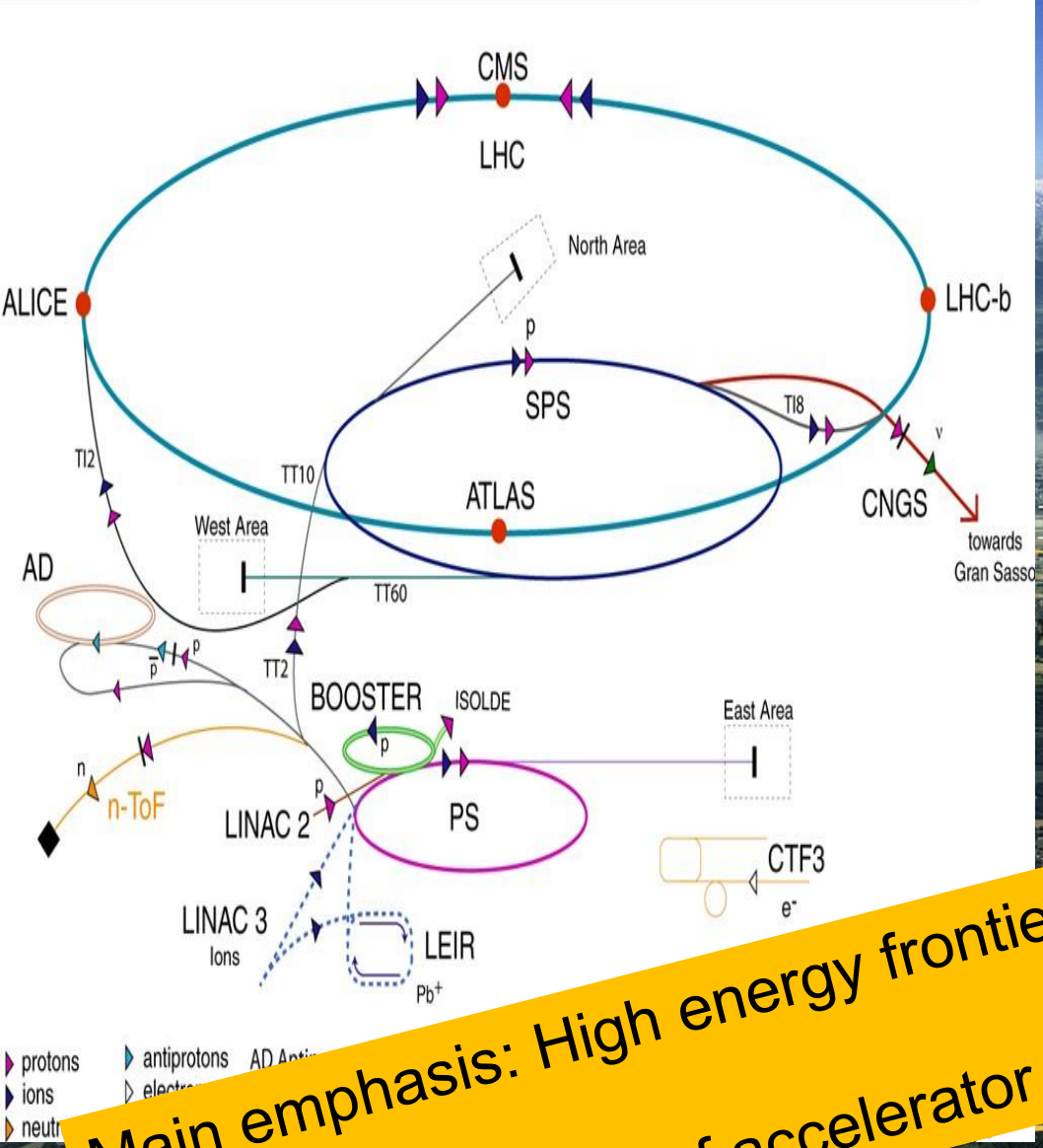
*Accelerating Science and Innovation*

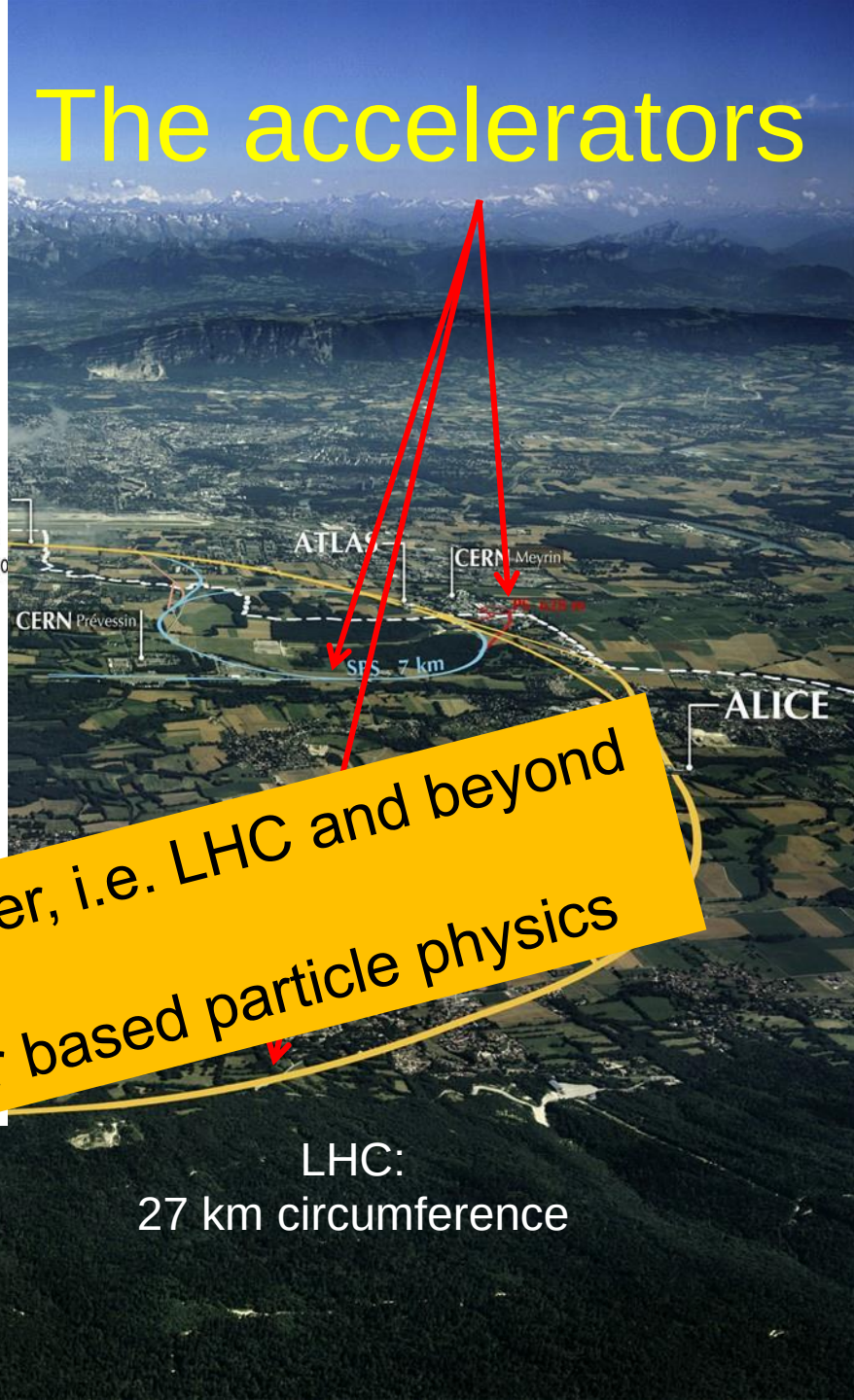
# CERN
# Update & Perspectives

R.-D. Heuer, CERN

Amsterdam, June 26, 2014

# 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***

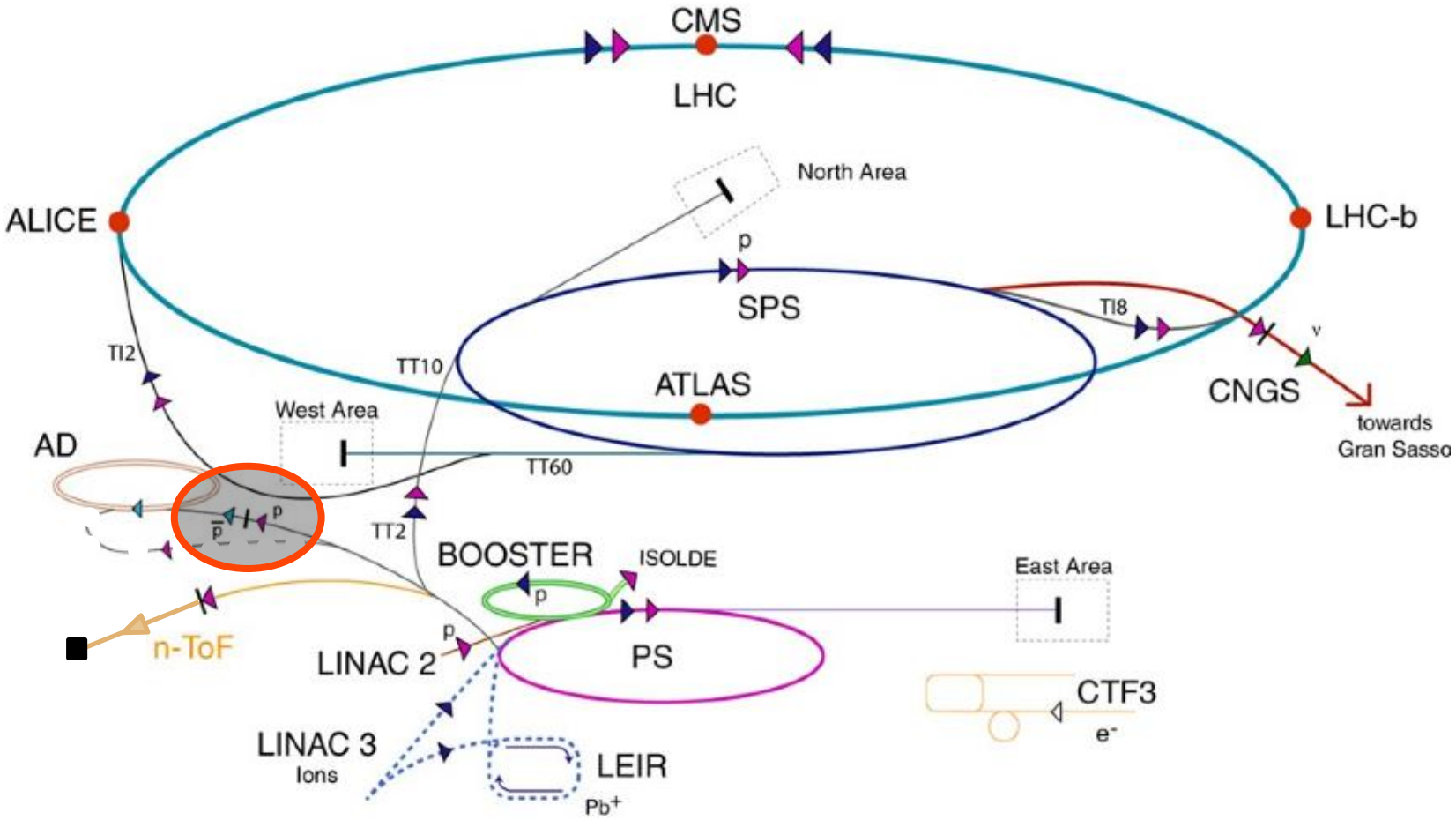
## In the past few years

***Several breakthroughs !***

***Steady progress of other programs***

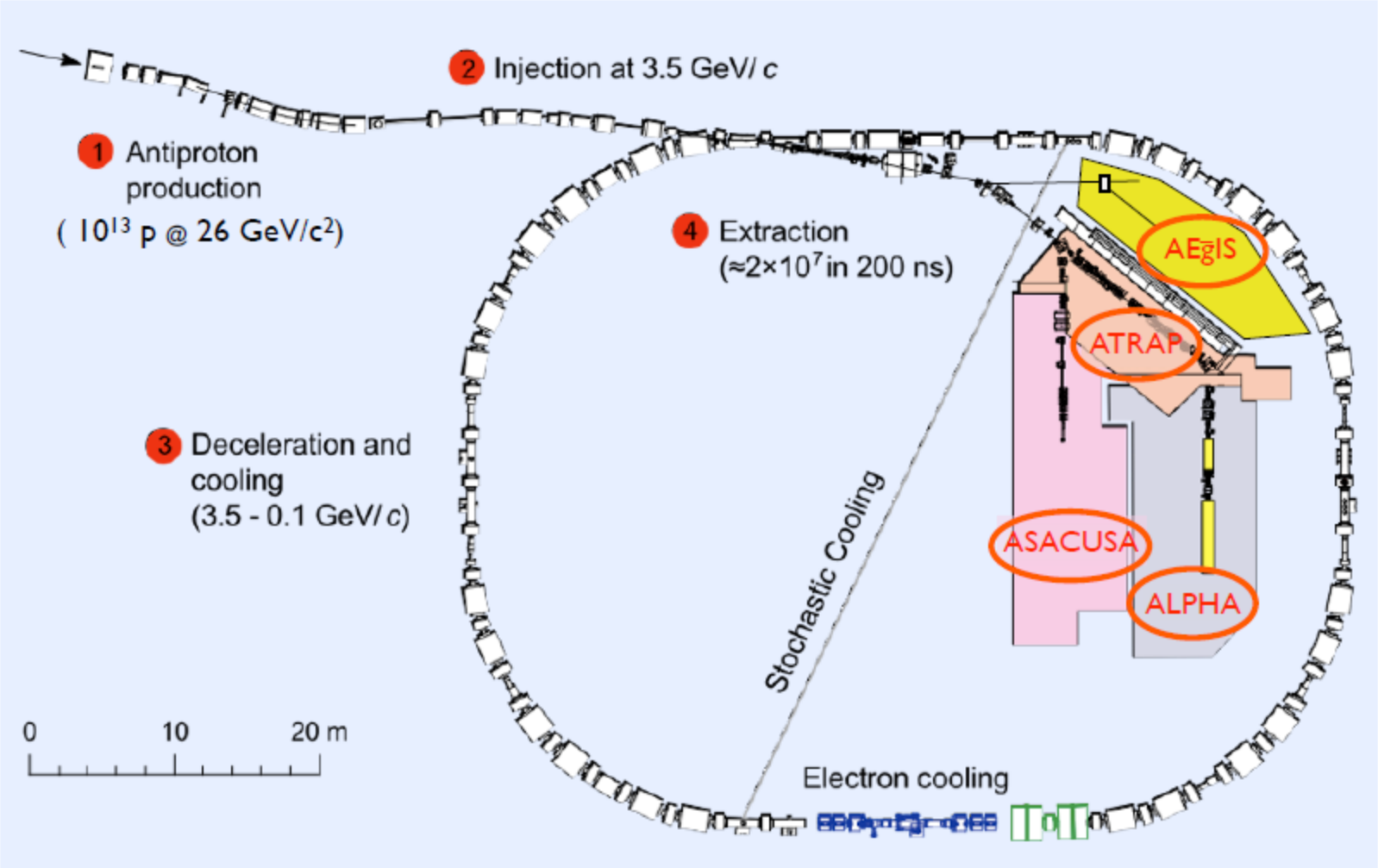
***New mid-term and long-term projects started or in discussion***

# CERN Accelerator Complex



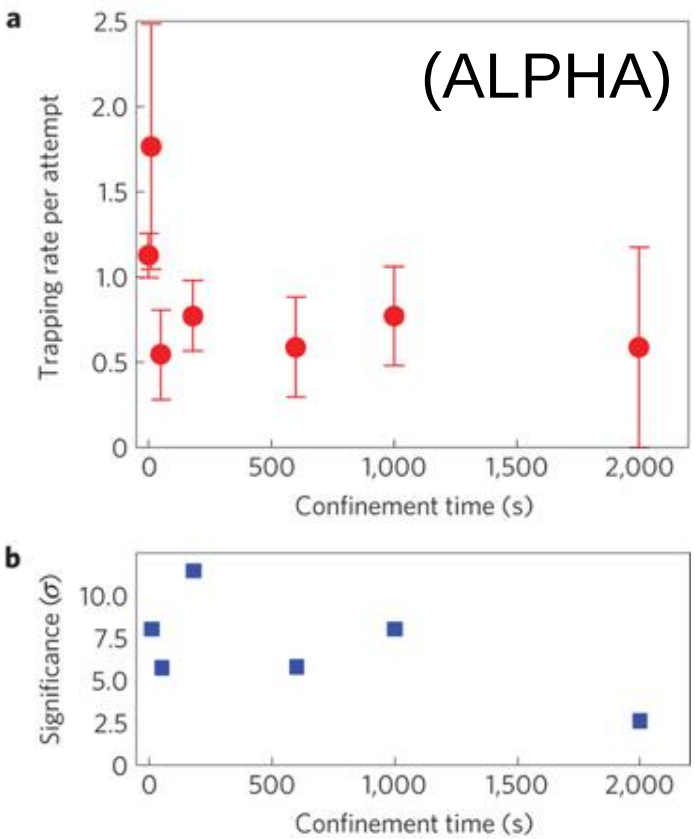
# AD (current situation)

## Antiproton decelerator

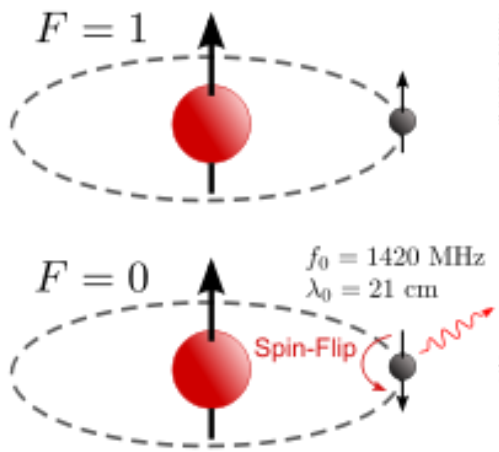


# Spectroscopy with trapped antihydrogen?

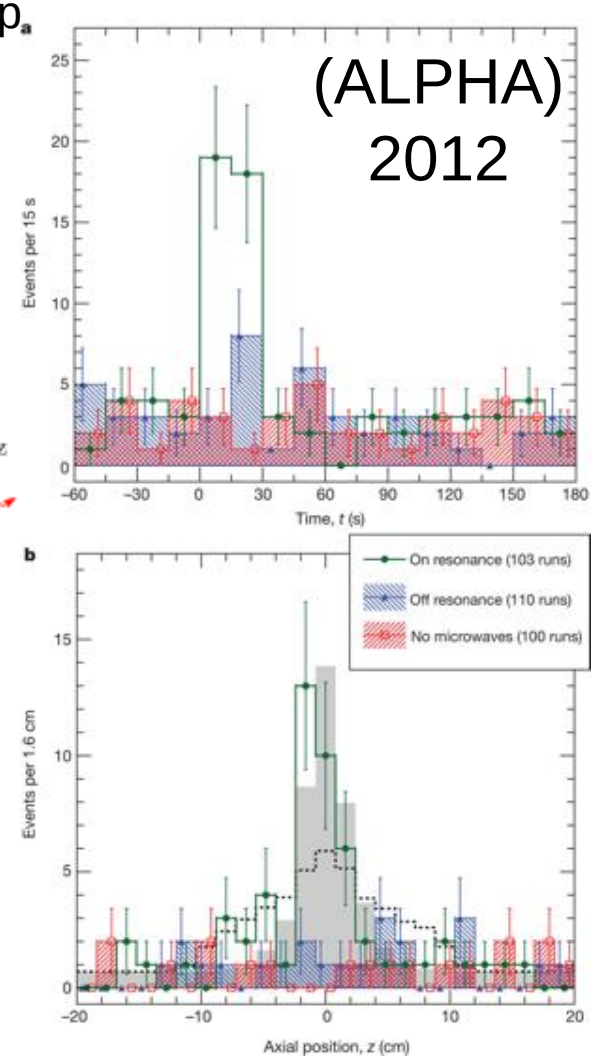
Antihydrogen atom trapping time




Spectroscopy:
HFS
via microwave



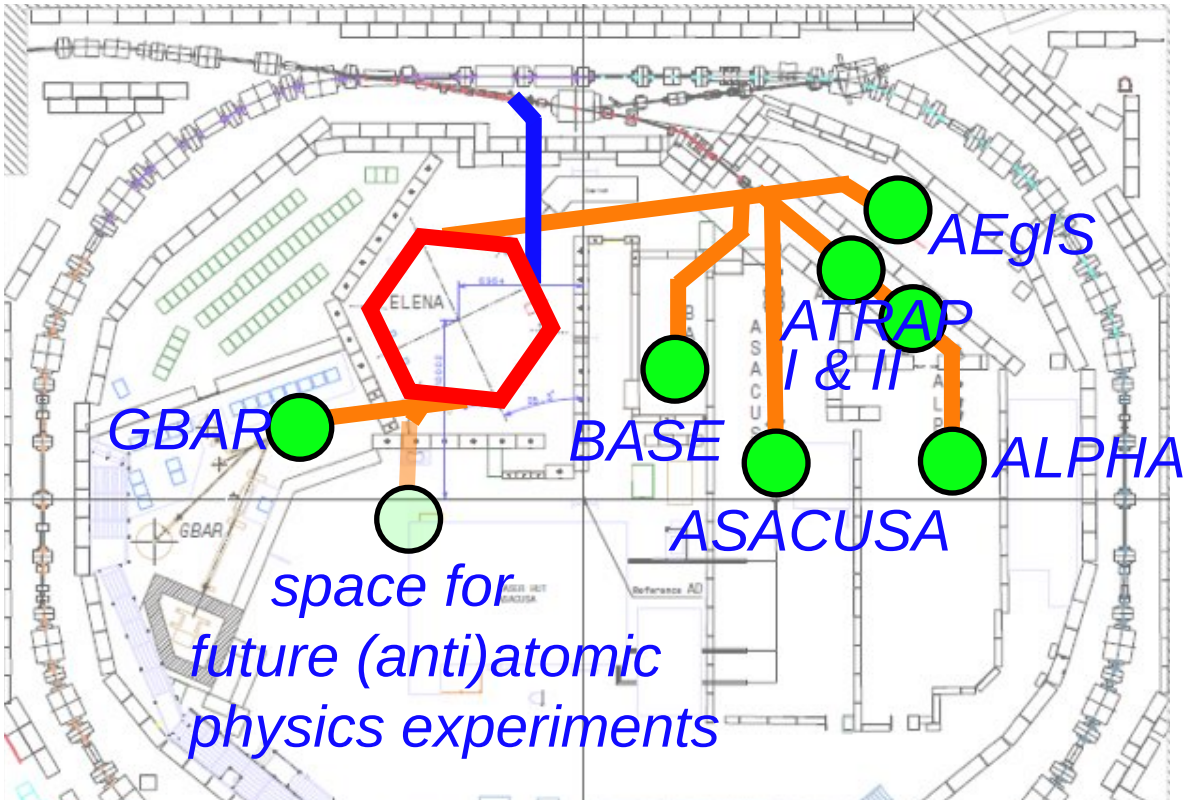

but: B-field varies strongly over trap




Next steps: better cooling, more atoms, laser spectroscopy

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

# ➔ELENA (starts 2017)




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

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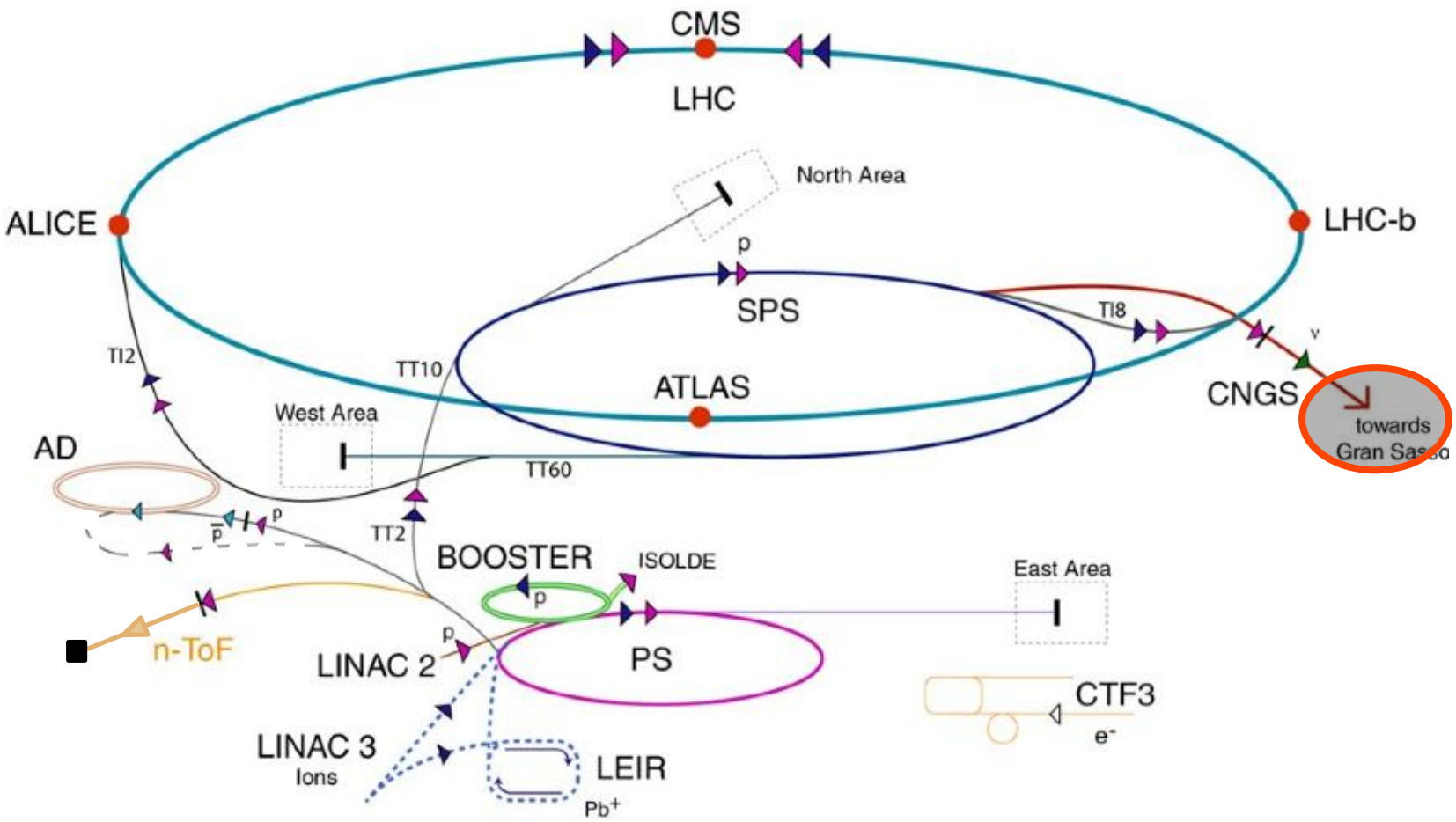
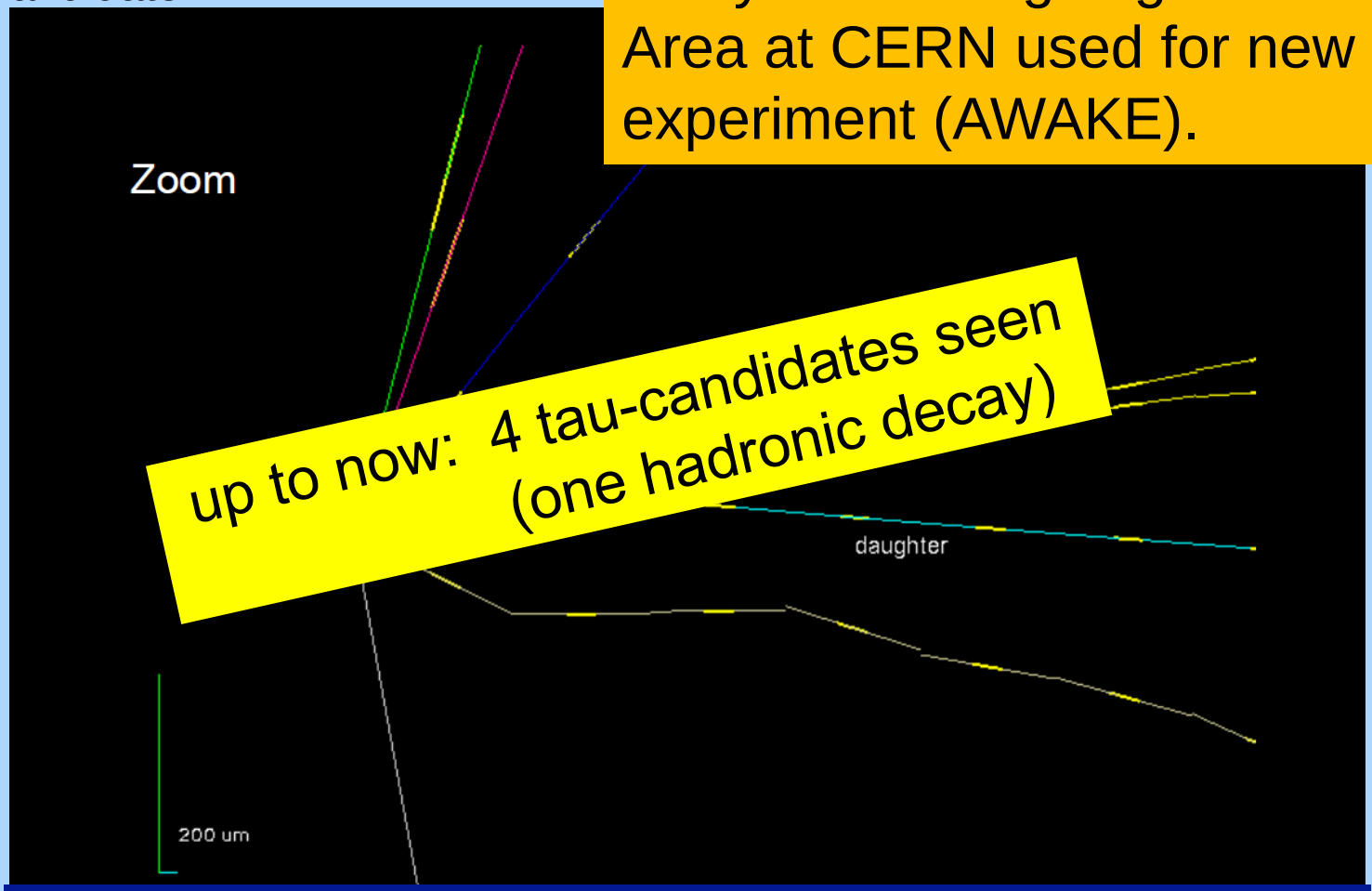


# CNGS - OPERA

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

First $\upsilon_\tau$ Candidate




up to now: 4 tau-candidates seen (one hadronic decay)

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

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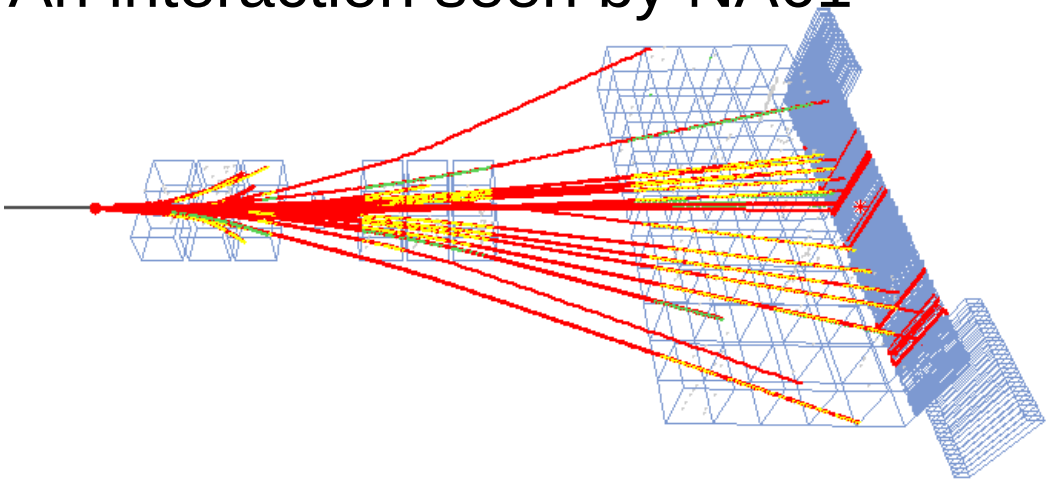
# Searches, Predictions, Spectra - the NA61 experiment

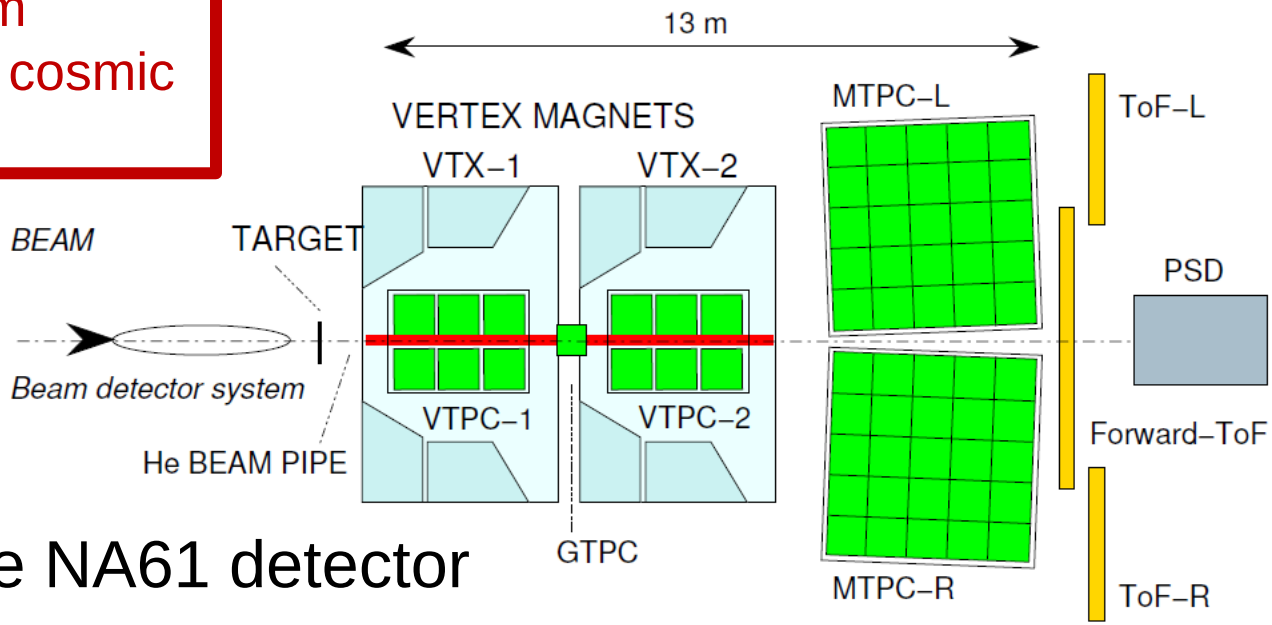
- NA61 measures the production of hadrons in different types of collisions: Nucleus-nucleus (heavy-ion) collisions to investigate properties of the transition line between quark-gluon plasma and hadron gas (deconfinement);

- Hadron-nucleus interactions to determine neutrino beam properties and to model cosmic ray showers

NA61/Shine
Data taking since 2007
120 physicists, 31 institutes, 15 countries

An interaction seen by NA61

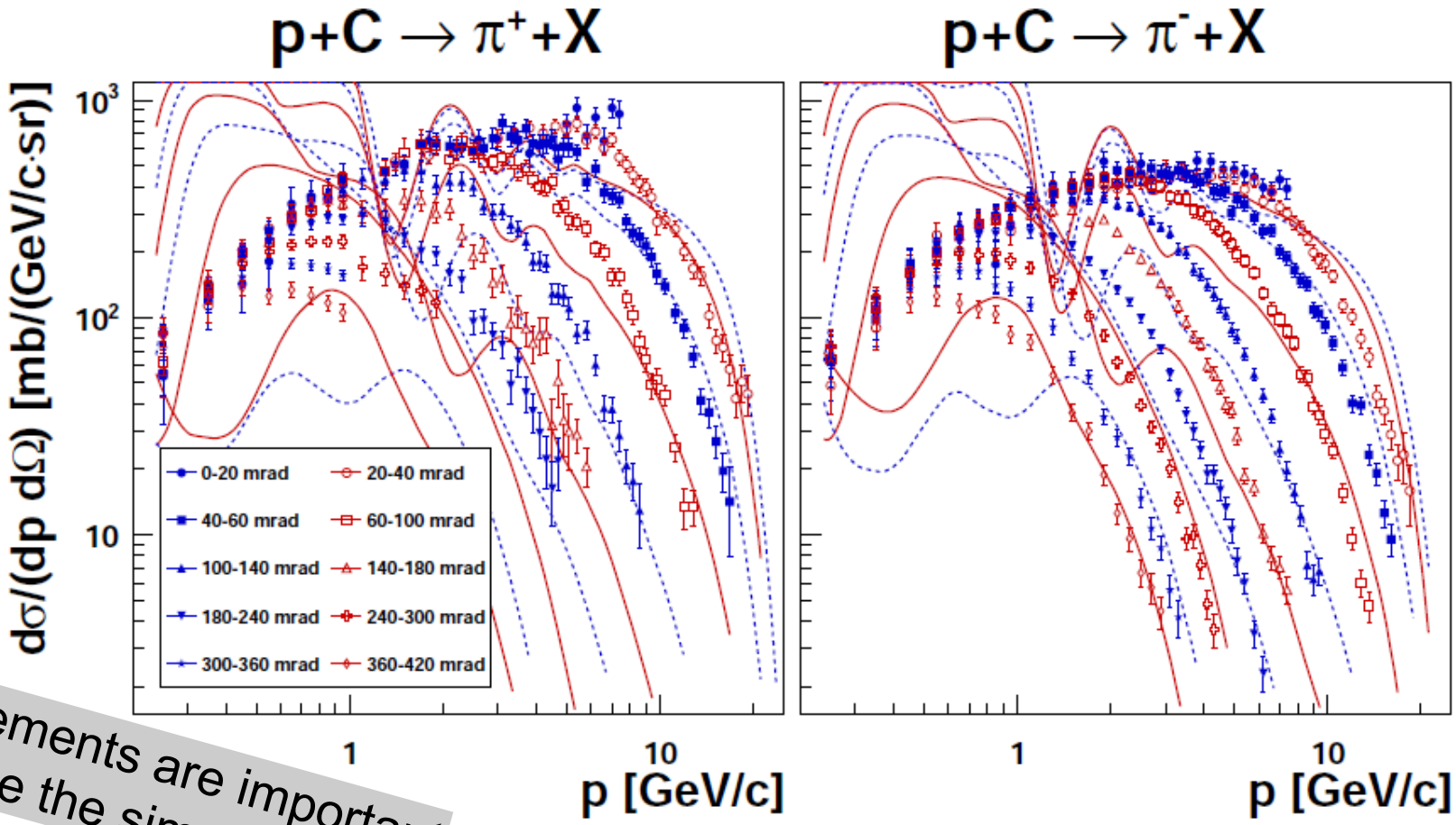





The NA61 detector

# Precise data for neutrino experiments

## Inclusive $\pi^+$ spectra in p+C at 31 GeV/c




Measurements are important to tune the simulation!

comparison to Gheisha2002

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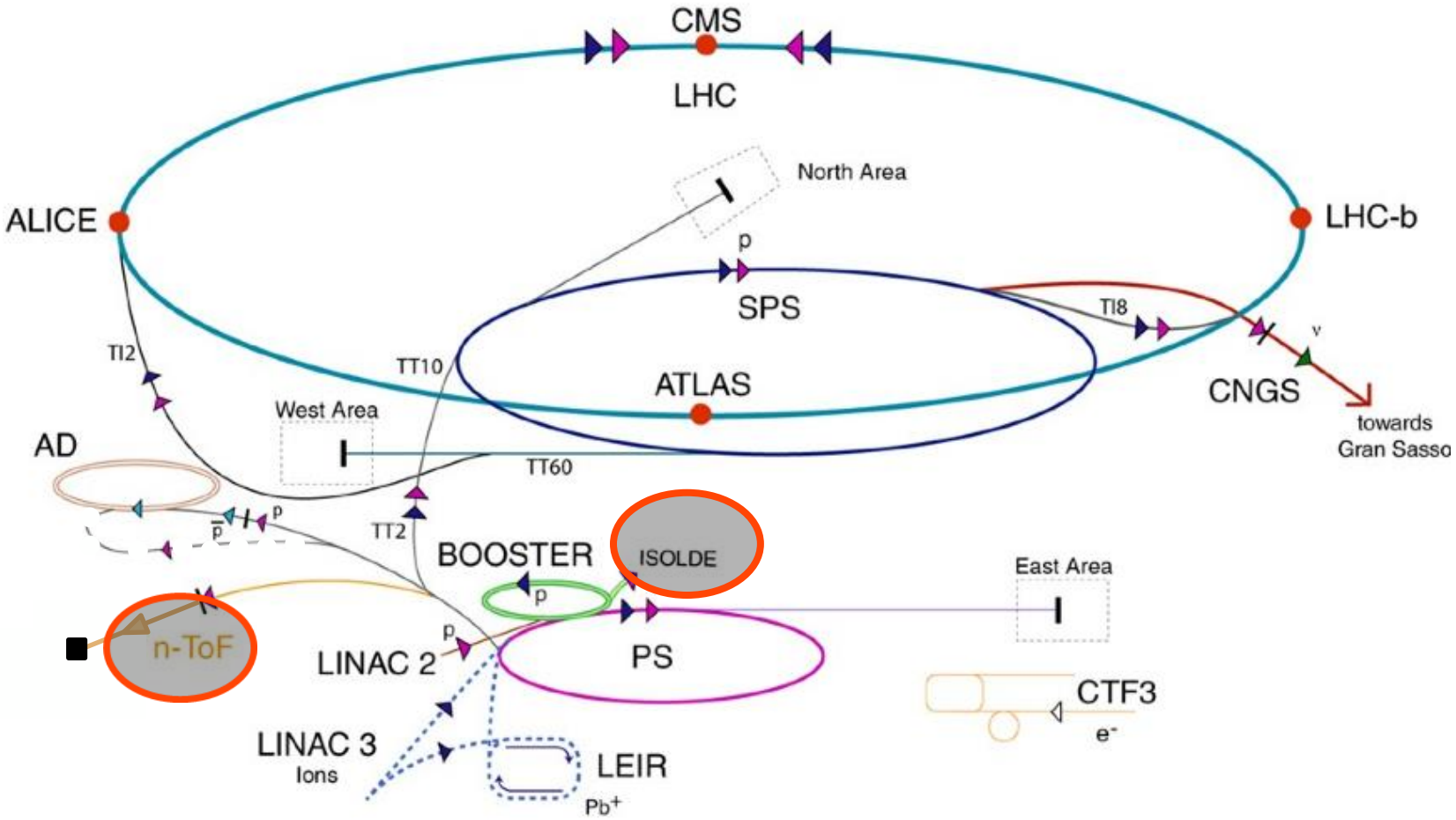
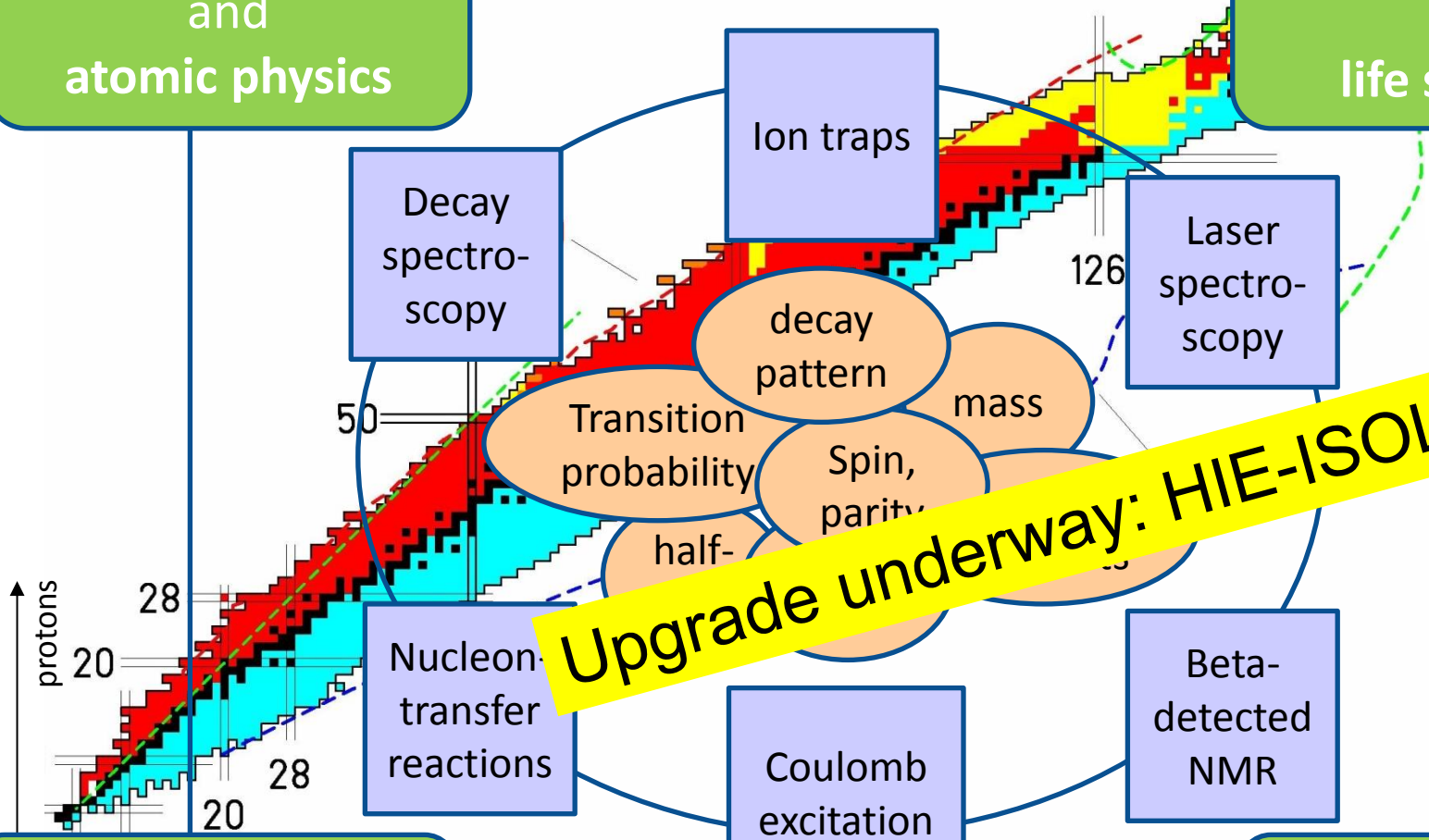


# Research with radioactive nuclides

More than 700 nuclides of over 70 chemical elements delivered

**Nuclear physics** and **atomic physics**

**Material science** and **life sciences**




Ion traps

Decay spectro-scopy

Laser spectro-scopy

Upgrade underway: HIE-ISOLDE

Nucleon-transfer reactions

Coulomb excitation

Beta-detected NMR

**Fundamental interactions**

**Nuclear astrophysics**

Techniques: all available at ISOLDE

# n_TOF physics

**100 members, 32 institutions**

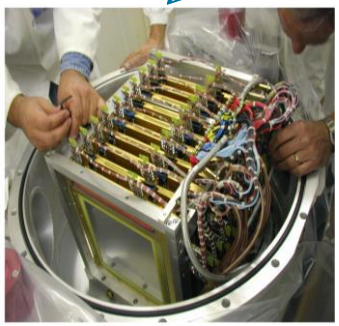
Nuclear technologies | Nuclear Astrophysics | Medical applications | Basic Nucl. Phys.

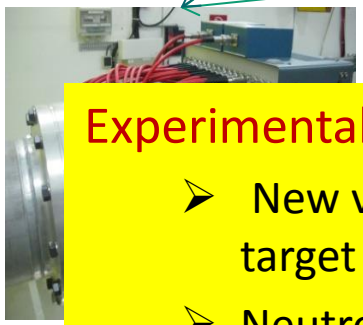
FF Ang. Distribution
$^{237}Np$, $^{234,235,238}U$

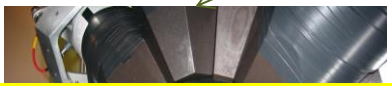
Fission
$^{240,242}Pu$, $^{235}U$

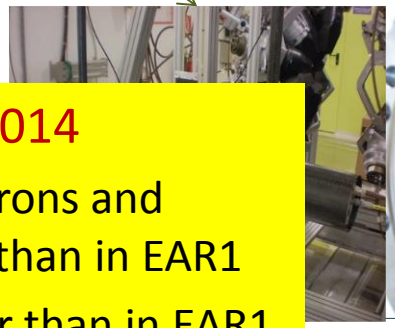
Neutron capture
$^{25}Mg$, $^{88}Sr$, $^{93}Zr$, $^{235}U$

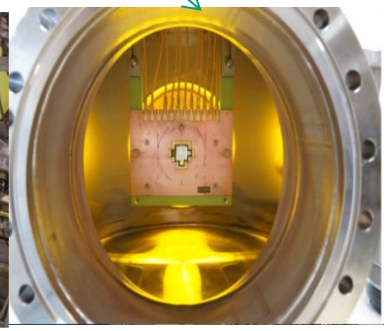
(n,chp)
$^{10}B$, $^{27}Al$, $^{33}S$, $^{59}Ni$,





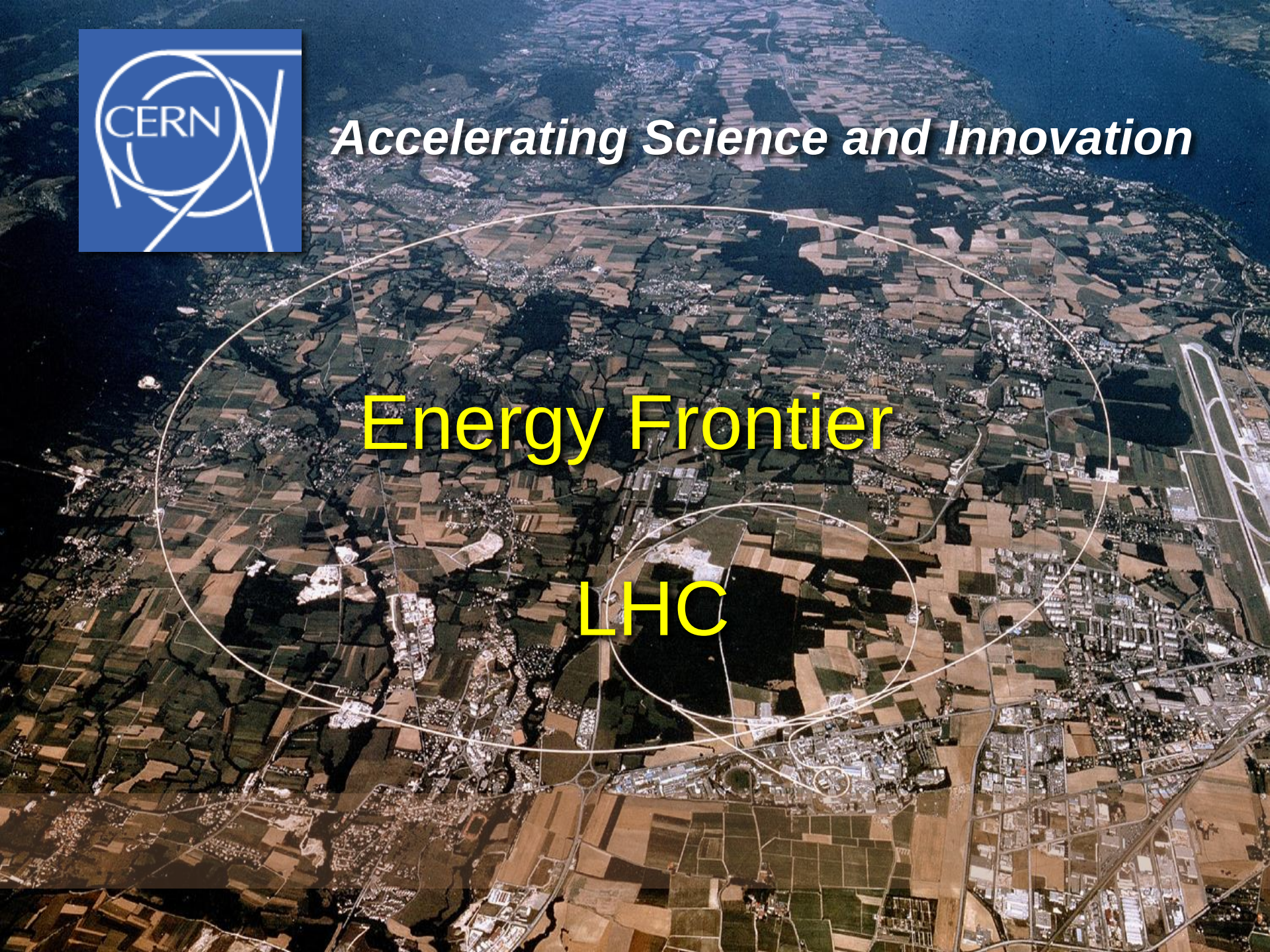






Experimental Area 2 ready in 2014

- 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

LHC run 1
at 7 and 8 TeV

a great success

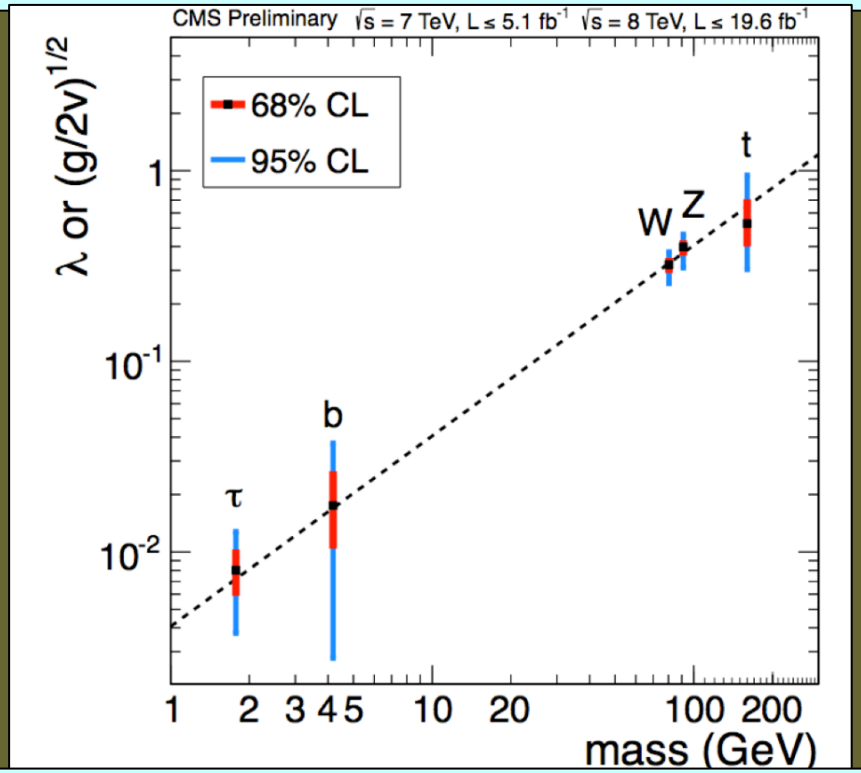
p-p / Pb-Pb / p-Pb

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

# 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**

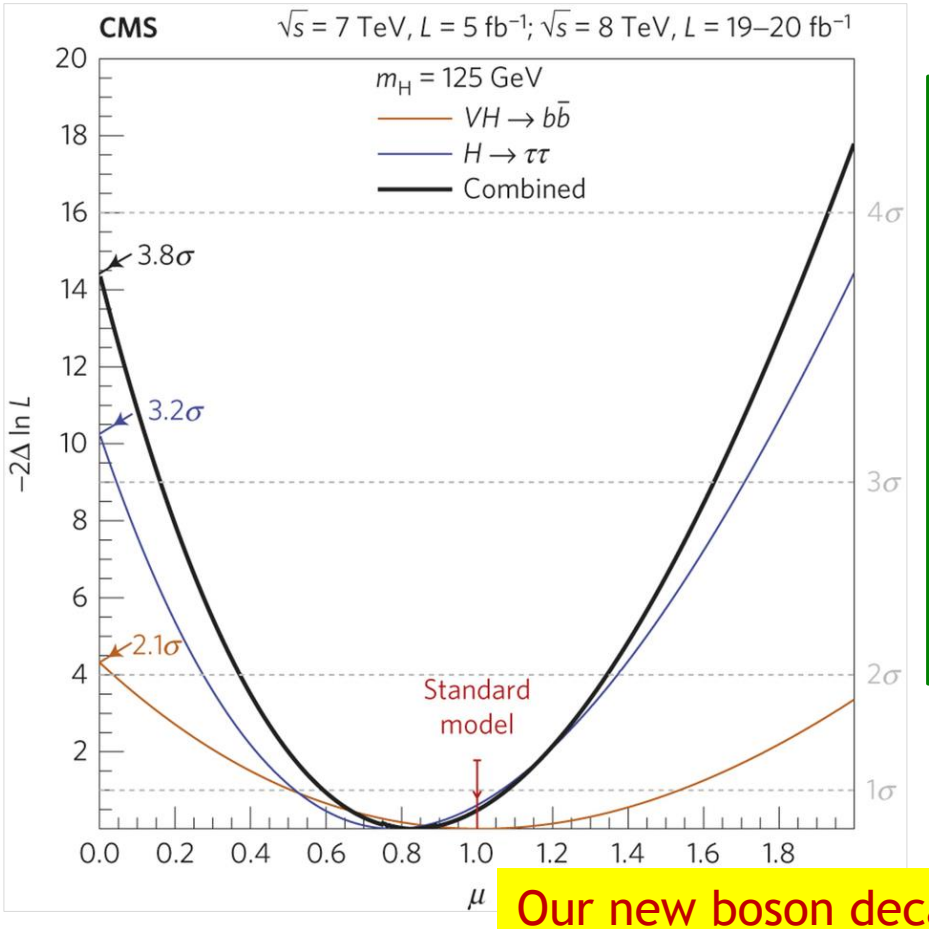
**What about the “Dark Universe” ?**

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

**… information on Dark Matter**
**… first hints on Dark Energy**

# H → bb, ττ

# H → ττ




**Strong evidence for fermionic (tau) decays of the Higgs boson, at the 4.1σ level**

*Confirms and strengthens previous evidence from CMS (3.4σ excess at 125 GeV combining bb and ττ), now updated to combined 4.0σ excess*

Our new boson decays to fermions as well as bosons!

published (Nature)

preliminary

# LHCb 2012:

The search for $B_{s\,(d)} \rightarrow \mu\,\mu$

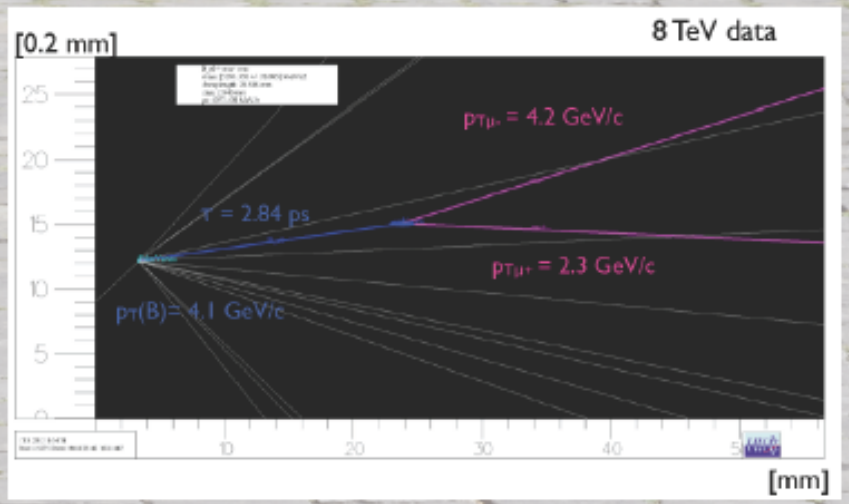
Predicted to be very rare in SM due to GIM & helicity suppression:

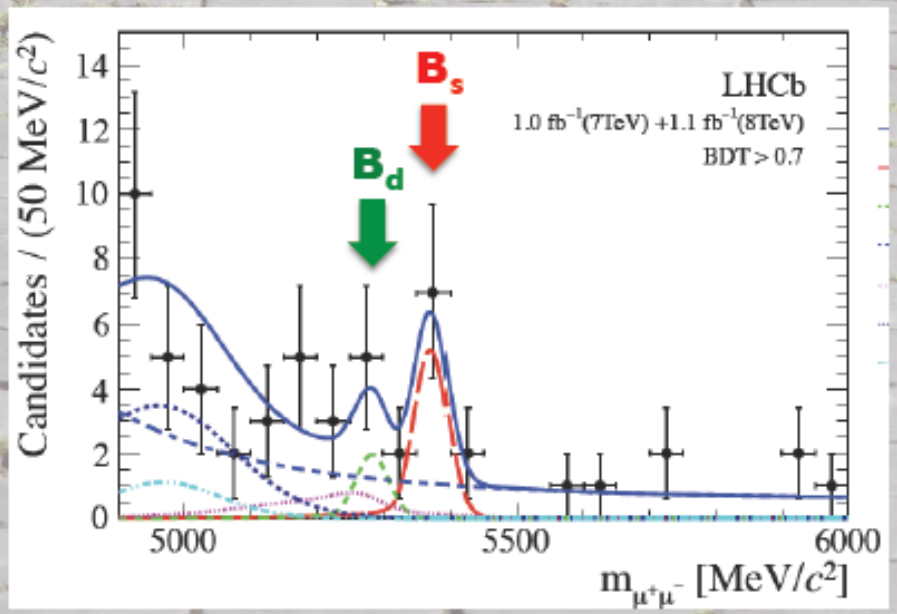
Precise predictions in SM:

- $BR(B_s \rightarrow \mu\,\mu) = 3.5 \pm 0.2\ 10^{-9}$
- $BR(B_d \rightarrow \mu\,\mu) = 1.1 \pm 0.2\ 10^{-10}$

"Golden channel" for New Physics effects

$$\mathrm{Br}_{\mathrm{MSSM}}(B_q \to \ell^+\ell^-) \propto \frac{M_b^2 M_\ell^2 \tan^6\beta}{M_A^4}$$




With 2011+2012 data (2.1/fb) LHCb has got the first evidence of $B_s \rightarrow \mu\,\mu$ decay at ~ 3.5 σ

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$$

in agreement with SM.

"Background only" p value ~ $5\ 10^{-4}$

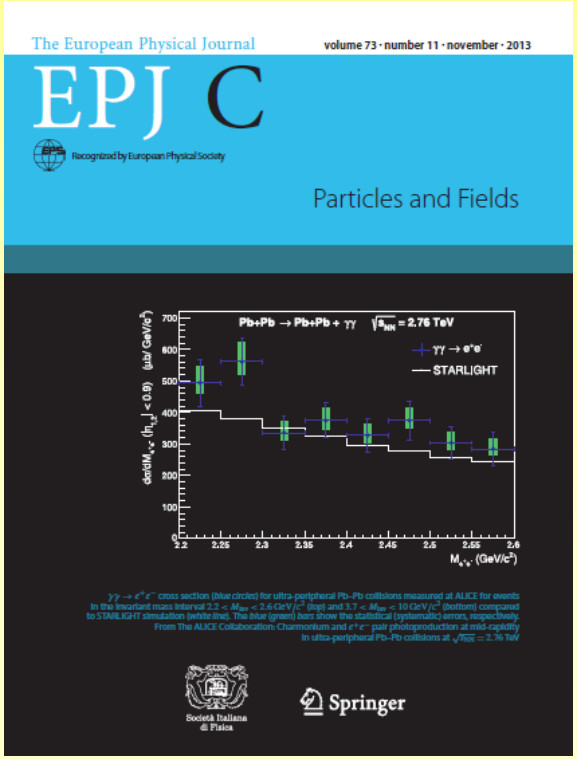
Also best limit on $B_d \rightarrow \mu\,\mu$

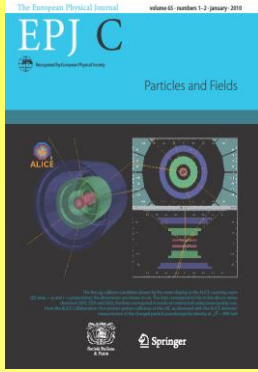
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 9.4 \times 10^{-10} \text{ at 95\% CL}$$

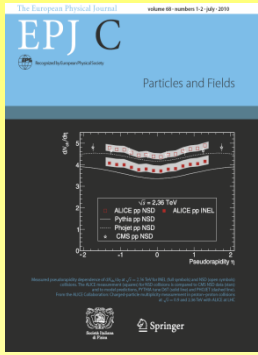
# Results keep flowing

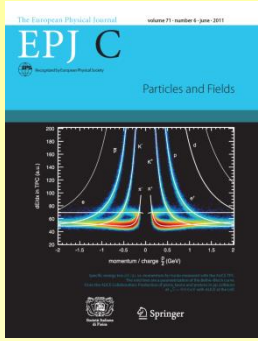
- A huge scientific output
  - **77 ALICE papers on arXiv**

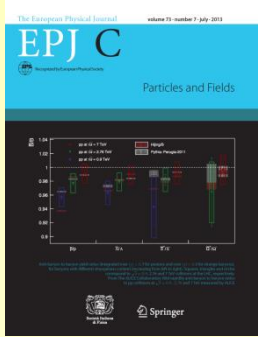
  - **High impact papers:** the top cited paper at the LHC after the Higgs discovery ones is the ALICE paper on flow in HI collisions, and out of the 10 top cited physics papers at the LHC 3 are from ALICE and one from ATLAS-Heavy Ion program (source: ISI)
  - **Several hundred** presentations at international conferences *each year*



## 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 …

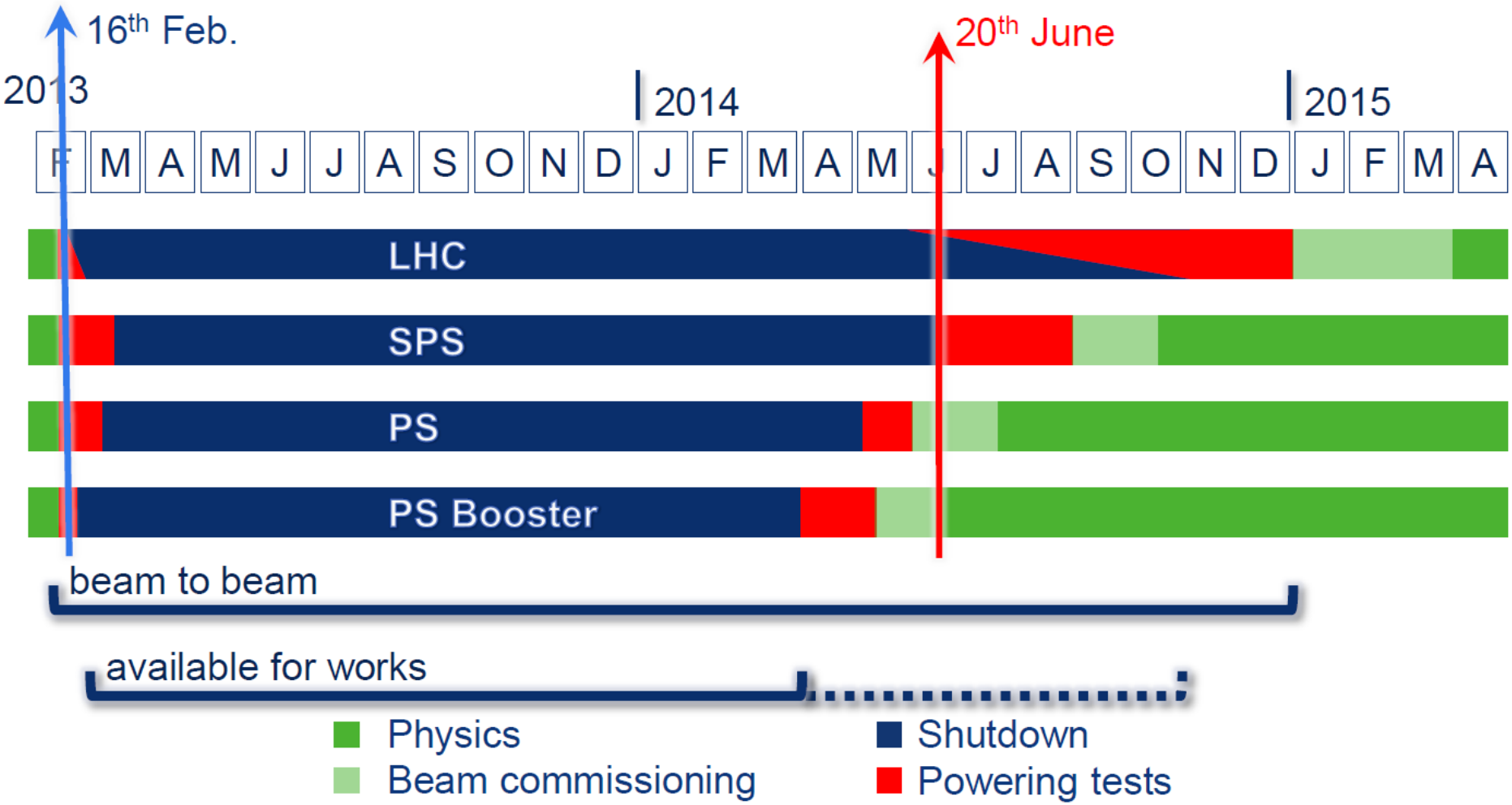
2) We have **completed** the Standard Model: Discovery of the messenger of the BEH-field, the Higgs boson discovery
(over 50 years of theoretical and experimental efforts !)

3) We found interesting properties of the hot dense matter

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

# What's next ?

# LS 1 from 16th Feb. 2013 to Dec. 2014



# The main 2013-14 LHC consolidations

**Opening:100%**
1695 Openings and final reclosures of the interconnections
**Closure: 100%** 18th June

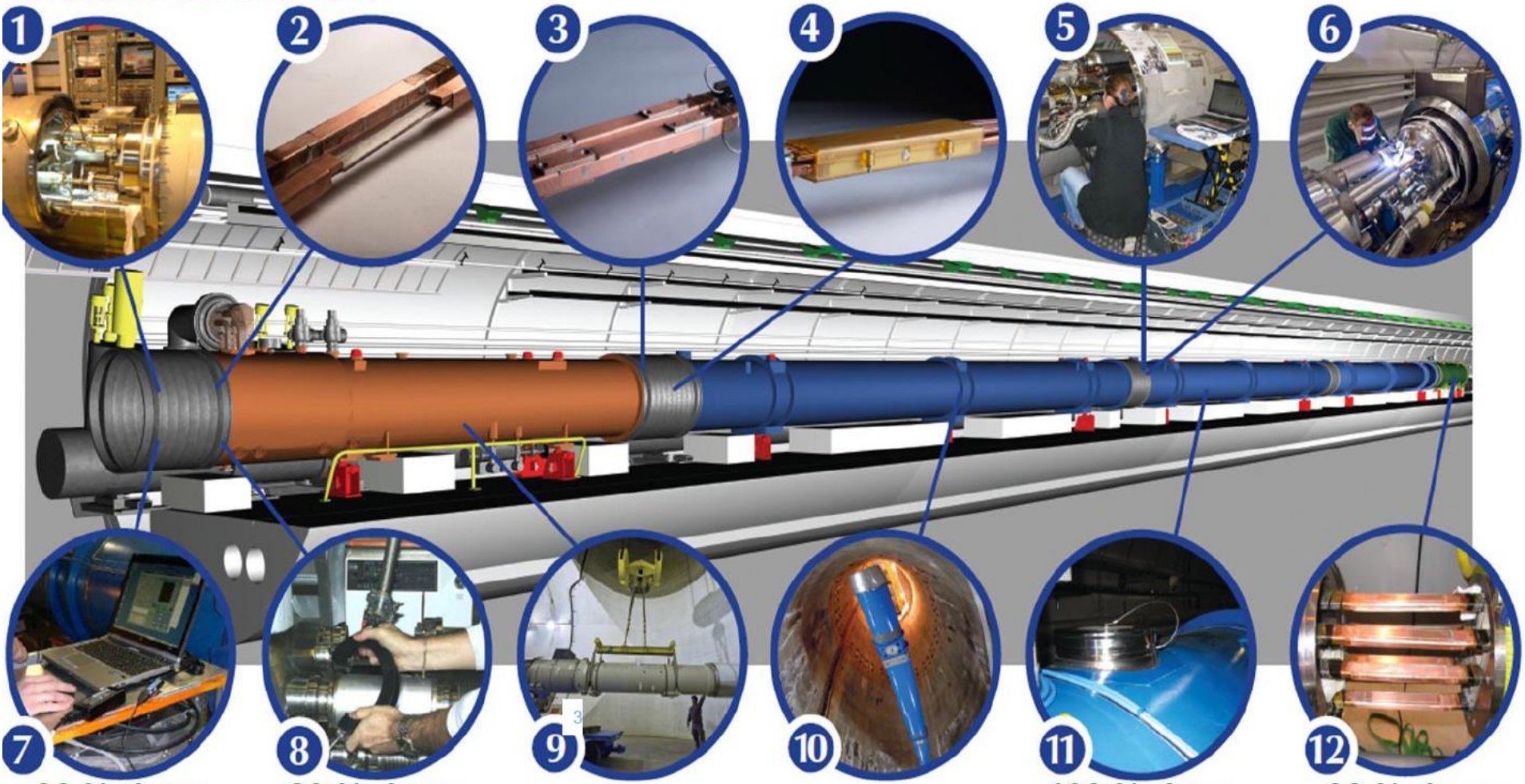
**100 % done**
Complete reconstruction of 3000 of these splices

**100 % done**
Consolidation of the 10170 13kA splices, installing 27 000 shunts

**100 % done**
Installation of 5000 consolidated electrical insulation systems

**100 % done**
300 000 electrical resistance measurements

**100 % done**
10170 orbital welding of stainless steel lines




**90 % done**
18 000 electrical Quality Assurance tests

**80 % done**
10170 leak tightness tests

3 quadrupole magnets to be replaced
**Done**

15 dipole magnets to be replaced
**Done**

**100 % done**
Installation of 612 pressure relief devices to bring the total to 1344

**98 % done**
Consolidation of the 13 kA circuits in the 16 main electrical feed-boxes

# 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 fronti machine
- Invest
  - Powe , triggers, comp ting
    - 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

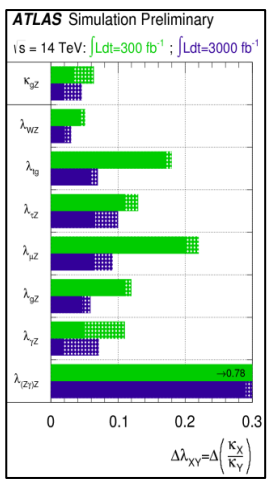
# LHC --> HL-LHC: *THE* Higgs factory

today : ATLAS+CMS have 1400 Higgs events

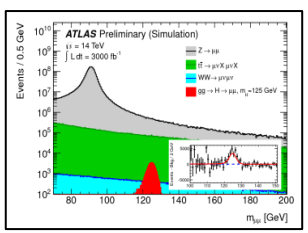
HL-LHC: (3000fb-1) > 3M/170M useful for precise measurement

- ❑ 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

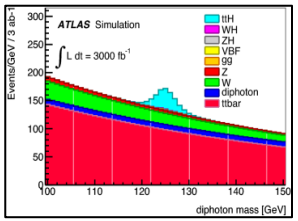



x 1.5 to 2 for 300 --> 3000fb-1




ttH

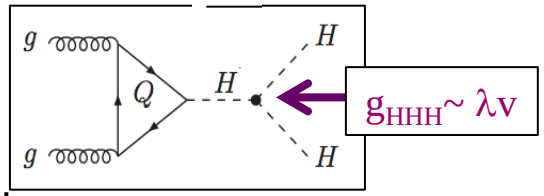
↳ γγ




H —–> μμ

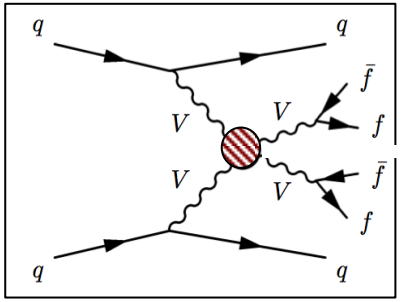
+ Access to rare processes

## Self-coupling




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
  - ...siders the global context
  - Resolves key issues for the field
  - Provides a continuous flow of results while making essential investments for the future

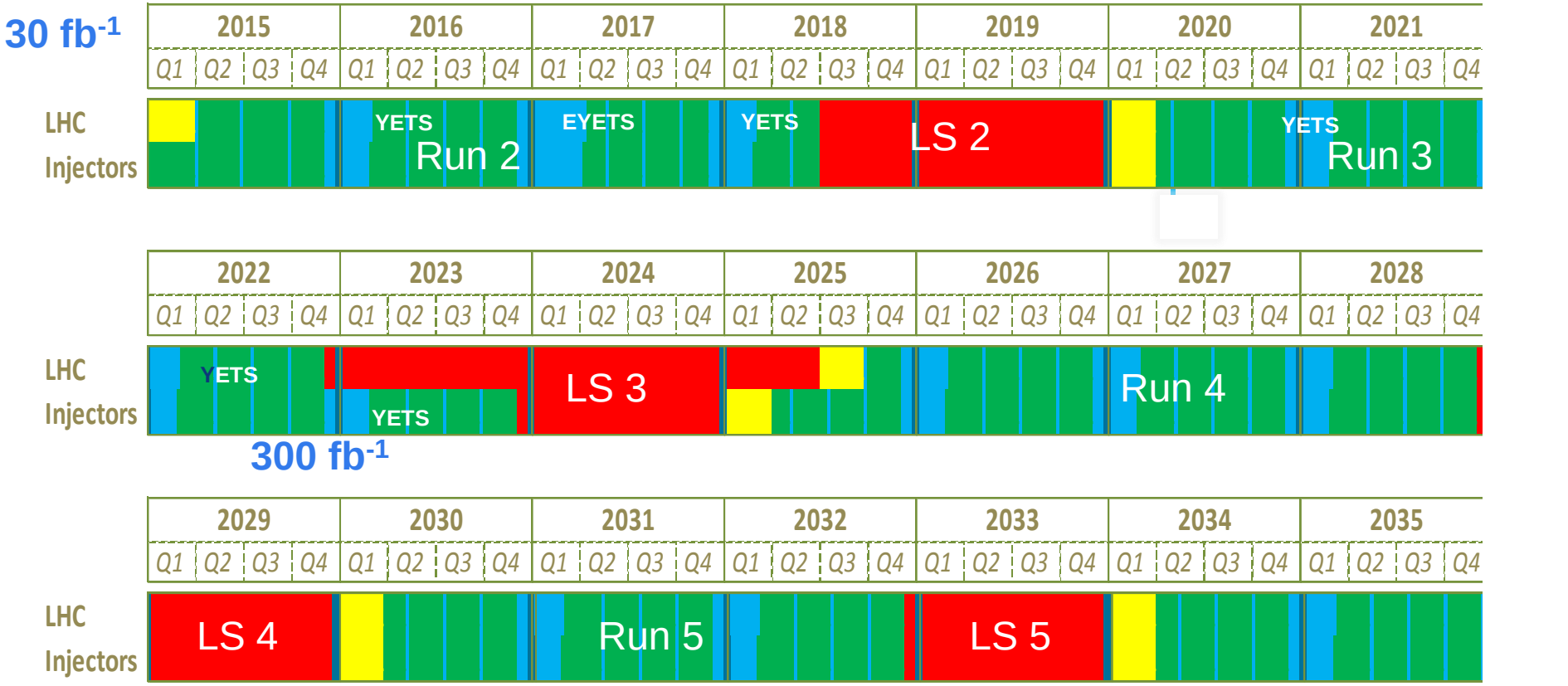
**Recommendations in line with the European Strategy**

# 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



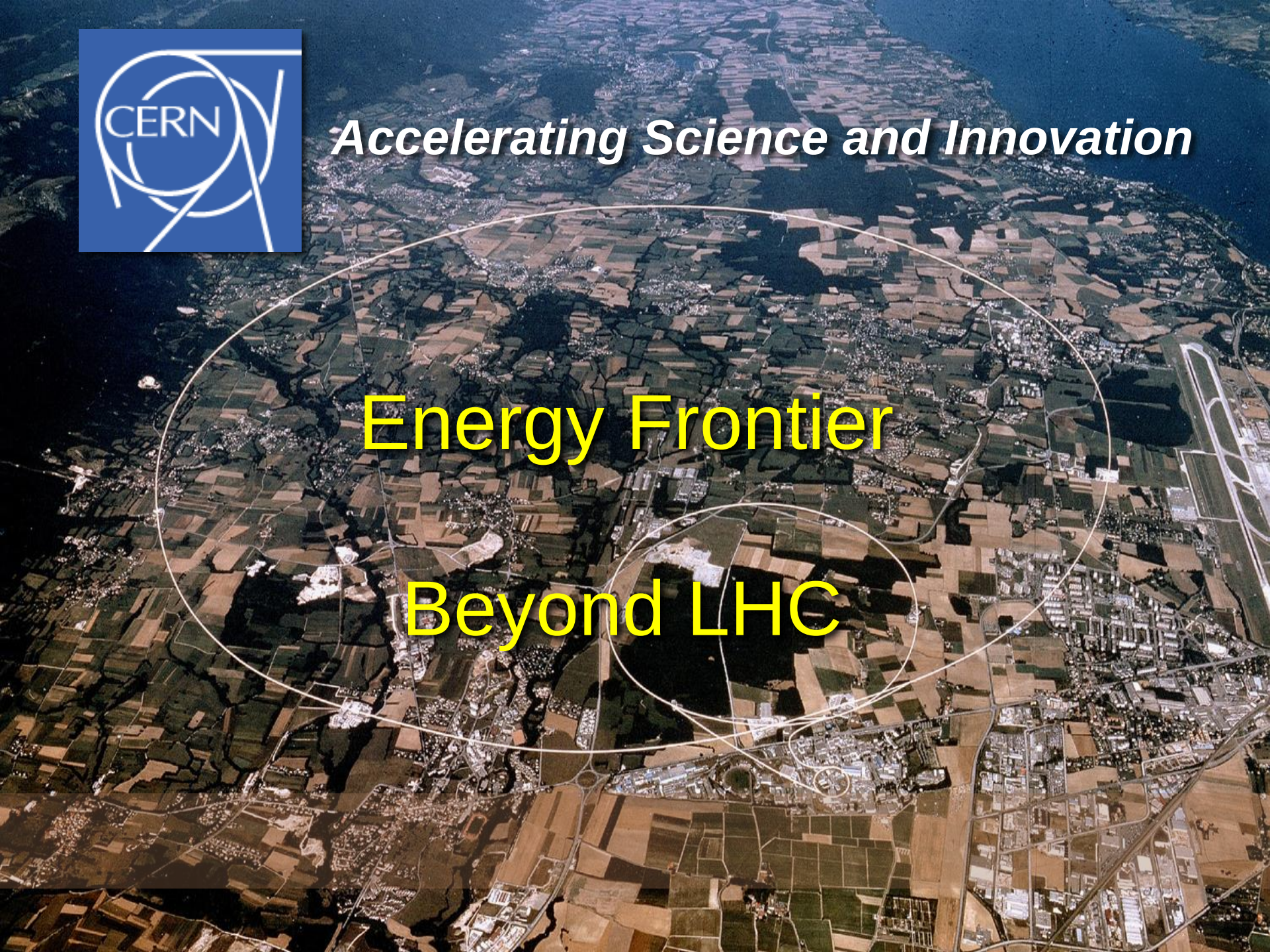

(Extended) Year End Technical Stop: (E)YETS

# LHC

## Key message

There is a
ntier
TeV
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**



*Accelerating Science and Innovation*

# Energy Frontier

# Beyond LHC

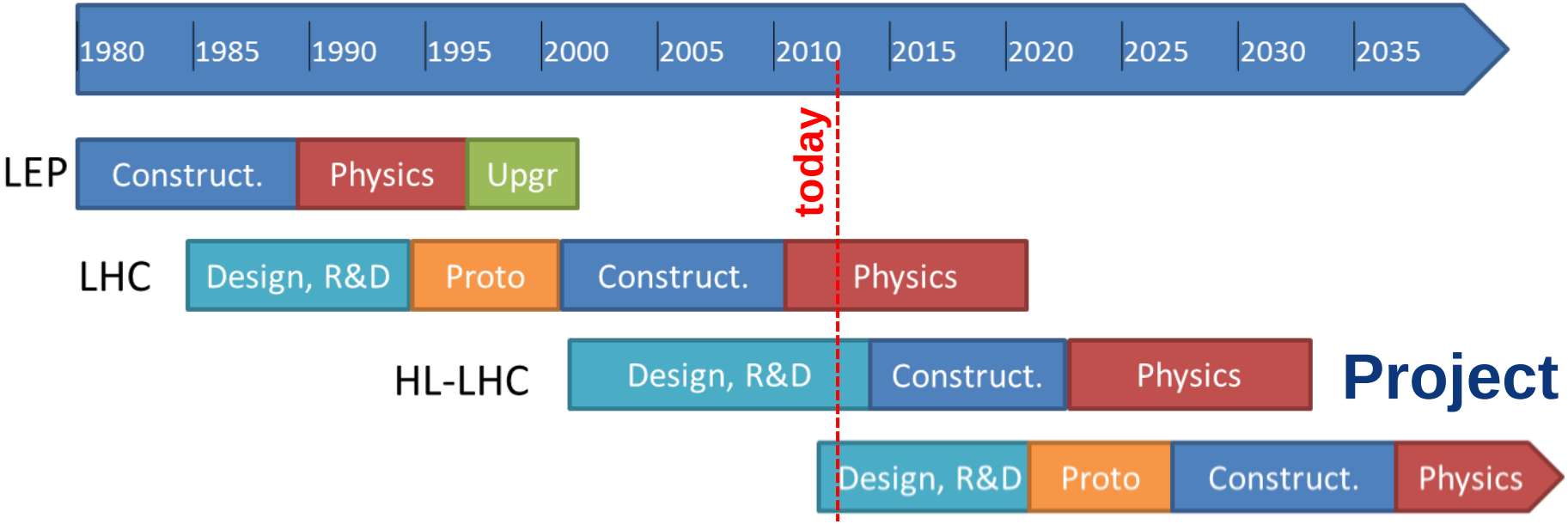
# European Strategy for Particle Physics

## 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 <u>design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high energy frontier machines</u>. 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**

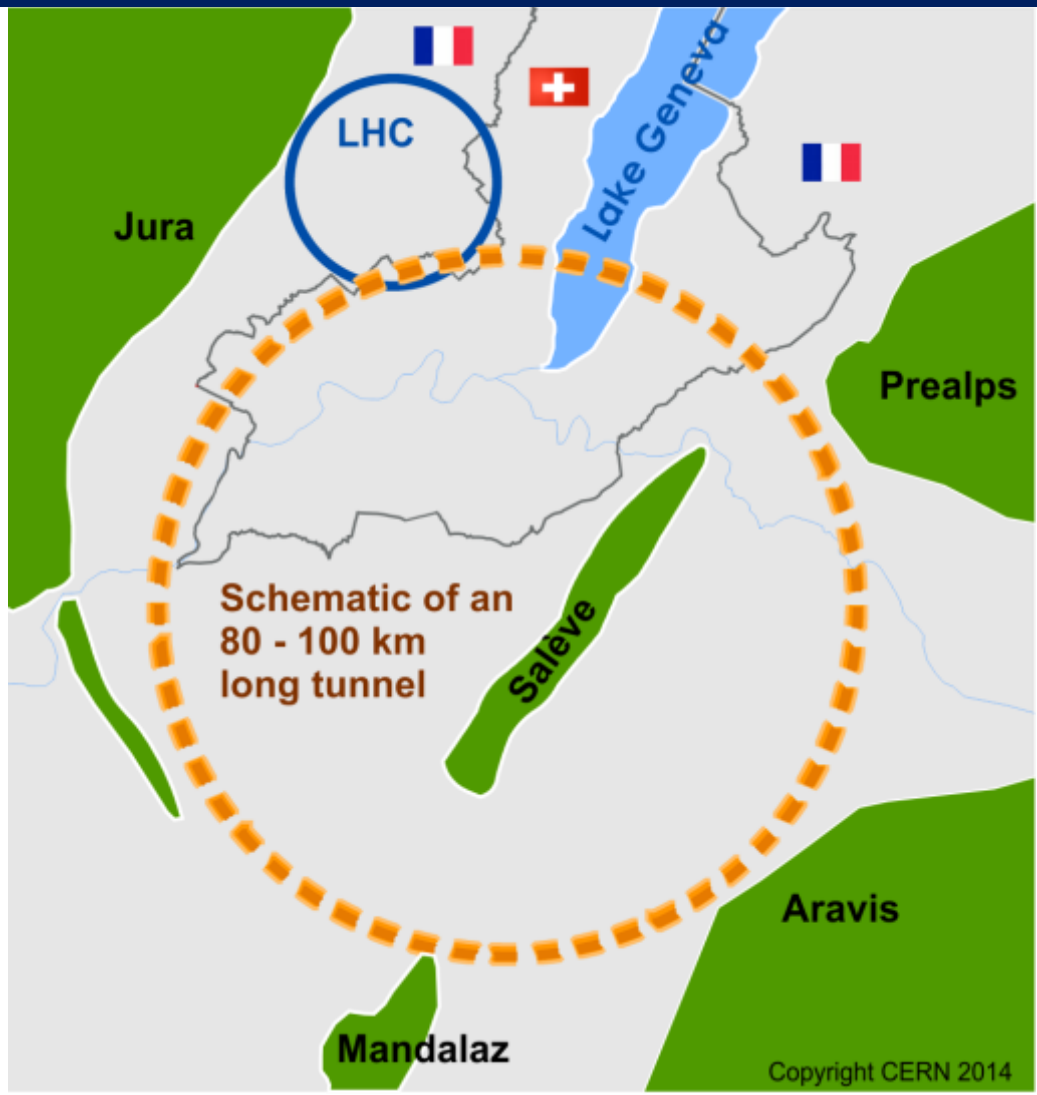
# Future Circular Collider Study - SCOPE
## CDR and cost review for the next ESU (2018)

**Forming an international collaboration to study:**

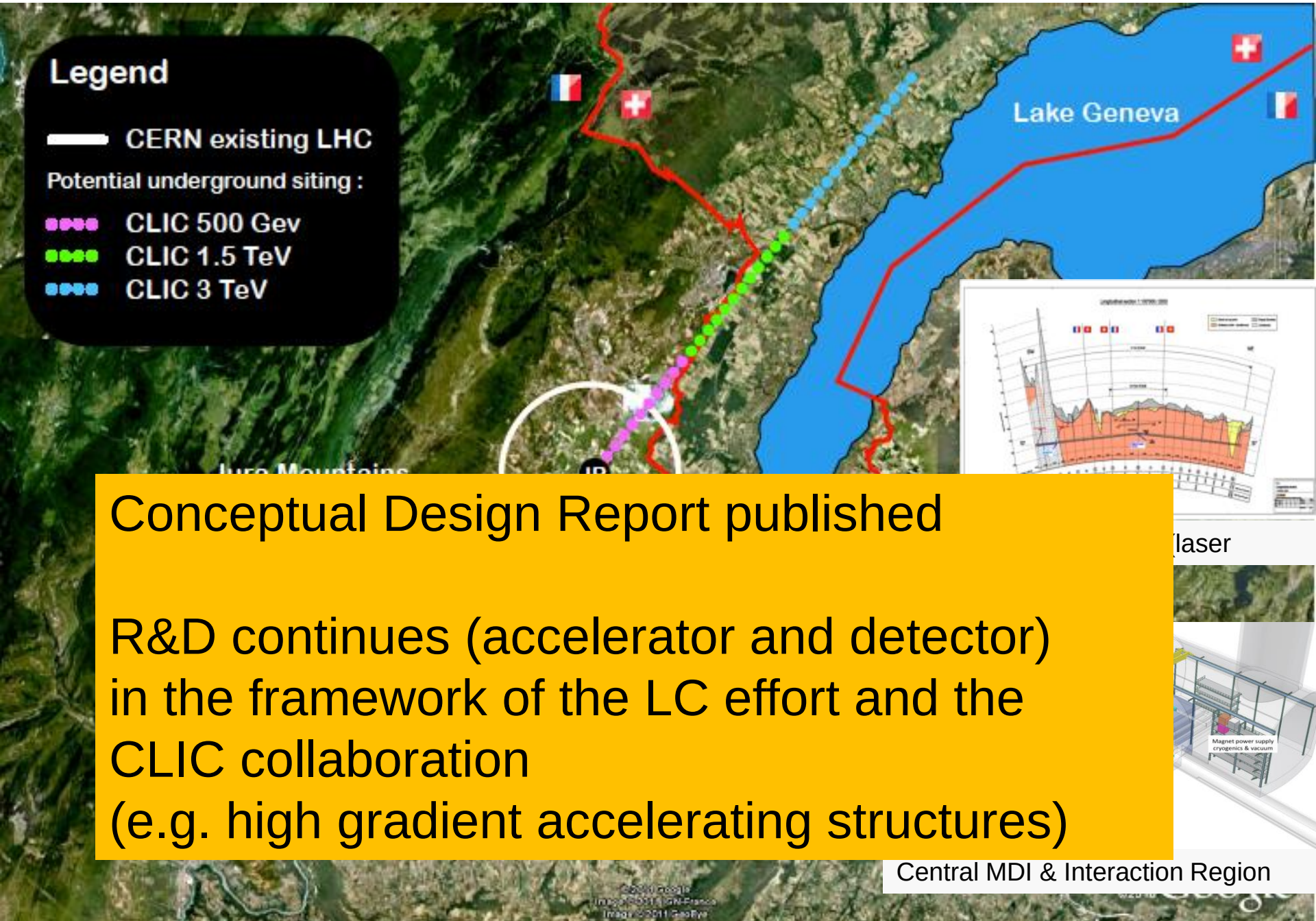
- ***pp*-collider (*FCC-hh*)**
  → defining infrastructure requirements

**~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 t priority.

e) There positron collider, comple the properties of the Higgs boson and othe ted 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)

## 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.**

# 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.***

- Honor ongoing obligations 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

# 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