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# CERN roadmap: High Energy frontiers

## CLIC Workshop 2015

26-30 September 2015 - CERN

# Outline

**-LS1 status**

**-Run 2 (from LS1 to LS2)** ⇒ ***13-14 TeV***
**-LS2 and Run 3** ⇒ **300 fb$^{-1}$**

**-High Luminosity LHC project**
**-LHC Roadmap up 2035** ⇒ **~3'000 fb$^{-1}$**

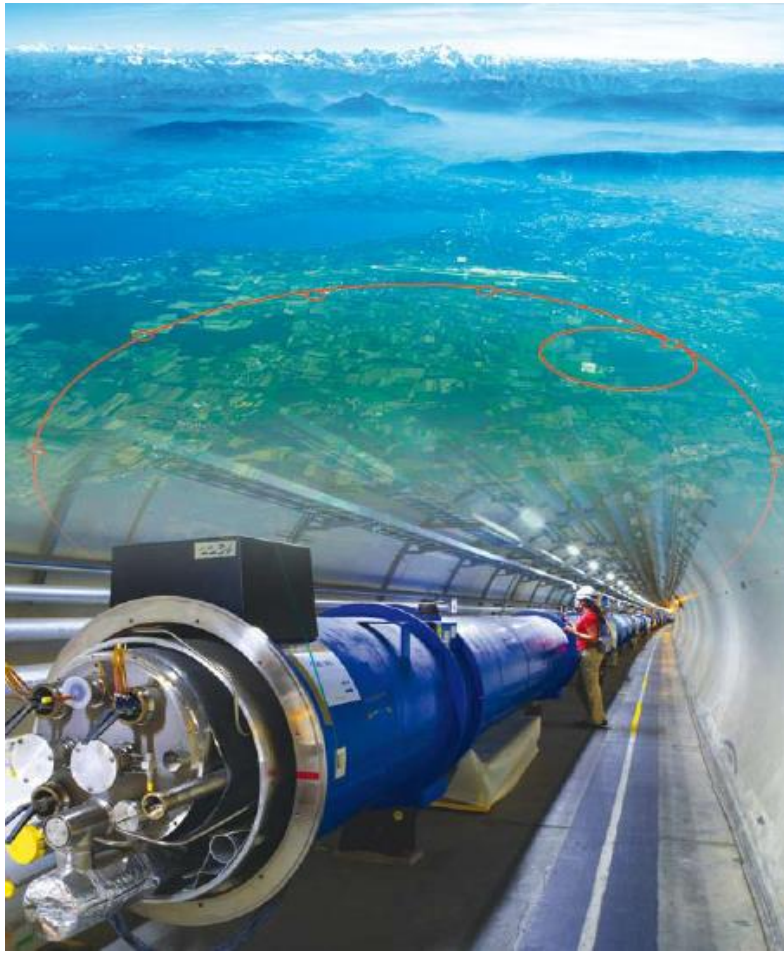
**- Post-LHC machines**

# LHC (Large Hadron Collider)

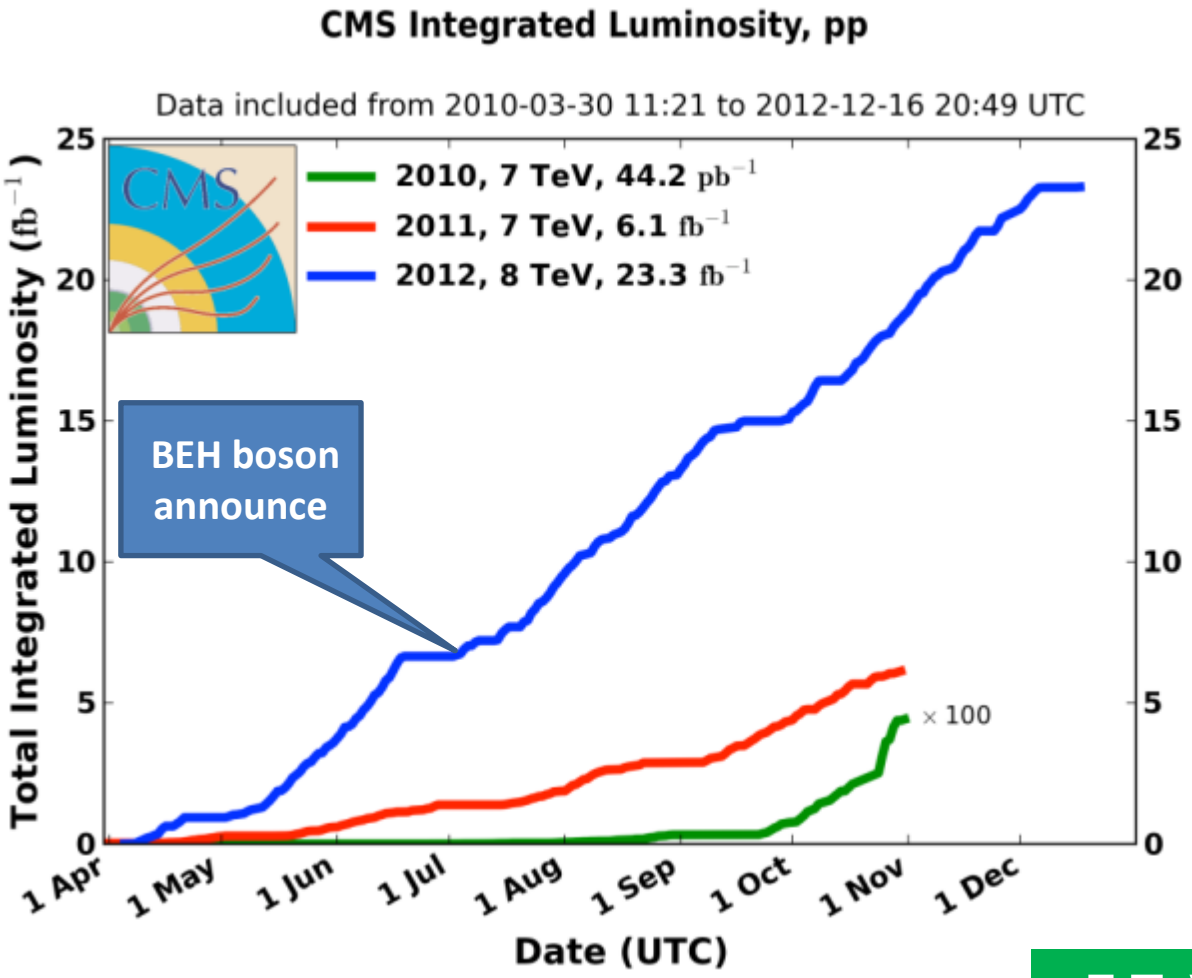
**14 TeV proton-proton accelerator-collider built in the LEP tunnel**

Lead-Lead (Lead-proton) collisions

**1983 : First studies for the LHC project**
**1988 : First magnet model (feasibility)**
**1994 : Approval of the LHC by the CERN Council**
**1996-1999: Series production industrialisation**
**1998 : Declaration of Public Utility & Start of civil engineering**
**1998-2000: Placement of the main production contracts**
**2004 : Start of the LHC installation**
**2005-2007: Magnets Installation in the tunnel**
**2006-2008: Hardware commissioning**
**2008-2009: Beam commissioning and repair**
**2009-2035: Physics exploitation**



# LHC 2010-2012: a rich harvest of collisions




**Σ ~30 fb$^{-1}$**

2010: **0.04 fb$^{-1}$**
- 7 TeV CoM
- Commissioning

2011: **6.1 fb$^{-1}$**
- 7 TeV CoM
- … exploring limits

2012: **23.3 fb$^{-1}$**
- 8 TeV CoM
- … production

**7 TeV and 8 TeV in 2012**

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

2013 — 16th Feb. — 2014 — 2015 — 28th Jan.

F M A M J J A S O N D J F M A M J J A S O N D J F M A

LHC

SPS

PS

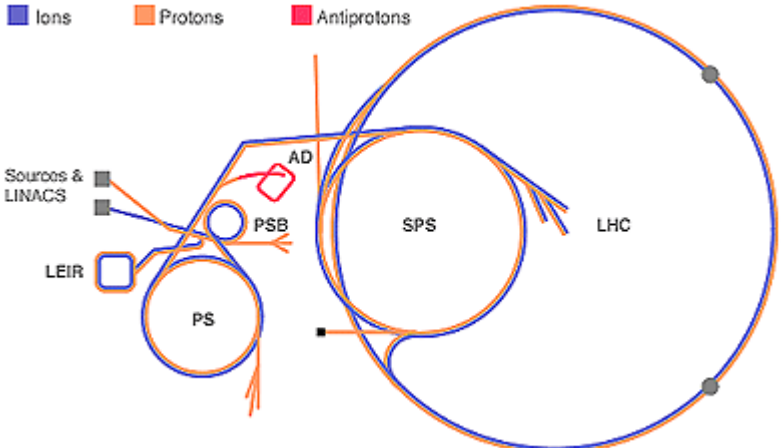
PS Booster

beam to beam

available for works

Physics
Beam commissioning
Shutdown
Powering tests

**Safety First, Quality Second, Schedule Third.**



# The main 2013-14 LHC consolidations

1695 Openings and final reclosures of the interconnections

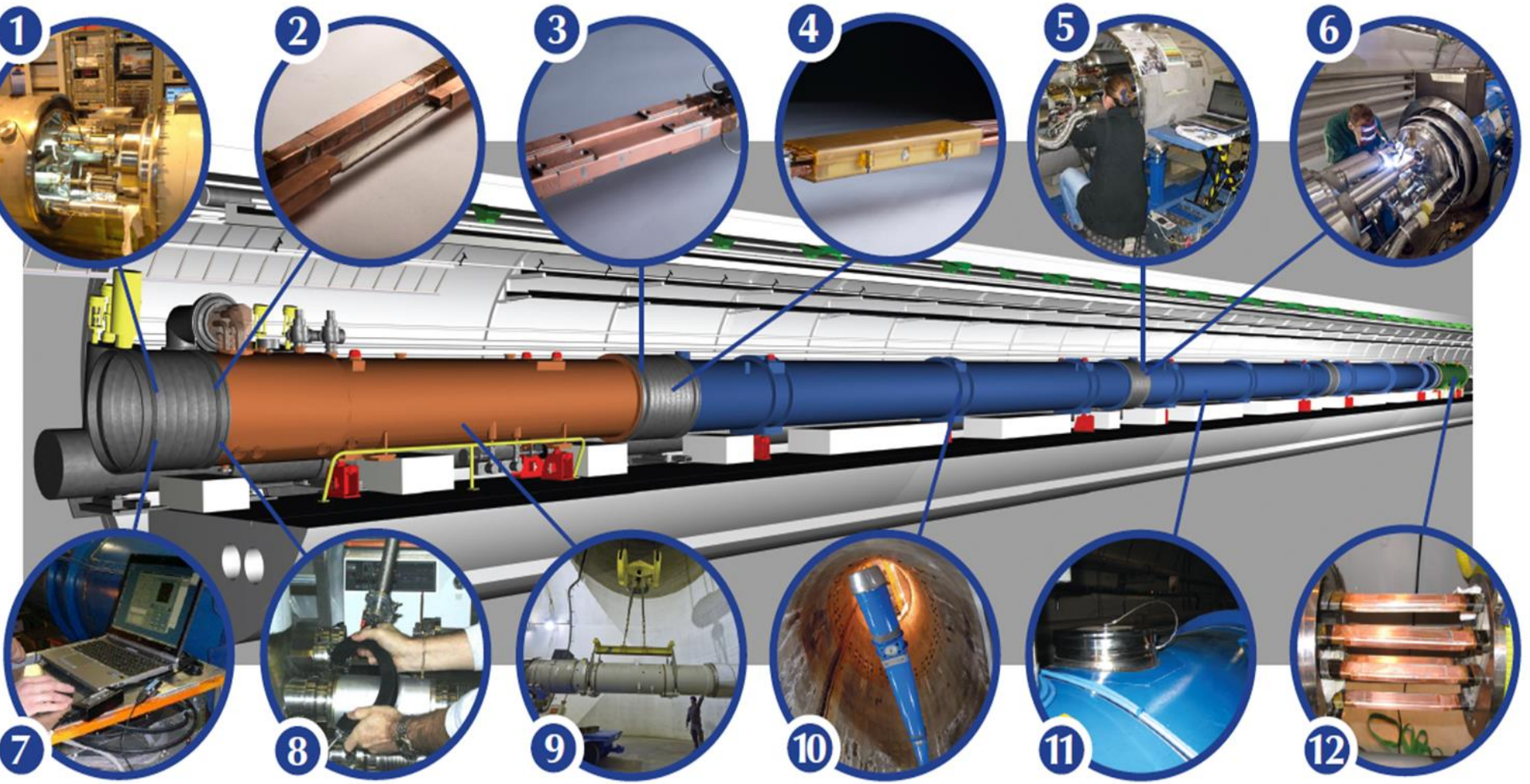
Complete reconstruction of 3000 of these splices

Consolidation of the 10170 13kA splices, installing 27 000 shunts

Installation of 5000 consolidated electrical insulation systems

300 000 electrical resistance measurements

10170 orbital welding of stainless steel lines




18 000 electrical Quality Assurance tests

10170 leak tightness tests

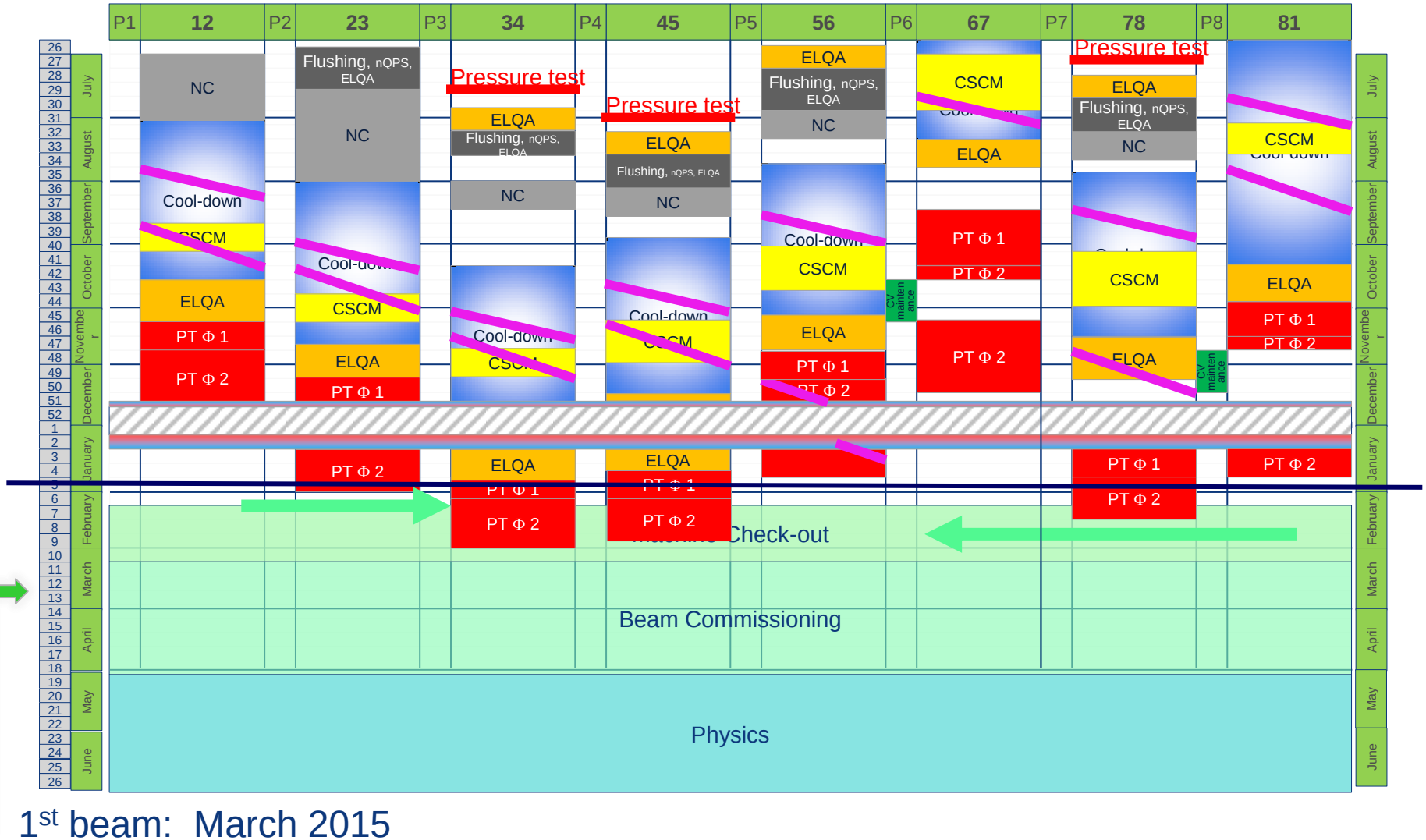
3 quadrupole magnets to be replaced

15 dipole magnets to be replaced

Installation of 612 pressure relief devices to bring the total to 1344

Consolidation of the 13 kA circuits in the 16 main electrical feed-boxes

# LHC schedule V4.1




1st beam: March 2015

# Maximum beam energy : **13 TeV c.m. in 2015**

Decision to run at a **maximum** energy of 6.5 TeV per beam during the powering tests and during 2015.
(10 to 15 training quenches per sector are expected to be needed to reach that energy).

*"We accept the risk that results from late quench tests could force to run at lower energy"*

*Emilio Meschi – LHC physics coordinator*

**NO change of beam energy in 2015.**

*A decision regarding the possibility of increasing the energy will be taken later in 2015, based on the experience gained in all eight sectors at 6.5 TeV per beam during powering tests and operation with beams.*

# LHC goal for **2015 and for Run 2 and 3**

**Priorities for the 2015 run :**

- **Establish proton-proton collision at 13 TeV with 25ns and *low* β* to prepare production run in 2016.**
  **Optimisation of physics-to-physics duration**
- **Later in 2015: decision on special runs "when and duration" (90m optics): not in the 1st part of the year. Waiting LHCC recommendation**
- **Pb-Pb run: one month at the end of 2015**

The goal for Run 2 luminosity is 1.3 x $10^{34}$ $cm^{-2}$ $s^{-1}$ and operation with 25 ns bunch spacing (2800 bunches), giving an estimated pile-up of 40 events per bunch crossing.

*"A maximum pileup of ~50 is considered to be acceptable for ATLAS and CMS"*

# LHC goal for **2015 and for Run 2 and 3**

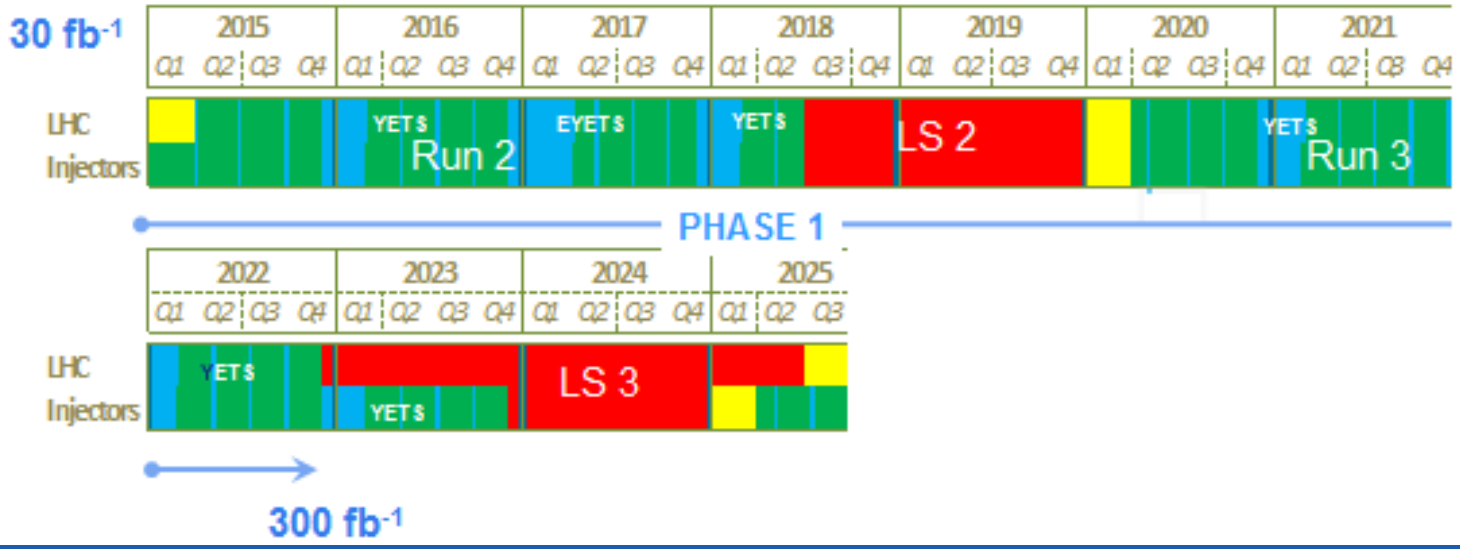
**Integrated luminosity goal:**

**2015 : 10 fb$^{-1}$**

**Run2: ~100-120 fb$^{-1}$**

**(better estimation by end of 2015)**

**300 fb$^{-1}$ before LS3**



# CERN Medium – Long Term Strategy

**The CERN Medium Term Plan approved by June'14 Council,** implements the European Strategy including a long-term outlook.

The scientific programme is concentrated around four priorities:

1. **Full LHC exploitation** – the highest priority - including the construction of the High Luminosity Upgrade until 2025
2. **High Energy Frontier** – CERN's role and preparation for the next large scale facility
3. **Neutrino Platform** – allow for to contribute to a future long baseline facility in the US and for detector R&D for neutrino experiments
4. **Fixed-target programme** – maintain the diversity of the field and honour ongoing obligations by exploiting the unique facilities at CERN

# The European Strategy for Particle Physics
Update 2013

*Europe*
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## Near-term & Mid-term High-energy Colliders

**LARGE HADRON COLLIDER**

- **The HL-LHC is strongly supported and is the first high-priority large-category project in our recommended program. It should move forward without significant delay to ensure that accelerator and experiments can continue to function effectively beyond the end of this decade and meet the project schedule.**
- *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.***

**HL-LHC from a study to a PROJECT**

**300 fb$^{-1}$ → 3000 fb$^{-1}$**

including LHC injectors upgrade **LIU**

(Linac 4, Booster 2GeV, PS and SPS upgrade)

# Goals and means of the LIU project

## Increase intensity/brightness in the injectors to match HL-LHC requirements

⇒ Enable Linac4/PSB/PS/SPS to accelerate and manipulate higher intensity beams (efficient production, space charge & electron cloud mitigation, impedance reduction, feedbacks, etc.)

⇒ Upgrade the injectors of the ion chain (Linac3, LEIR, PS, SPS) to produce beam parameters at the LHC injection that can meet the luminosity goal

## Increase injector reliability and lifetime to cover HL-LHC run (until ~2035) closely related to consolidation program

⇒ Upgrade/replace ageing equipment (power supplies, magnets, RF…)

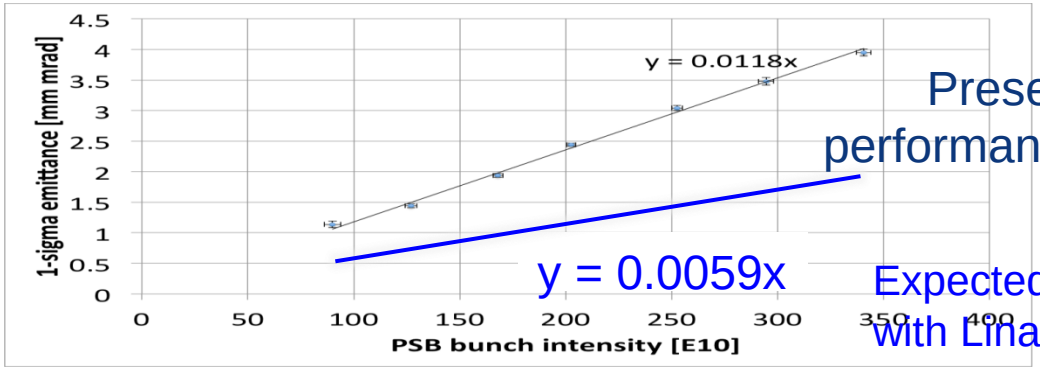
⇒ Improve radioprotection measures (shielding, ventilation…)

# LIU Proton target → HL-LHC beam parameters

| 25 ns | $\mathcal{N}$ (x $10^{11}$ p/b) | ε (μm) | $B_l$ (ns) |
|---|---|---|---|
| Achieved in 2012 | 1.2 | 2.6 (std)<br>1.4 (BCMS) | 1.5 |
| **HL-LHC** | **2.3** | **2.1** | **1.7** |

**Injectors must produce 25 ns proton beams with about double intensity and higher brightness:** A cascade of improvements is needed across the whole injector chain to reach this target

Ex: Linac4 will replace Linac2
12 MeV acceleration validated



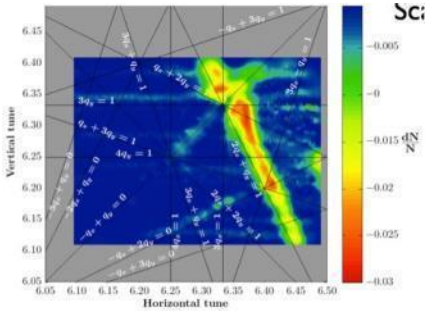
# LS2 : (mid 2018-2019), LHC Injector Upgrades (LIU)

**LINAC4 – PS Booster:**

- $H^-$ injection and increase of PSB injection energy from 50 MeV to 160 MeV, to increase PSB space charge threshold
- New RF cavity system, new main power converters
- Increase of extraction energy from 1.4 GeV to 2 GeV

**PS:**

- Increase of injection energy from 1.4 GeV to 2 GeV to increase PS space charge threshold
- Transverse resonance compensation
- New RF Longitudinal feedback system
- New RF beam manipulation scheme to increase beam brightness




**SPS**

- Electron Cloud mitigation – strong feedback system, or coating of the vacuum system
- Impedance reduction, improved feedbacks
- Large-scale modification to the main RF system

**These are only the main modifications and this list is far from exhaustive**

***Project leader: Malika Meddahi, Deputy: Giovanni Rumolo***

# Goal of High Luminosity LHC (HL-LHC):

**The main objective of HiLumi LHC Design Study is to determine a hardware configuration and a set of beam parameters that will allow the LHC to reach the following targets:**

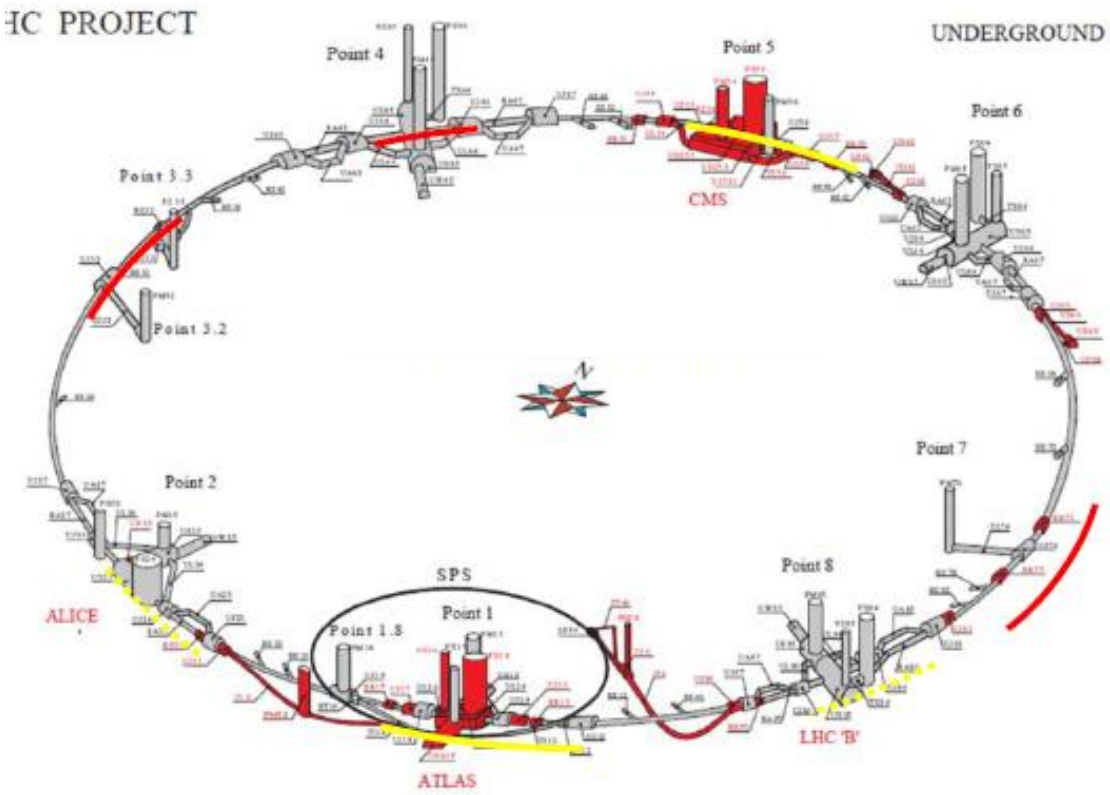
Prepare machine for operation **beyond 2025 and up to 2035**

Devise beam parameters and operation scenarios for:

- enabling a total integrated luminosity of **3000 fb$^{-1}$**
- implying an integrated luminosity of **250-300 fb$^{-1}$ per year**,
- design for **$\mu \sim 140$ ($\sim 200$)** (➔ peak luminosity of **5 (7) $10^{34}$ cm$^{-2}$ s$^{-1}$**)
- design equipment for 'ultimate' performance of **7.5 $10^{34}$ cm$^{-2}$ s$^{-1}$** and **4000 fb$^{-1}$**

**=> Ten times the luminosity reach of first 10 years of LHC operation**

# 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**

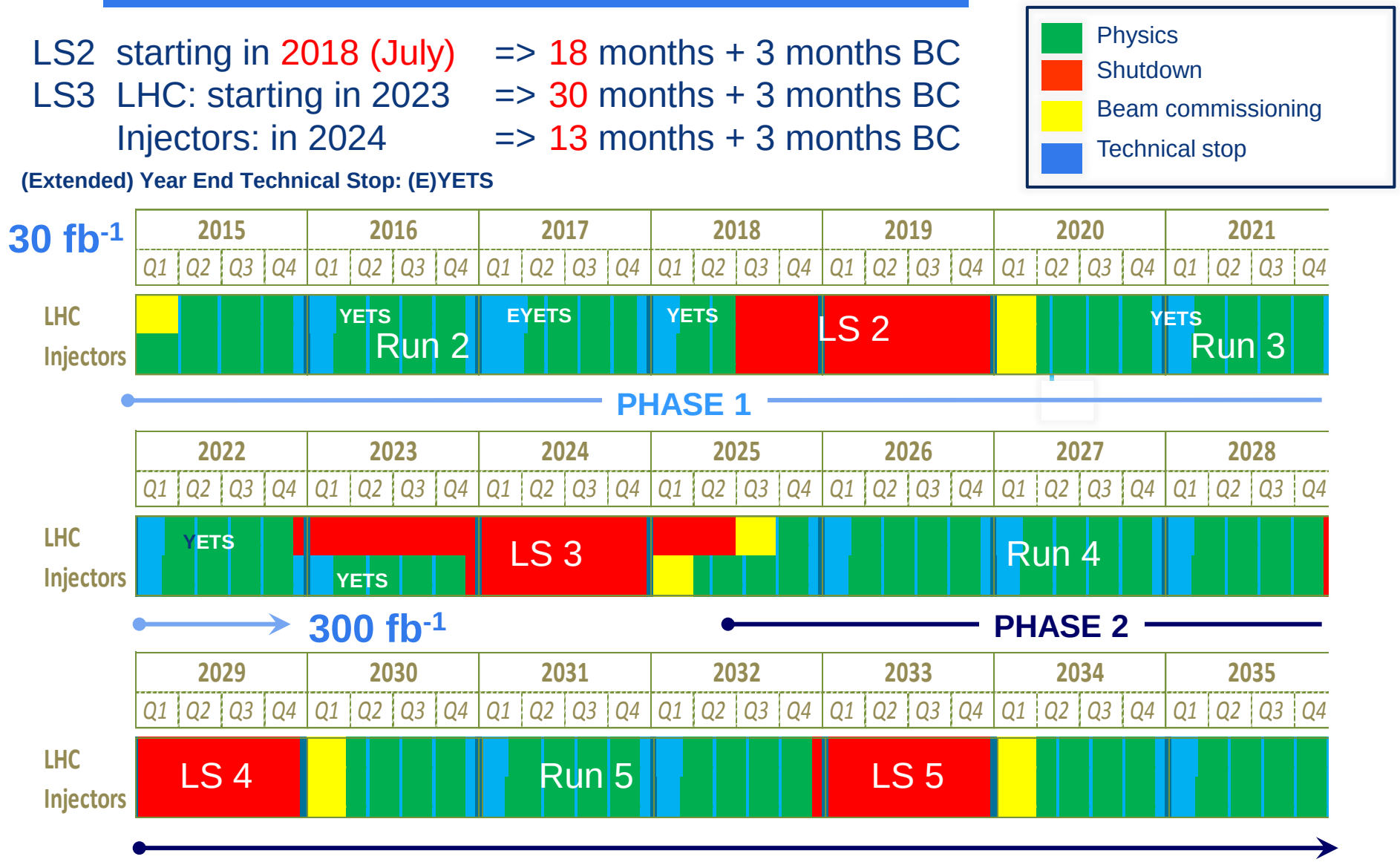
**Project leader: Lucio Rossi; Deputy: Oliver Brüning**

# High Luminosity LHC Participants

# LHC roadmap: 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



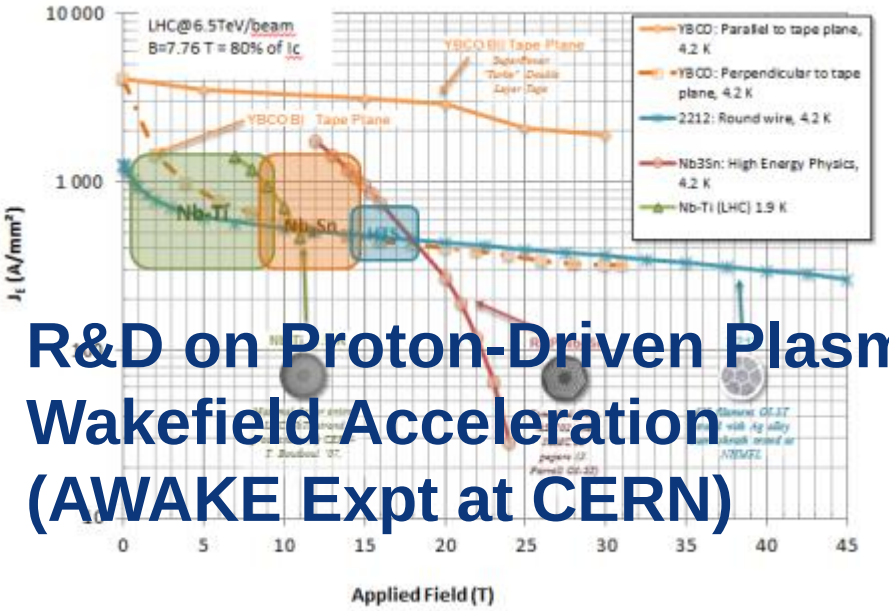



**Goal of 3'000 fb-1 by mid 2030ies**

"to propose an ambitious **post-LHC accelerator project at CERN** by the time of the next Strategy update"

***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.***

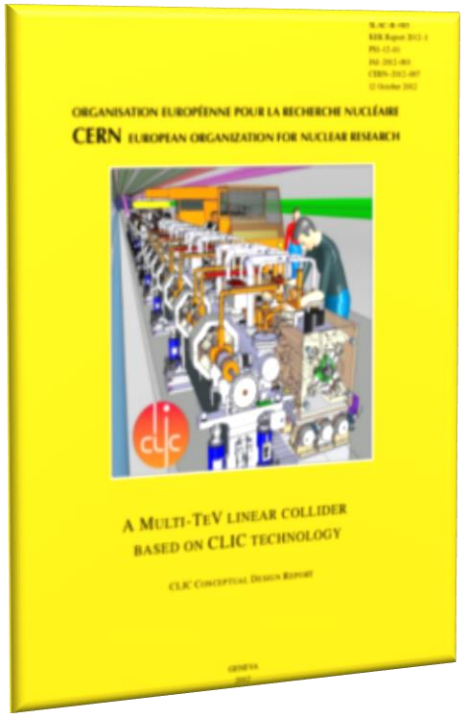
## HFM - FCC

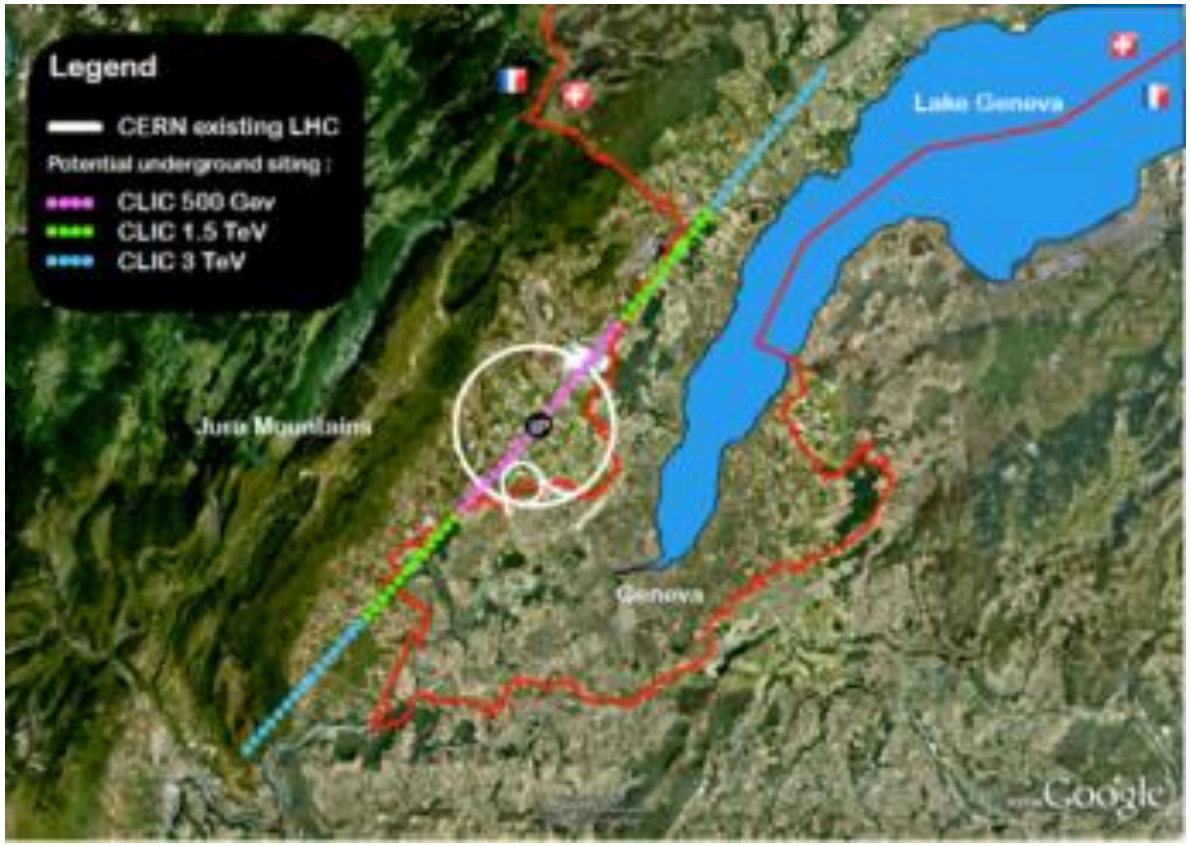



**R&D on Proton-Driven Plasma Wakefield Acceleration (AWAKE Expt at CERN)**

## HGA - CLIC

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




**Highest possible energy $e^+e^-$ with CLIC (CDR 2012)**

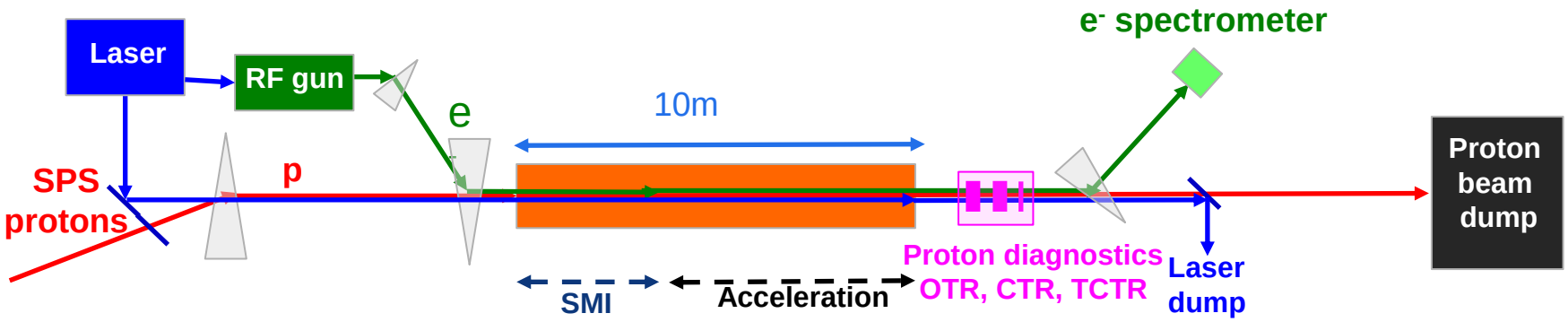
**Multi-lateral collaboration**

# AWAKE

- **AWAKE**: Advanced Proton Driven Plasma Wakefield Acceleration Experiment
  - Use SPS 400 GeV/c proton beam as **drive beam**
  - Inject 15 MeV/c electron beam as **witness beam**
  - 2 TW laser beam for plasma ionization and seeding of the Self-Modulation-Instability (i.e. production of micro-bunches from long SPS bunch)
- Proof-of-Principle Accelerator R&D experiment at CERN
  - **First proton driven wakefield experiment worldwide**
  - Demonstration of high-gradient acceleration of electrons
- AWAKE Collaboration: 16 Institutes world-wide

**Final Goal: Design high quality & high energy electron accelerator based on acquired knowledge.**

# AWAKE Experimental Program




- Perform **benchmark experiments using proton bunches** to drive wakefields for the first time ever.
- Understand **the physics of self-modulation instability** processes in plasma.
- **Probe the accelerating wakefields with externally injected electrons**, including energy spectrum measurements for different injection and plasma parameters.

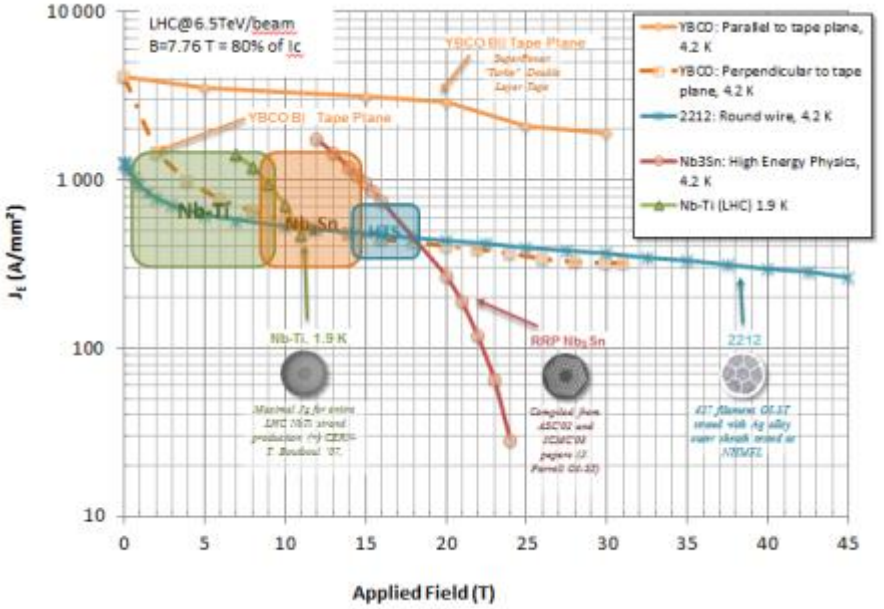
# Beam-Driven Wakefield Acceleration: Landscape

| Facility | Where | Drive (D) beam | Witness (W) beam | Start | End | Goal |
|---|---|---|---|---|---|---|
| AWAKE | CERN, Geneva, Switzerland | 400 GeV **protons** | Externally injected electron beam (PHIN 15 MeV) | 2016 | 2020+ | **Use for future high energy e-/e+ collider.**<br>- Study Self-Modulation Instability (SMI).<br>- Accelerate externally injected electrons.<br>- Demonstrate scalability of acceleration scheme. |
| SLAC-FACET | SLAC, Stanford, USA | 20 GeV electrons and positrons | Two-bunch formed with mask ($e^-/e^+$ and $e^-$-$e^+$ bunches) | 2012 | Sept 2016 | - Acceleration of witness bunch with high quality and efficiency<br>- Acceleration of positrons<br>- FACET II proposal for 2018 operation |
| DESY-FLASH Forward | DESY, Hamburg, Germany | X-ray FEL type electron beam 1GeV | D + W in FEL bunch.<br>Or independent W-bunch (LWFA). | 2016 | 2020+ | - Application (mostly) for x-ray FEL<br>- Energy-doubling of Flash-beam energy<br>- Upgrade-stage: use 2 GeV FEL D beam |
| DESY-Zeuthen | PITZ, DESY, Zeuthen, Germany | 20 MeV electron beam | No witness (W) beam, only D beam from RF-gun. | 2015 | ~2017 | - Study Self-Modulation Instability (SMI) |
| Brookhaven ATF | BNL, Brookhaven, USA | 60 MeV electrons | Several bunches, D+W formed with mask. | On going | | - Study quasi-nonlinear PWFA regime.<br>- Study PWFA driven by multiple bunches<br>- Visualisation with optical techniques |

# “to propose an ambitious **post-LHC accelerator project at CERN** by the time of the next Strategy update”

***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.***

## HFM – FCC-hh




## HGA - CLIC

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

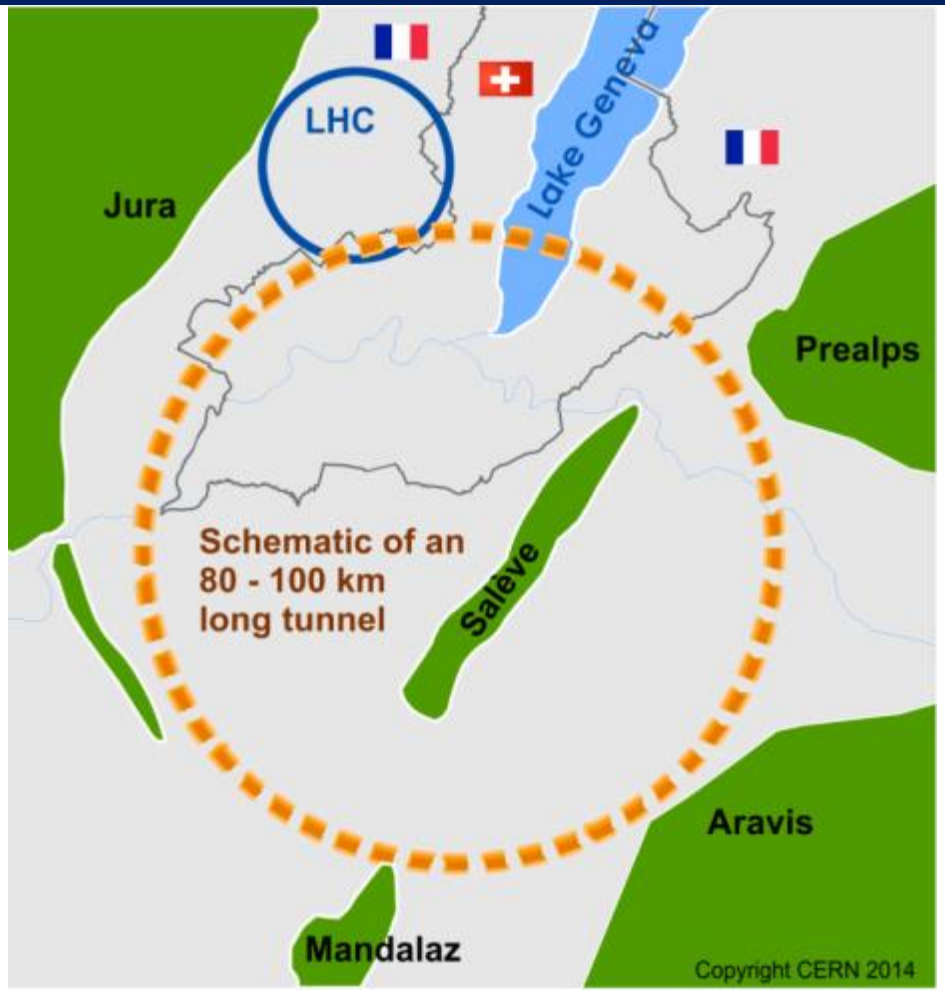
**Forming an international collaboration to study:**

- ***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**



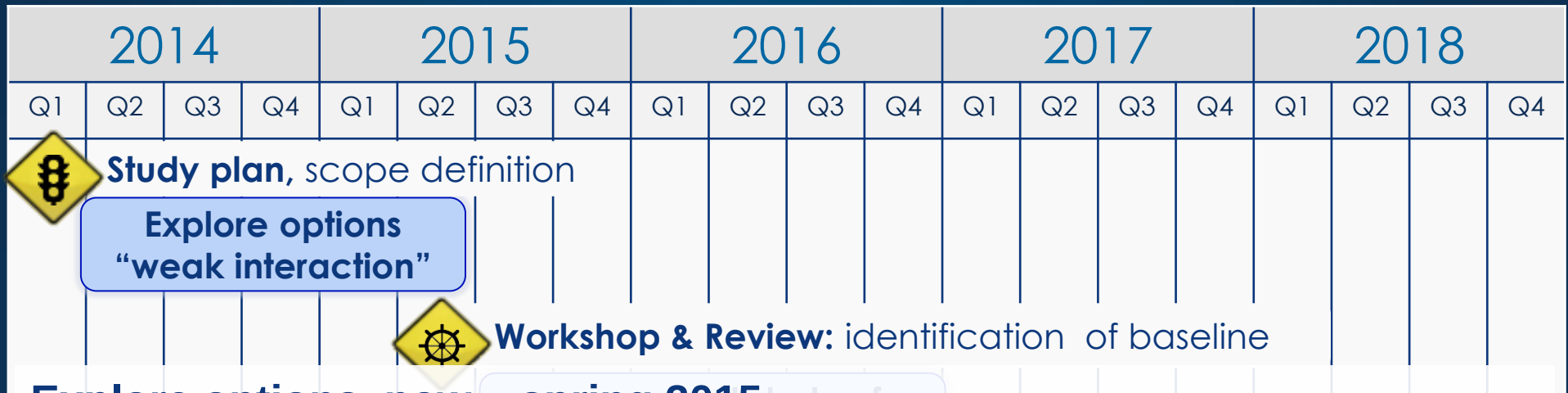

**FCC: 80-100 km infrastructure in Geneva area**


FCC hh ee he

# FCC Kick-off Meeting
# University of Geneva
# 12-15 February 2014

## >340 participants

# Study Time Line




**Explore options, now – spring 2015:**

- **Investigate different options in all technical areas, taking a broad view**
- **Deliverables: description/comparison of options with relative merits/cost, understand relative impact of options on overall study/project**
- **FCC workshop to converge to common baseline with small number of options**
- **1st Yearly FCC Workshop 23 – 27 March 2015, Washington DC**
- **Followed by review ~2 months later, begin June 2015**


FCC Week 2015
IEEE International Future Circular Collider Conference
March 23 - 27, 2015 | Washington DC, USA
Organising & Scientific Program Committee:
N. Arkani-Hamed (Princeton)
A. Ball (CERN)
B. Barletta (MIT)
M. Benedikt (CERN)
F. Bordry (CERN)
L. Bottura (CERN)
O. Brüning (CERN)
W. Chou (FNAL, IHEP)
P. Collier (CERN)
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Further information and registration
http://cern.ch/fccw2015
EuCARD²

# 3rd Workshop on Energy for Sustainable Science 29-30 October 2015 at DESY

CERN · ESS EUROPEAN SPALLATION SOURCE · ERF European Association of National Research Facilities, Open to International Access

Workshop Energy for Sustainable Science

Energy Management for Large-Scale Research Infrastructures

*13-14 October 2011, ESS-LUND, Sweden*

*CERN, the European Organization for Nuclear Research, ERF, the European Association of National Research Facilities, and ESS, the European Spallation Source, are delighted to invite you to indicate your interest in attending the first joint workshop on Energy Management for large-scale research infrastructures.*

Volatile energy costs, a tight budget climate and increasing environmental concerns are all inciting large-scale research facilities across the globe to develop mid- and long-term strategies aimed at achieving for the future a reliable, affordable and sustainable energy supply that is carbon neutral.

The workshop will bring together international experts on energy and representatives from laboratories and future projects all over the world in order to identify the challenges and best practice in respect of energy efficiency and optimization, solutions and implementation as well as to review the challenges represented by potential future technical solutions and the tools for effective collaboration.

Topics for discussion will include:

- **Technical challenges in availability and quality:** efficiency and optimization of energy supply, energy recovery, storage and stability
- **Strategic and financial challenges for the future:** impact of GRID regulation, investment optimization, procurement strategy
- **Challenges for heat recycling systems and water saving:** energy conversion, heat recovery, high-temperature cooling loops

**Costs**

Participation is by invitation and free of charge. Participants must cover their own travel and accommodation expenses.
As participation in the Workshop is limited by the availability of accommodation, you are strongly advised to indicate your interest in attending the Workshop as soon as possible.
In order to ensure that the participating research facilities are as broadly represented as possible, the Workshop organizers will issue a formal invitation confirming attendance at the Workshop in due course.

**Additional Information & Registration**

www.esss.se/energysworkshop

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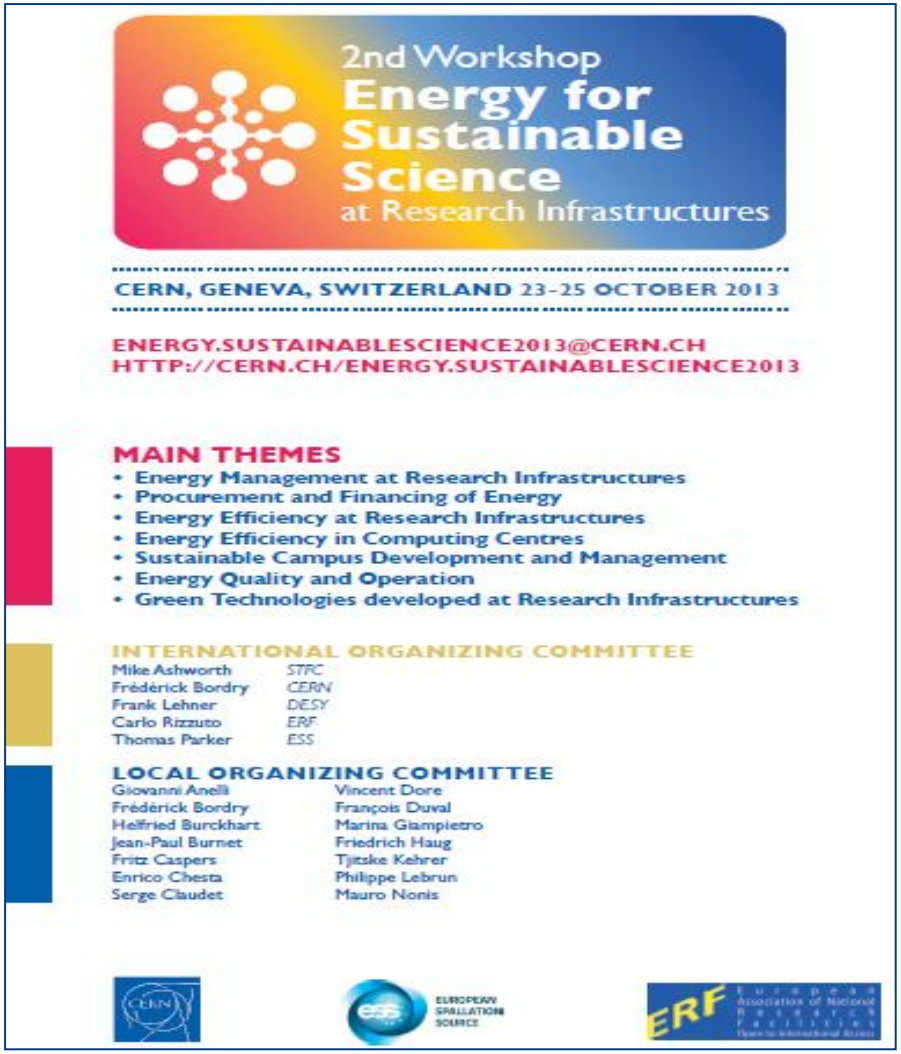

2nd Workshop Energy for Sustainable Science at Research Infrastructures

CERN, GENEVA, SWITZERLAND 23-25 OCTOBER 2013

ENERGY.SUSTAINABLESCIENCE2013@CERN.CH
HTTP://CERN.CH/ENERGY.SUSTAINABLESCIENCE2013

**MAIN THEMES**

- Energy Management at Research Infrastructures
- Procurement and Financing of Energy
- Energy Efficiency at Research Infrastructures
- Energy Efficiency in Computing Centres
- Sustainable Campus Development and Management
- Energy Quality and Operation
- Green Technologies developed at Research Infrastructures

**INTERNATIONAL ORGANIZING COMMITTEE**

| | |
|---|---|
| Mike Ashworth | STFC |
| Frédérick Bordry | CERN |
| Frank Lehner | DESY |
| Carlo Rizzuto | ERF |
| Thomas Parker | ESS |

**LOCAL ORGANIZING COMMITTEE**

| | |
|---|---|
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| Frédérick Bordry | François Duval |
| Helfried Burckhart | Marina Giampietro |
| Jean-Paul Burnet | Friedrich Haug |
| Fritz Caspers | Tjitske Kehrer |
| Enrico Chesta | Philippe Lebrun |
| Serge Claudet | Mauro Nonis |

CERN · ESS EUROPEAN SPALLATION SOURCE · ERF European Association of National Research Facilities, Open to International Access

- CERN is presently exploiting the physics potential of the LHC
- After the long shutdown LS1 the LHC will operate at 13 TeV in 2015 and later towards 14 TeV (2015-2023). Goal 300 $fb^{-1}$
- The high luminosity project HL-LHC will allow to collect ten times more data (2025 - mid 2030ies) Goal of 3'000 fb-1

- Depending on the physics findings of the LHC "precision" e+e- linear colliders might be built in Japan (ILC) or at CERN (CLIC)

- CERN is hosting a study performed in international collaboration for a Future Circular Colliders in the Geneva area with a circumference of 80 – 100km:
  - pp-collider (FCC-pp) defining the infrastructure requirements
  - e+e- collider (FCC-ee) as potential intermediate step
  - p-e (FCC-ep) option
  - HE-LHC is also a possible option: High Field Magnets in the present LHC tunnel

- **Global collaboration on future accelerators will lead to technological breakthroughs and R&D on new concepts.**

- **Multiple synergies and interest in common R&D activities: for other accelerator areas e.g. intensity frontier, for nuclear science (FRIB), fusion (ITER,…), energy distribution, manufacturing techniques, space applications, medical applications, ...**

# Thanks for your attention


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