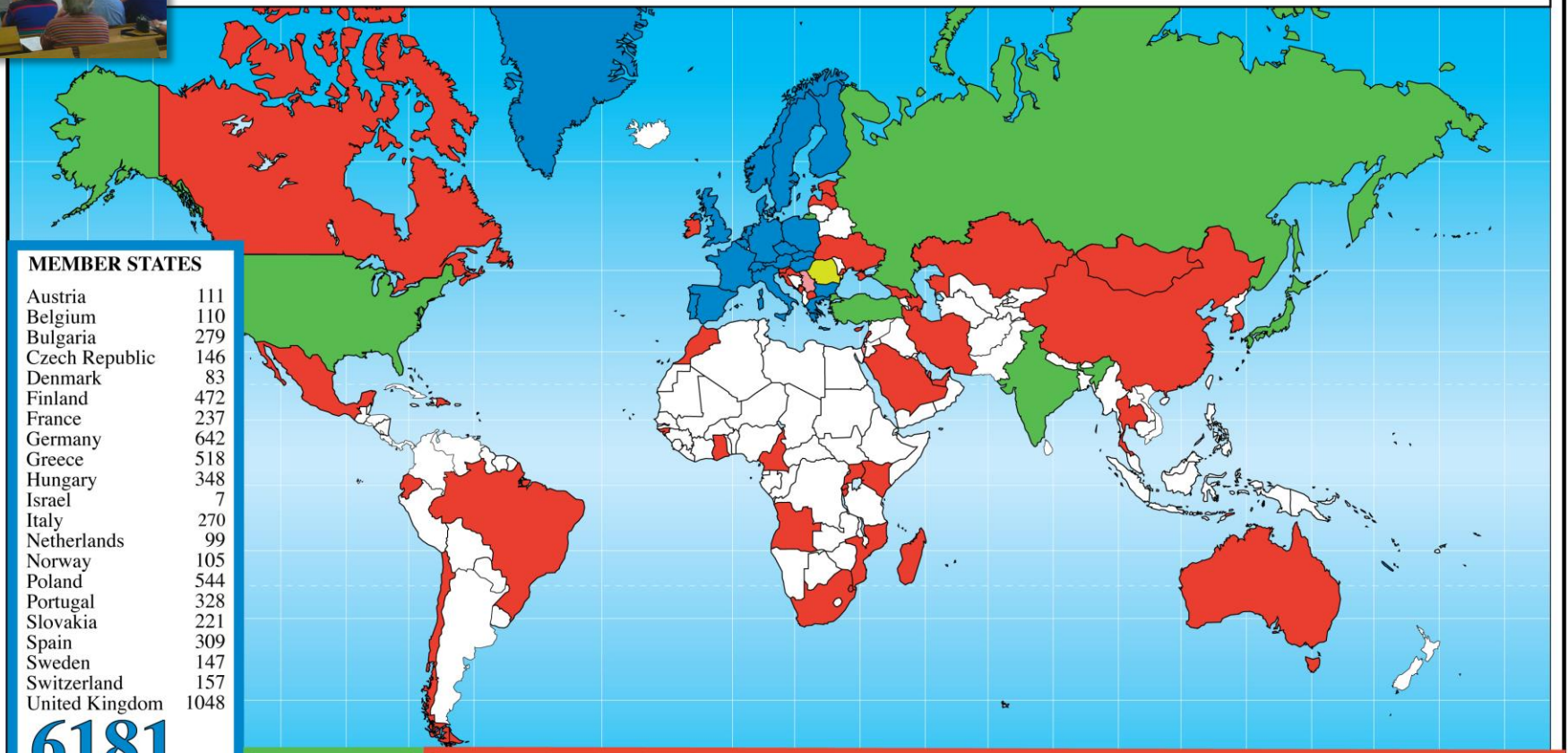


Teachers Programme: courses of one week duration in the mother language of the teachers

Today: ~1000 teachers per year

CERN Teacher Programme

Teacher Programme Participants 1998 - 2013 (Total: 7067)



MEMBER STATES

Austria	111
Belgium	110
Bulgaria	279
Czech Republic	146
Denmark	83
Finland	472
France	237
Germany	642
Greece	518
Hungary	348
Israel	7
Italy	270
Netherlands	99
Norway	105
Poland	544
Portugal	328
Slovakia	221
Spain	309
Sweden	147
Switzerland	157
United Kingdom	1048

6181

CANDIDATE FOR ACCESSION

Romania	12

ASSOCIATE MEMBER IN THE PRE-STAGE TO MEMBERSHIP

Serbia	14

OBSERVER STATES

India	2
Japan	5
Russia	193
Turkey	3
USA	65

268

OTHERS

Angola	4	China	1	Ireland	5	Morocco	2	Swaziland	1
Australia	5	Croatia	1	Kazakhstan	3	Mozambique	17	Thailand	7
Azerbaijan	1	Cyprus	8	Kenya	4	Qatar	1	T.F.Y.R.O.M.	11
Brazil	114	Dominican Rep.	21	Latvia	1	Rwanda	17	Timor-Leste	7
Burundi	1	Ecuador	2	Lebanon	1	Sao Tome	4	Uganda	3
Cameroon	3	Estonia	46	Madagascar	2	Saudi Arabia	1	Ukraine	77
Canada	3	Georgia	74	Malta	36	Singapore	2	U.A.E.	1
Cape Verde	3	Ghana	6	Mexico	6	Slovenia	21		
Chile	3	Guinea Bissau	1	Mongolia	1	South Africa	6		
		Iran	1	Montenegro	13	South Korea	44		

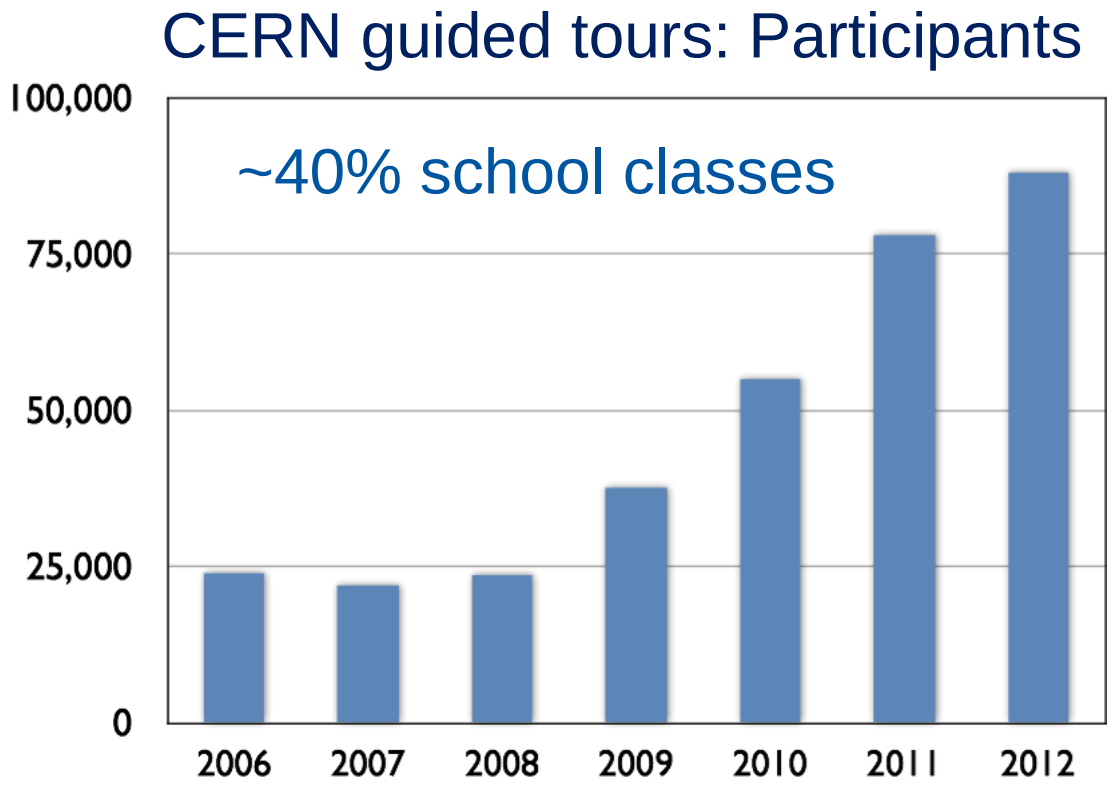
592

Education and Capacity Building at CERN

- Teachers Programs
  - international and ‘national’ programs at CERN and remotely
- School Students Programs
  - “slip into the skin of a researcher”
  - special competitions (e.g. in Spain)
- High School Students Programs
  - S’Cool Lab
  - Beamline for Schools
  - Masterclasses
- Summer Students Program

CERN | 60 YEARS / ANS CERN

Education and Capacity Building at CERN



2013:
~95,000 participants per year

Over 200,000 requests

Bridge the Gap between Science and Society

CERN

– innovate, discover, publish, share

… and bring the world together