Accelerating Science and Innovation

CERN Vision
for Physics at higher luminosity
and higher energy

R.-D. Heuer, CERN

Daresbury, Nov 11, 2013

LHC run 1
at 7 and 8 TeV

a great success

Four main results from LHC Run-1

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

Note: the last point implies that, if New Physics exists at the TeV scale and is discovered at $\sqrt{s}$ ~ 14 TeV in 2015++, its spectrum is quite heavy → it will require a lot of luminosity (→ HL-LHC 3000 fb^{-1}) and energy to study it in detail → implications for future machines

This is VERY puzzling ….

On one hand, the LHC results imply that the SM technically works up to scales much higher than the TeV scale, and limits on new physics seriously challenge the simplest attempts (e.g. minimal SUSY) to fix its weaknesses

On the other hand: there is strong evidence that the SM must be modified with the introduction of new particles and/or interactions at some energy scale to address fundamental outstanding questions, including the following

Why is the Higgs boson so light (so-called "naturalness" or "hierarchy" problem) ?

What is the nature of the matter-antimatter asymmetry in the Universe ?

Why is Gravity so weak ?

And perhaps the most disturbing one …

The DARK Universe (96%):
73% Dark Energy
23% Dark Matter

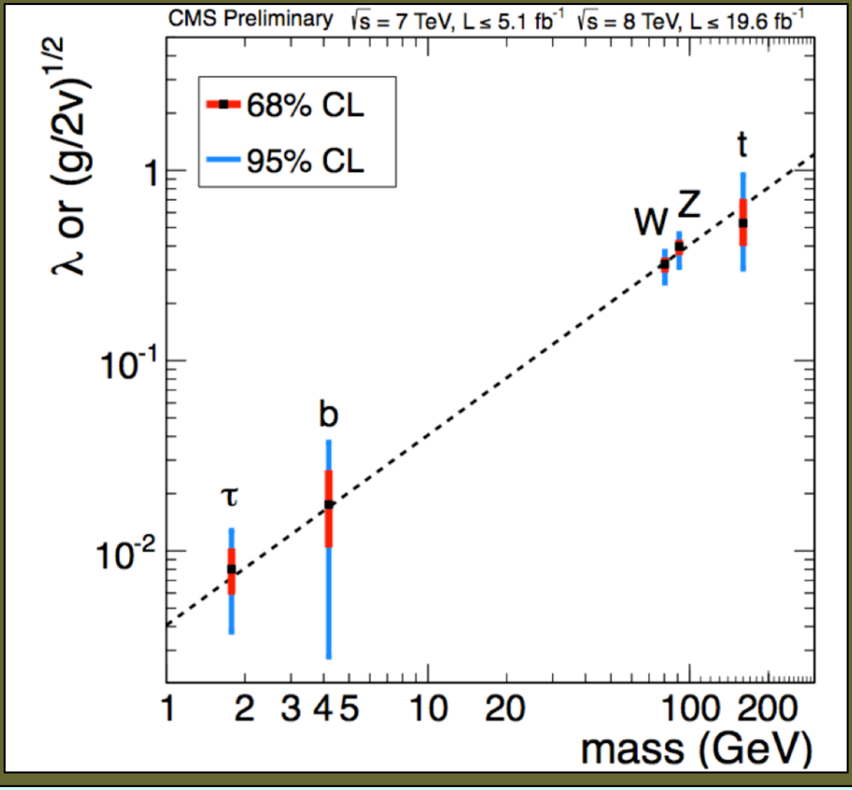
Only 4% is ordinary (visible) matter

DARK …. MATTERS !

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

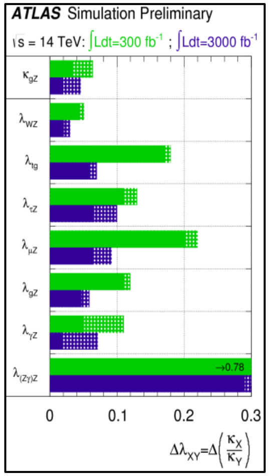
Fabiola:

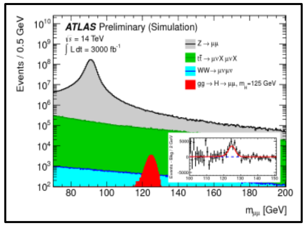
LHC --> HL-LHC: *THE* Higgs factory

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

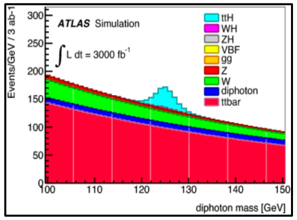
- ❑ Measure as many Higgs couplings to fermions and bosons as precisely as possible
- ❑ Measure Higgs self-couplings (give access to λ)
- ❑ Verify that the Higgs boson fixes the SM problems with W and Z scattering at high E

Couplings





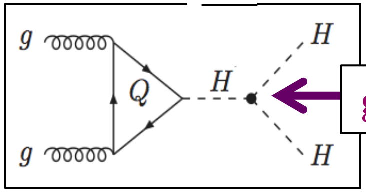
ttH
↳ γγ



H --> μμ

x 1.5 to 2 for 300 --> 3000fb-1 + Access to rare processes

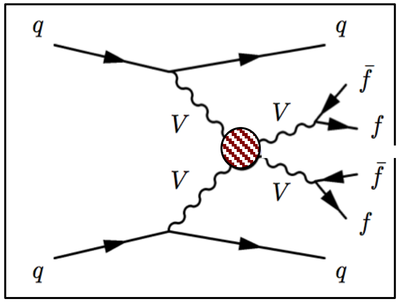
Self-coupling



$g_{HHH} \sim \lambda v$

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

Vector boson fusion



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

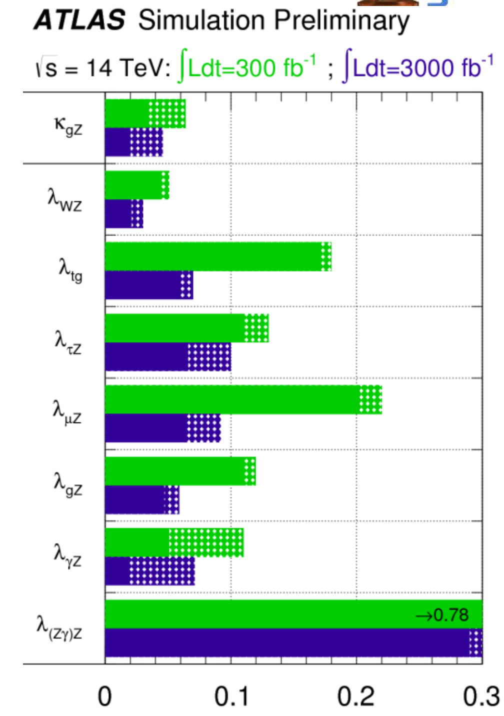
post- H(126)-discovery

- 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
- Investment is critical
  - Powerful detectors, 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!

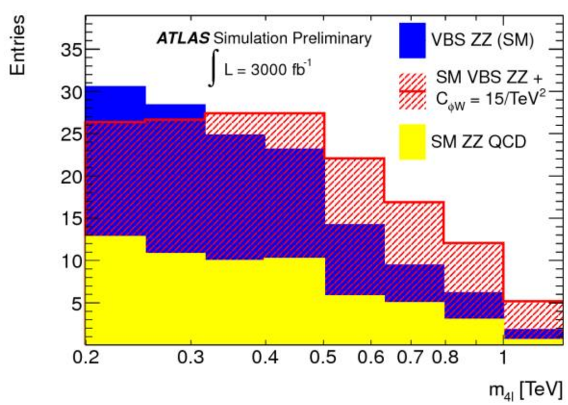
HL-LHC Physics

- The HL-LHC data sample of 3000 fb^{-1} at 14 TeV centre-of-mass energy will provide unprecedented and unparalleled physics opportunities at the energy frontier:
  - to measure the H(125) in many production and decay modes, and to measure HH production in order to probe the HHH coupling
  - to extend the mass reach for new particle searches by ~1 TeV
  - to probe for new physics in longitudinal vector-boson scattering
  - to study in depth further new physics which may be discovered at the LHC in the next decade

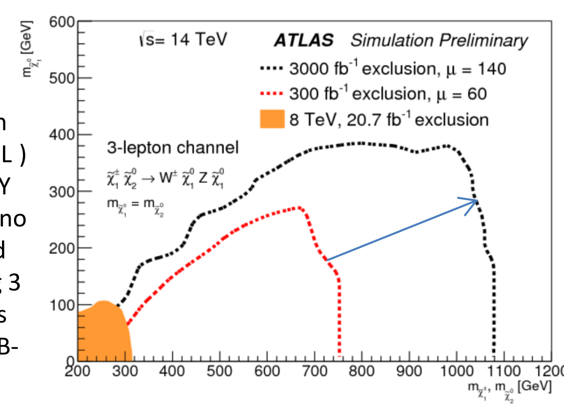


Higgs coupling precisions for 300 and 3000 fb^{-1}, with different systematic error assumptions ATLAS-PHYS-PUB-2013-014 $\Delta\lambda_{XY}=\Delta\left(\frac{\kappa_X}{\kappa_Y}\right)$

Invariant mass distribution for vector-boson scattering , in SM and with anomalous coupling ATLAS-PHYS-PUB-2013-007



Example search sensitivity (95%CL) for sample SUSY model with EW-ino production and decays including 3 prompt leptons ATLAS-PHYS-PUB-2013-011



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.*

LHC

Key message

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

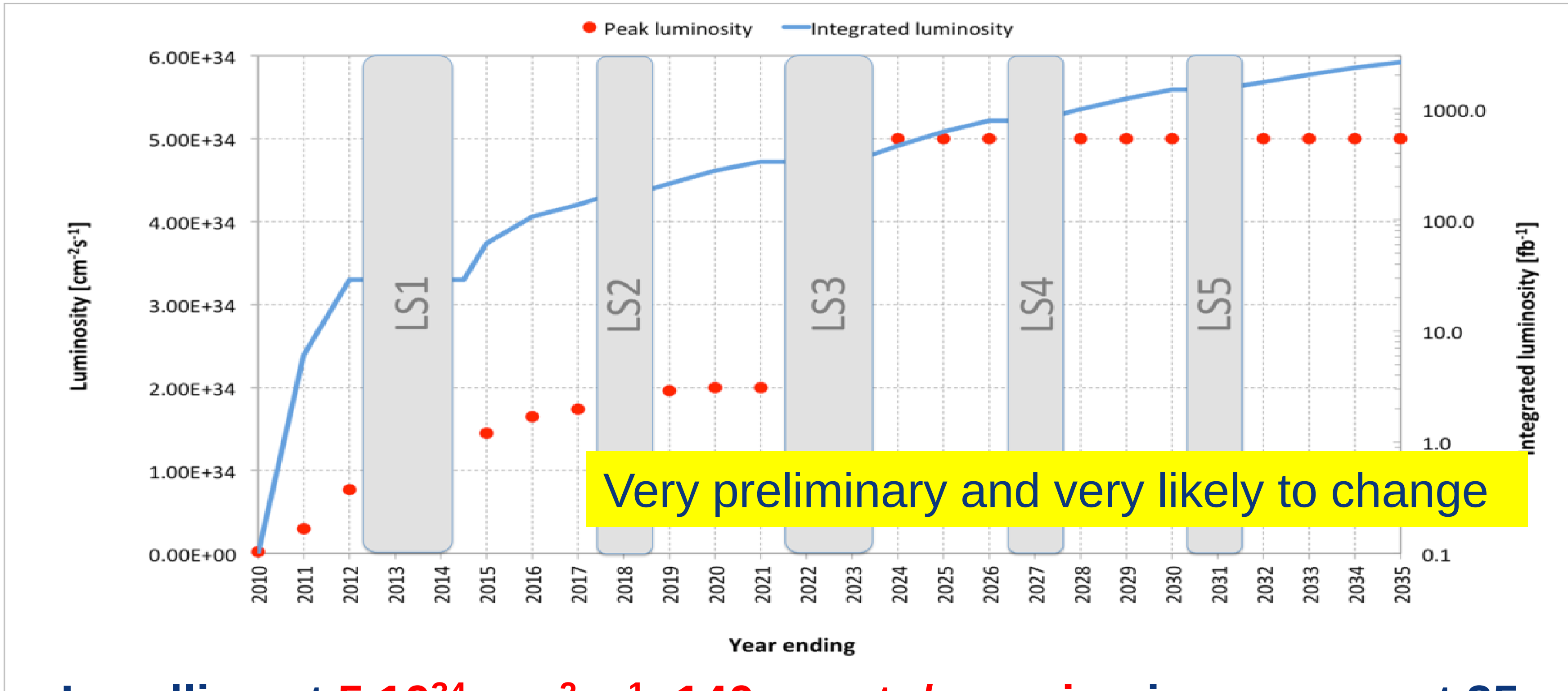
There is a … ntier

… TeV

14 TeV design luminosity

14 TeV high luminosity (HL-LHC)

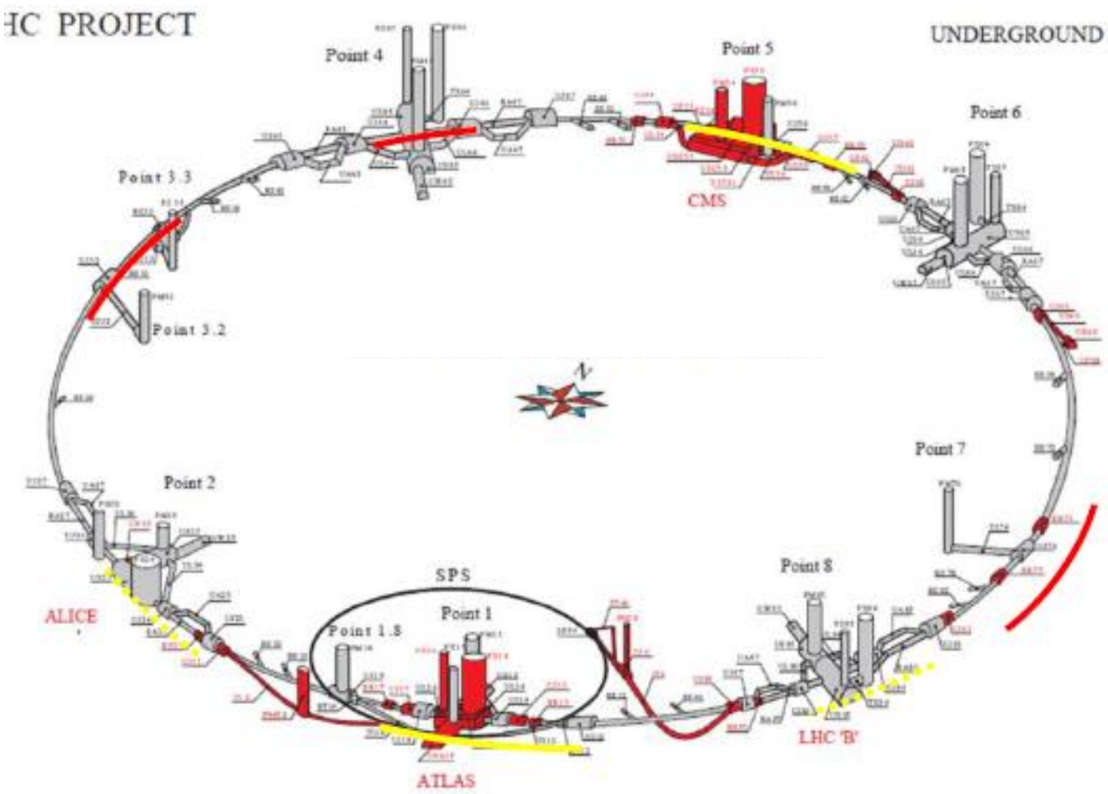
Possible plan of HL-LHC (baseline)



Levelling at 5 10^{34} cm^{-2} s^{-1}: 140 events/crossing in average, at 25 ns; several scenarios under study to limit to 1.0 → 1.3 event/mm

Total integrated luminosity of 3000 fb^{-1} for p-p by 2035, with LSs taken into account and 1 month for ion physics per year.

The HL-LHC Project

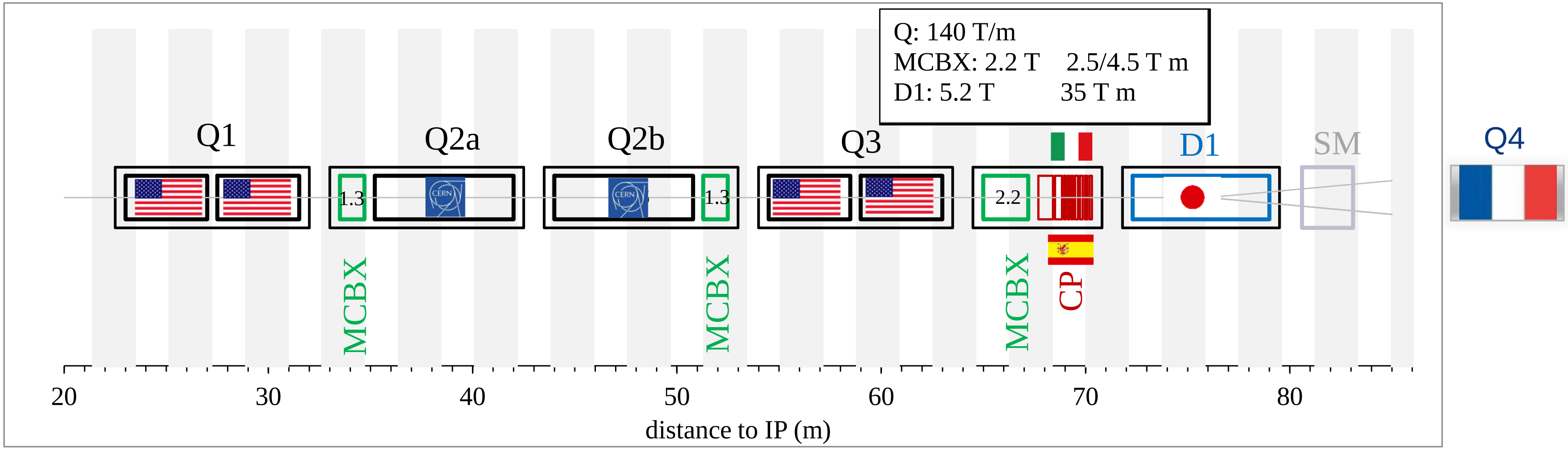


- New IR-quads Nb_3Sn (inner triplets)
- New 11 T Nb_3Sn (short) dipoles
- Collimation upgrade
- Cryogenics upgrade
- Crab Cavities
- Cold powering
- Machine protection
- …

Major intervention on more than 1.2 km of the LHC

Setting up International collaboration

with national laboratories but also involving industrial firms



Baseline layout of HL-LHC IR region

Experiments from LHC to HL-LHC

- An extensive and rich physics program
- Maintain full sensitivity for discovery
  - And precision measurements at low p_T

- Pileup
  - <PU> ≈ 50 events per crossing by LS2
  - <PU> ≈ 60 events per crossing by LS3
  - <PU> ≈ 140 events per crossing by HL-LHC
    - Lumi-leveling at $5x10^{34}cm^{-2}s^{-1}$

- Radiation damage
  - Requires work to maintain calibration
  - Limits performance-lifetime of the detectors
    - Light loss (calorimeters)
    - Increased leakage current (silicon detectors)

R&D

- R&D is key to cost-effective solutions to high radiation, PU
  - R&D has been ongoing for many years in some cases
    - Tracker, Track Processor, Trigger, Calorimeters, etc.
  - Final design choices needed in 3-4 years for current baseline schedule
  - Key areas of development include
    - Radiation tolerant silicon sensors (pixels and strips)
    - Radiation tolerant ASIC development (including 65 nm processing)
    - High bandwidth and radiation tolerant optical data transmission
    - Radiation tolerant powering scheme
    - Light structures, detector assemblies, high density interconnections
    - Fast processors for track-triggers
    - Rad-tolerant crystals, tiles, fibres, photo-detectors for calorimeters
    - High rate gas chambers with improved spatial and timing resolution
    - Demonstration of high precision timing in calorimeter pre-sampling
    - Software for new technologies (multicore processing, GPU, etc...)
- **Many of these areas are common between experiments**

Computing: Software

- Moore's law only helps us if we can make use of the new multi-core CPUs with specialised accelerators etc. (Vectorisation, GPUs, …)
  - No longer benefit from simple increases in clock speed
- Ultimately this requires HEP software to be re-engineered to make use of parallelism at all levels
  - Vectors, instruction pipelining, instruction level pipelining, hardware threading, multi-core, multi-socket.
- Need to focus on commonalities:
  - GEANT, ROOT, build up common libraries
- This requires significant effort and investment in the HEP community
  - Concurrency forum already initiated
  - Ideas to strengthen this as a collaboration to provide roadmap and incorporate & credit additional effort

Key message

We need a strong engagement by all partners to make HL-LHC a success and to fully exploit its unique physics capabilities

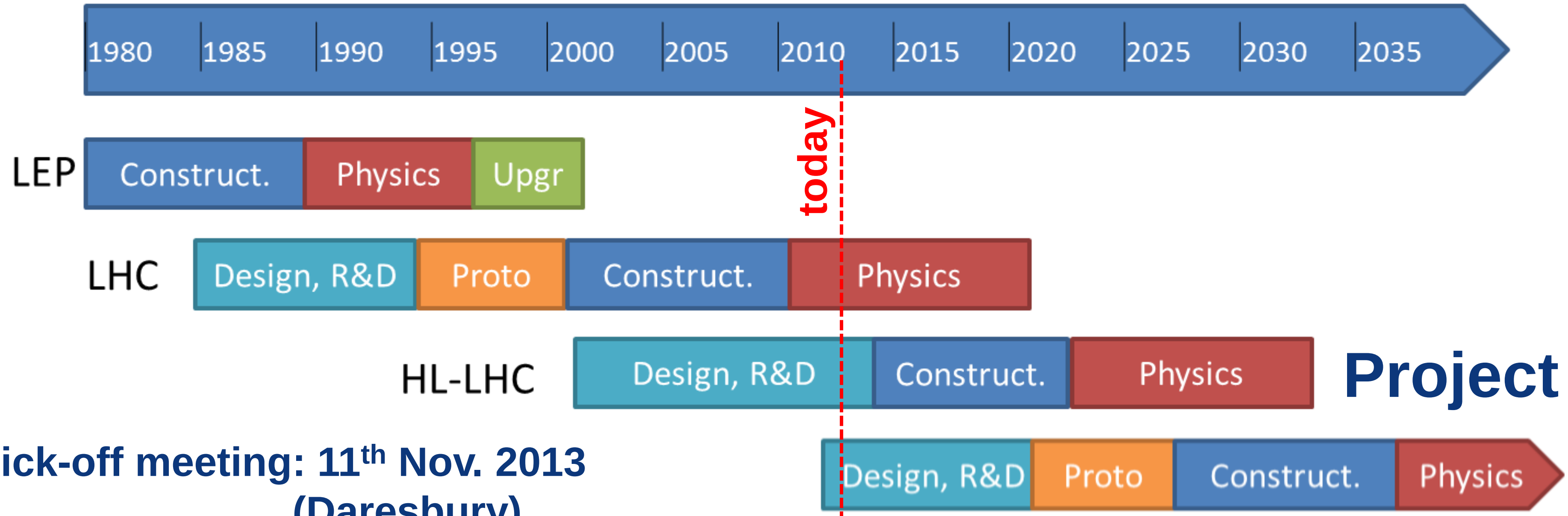
European Strategy for Particle Physics

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.***

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



Kick-off meeting: 11th Nov. 2013 (Daresbury)

FCC Study : p-p towards 100 TeV

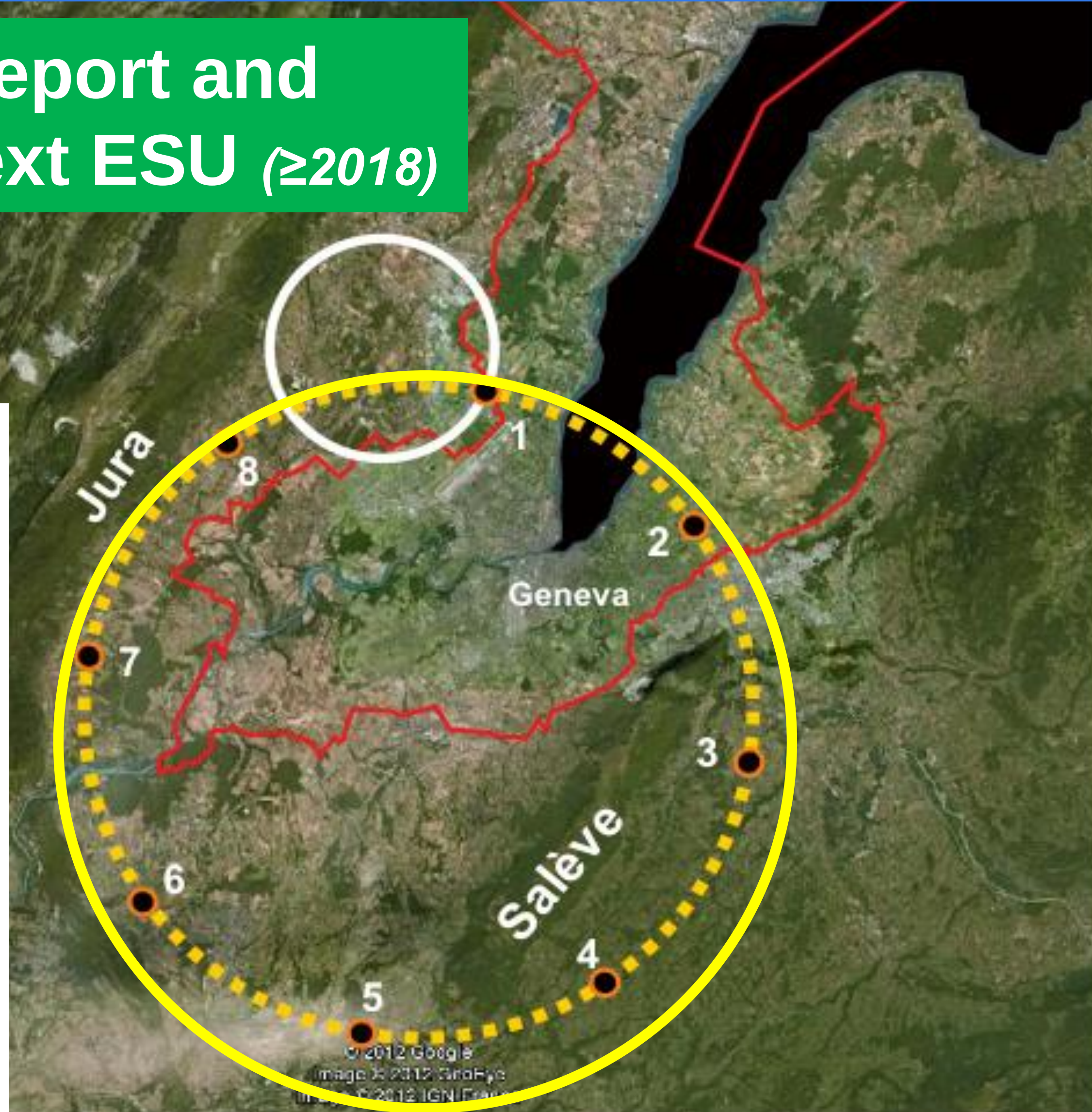
Kick-off meeting: mid-February 2014

FCC: Future Circular Colliders

80-100 km tunnel infrastructure in Geneva area – design driven by pp-collider requirements

with possibility of e+-e- (TLEP) and p-e (VLHeC)

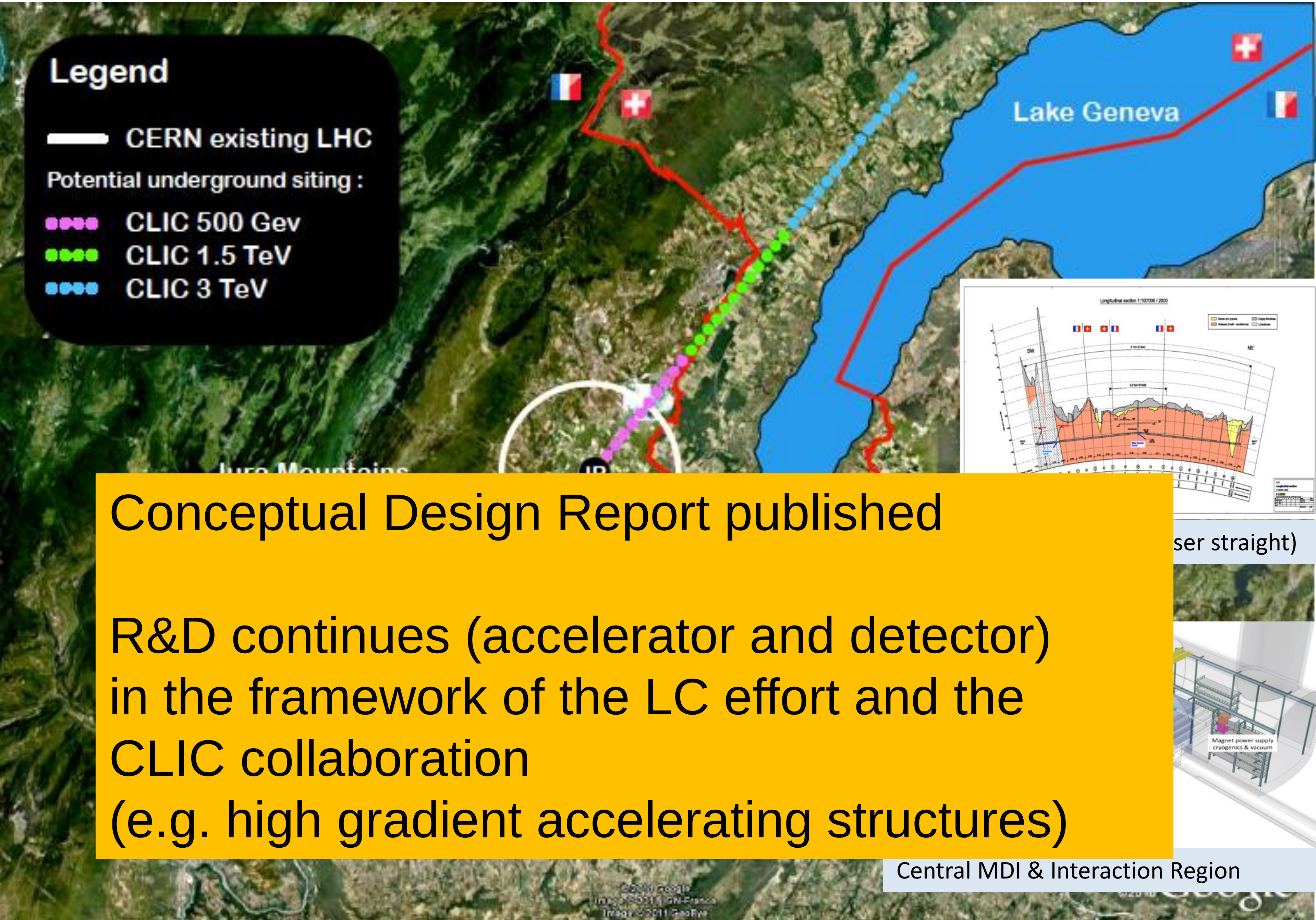
Conceptual Design Report and cost review for the next ESU *(≥2018)*



FCC Design Study Kick-off Meeting: 12-14. February 2014 in Geneva area

- ***Establishing international collaborations***
- ***Set-up study groups and committees***

CLIC near CERN



Central MDI & Interaction Region

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)

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At CERN ILC efforts continue
in the framework of the LC efforts.
Hosting LCC Directorate at CERN

e) There i ositron collider, complen the properties of the Higgs boson and other ited precision and whose energy can be upgraded. esign Report of the International Linear Collider (ILC) has b 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.***

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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.

CERN Neutrino "Platform"

- enable large scale detector development and tests for neutrino detectors:
  WA104 refurbish ICARUS T600
  R&D on new Large LAr detector ("ICARUS++")
  R&D for air core muon detector
  WA105 R&D on 2-phase LAr prototype

- study for a neutrino (test)beam in the North Area started

- Discussion with US (Fermilab) started concerning LBNE common efforts on detector AND accelerator topics

Needs global collaboration and long-term sustained efforts and support

Global Collaboration

To realise our ambitious accelerator based large scale facilities and to fully exploit their excellent physics capabilities we need

- coherent and strong efforts in all regions;

- long term stability and support in all regions;

- careful adjustment of schedules for these facilities

Global collaboration
≡
Global Partnership
with
long-term support