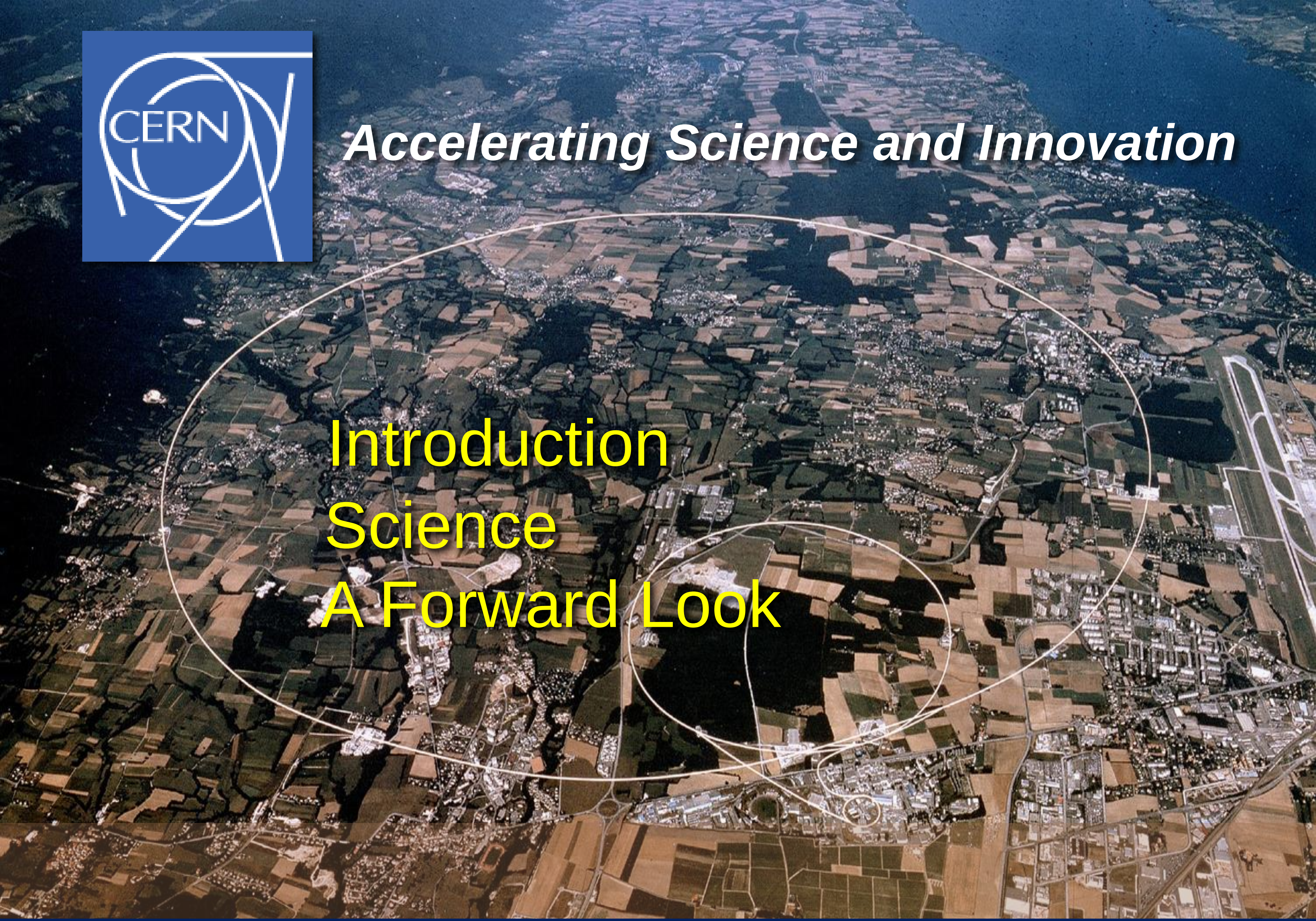
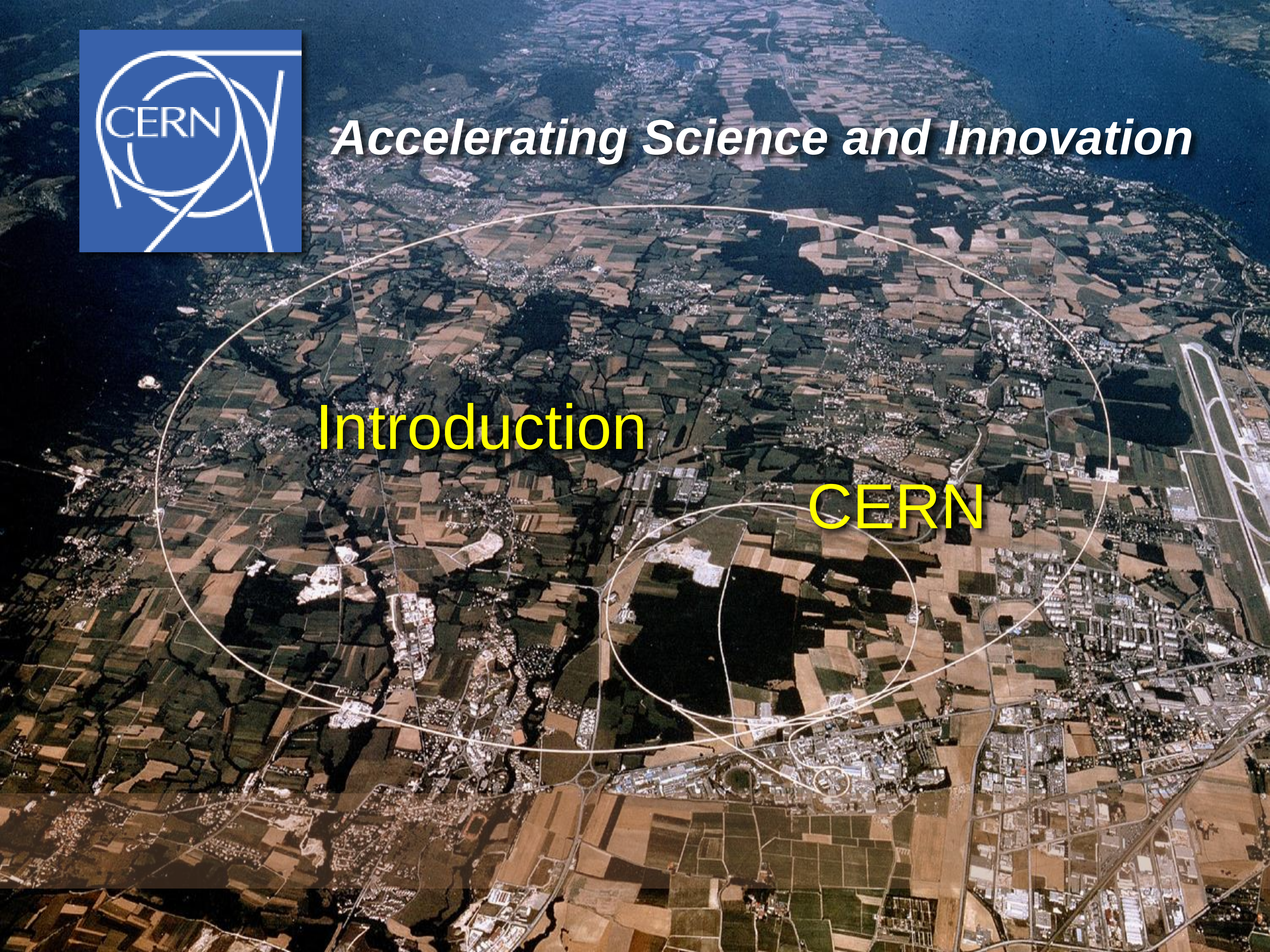


Accelerating Science and Innovation

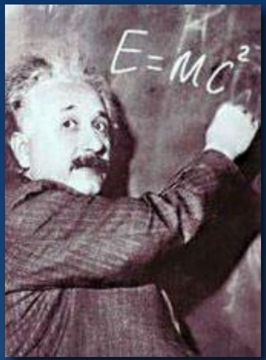
Introduction
Science
A Forward Look

R.-D. Heuer, CERN
European School of High-Energy Physics, Bansko, BG – 5 September 2015


CERN
Accelerating Science and Innovation
Introduction
CERN

Innovation
Education
CERN
uniting people
Research

The Mission of CERN



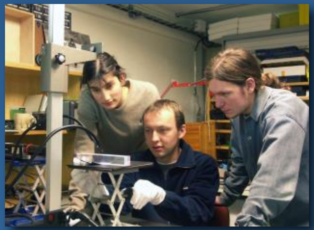
- Push back the frontiers of knowledge

  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: founded in 1954: 12 European States

"Science for Peace"

Today: 21 Member States

- ~ 2300 staff
- ~ 1300 other paid personnel
- ~ 11500 scientific users

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

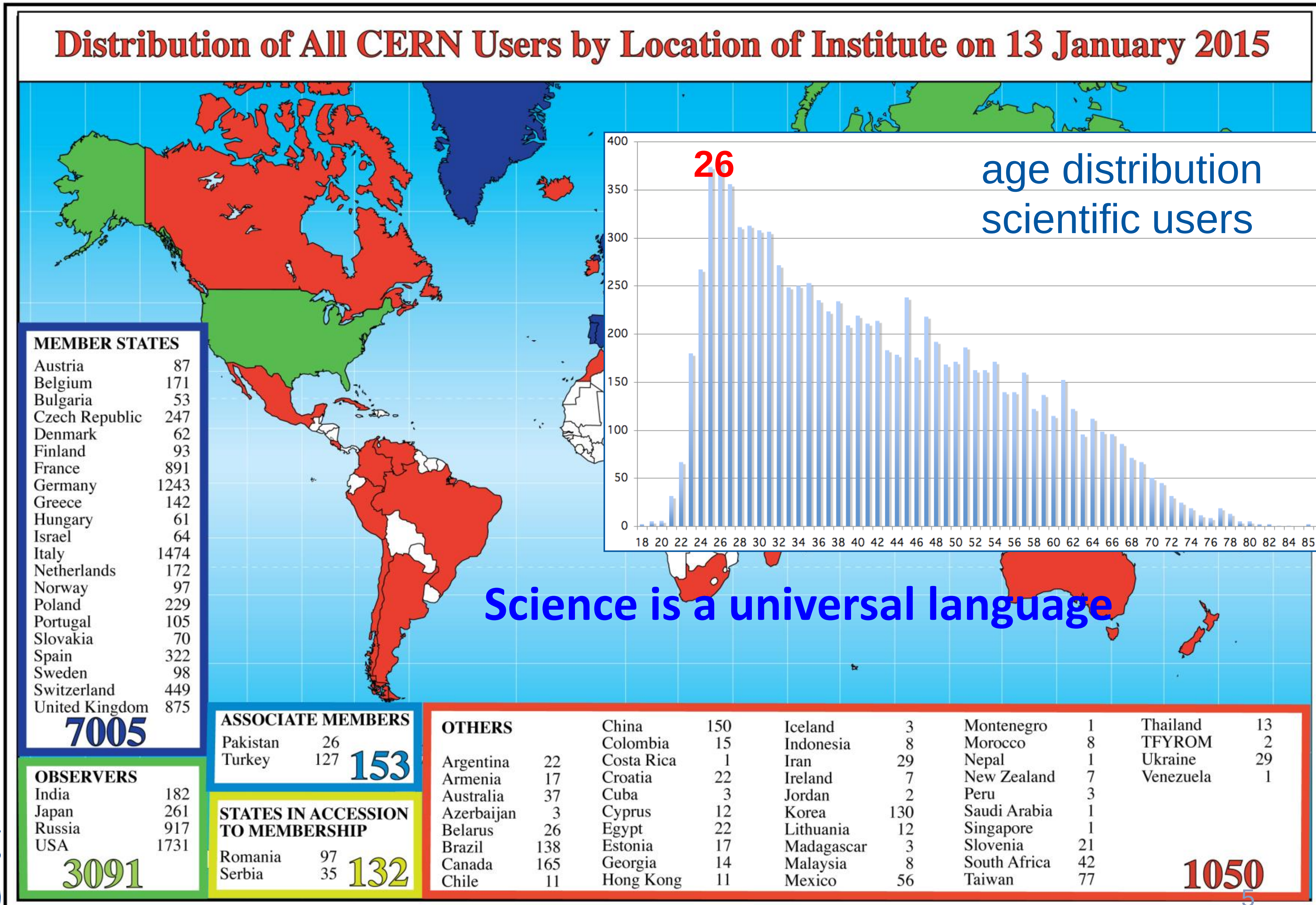
States in accession to Membership: Romania, Serbia

Associate Member States: Pakistan, Turkey

Applications for Membership or Associate Membership: Brazil, Croatia, Cyprus, Russia, Slovenia, Ukraine

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

Breaking the Walls between Cultures and Nations since 1954

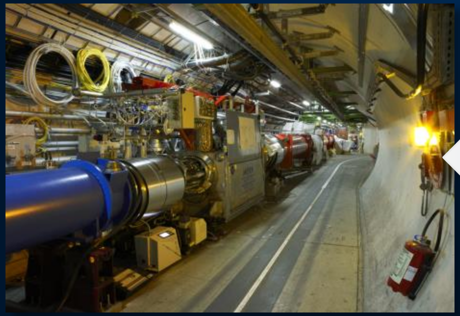


Innovation
Education
CERN
uniting people
Research

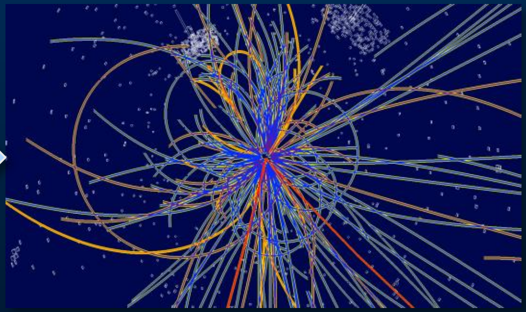
CERN: Particle Physics and Innovation

- Interfacing between fundamental science and key technological developments

- CERN Technologies and Innovation



Accelerating particle beams



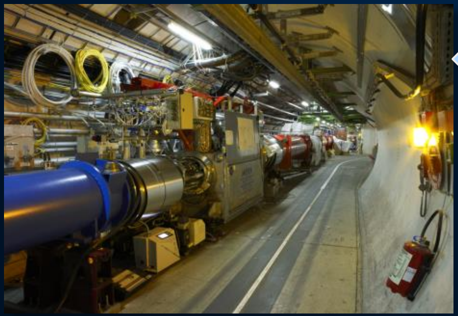
Detecting particles

Large-scale computing (Grid)

Innovation Education
CERN
uniting people
Research

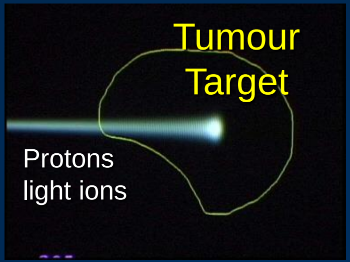
CERN Technologies and Innovation
Example: Medical applications

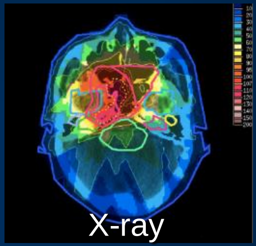
Combining Physics, ICT, Biology and Medicine to fight cancer

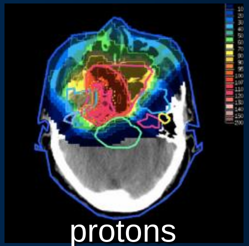


Accelerating particle beams
~30'000 accelerators worldwide
~17'000 used for medicine

Hadron Therapy

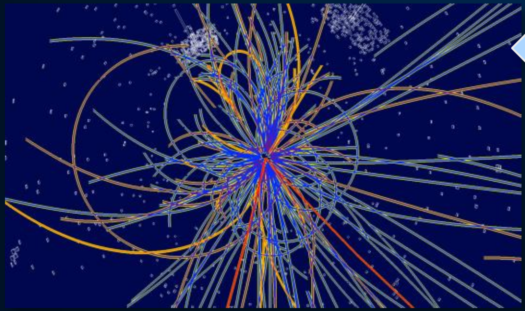






Leadership in Ion Beam Therapy now in Europe and Japan

>70'000 patients treated worldwide (30 facilities)
>21'000 patients treated in Europe (9 facilities)

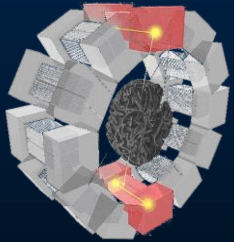


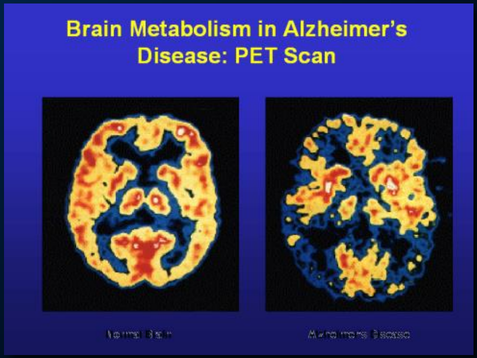
Detecting particles

Imaging

PET Scanner

Clinical trial in Portugal for new breast imaging system (ClearPEM)





The CERN Initiatives

- Radio-Isotopes (imaging and possibly treatment)
- Detectors for beam control and medical imaging, D[illegible]tics and Dosimetry for control of radiation
- Biomedical Facility
  - creation of a facility at CERN that provide[illegible]erent types and energies to external users for radiobi[illegible]evelopment
  - Iterative experimental verificati[illegible]lts
- Large Scale Compu[illegible](simulations, treatment planning telem[illegible]
- Compute[illegible]or Medical Applications
- New Up[illegible]dical Accelerator Design
  - coordina[illegible]international collaboration to design a new compact, cost-effective accelerator facility, using the most advanced technologies

Each Initiative is part of a package but also is important as a stand-alone project

Will be carried out in a global collaboration

Education and Capacity Building at CERN

- Teachers Programs
  - international and 'national' programs
    at CERN and remotely

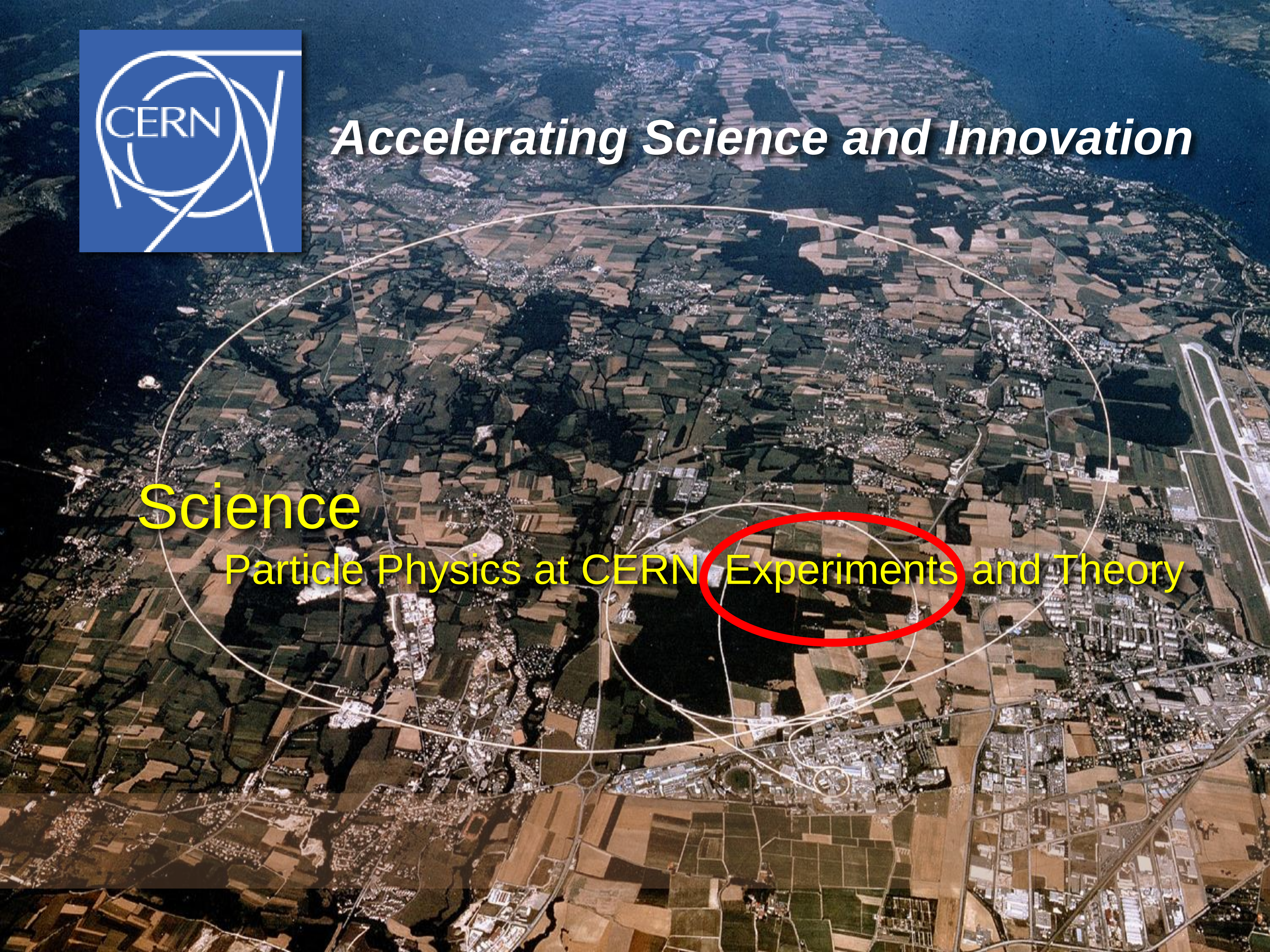
Education and Capacity Building

Teachers from
81 countries

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

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
- High School Students Programs
  - S’Cool Lab
  - Beamline for Schools
  - Masterclasses
- Summer Students Program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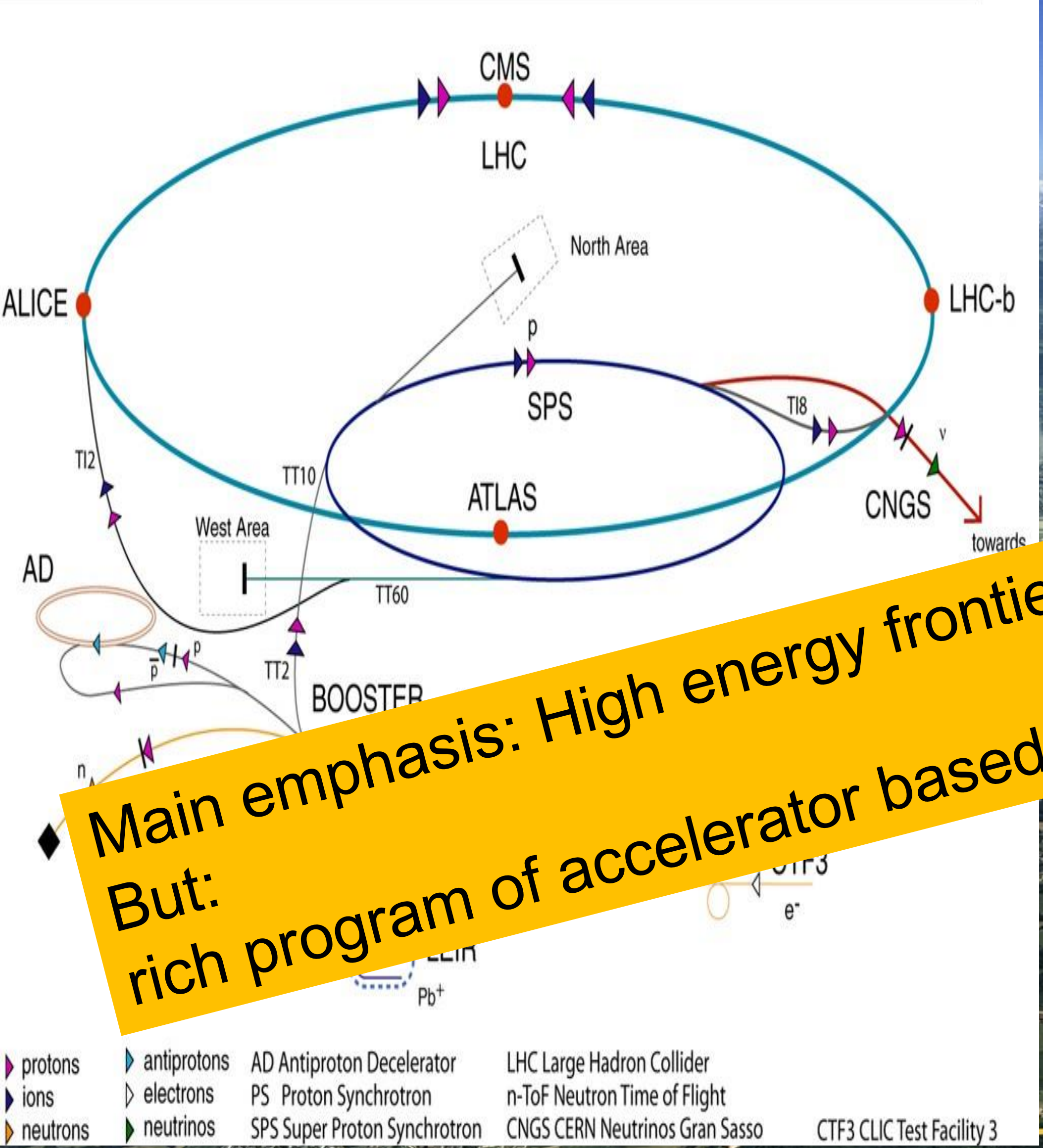
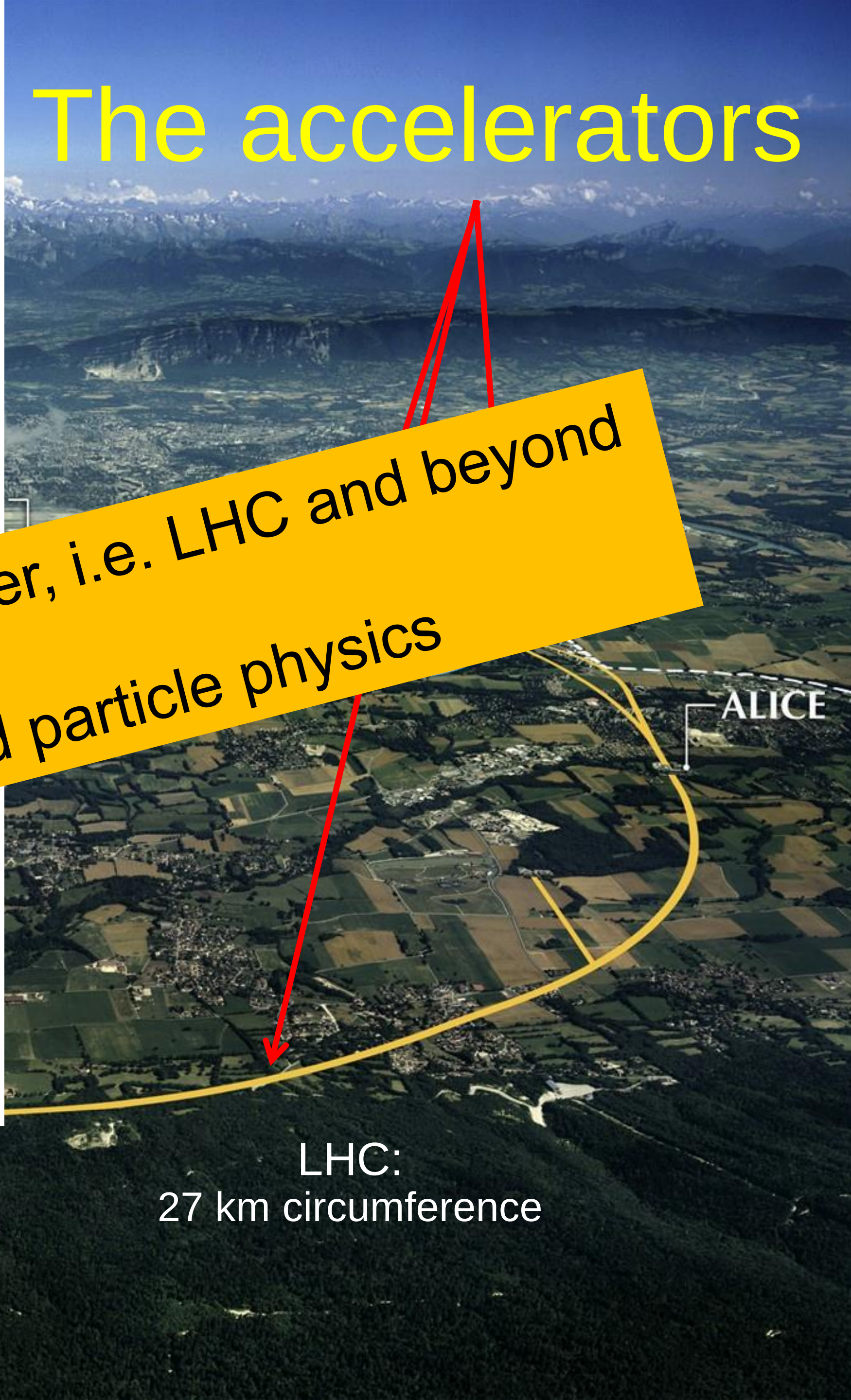
Science
Particle Physics at CERN: Experiments and Theory

The accelerators





Main emphasis: High energy frontier, i.e. LHC and beyond

But:

rich program of accelerator based particle physics

LHC:
27 km circumference

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

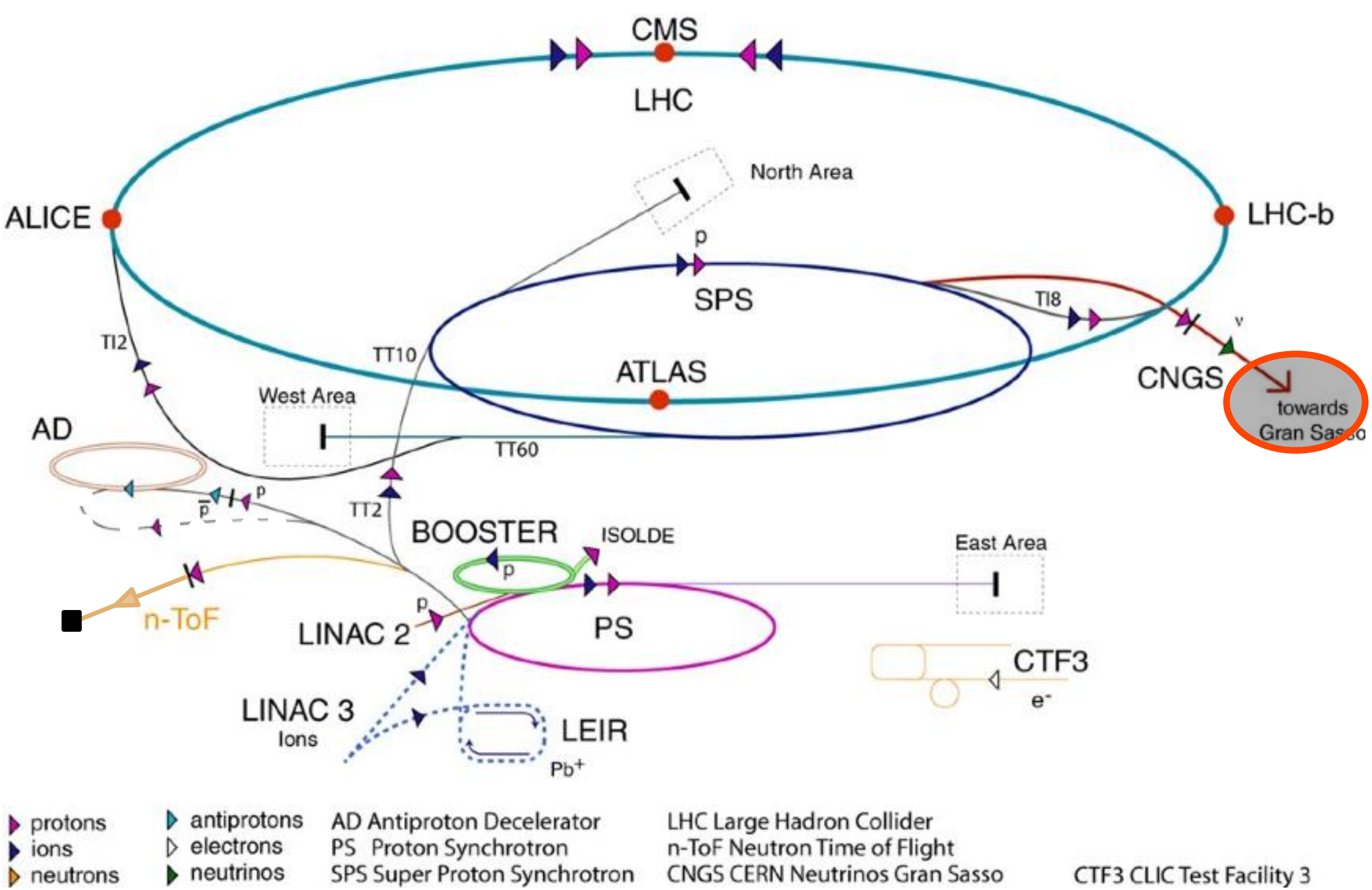
Non-LHC Particle Physics = o(1000) physicists / o(20) experiments

Scientific Diversity at **unique facilities**

CERN maintains and upgrades these facilities

Complemented and supported by Theory

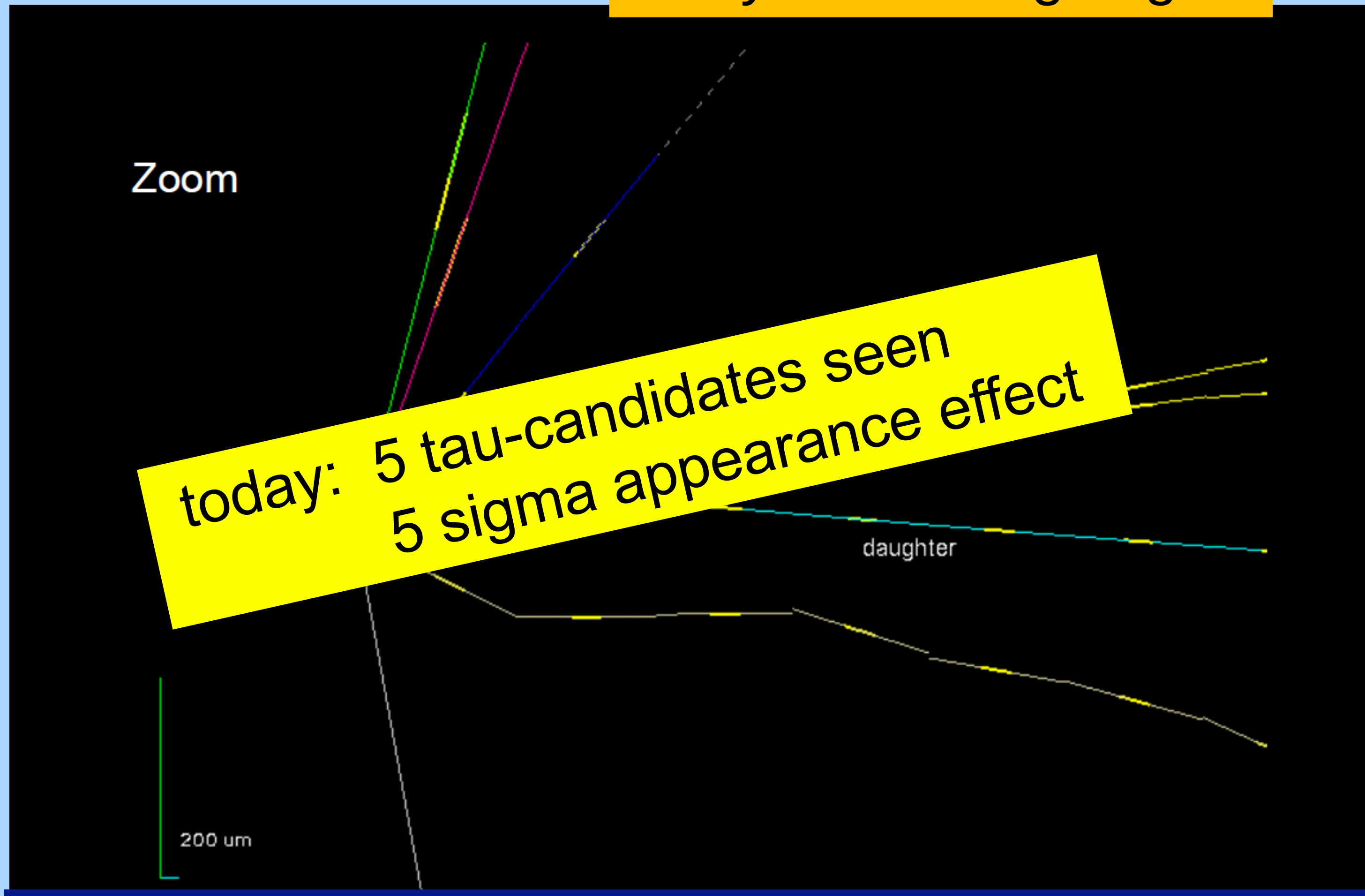
CERN Accelerator Complex



CNGS - OPERA

Data taking terminated, analysis still ongoing.

First υ_τ Candidate



today: 5 tau-candidates seen
5 sigma appearance effect

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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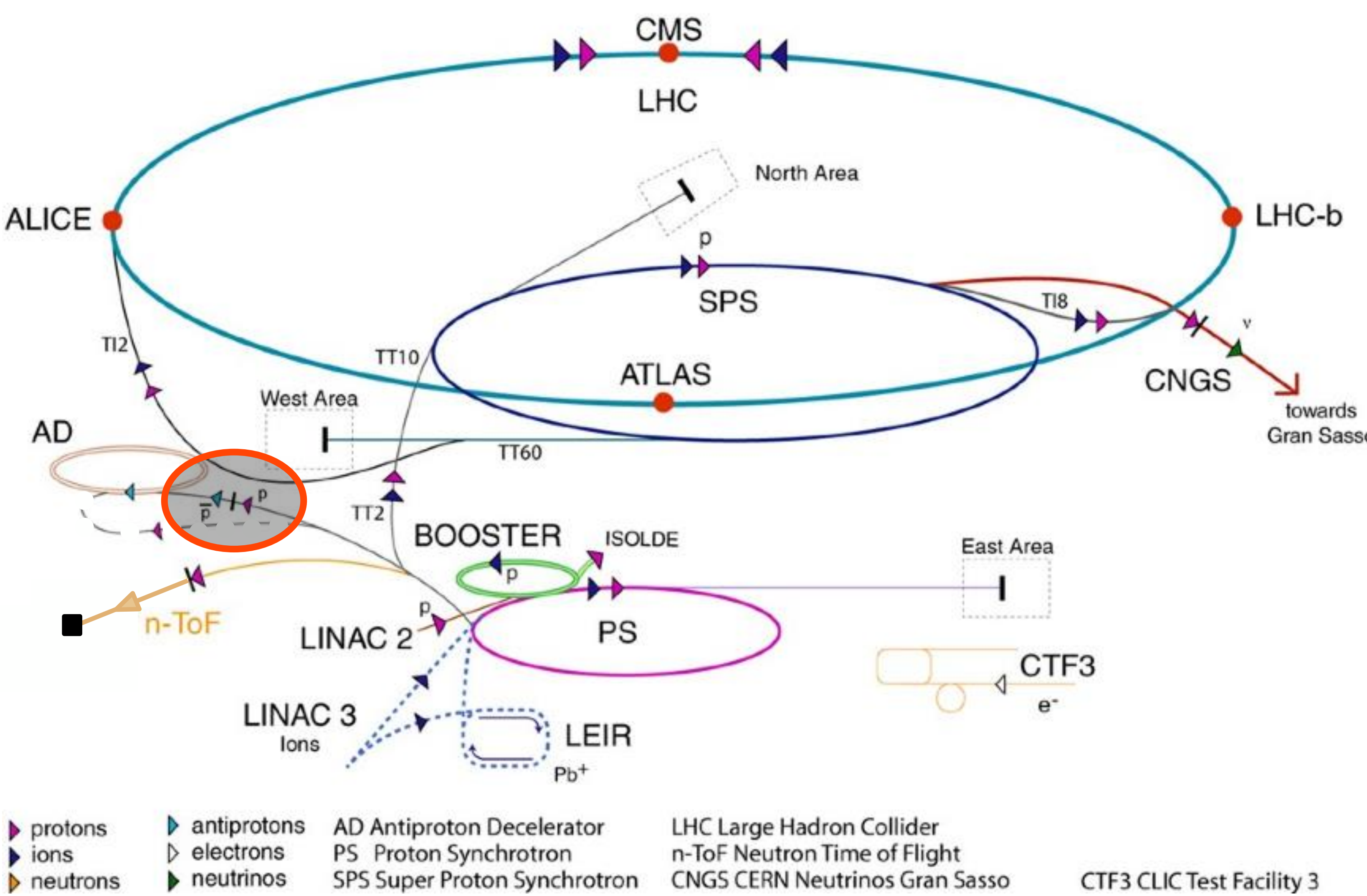
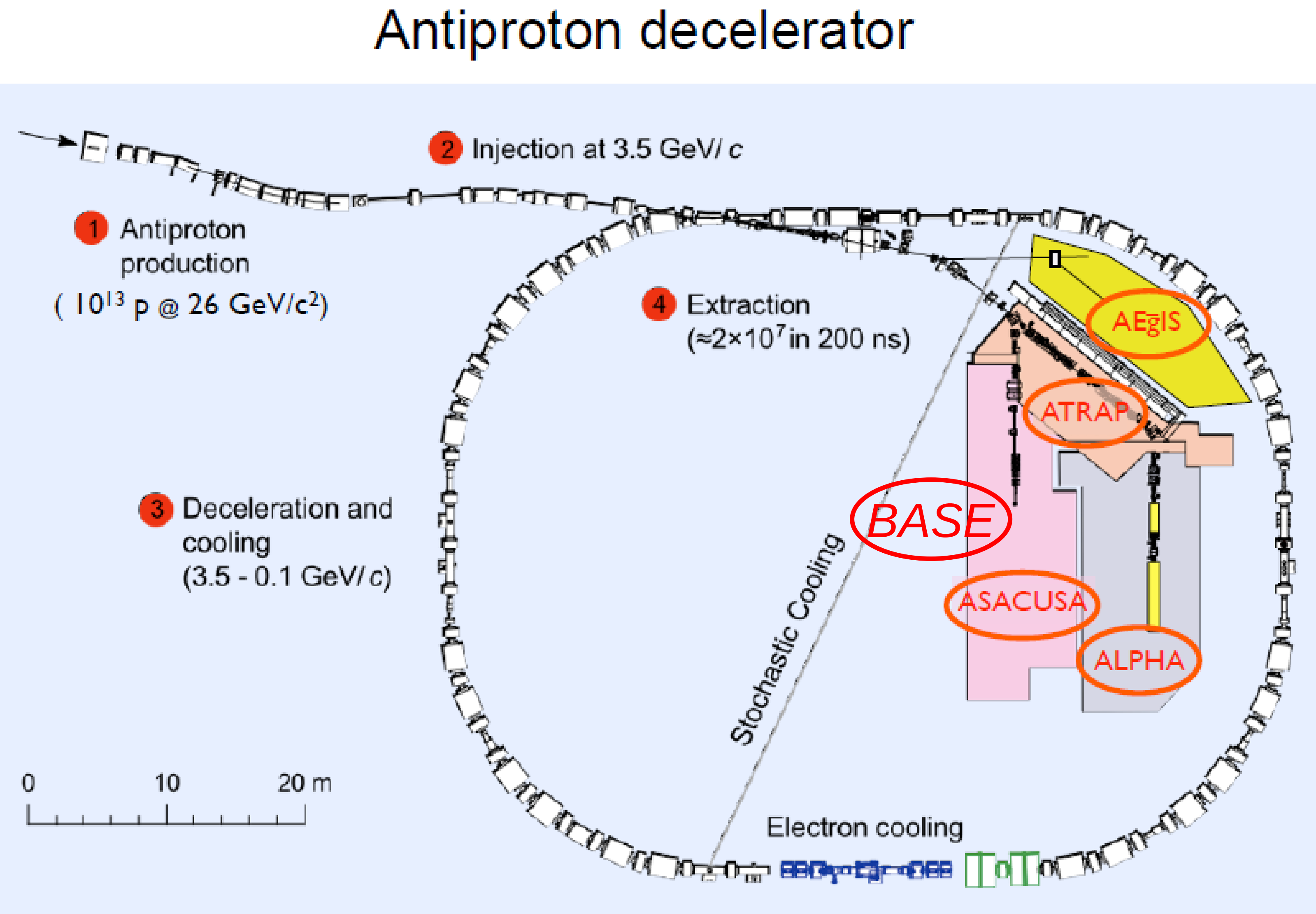
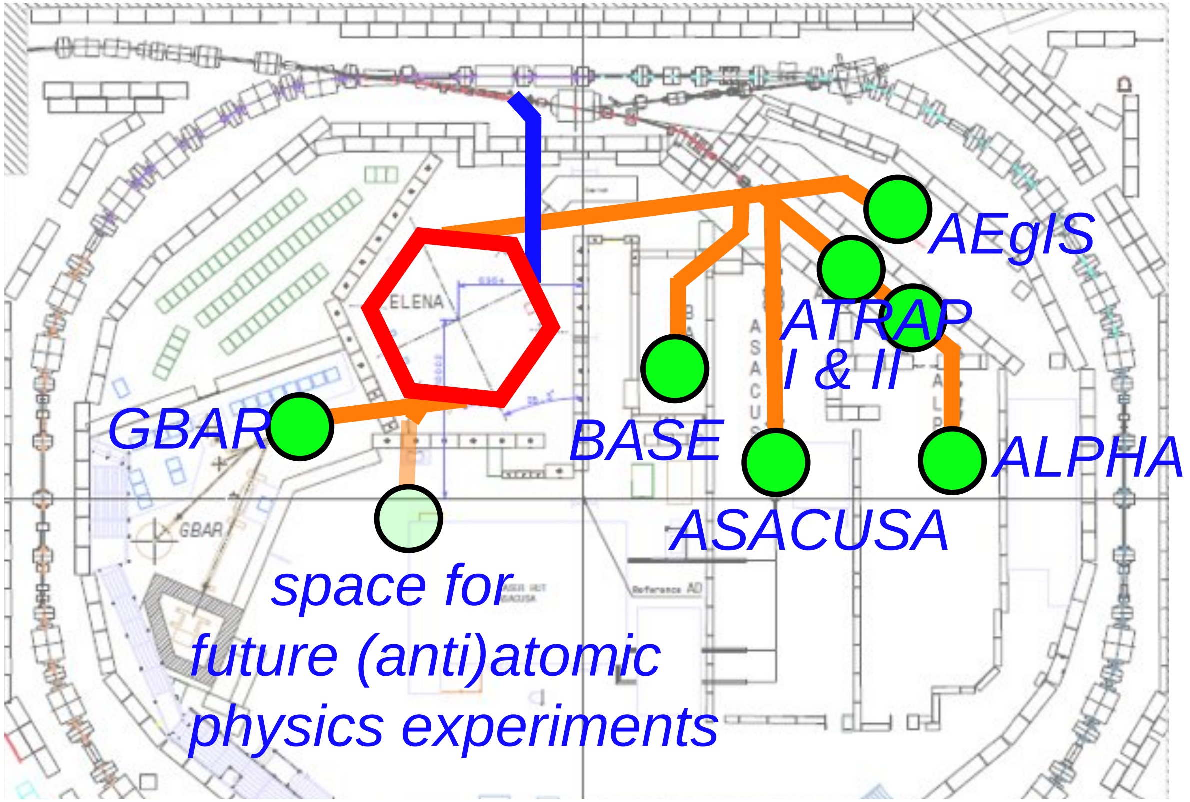


AD (current situation)



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

High Energy Frontier

LHC

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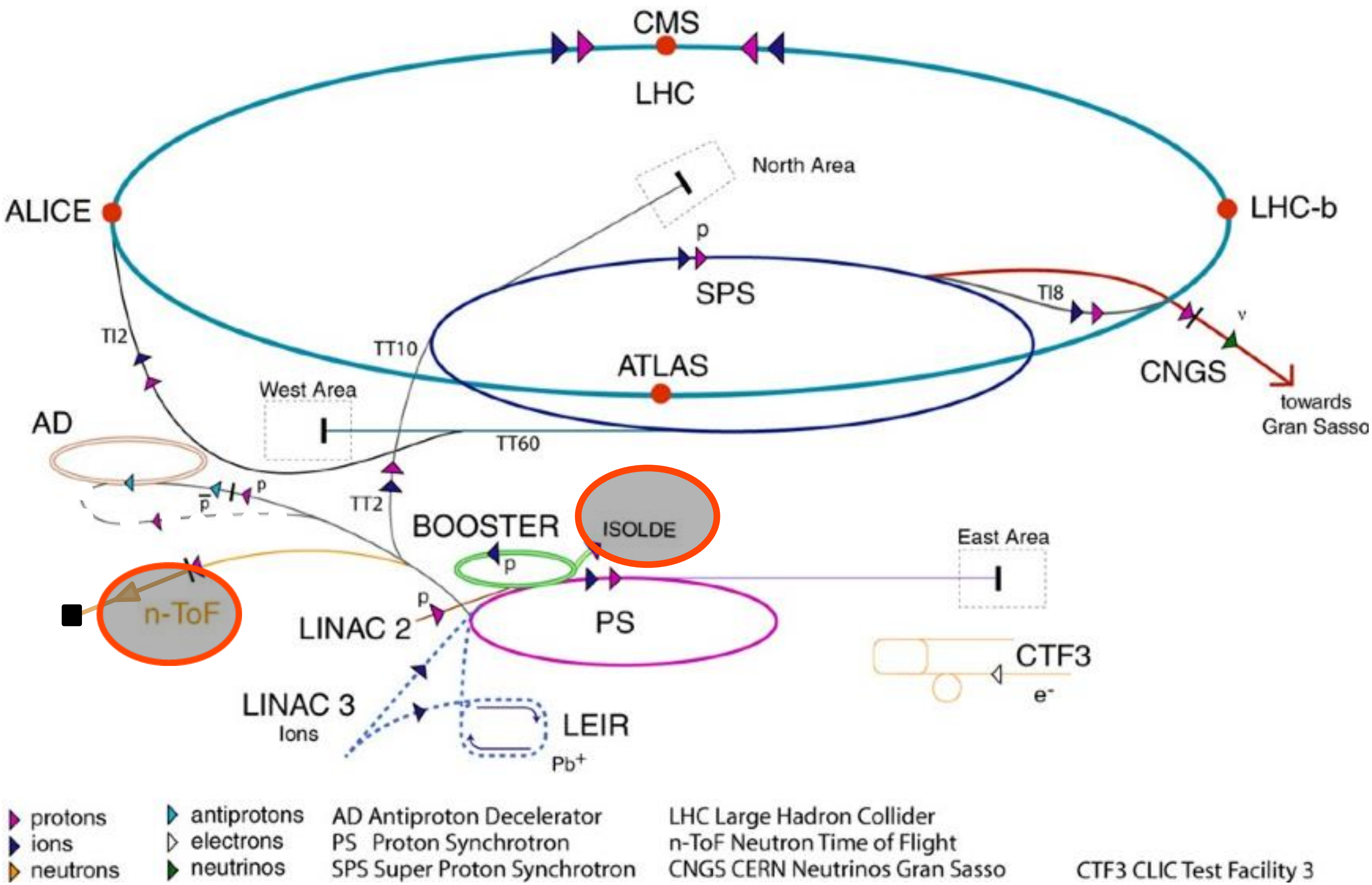
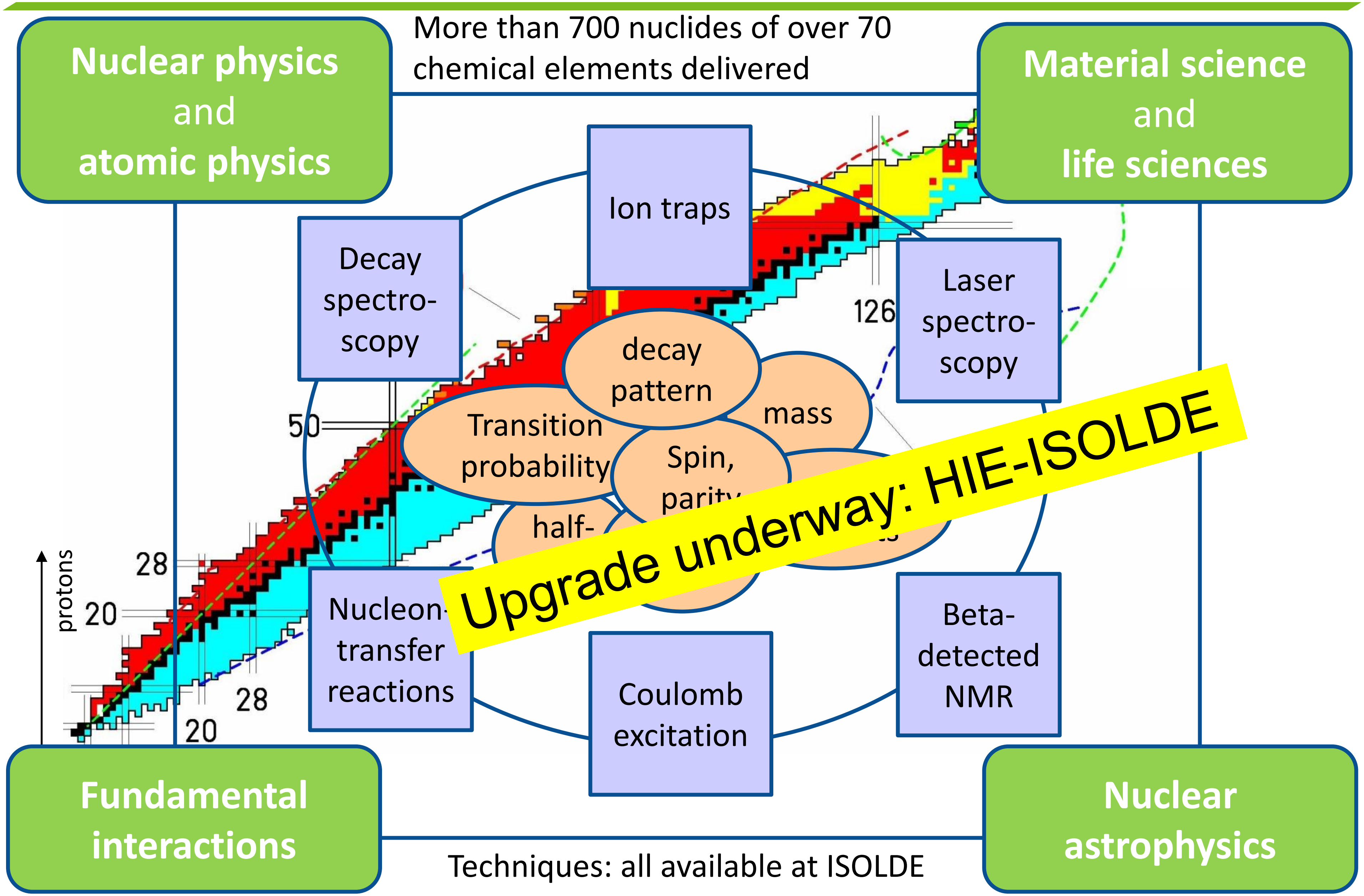
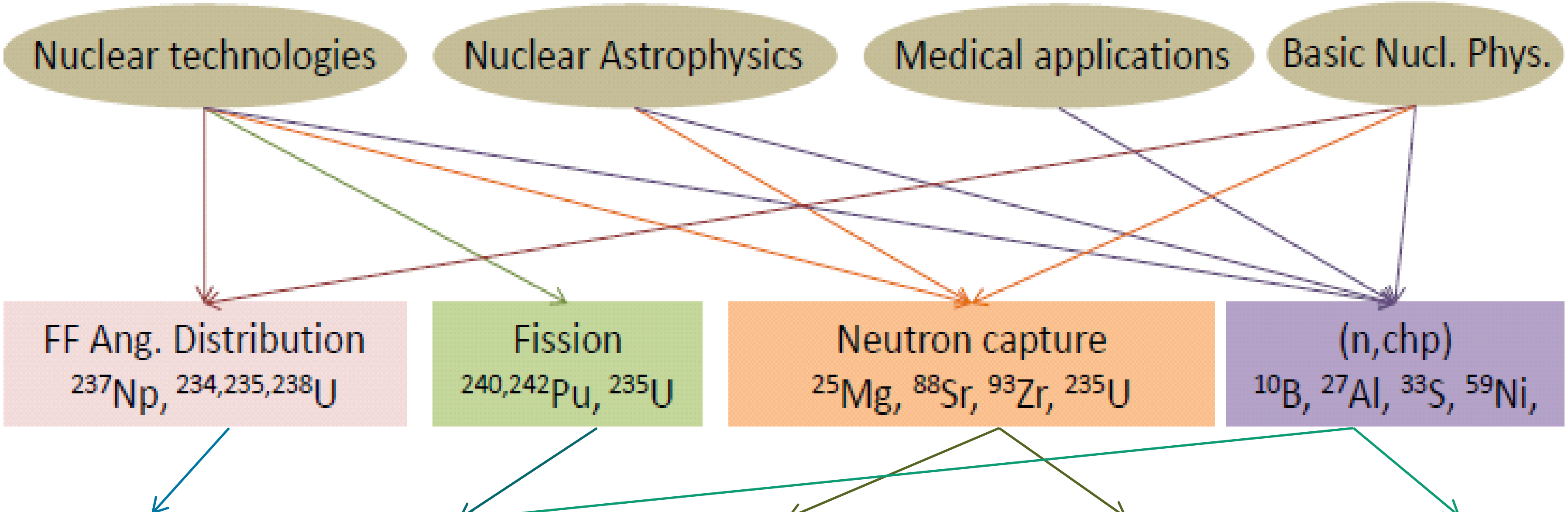


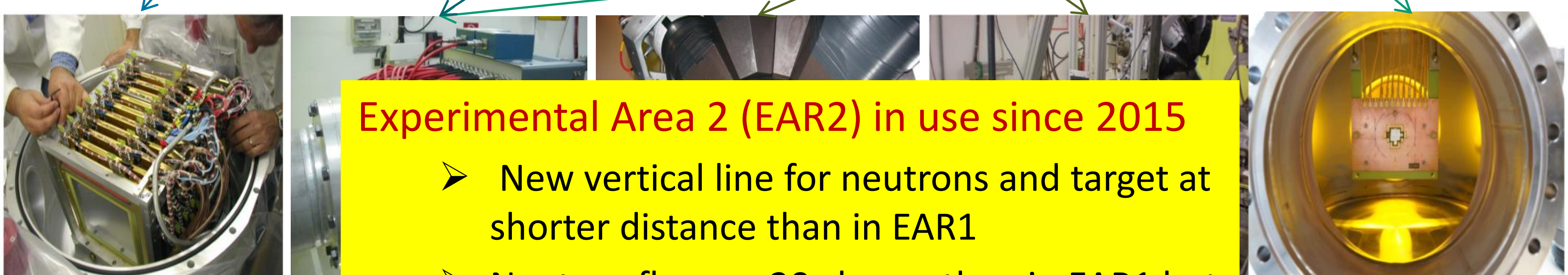
Research with radioactive nuclides



n_TOF physics

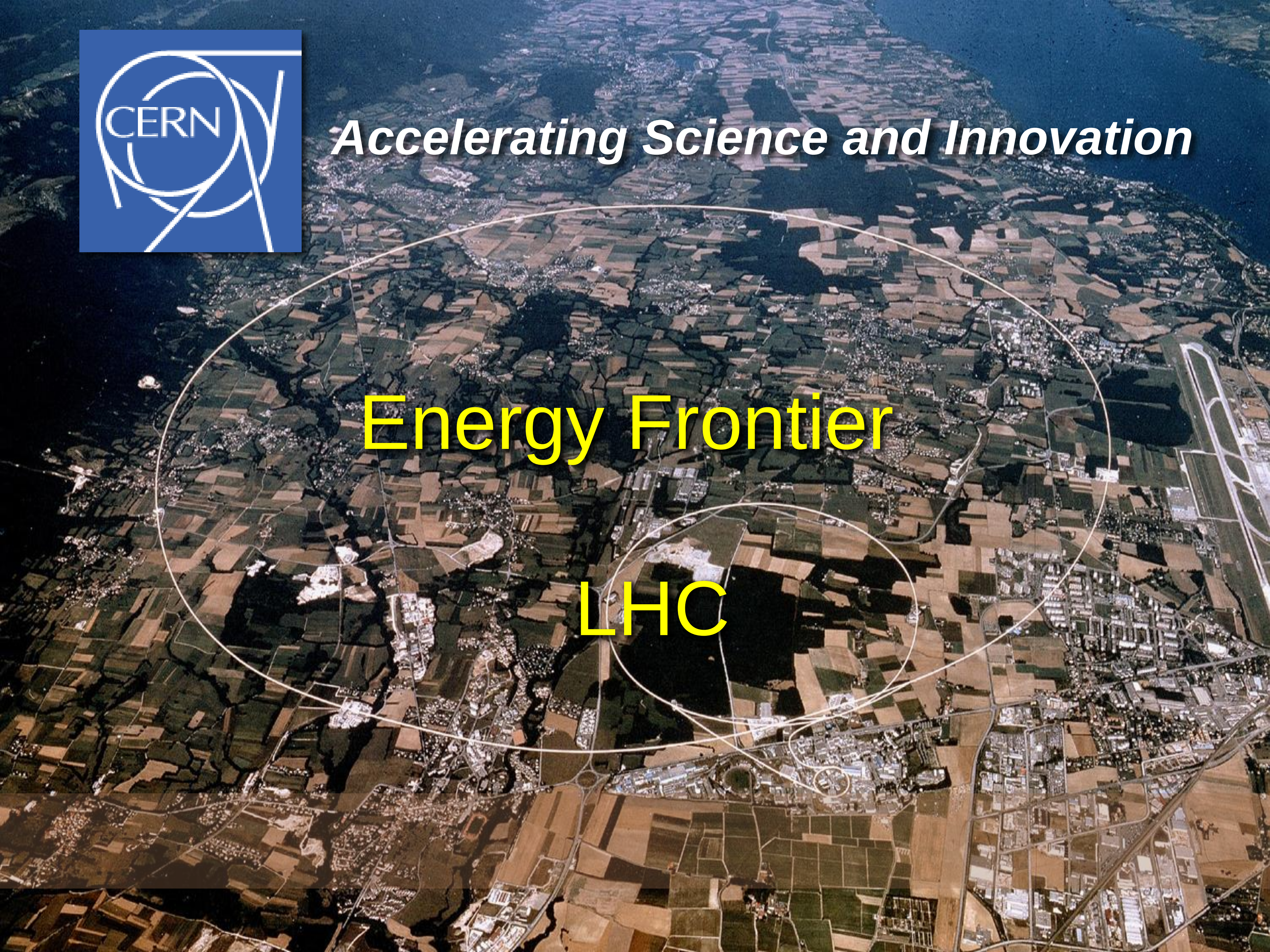
100 members, 32 institutions



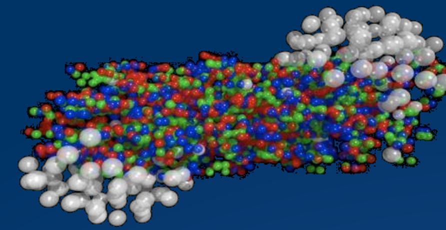


Experimental Area 2 (EAR2) in use since 2015

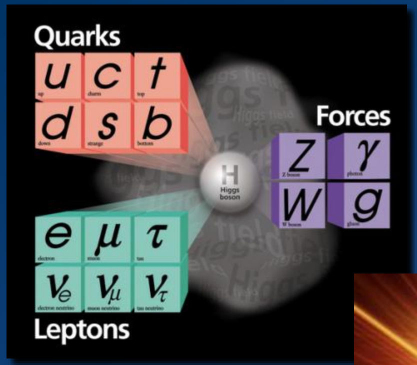
- New vertical line for neutrons and target at shorter distance than in EAR1
- Neutron fluence 20x larger than in EAR1 but lower resolution due to shorter TOF


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?

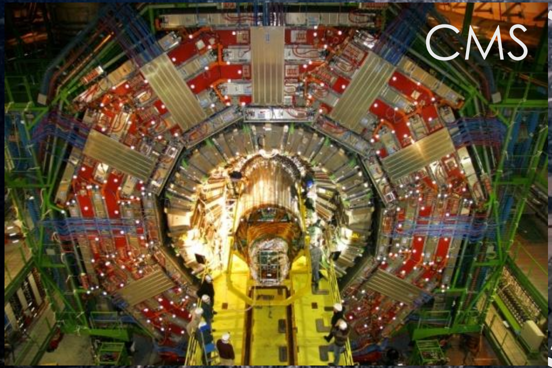


Have we found the Higgs particle that is 'responsible for giving mass' to all particles?

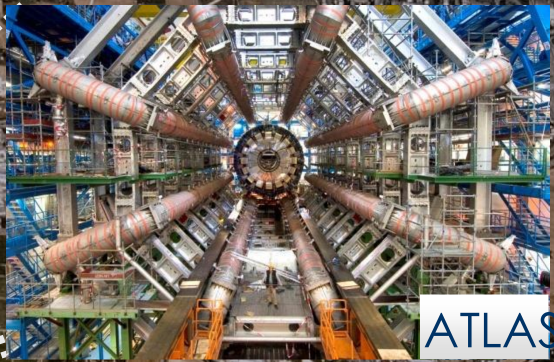
Will we find the reason why antimatter and matter did not completely destroy each other?

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

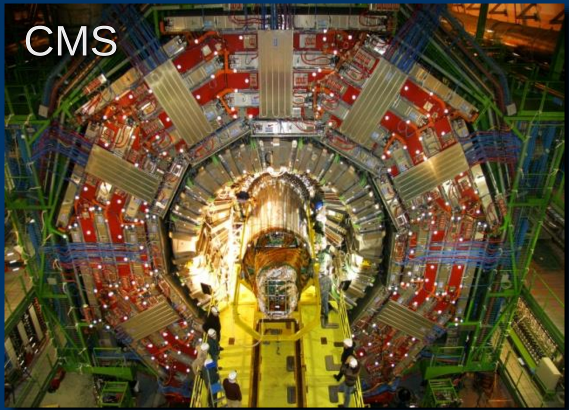


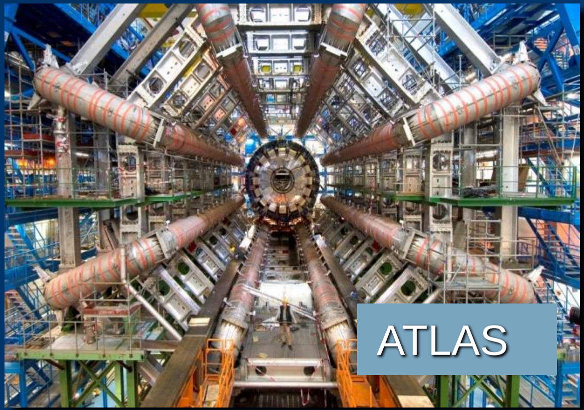
Exploration of a new energy frontier
Proton-proton and Heavy Ion collisions
at E_{CM} up to 14 TeV



LHC Experiments → complementary

Specialised detector to study b-quarks → CPV



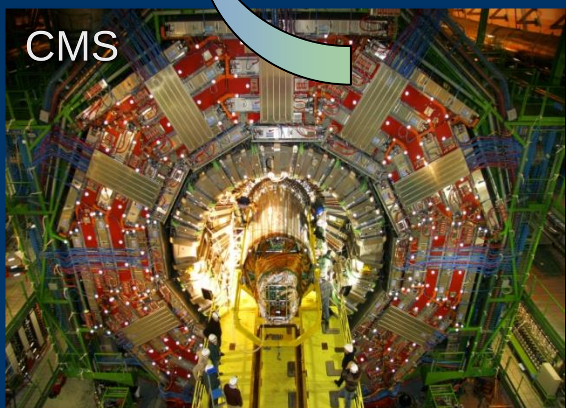


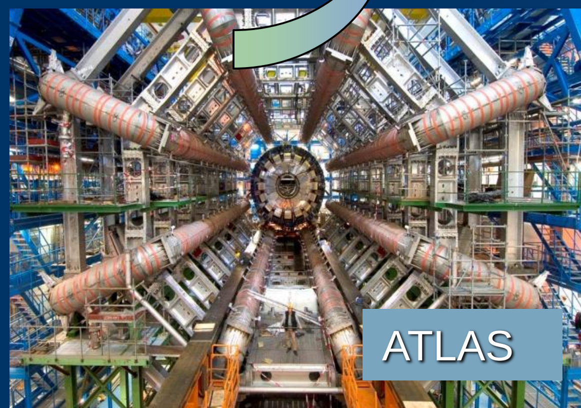
General purpose detectors

Specialised detector to study heavy ion collisions

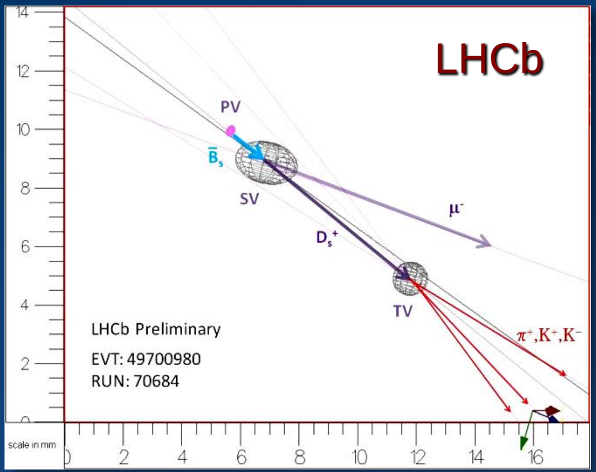
LHC Experiments → complementary

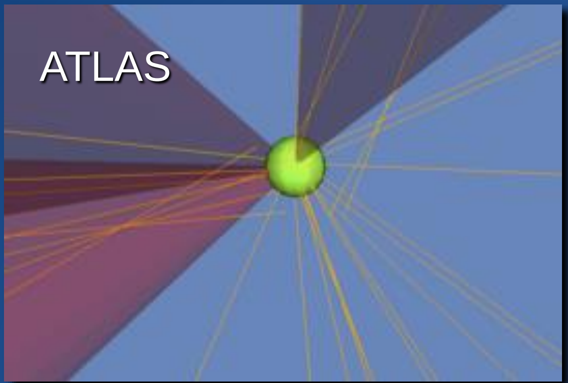
Overlap in physics reach





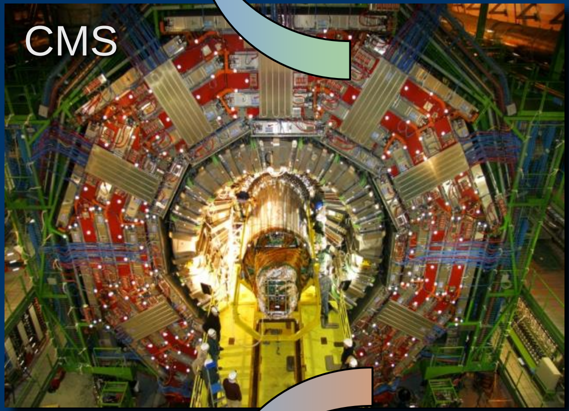
Key feature: reconstruct secondary vertex

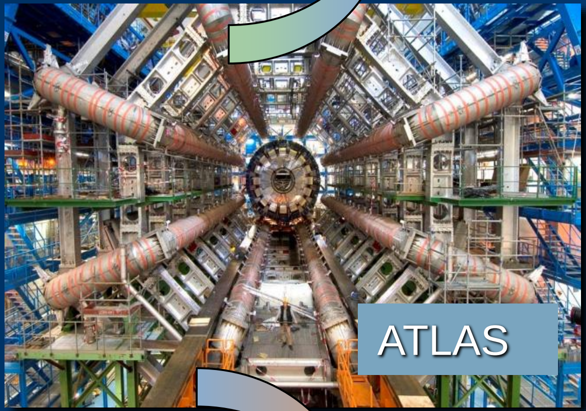


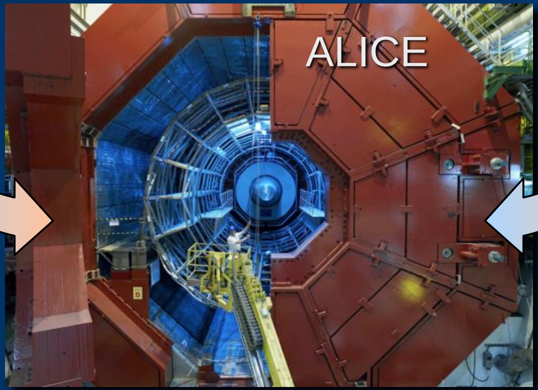


LHC Experiments → complementary

Overlap in physics reach

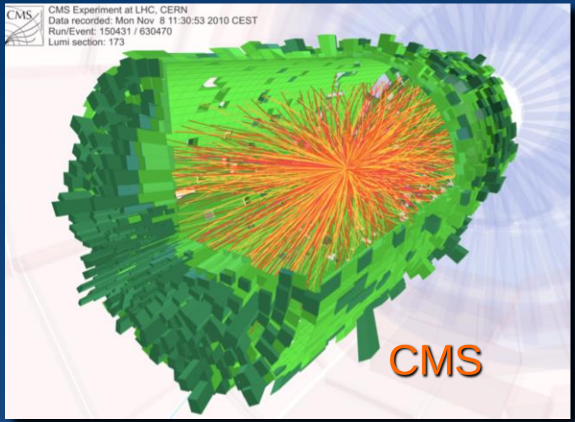


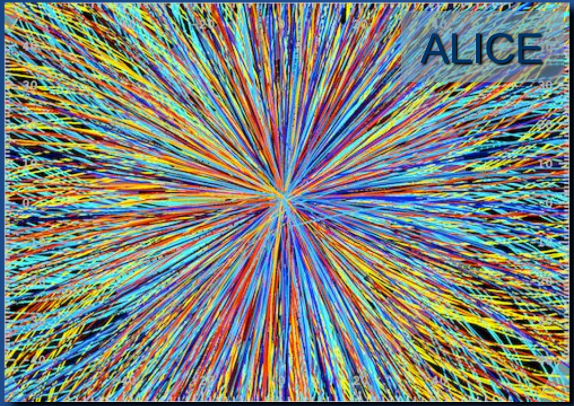


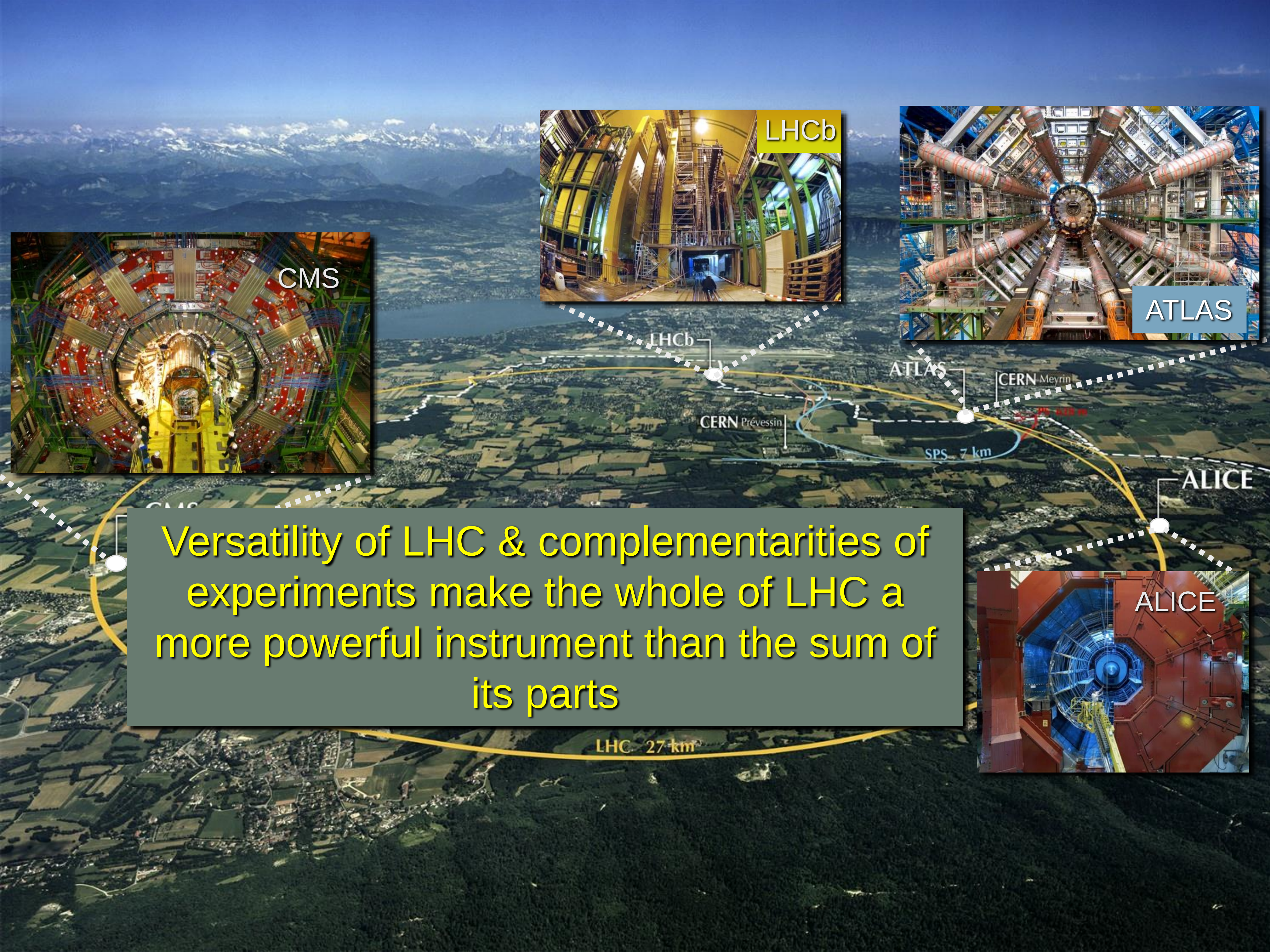


Overlap in physics reach

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

Four main results from LHC Run-1

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

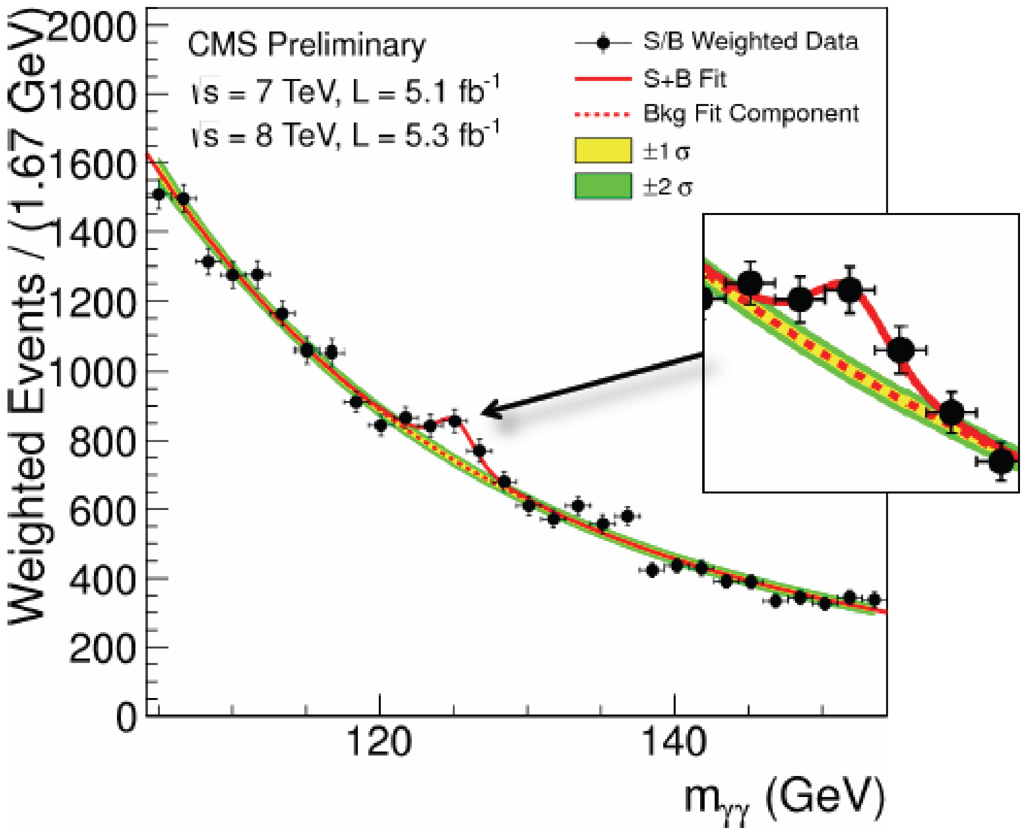
2) We have **completed** the Standard Model: Discovery of the messenger of the BEH-field, the Higgs boson discovery
(over 50 years of theoretical and experimental efforts !)

3) We found interesting properties of the hot dense matter

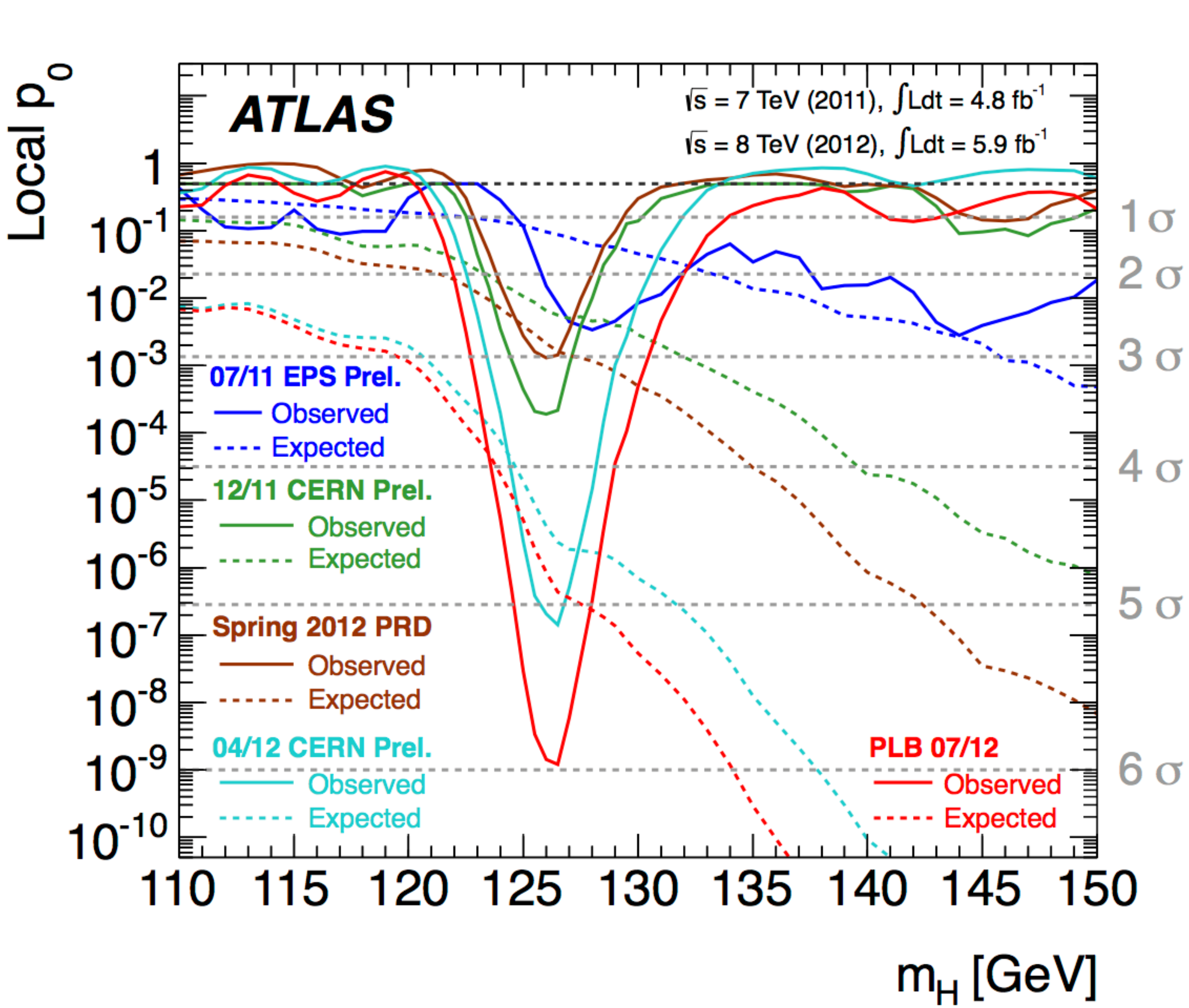
4) We have no evidence of new physics (YET)

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



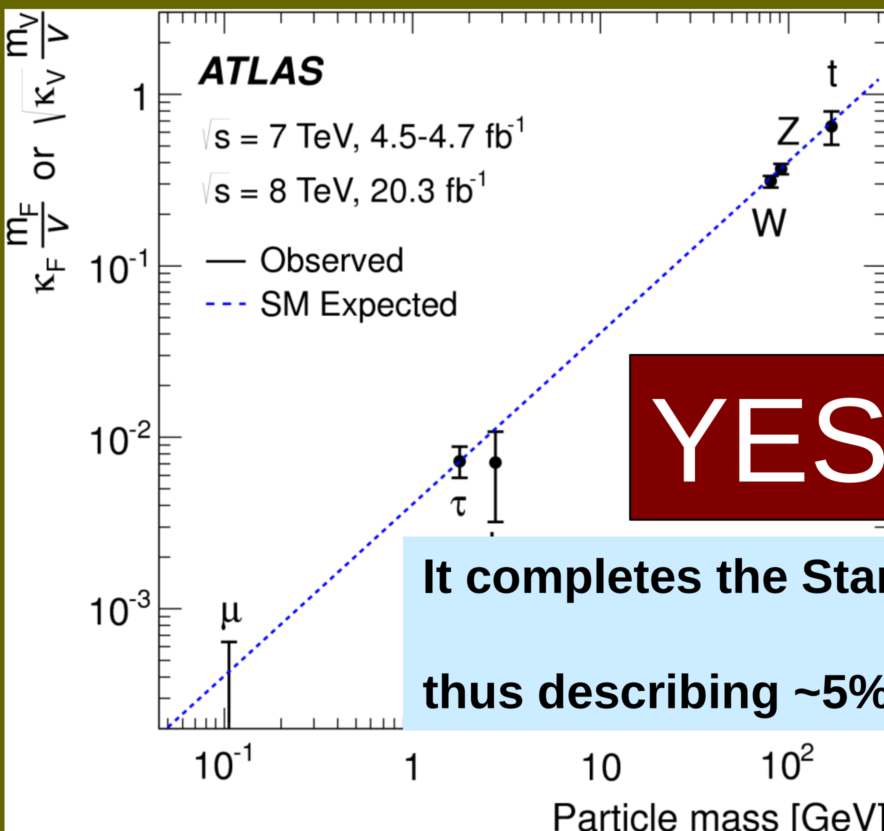
Evolution of the excess with time

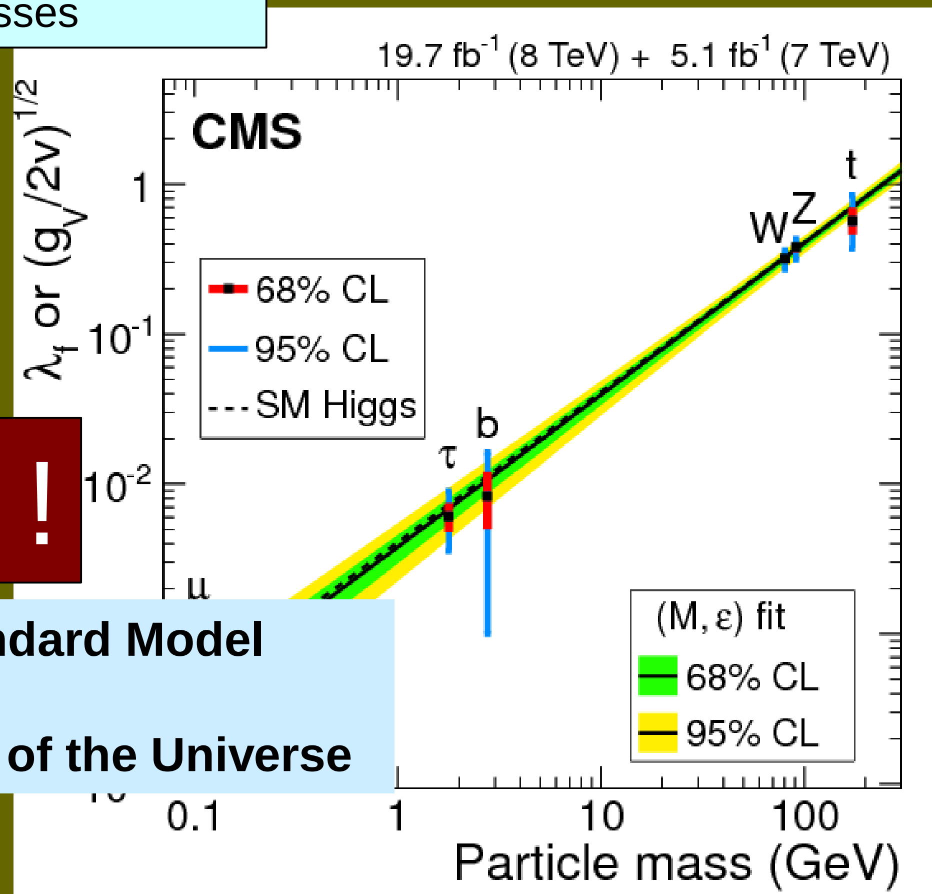


Is the new particle a Higgs boson ?

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





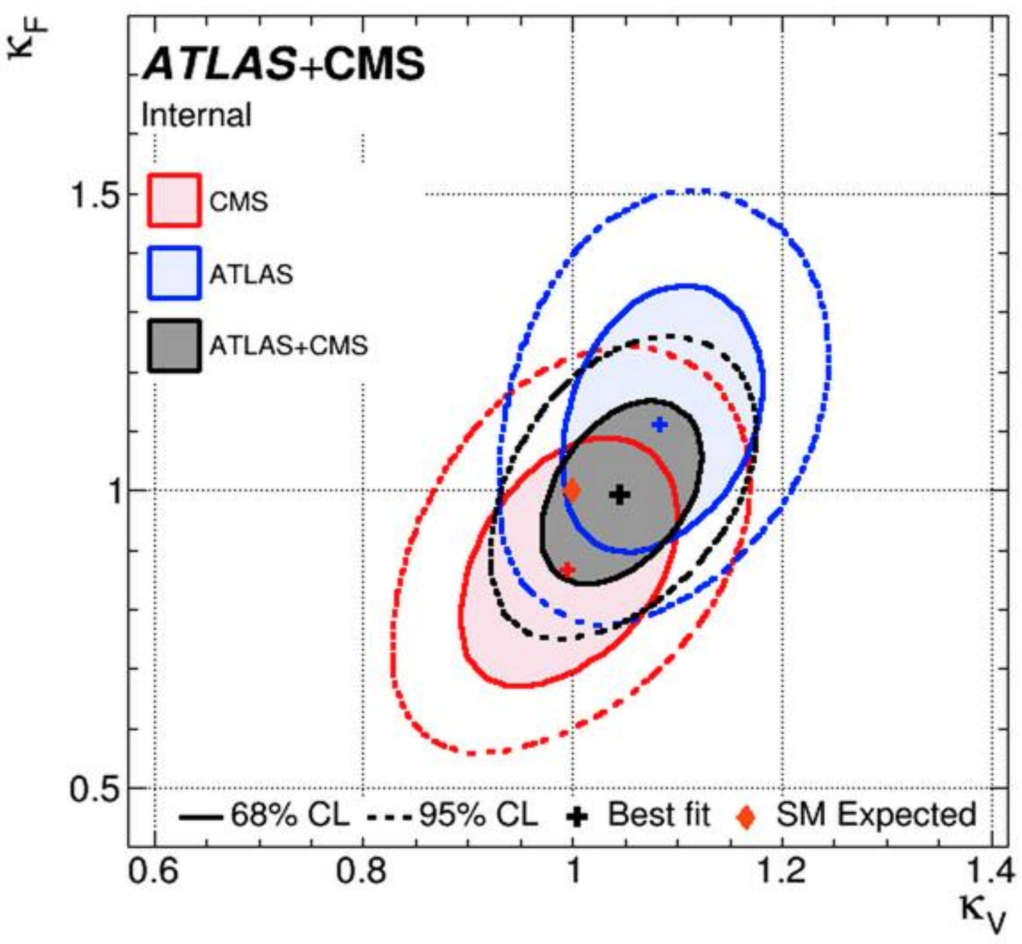
YES !

It completes the Standard Model

thus describing ~5% of the Universe

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

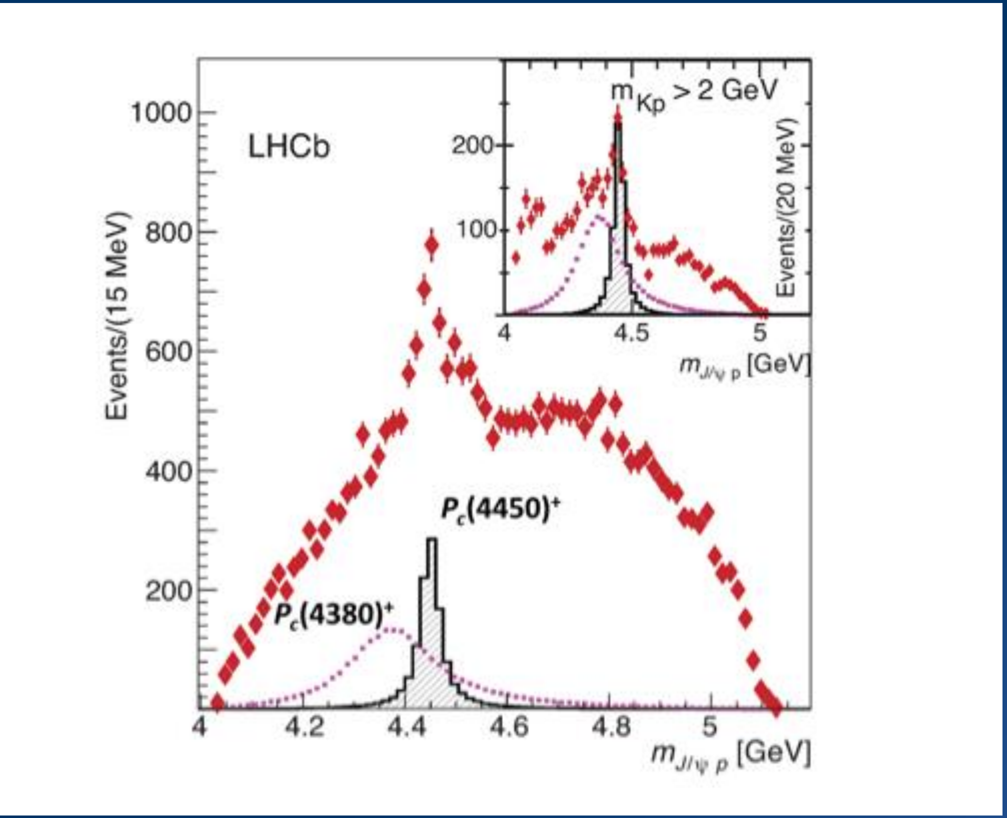
Higgs couplings combined results



Results of the analyses by individual experiments (coloured) and both experiments together (black), showing the improvement in precision resulting from the combination of results.

Observation of Pentaquark States

(LHCb 2015, with data from Run1)



The mass of J/ψ–proton (J/ψ p) combinations from Λb → J/ψpK-decays. The data are shown as red diamonds. The predicted contributions from the Pc(4380)+ and Pc(4450)+ states are indicated in the purple and black distributions, respectively. Inset: the mass of J/ψ p combinations for a restricted range of the K-p mass, where the contribution of the wider Pc(4380)+ state is more pronounced. (The other contributions from conventional hadrons, which are responsible for the remaining features in the data distributions, are not displayed.)

Comparison q/m for nuclei/antinuclei (p, d, ^{3}He)

BASE

LHC

AD

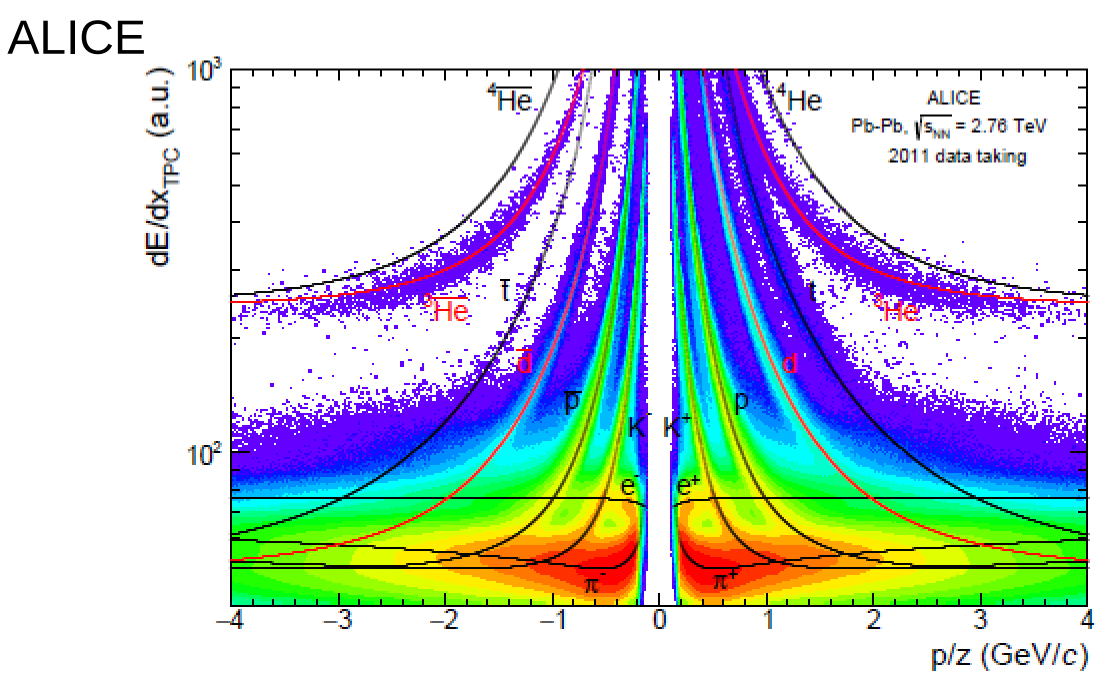


Fig. 1: Specific energy loss of the tracks (dE/dx) in the TPC versus rigidity for negative and positive particles. Lines represent the parameterization of the Bethe-Bloch formula for various particle species (the red lines correspond to (anti-)deuteron and (anti-)^{3}He nucleus). Most of the nuclei at low rigidity are produced from the material "knock out": to reject them, the information of the distance of closest approach of the tracks to the reconstructed primary vertex is used (see text).

BASE: CPT confirmed to 69 x 10 $^{-12}$

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What's next ?

YEARS/ANS CERN

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 also a superb **intensity** fr… 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!

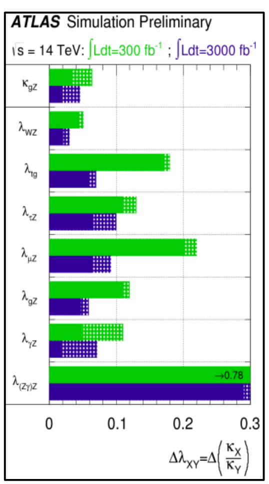
Fabiola:

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

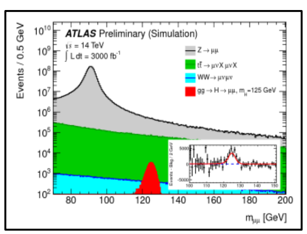
today : ATLAS+CMS have 1400 Higgs events
HL-LHC: (3000fb-1) > 3M/170M useful for precise measurement

- ❑ 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

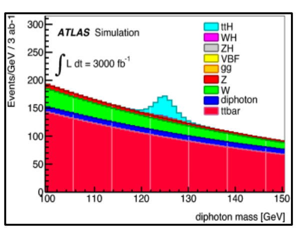
Couplings



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



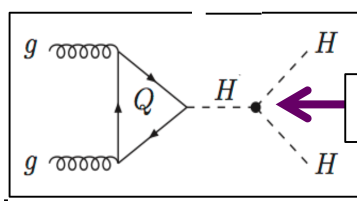
ttH
↳ γγ



H ––> μμ

Access to rare processes

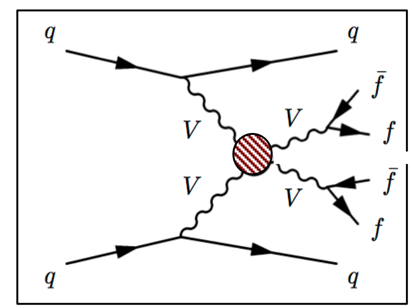
Self-coupling



$g_{HHH} \sim \lambda v$

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: Large-scale scientific activities

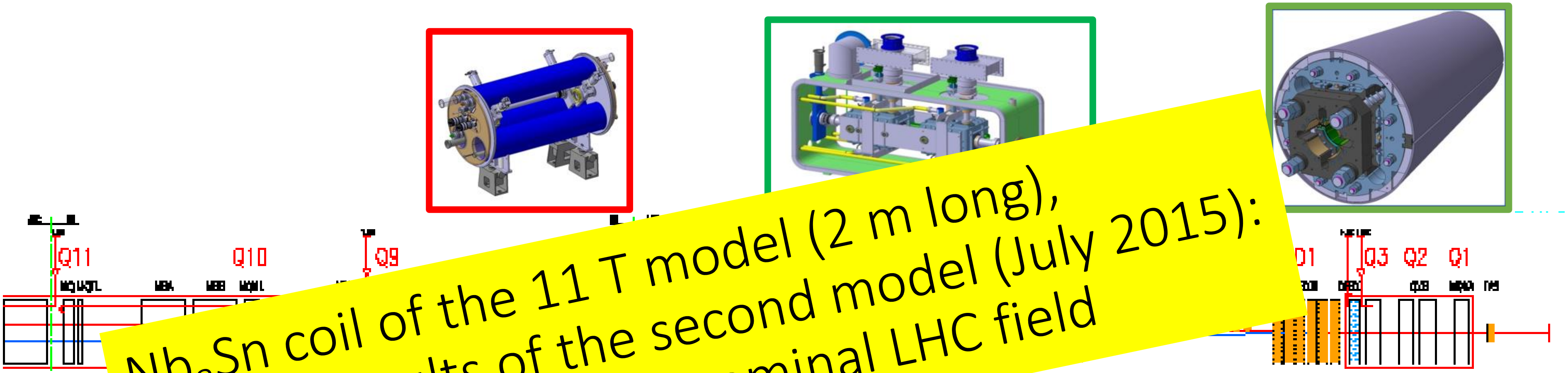
***Europe's top priority** should be the **exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors** with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting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

US Strategy for Particle Physics (P5 report):

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.

One of the largest HEP accelerator in construction



Nb$_3$Sn coil of the 11 T model (2 m long), quench results of the second model (July 2015): excellent, well beyond nominal LHC field

…ing Section (MS)

Interaction Region (ITR)

1. In IP2: new DS collimation with 11 T
2. In IP7 new DS collimation with 11 T

Cryogenics, Protection, Interface, Vacuum, Diagnostics, Inj/Extr… extension of infrastr.

Complete change and new lay-out

1. TAN
2. D2
3. CC
4. Q4
5. All correctors
6. Q5 (Q6 @1.9 K?)
7. New MQ in P6
8. New collimators

Complete change and new lay-out

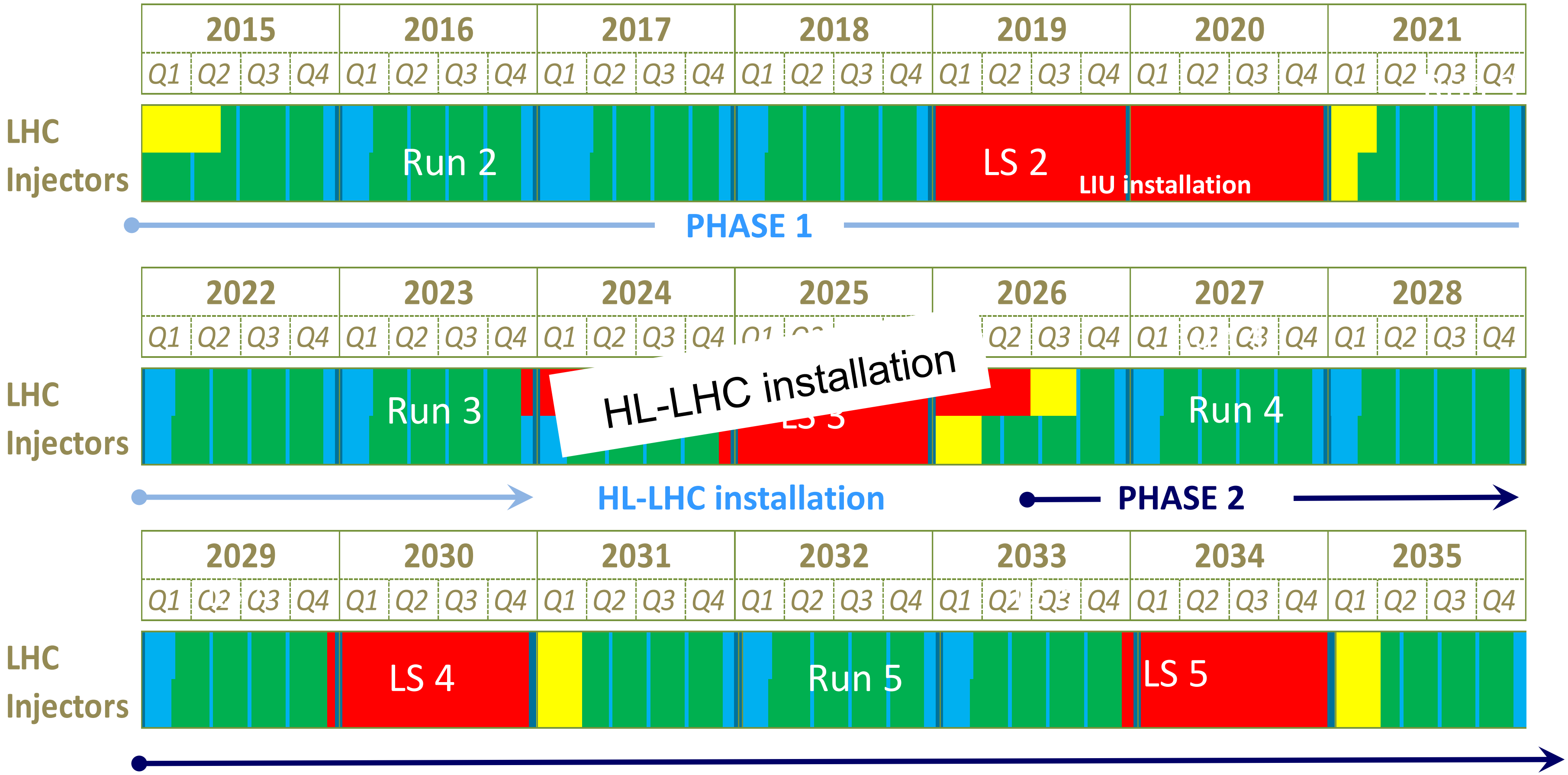
1. TAS
2. Q1-Q2-Q3
3. D1
4. All correctors
5. Heavy shielding (W)

> 1.2 km of LHC

LHC roadmap

LS2 starting in 2019 => 24 months + 3 months BC
LS3 LHC: starting in 2024 => 30 months + 3 months BC
Injectors: in 2025 => 13 months + 3 months BC

- Physics
- Shutdown
- Beam commissioning
- Technical stop



Key message

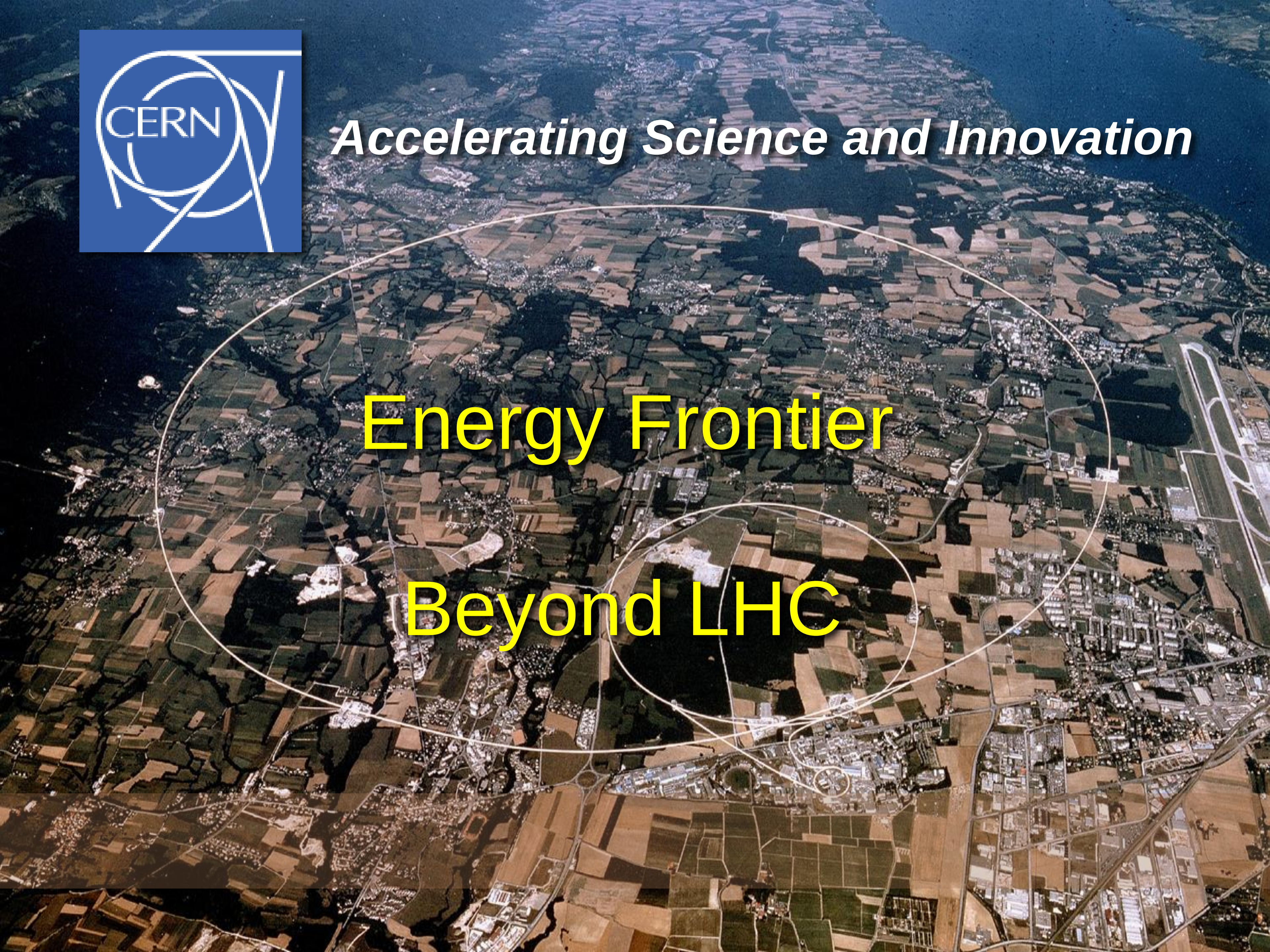
Upgrades to accelerator complex, detectors, and computing Grid are vital to fully exploit the physics potential of LHC

There is a ... ntier

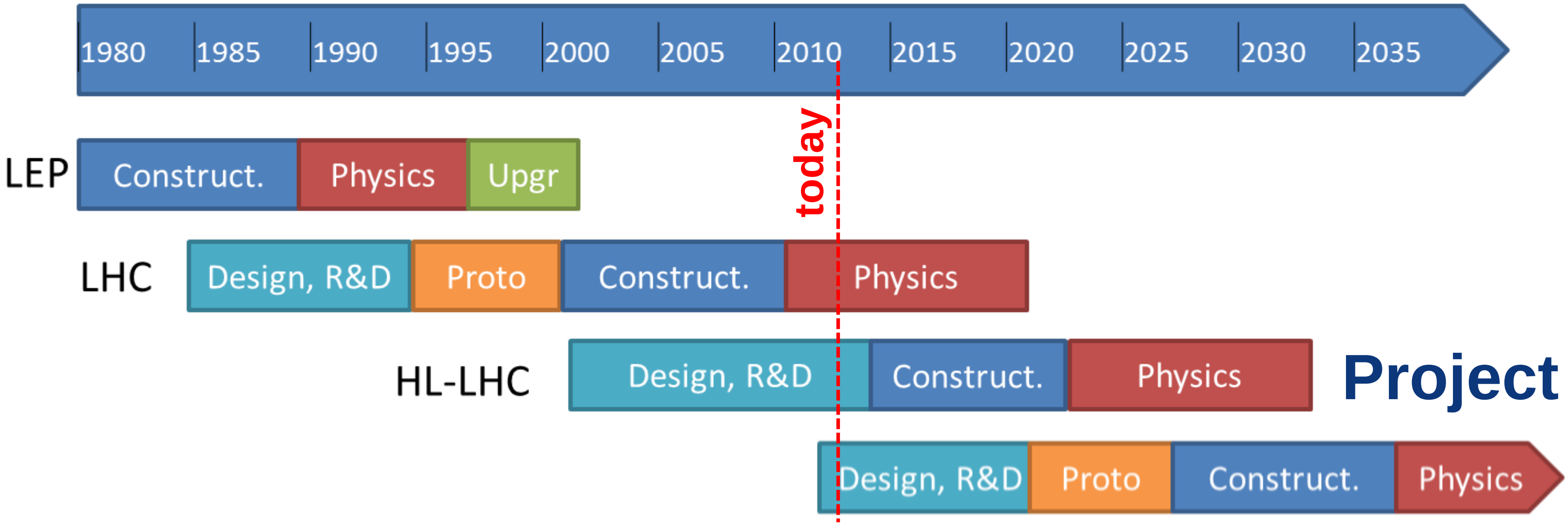
... eV (essentially done)

14 TeV design luminosity

14 TeV high luminosity (HL-LHC)


CERN
Accelerating Science and Innovation
Energy Frontier
Beyond LHC

“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 Geneva

First Coll. Meeting: March 2015 Washington

FCC: Future Circular Colliders

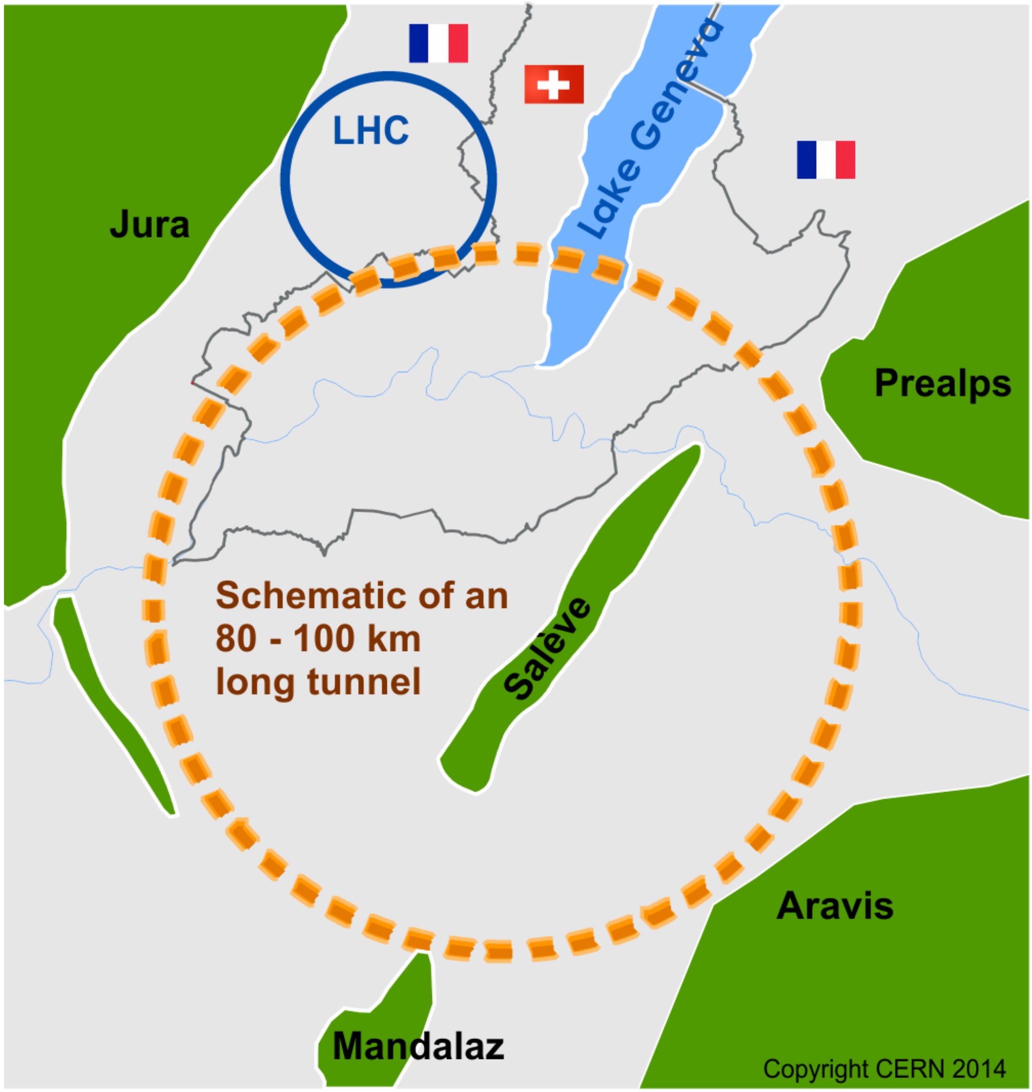
Future Circular Collider Study
CDR and cost review for the next ESU (2018)

<u>**international collaboration**</u>
to study:

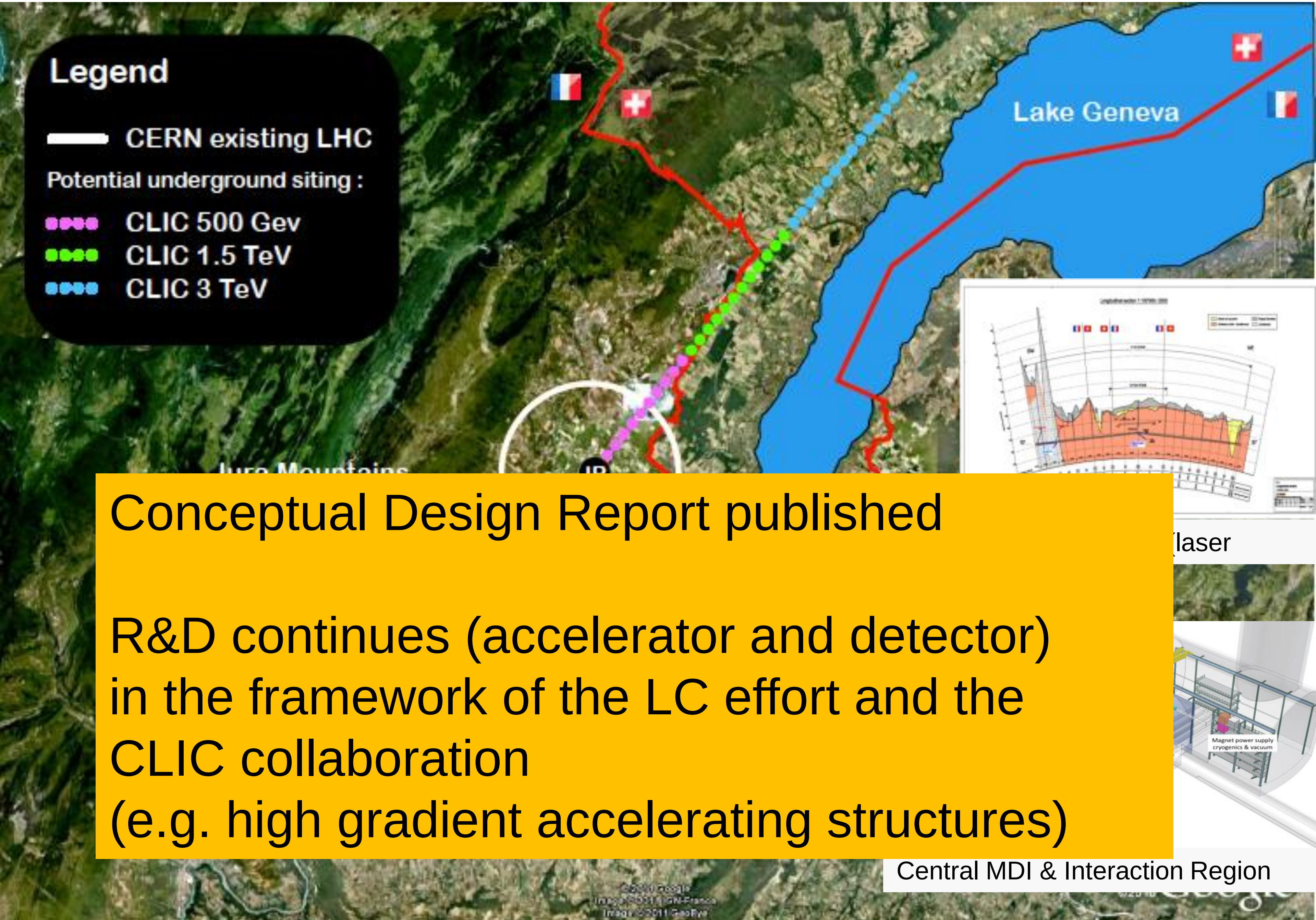
- ***pp*-collider (*FCC-hh*)**
  → defining infrastructure requirements

~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[illegible]ities requiring significant resources, sizeable co[illegible]itment, the following four activities h[illegible] priority.

e) Ther[illegible]positron collider, comple[illegible] the properties of the Higgs boson and othe[illegible]nted precision and whose energy can be upgraded[illegible]Design Report of the International Linear Collider (ILC) has [illegible]ompleted, 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

YEARS / ANS CERN


CERN
Accelerating Science and Innovation
Intensity Frontier

European Strategy for Particle Physics: Large-scale scientific activities

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.

US Strategy for Particle Physics (P5 report):

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.**

Scientific Strategy – Neutrinos

- Neutrino programme established at CERN through the “Neutrino Platform”
- Neutrino platform is well underway & active. It enables European groups to develop their detector parts for participation at neutrino facilities. In addition, proposals from non-European groups received.
- Collaboration with Fermilab established for long-term neutrino programme, in particular through support from CERN to the Dune infrastructure
- This collaboration is also vital for the US contribution to the LHC and its upgrades
- Very limited resources available at CERN. Need to define best use for the community. The CERN plan submitted to Council contains one full cryostat as in-kind contribution to Dune. Coordination in Europe concerning further contributions to this infrastructure required and under way.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Diversity

European Strategy for Particle Physics

A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments.
The CERN Laboratory should maintain its capability to perform unique experiments.
CERN should continue to work with NuPECC on topics of mutual interest.

- Exciting physics at **unique facilities**
  - Na61, Na62
  - N_Tof area 2
  - HIE-ISOLDE construction
  - ELENA construction including consolidation of the AD facility
  - Maintain experimental areas for fixed-target experiments

CERN | YEARS/ANS CERN

Conclusion

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