The future of Particle Physics

……

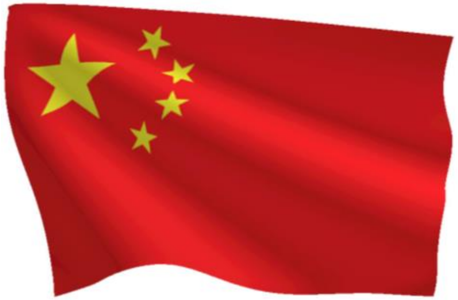
from an accelerating point of view

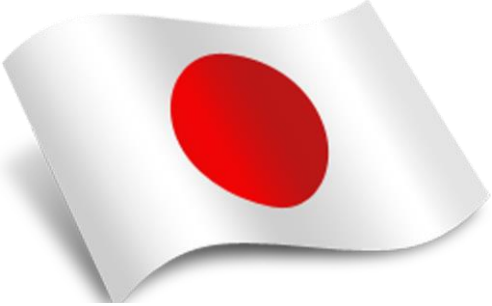
Isabel Bejar Alonso with slides coming from all the physics community

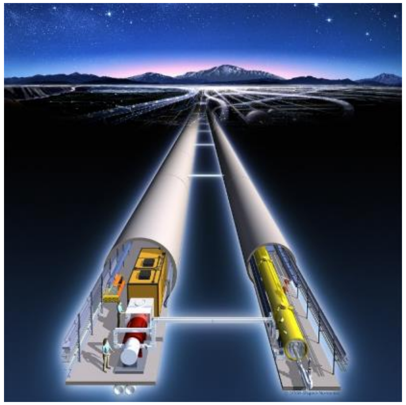
HL-LHC Configuration, Quality, Risk and Resources Officer

¿Qué será … será ….?

Habrá que preguntarse ...
¿En las manos de quienes está …?





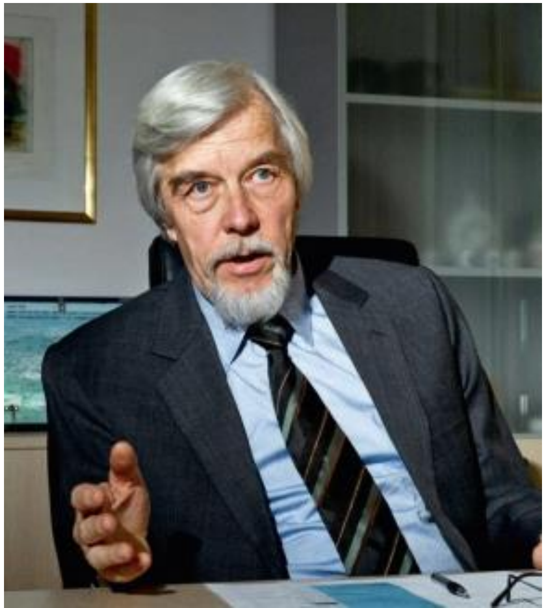


O ... ¿Quienes tienen dinero para financiar ciencia básica?





O son los lideres que inspiraran a nuestros politicos …



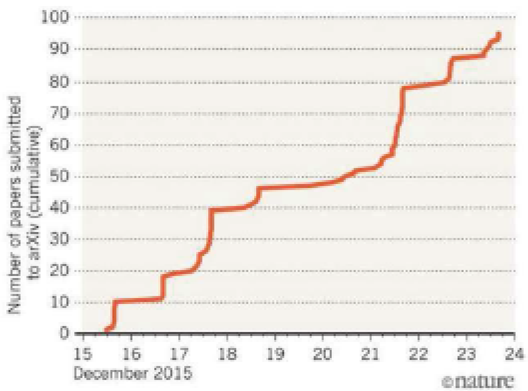
O la física que puede llegar …

1. A new resonance at 750 GeV?

Tsunami of theory papers trying to interpret the 750 GeV diphotons:

10 papers the very first day,
100 at the end of the year,
about 250 papers as of today..

Nature article/Dorigo/Jester blogs:



Florilège of explanations:

- cascading heavy quarks,
- collimated 2x2 photons,
- new gauge bosons Z'+X
- sgoldstinos and other SUSY,
- quirks, hidden valleys?
- statistical fluctuation...

But most papers are talking about a new heavy resonance:

- Dark matter mediators
- Technipions/Goldstones, ..
- Axions,radions/dilatons,..
- Gravitons or any spin 2...
- Higgs bosons...

and other possibilities...

I try a quick/basic interpretation (adding a little to Alessandro...)

Moriond-QCD, 19/03/2016 Implications of a 750 GeV state – Abdelhak Djouadi – p.4/

Lo que sabemos es que hoy en día hay una estrategia Europea que se esta repensando en este momento,
una estrategia Estadounidense que se presentó en 2014,
una estrategia japonesa y planes de crear grandes aceleradores en China …

Strategy USA - 2014

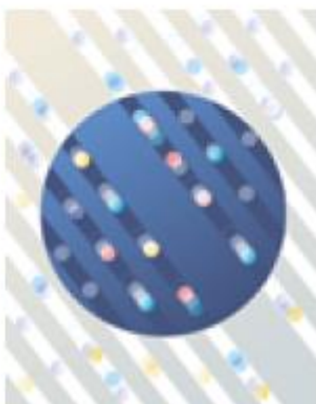
Particle physics is a highly successful, discovery-driven science. It explores the fundamental constituents of matter and energy, and it reveals the profound connections underlying everything we see, including the smallest and the largest structures in the Universe. Earlier investments have been rewarded with recent fundamental discoveries, and upcoming opportunities will push into new territory. Particle physics inspires young people to engage with science.

Drivers

Five intertwined scientific Drivers were distilled from the results of a yearlong community-wide study:

- Use the Higgs boson as a new tool for discovery
- Pursue the physics associated with neutrino mass
- Identify the new physics of dark matter
- Understand cosmic acceleration: dark energy and inflation
- Explore the unknown: new particles, interactions, and physical principles

Higgs boson



Neutrino mass

Dark matter

Cosmic acceleration

Explore the unknown

Strategy USA

- Large projects, in time order, include the **Muon g-2** and **Muon-to-electron Conversion (Mu2e)** experiments at Fermilab, strong collaboration in the high-luminosity upgrades to the Large Hadron Collider (**HL-LHC**), and a U.S.-hosted Long Baseline Neutrino Facility (**LBNF**) that receives the world's highest intensity neutrino beam from (PIP-II) at Fermilab.
- U.S. involvement in a Japanese-hosted International Linear Collider (**ILC**).
- Areas with clear U.S. leadership in which investments in medium- and small-scale experiments have great promise for near-term discovery include dark matter direct detection, the Large Synoptic Survey Telescope (LSST), the Dark Energy Spectroscopic Instrument (DESI), cosmic microwave background (CMB) experiments, short-baseline neutrino experiments, and a portfolio of small projects.

Strategy Europe

- Exploit its current world-leading facility for particle physics, the LHC, to its full potential over a period of many years, with a series of planned upgrades (**HL-LHC**);
- Continue to develop novel techniques leading to ambitious **future accelerator** projects on a global scale;
- Be open to engagement in a range of unique basic physics research projects alongside the LHC;
- Be open to **collaboration** in particle physics projects beyond the European region;
- Maintain a healthy base in fundamental physics research, with universities and national laboratories contributing to a strong European focus **through CERN**;
- Continue to invest substantial effort in communication, **education and outreach** to engage global publics with science.

CERN scientific roadmap today

Full exploitation of the LHC:

- ❑ Run 2 started last year → goal this year is $L=10^{34}$ at $\sqrt{s}$ =13 TeV, ~25 fb^{-1}
- ❑ building upgrade of injectors (LIU), collider (HL-LHC) and detectors (Phase-1 and Phase-2)

Diversity programme serving a broad community:

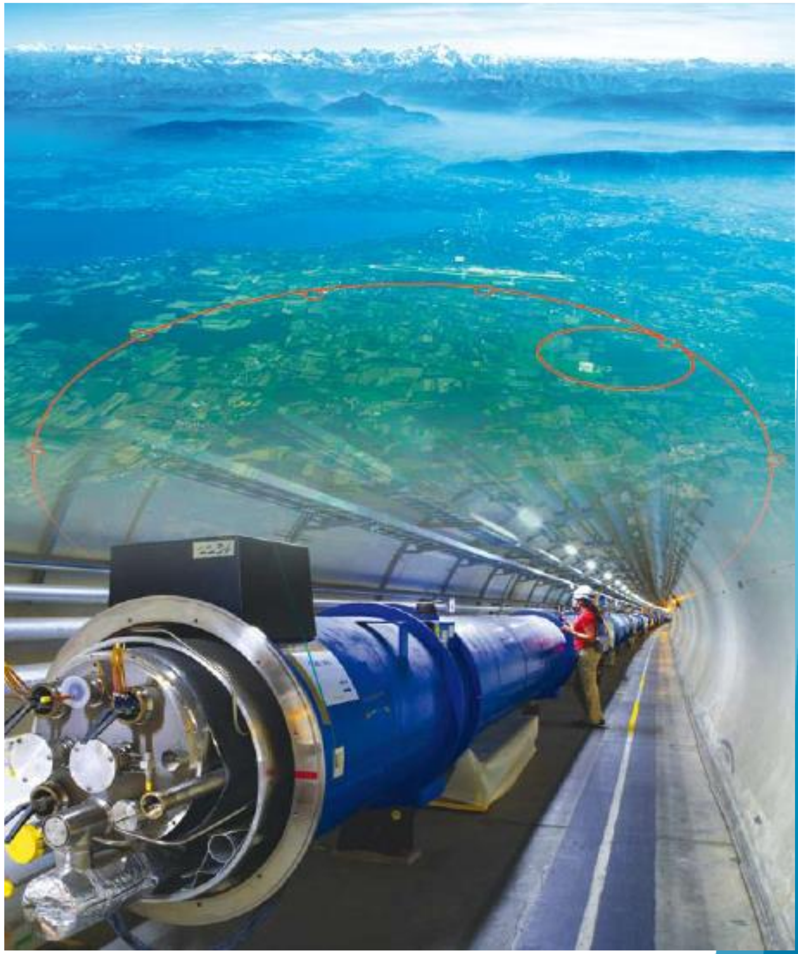
- ❑ ongoing experiments and facilities at Booster, PS, SPS and their upgrades (ELENA, HIE-ISOLDE)
- ❑ participation in accelerator-based neutrino projects outside Europe (presently mainly LBNF in the US) through the CERN Neutrino Platform

Preparation of CERN's future:

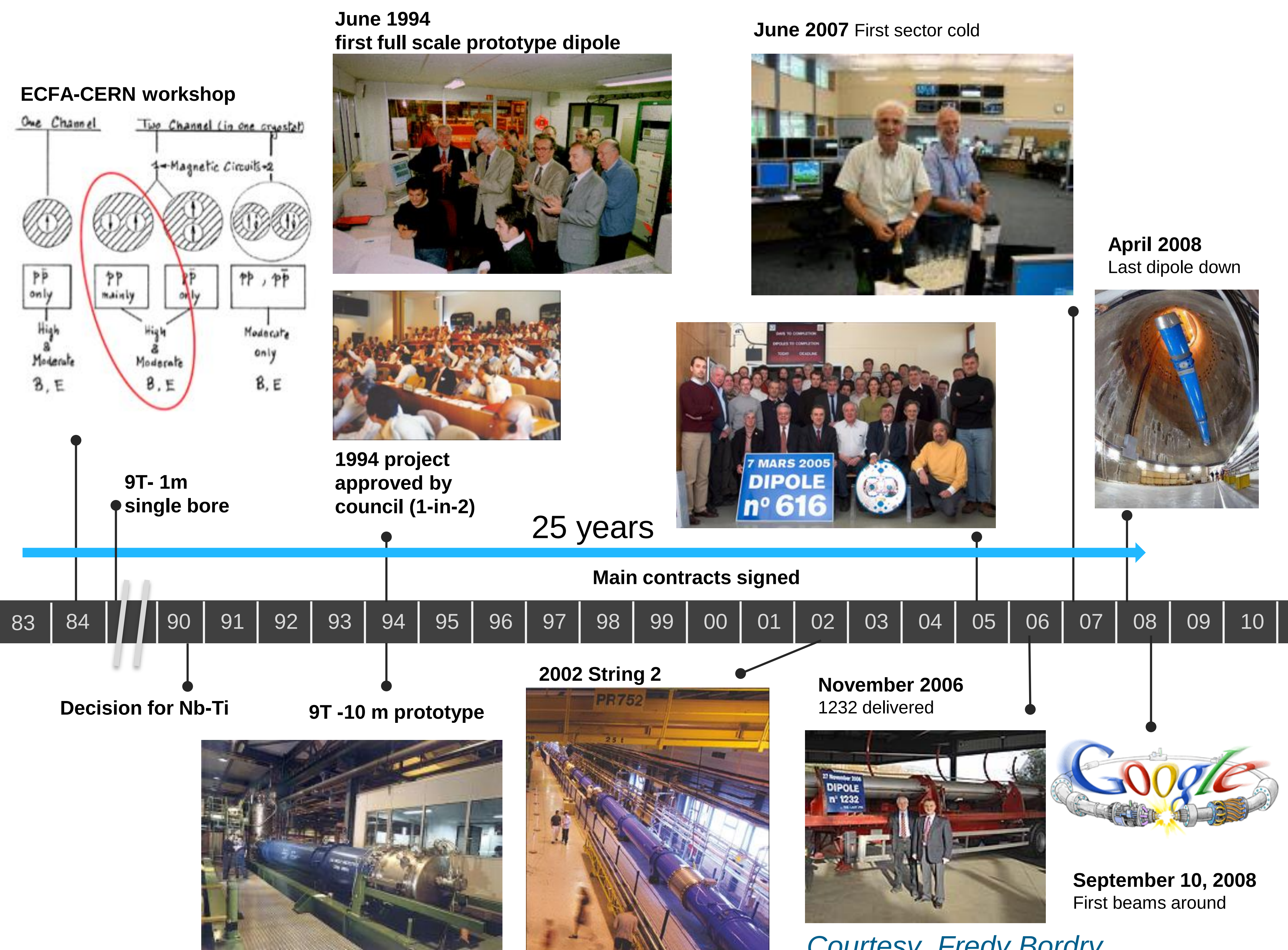
- ❑ vibrant accelerator R&D programme exploiting CERN's strengths and uniqueness (including superconducting high-field magnets, AWAKE, etc.)
- ❑ design studies for future accelerators: CLIC, FCC (includes HE-LHC)
- ❑ future opportunities for scientific diversity programme (new)

Full exploitation of the LHC: The LHC

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

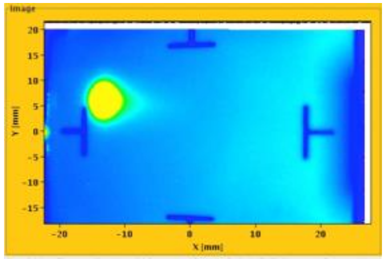


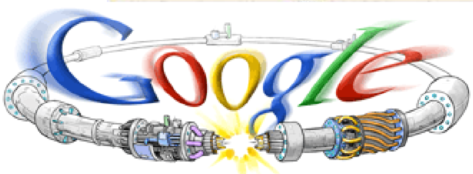
Courtesy Fredy Bordry



Courtesy Fredy Bordry

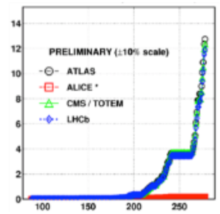
August 2008
First injection test





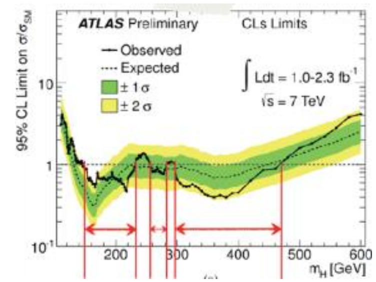
Sept. 10, 2008
First beams around

November 29, 2009
Beam back



Repair and Consolidation

October 14, 2010
L= $1\times10^{+32}$
248 bunches

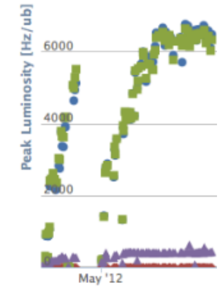


October, 2011
$3.5\times10^{+33}$, 5.7 fb^{-1}

First Hints!!

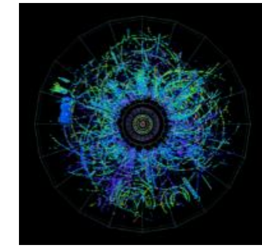
June 28 2011
1380 bunches

1380

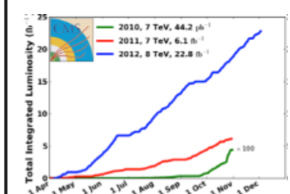


May 2012
Ramping
Performance

March 14th 2012
Restart
with Beam



Feb. 2013
p-Pb^{82+}
New Operation
Mode

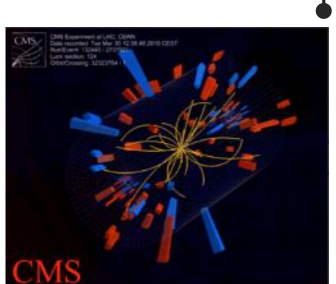


Nov. 2012
End of p^{+} Run 1

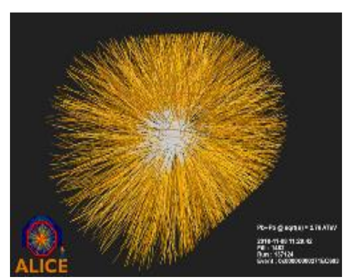
2008	2009	2010	2011	2012	2013

Sept. 19, 2008
Incident

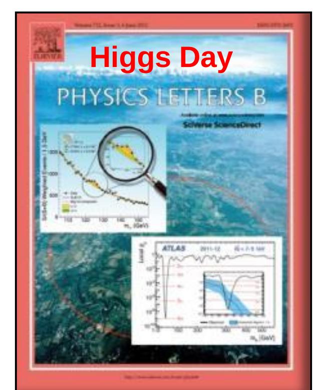
March 30, 2010
First collisions at 3.5 TeV



November 2010
Pb^{82+} Ions



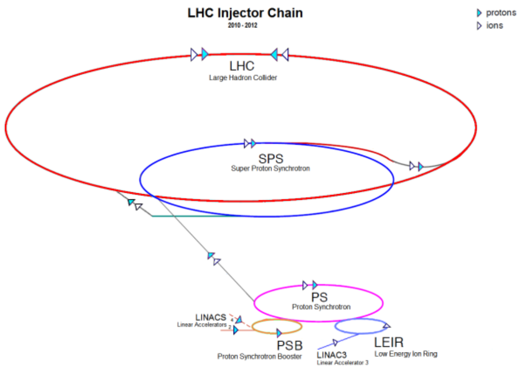
November 2011
Second Ion Run



LS1

Courtesy Fredy Bordry

Full exploitation of the LHC: LIU LHC Injector Upgrades

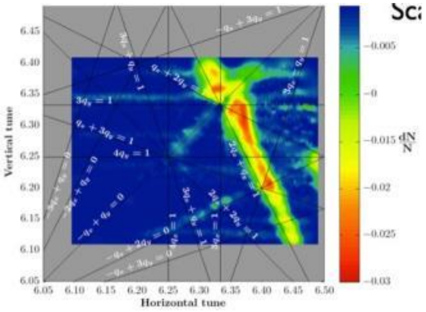


LINAC4 – PS Booster:

- 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

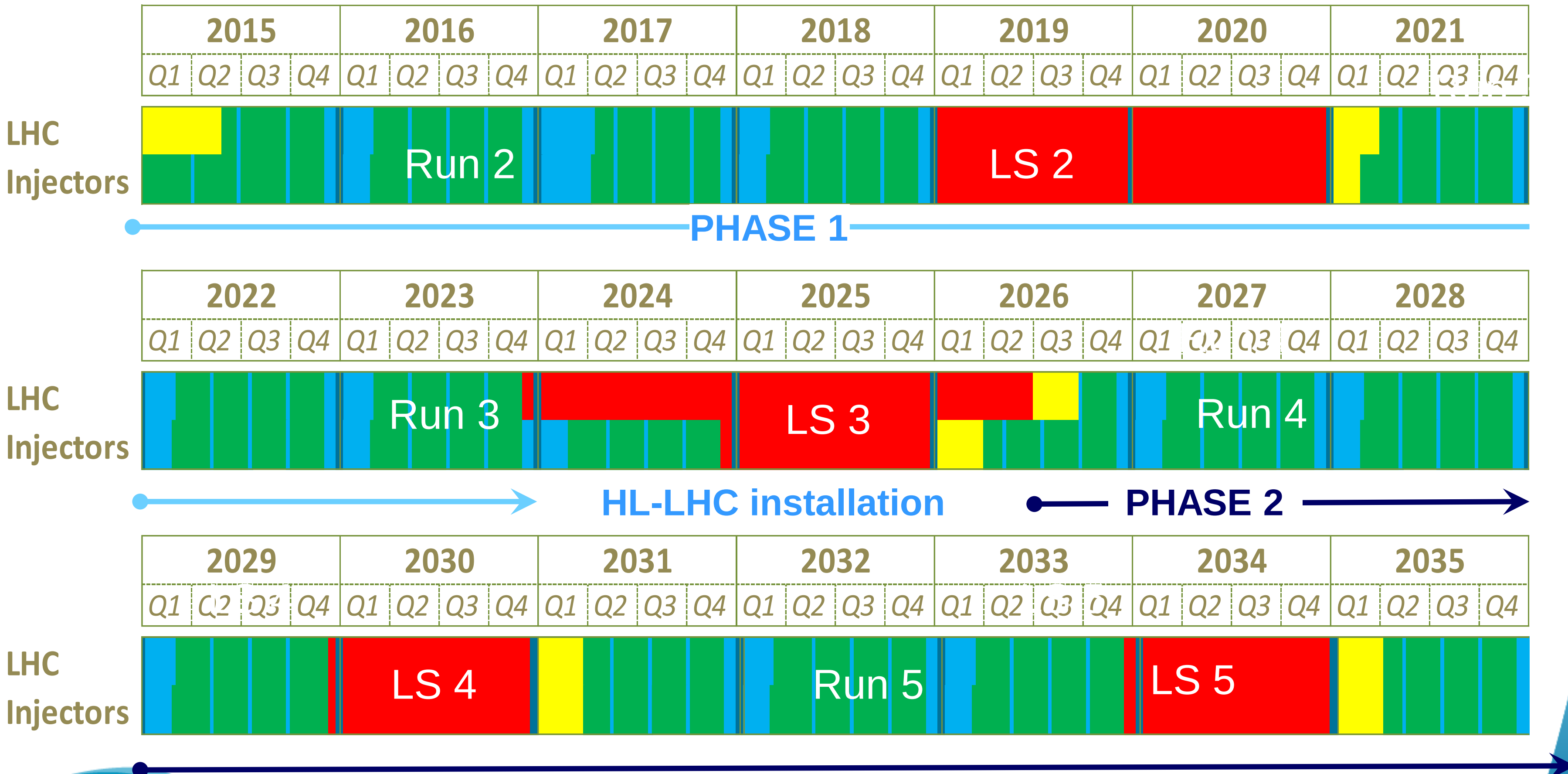
These are only the main modifications and this list is far from exhaustive

Project leadership: M. Meddahi

LHC roadmap: according to MTP 2016-2020 V1

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



The European Strategy for Particle Physics
Update 2013

c) *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.*

HL-LHC from a study to a PROJECT

$300\ fb^{-1} \rightarrow 3000\ fb^{-1}$

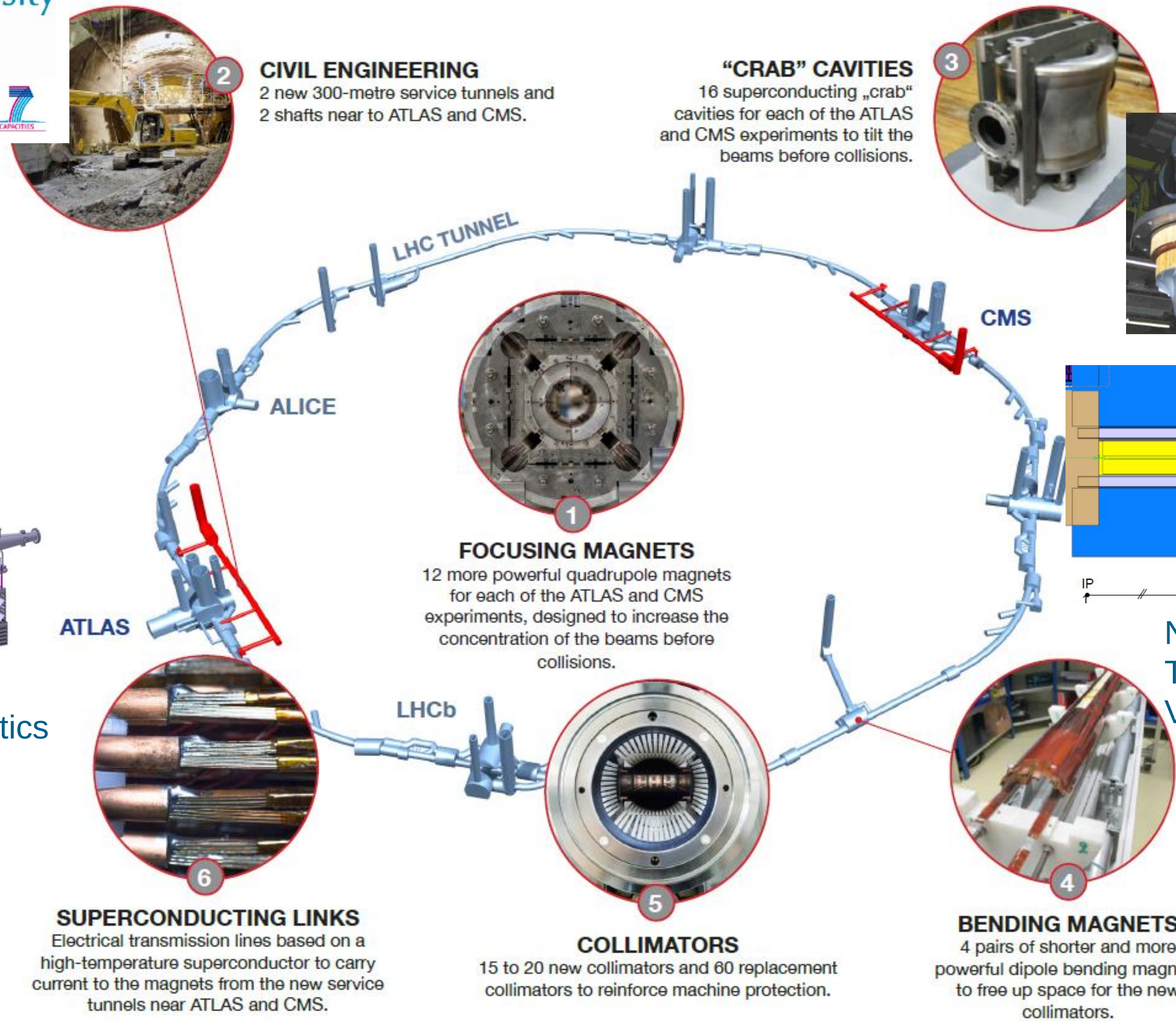
including LHC injectors upgrade **LIU**

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

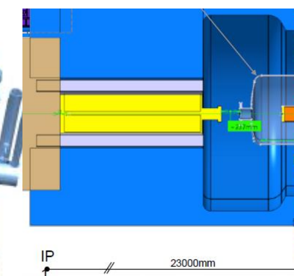
Update ESPP ~2019-2020!

Full exploitation of the LHC: HL-LHC

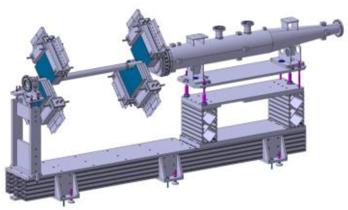
Cryo@P4



Cryo@ P1-P5

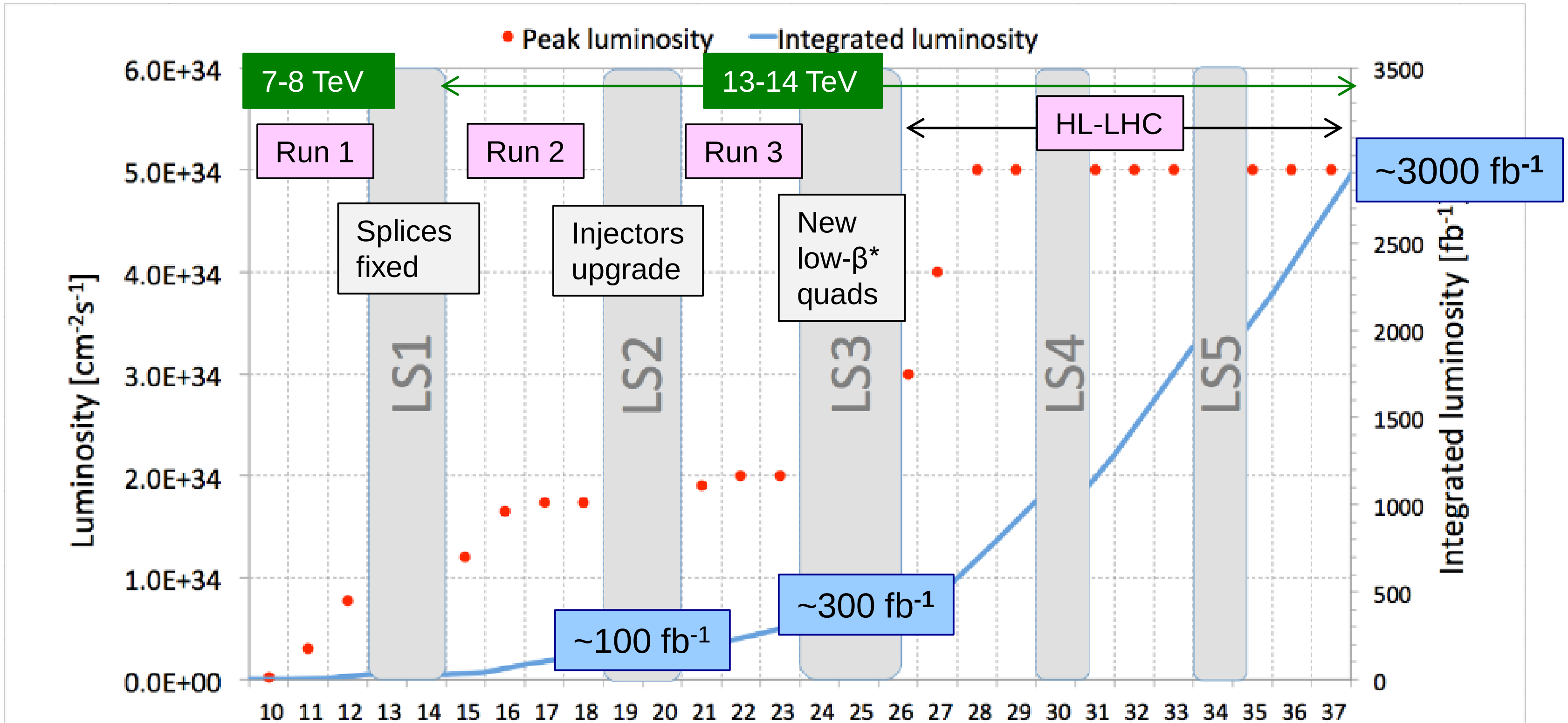


New TAS and VCX



Beam diagnostics BGV

Pero si volvemos a las transparencias presentadas por nuestra directora general …

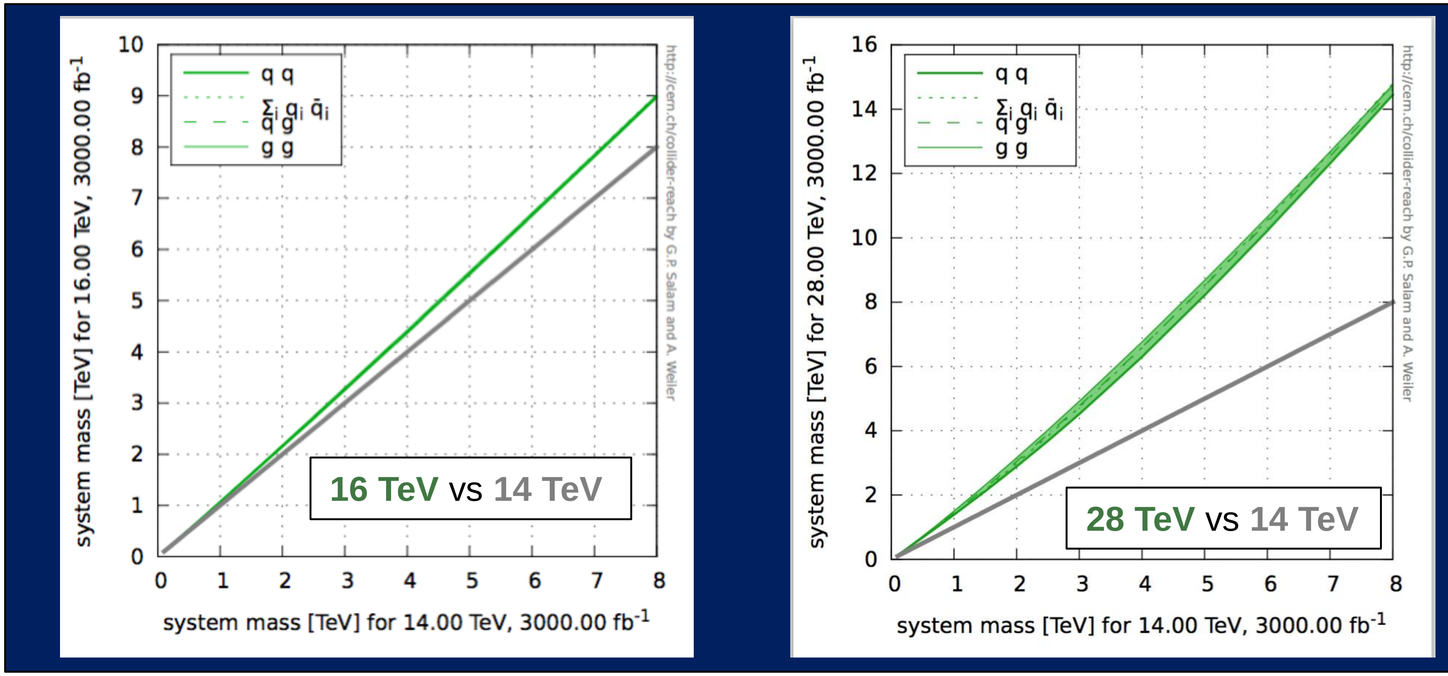


LHC is today's most powerful collider → full exploitation (√s ~ 14 TeV, 3000/fb) is mandatory:

- ❑ **If new physics discovered in Run 2-3:**
  → first detailed exploration of new physics with well understood machine and experiments while building next accelerator
- ❑ **If no new physics in Run 2-3:**
  → extend direct discovery potential by ~ 20-30% (up to m ~ 10 TeV)

In either case: measure H couplings to few percent (including 2nd generation: Hμμ)

Higher √s in the LHC tunnel ?



Various options, with increasing amount of HW changes, technical challenges, cost, and physics reach

WG set up to explore technical feasibility of pushing LHC energy to:

1) design value: 14 TeV
2) ultimate value: 15 TeV (corresponding to max dipole field of 9 T)
3) beyond (e.g. by replacing 1/3 of dipoles with 11 T Nb_3Sn magnets)

→ Identify open risks, needed tests and technical developments, trade-off between energy and machine efficiency/availability

→ Report on 1) end 2016, 2) end 2017, 3) end 2018 (in time for ES)

HE-LHC (part of FCC study): ~16 T magnets in LHC tunnel (→ √s~ 30 TeV)

- ❑ uses existing tunnel and infrastructure; can be built at fixed budget
- ❑ strong physics case if new physics from LHC/HL-LHC
- ❑ powerful demonstration of the FCC-hh magnet technology

¿Tal vez una indicación de que se pueda descubrir pronto algo?

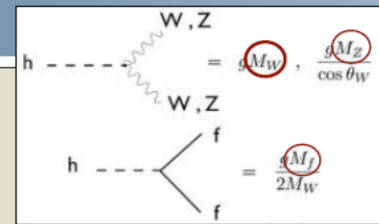
…

O simplemente una forma de tener planes alternativos si es el caso…

Pero si vemos las transparencias presentadas por nuestra directora general ayer…

La física de HL-LHC c

HL-LHC physics case



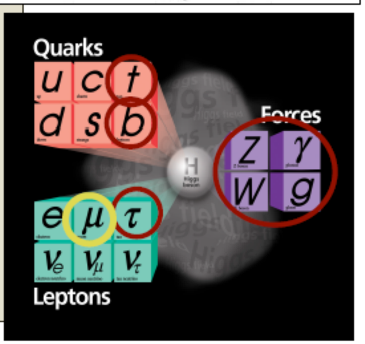
1 Precise measurements of the Higgs boson

Impact of New Physics on Higgs couplings to other particles:

$\Delta\kappa/\kappa \sim 5\%/\Lambda^2_{NP}$ (Λ_{NP} in TeV)

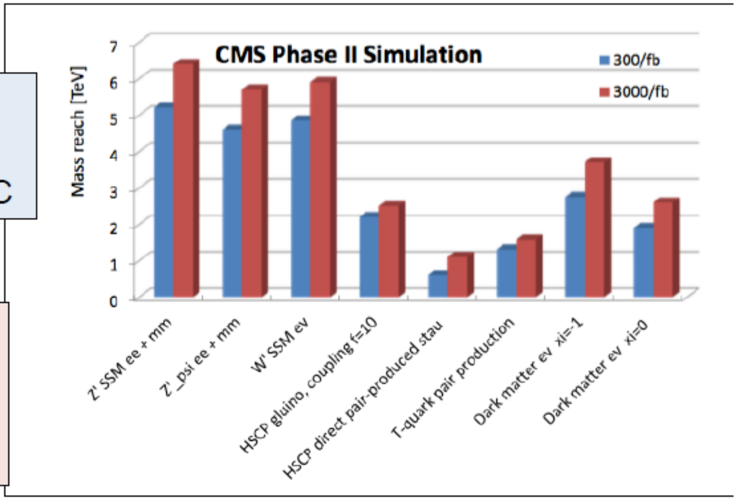
Precision ~2-5% at HL-LHC (~10% at nominal LHC)

In addition: measure H couplings to second-generation particles through rare **H→ μμ** decay. Nominal LHC: only couplings to (heavier) third-generation particles (top-quark, b-quark, τ-lepton) accessible



2 Discovery potential for new particles

~20-30% larger (up to m ~ 8 TeV) than nominal LHC



3 If new particles discovered in Run 2-3:
→ HL-LHC may find more and provide first detailed exploration of the new physics with well understood machine and experiments

Full exploitation of the LHC and HL-LHC

Conclusions on formal approval of HL-LHC

Full exploitation of the LHC physics potential with the HL-LHC phase is the top priority of the European Strategy and the highest near-term large-project priority of the US P5 roadmap. HL-LHC is a "landmark project" in the ESFRI roadmap.

It requires running the LHC beyond mid 2020 and the upgrade of several accelerator components. The HL-LHC project is well established in terms of beam parameters, technical requirements, needed technological developments. R&D and prototype work is well advanced.

Cost and schedule were consolidated in March 2015 and are included with a realistic budget profile in the MTP. The total construction cost amounts to 950 MCHF.

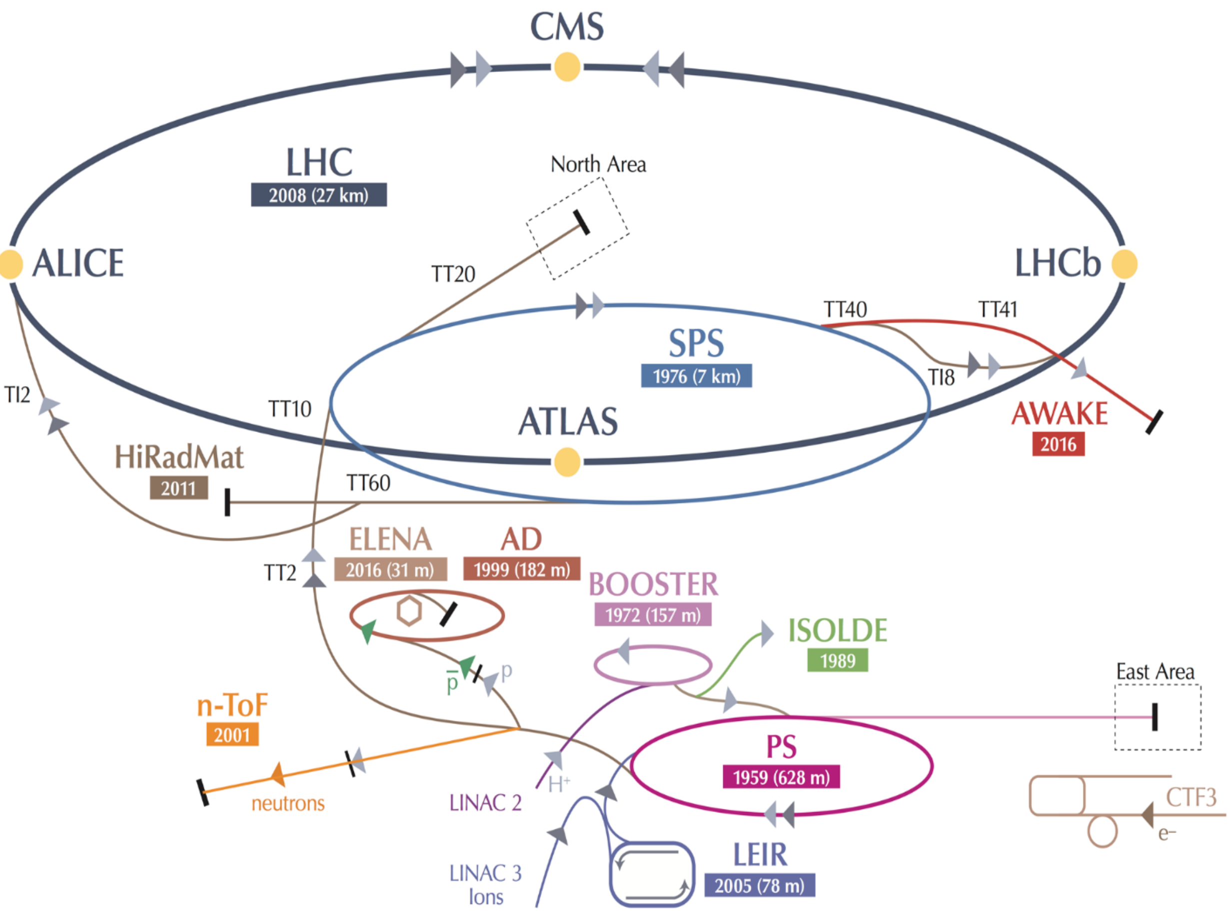
The LHC and its HL-LHC phase are CERN's flagship project for the next 20 years
→ crucial for the future of the Organization and particle physics worldwide

Diversidad …

y colaboración

(Neutrinos y no sólo)

Diversity programme serving a broad community



~20 experiments > 1200 physicists

AD: Antiproton Decelerator for antimatter studies

CAST, OSQAR: axions

CLOUD: impact of cosmic rays on aeorosols and clouds → implications on climate

COMPASS: hadron structure and spectroscopy

ISOLDE: radioactive nuclei facility

NA61/Shine: ions and neutrino targets

NA62: rare kaon decays

NA63: radiation processes in strong EM fields

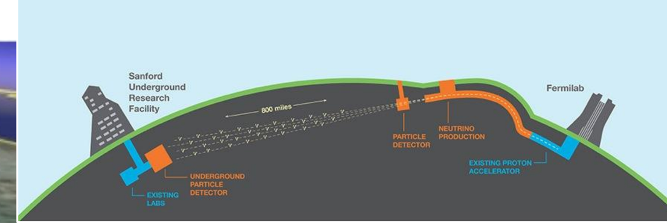
n-TOF: n-induced cross-sections

UA9: crystal collimation

Neutrino Platform: collaborating with experiments in US and Japan → see later

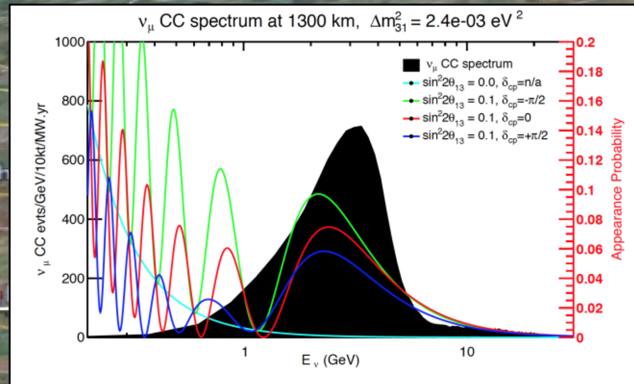
HiLumi HL-LHC PROJECT

Long Baseline Neutrino Facility (LBNF) at FNAL

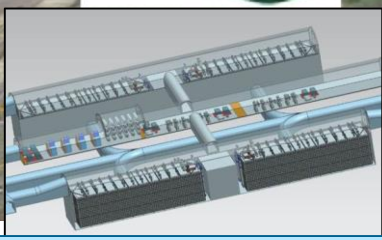


Sanford Underground Research Facility

South Dakota

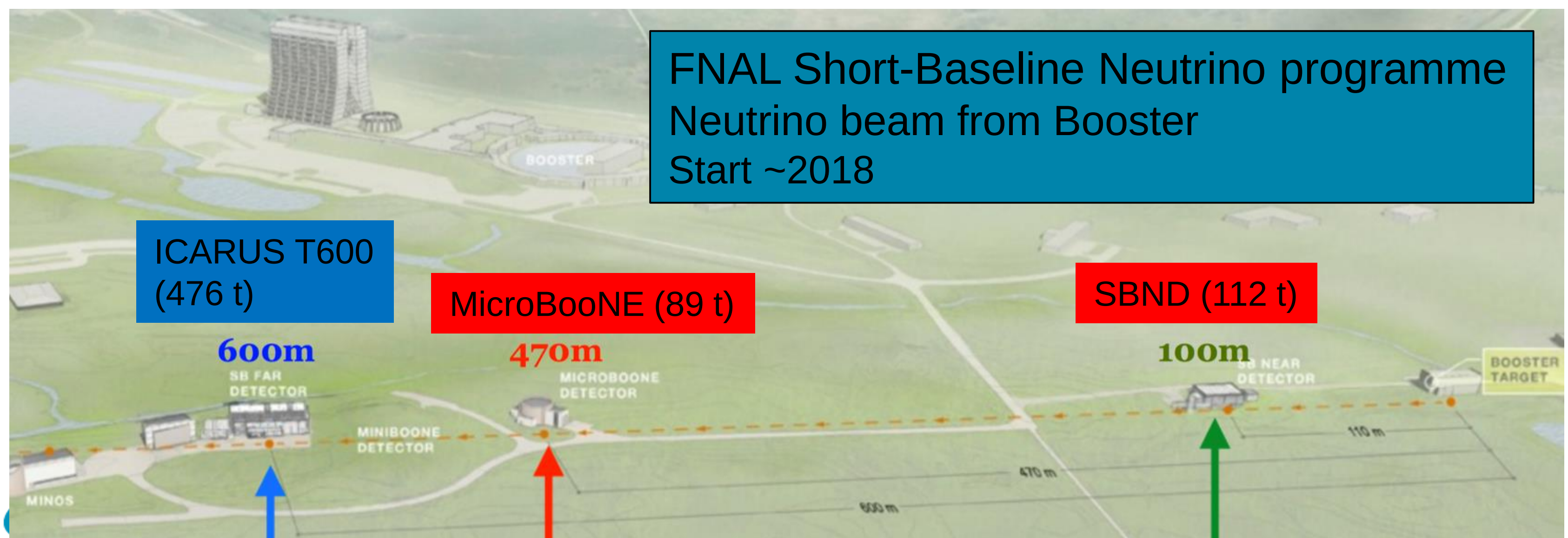


1.2 MW p beam, 60-120 GeV (PIP-II)
Wide-band ν beam 0.5-2.5 GeV



DUNE experiment:
4x10 kt LAr detectors
~1.5 km underground

Far site construction starts ~2017, 1st detector installed ~2022, beam from FNAL ~ 2026



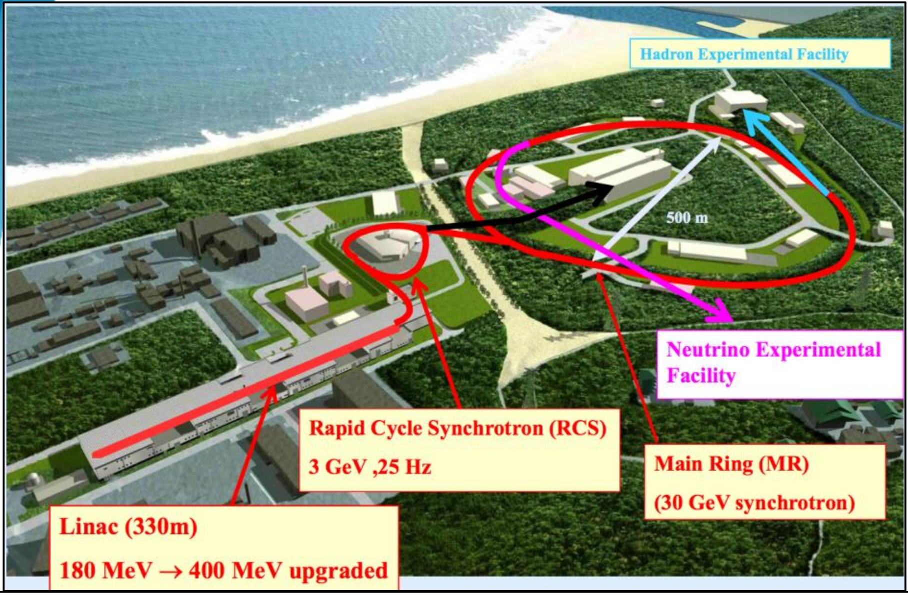
FNAL Short-Baseline Neutrino programme
Neutrino beam from Booster
Start ~2018

ICARUS T600 (476 t)

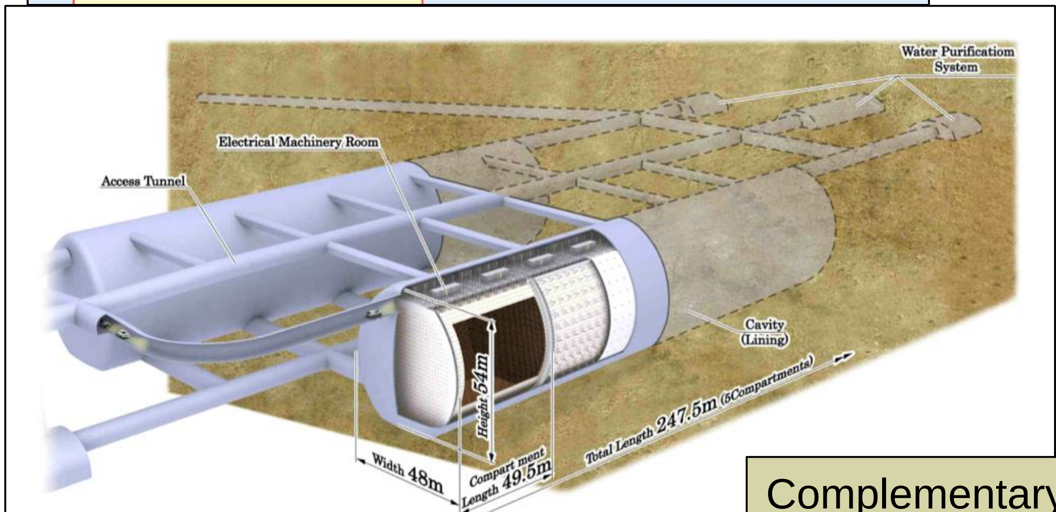
MicroBooNE (89 t)

SBND (112 t)

Hyper-Kamiokande, JPARC: construction could start ~2018



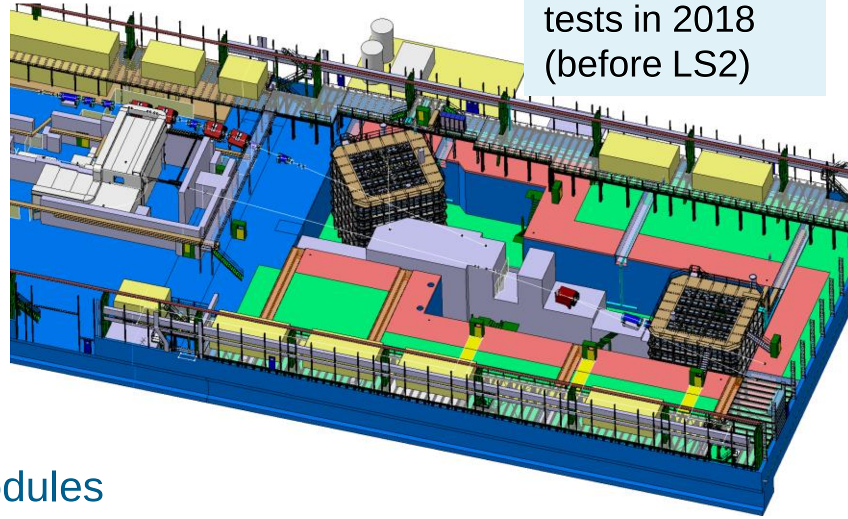
0.38 → 0.75 → > 1 MW p source
E_p = 30 GeV → E_ν~ 0.6 GeV
Narrow-band ν beam
→ high intensity at oscillation peak



~0.5 Mton Water Cerenkov detector (~20 x Super-K)
~ 1 km underground
~ 2.5^0 off-axis → narrow-band beam

Complementary to LBNE: different detector technology, shorter baseline (→ less sensitive to mass hierarchy), narrow-band beam (→ high statistics of ν/anti-ν at oscillation peak but limited measurement of oscillation spectrum)

CERN Neutrino Platform



ready for beam tests in 2018 (before LS2)

Mission:

- ❑ Provide charged beams and test space to neutrino community → North Area extension
- ❑ Support European participation in accelerator neutrino experiments in US and Japan:

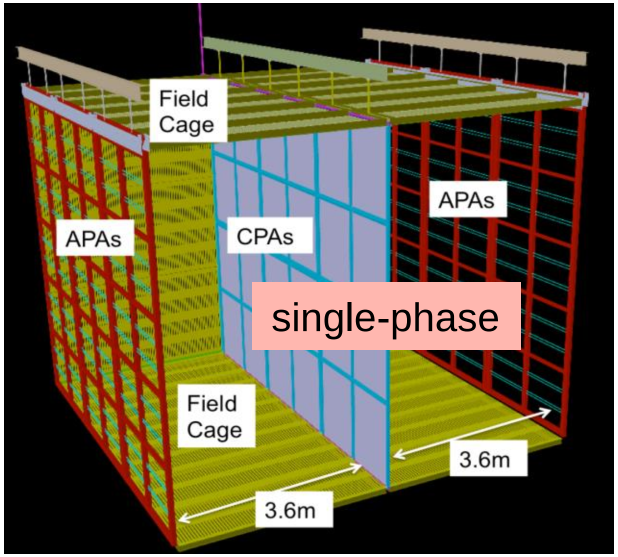
→ R&D to demonstrate large-scale LAr technology (cryostats, cryogenics, detectors)

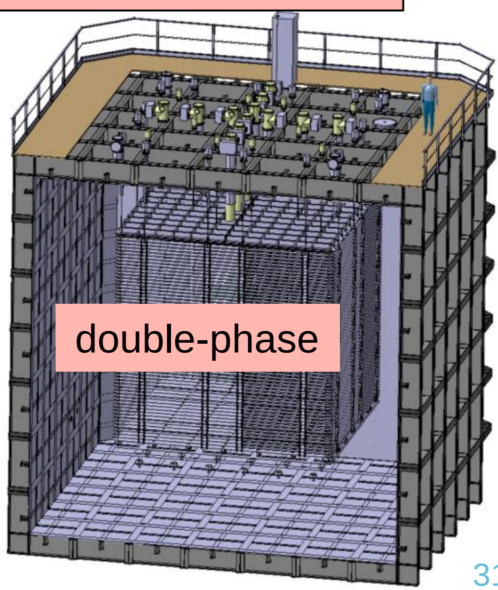
→ Construction of one cryostat for DUNE detector modules

→ Construction of BabyMIND magnet: muon spectrometer for WAGASCI experiment at JPARC

Refurbishment of ICARUS T600 for short baseline programme
→ ship to FNAL beg 2017

Construction and test of "full-scale" prototypes of DUNE drift cells: ~ 6x6x6 m^3, ~ 700 tons





FUTURO ….

¿¿Futuro??

Preparation of CERN’s future

FCC-hh: 100 TeV

- explore directly the 10-50 TeV E-scale
- provide conclusive exploration of EWSB dynamics
- study nature the Higgs potential and EW phase transition
- say final word about heavy WIMP dark matter
- etc.

FCC-ee: 90-350 GeV

- indirect sensitivity to E scales up to O(100 TeV) by measuring most Higgs couplings to O(0.1%), improving the precision of EW parameters measurements by ~20-200, $\Delta M_W < 1$ MeV, $\Delta m_{top} \sim 10$ MeV, etc.
- sensitivity to very-weakly coupled physics (e.g. light, weakly-coupled dark matter)
- etc.

FCC-ep: ~ 3.5 TeV

- unprecedented measurements of PDF and α_s
- new physics: leptoquarks, eeqq contact interactions, etc.
- Higgs couplings (e.g. Hbb to ~ 1%)
- etc.

Machines are complementary and synergetic, e.g. from measurement of ttH/ttZ ratio, and using ttZ coupling and H branching ratio from FCC-ee, FCC-hh can measure ttH to ~ 1%

Future opportunities other than high-energy colliders

A “Physics Beyond Colliders" Study Group has been put in place

Mandate
Explore opportunities offered by CERN accelerator complex and infrastructure to address outstanding questions in particle physics through projects:

- ❑ complementary to future high-energy colliders (HE-LHC, CLIC, FCC)
- ❑ exploiting unique capabilities of CERN accelerator complex and infrastructure
- ❑ complementary to other efforts in the world → optimise resources of the discipline globally

Examples: searches for rare processes and very-weakly interacting particles, electric dipole moments, etc.

→ Enrich and diversify CERN’s future scientific programme

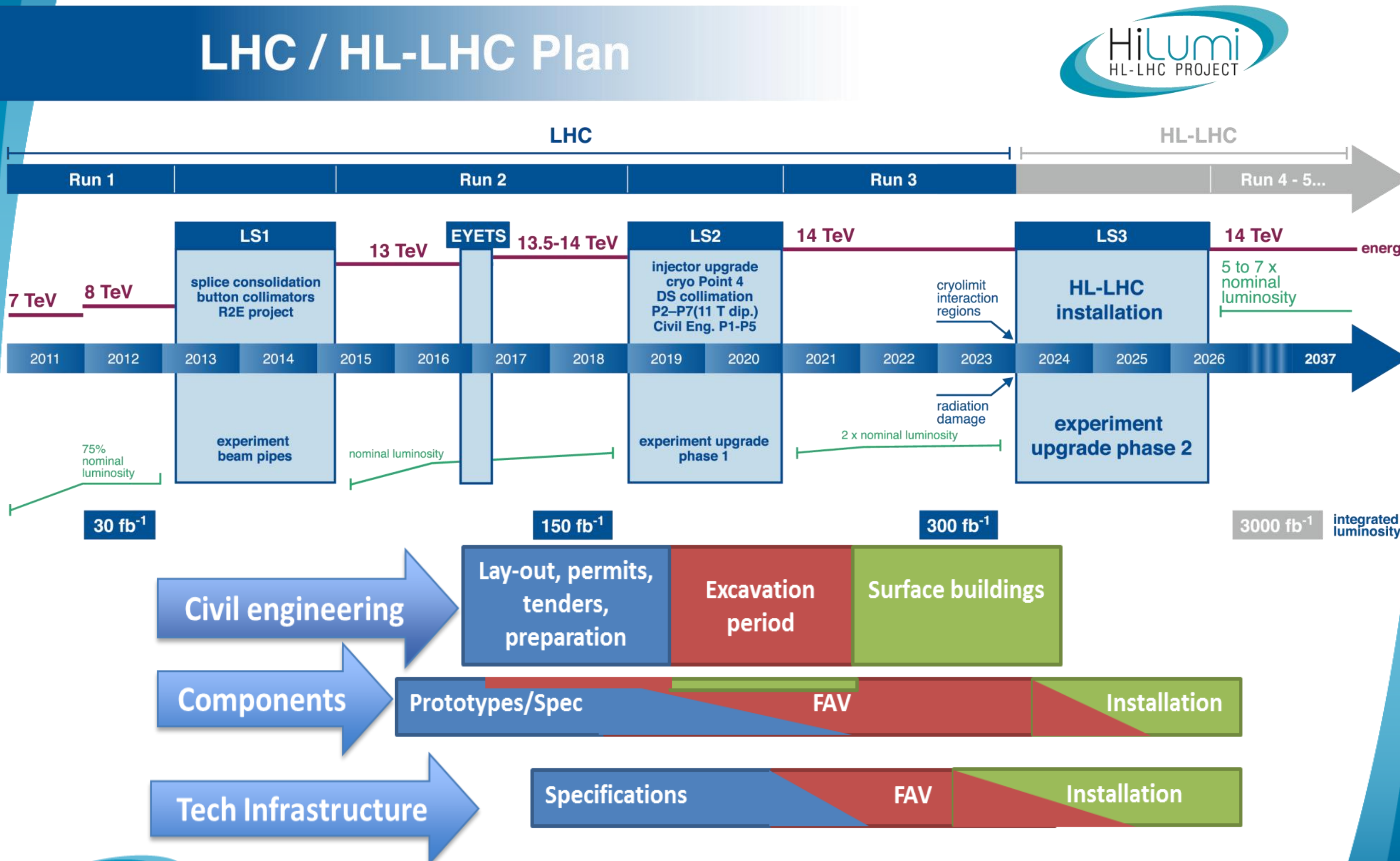
- ❑ Will bring together accelerator scientists, experimental and theoretical physicists
- ❑ Kick-off meeting in Summer 2016
- ❑ Final report end 2018 → in time for European Strategy

One of the goals is to involve interested worldwide community, and to create synergies with other laboratories and institutions in Europe (and beyond)

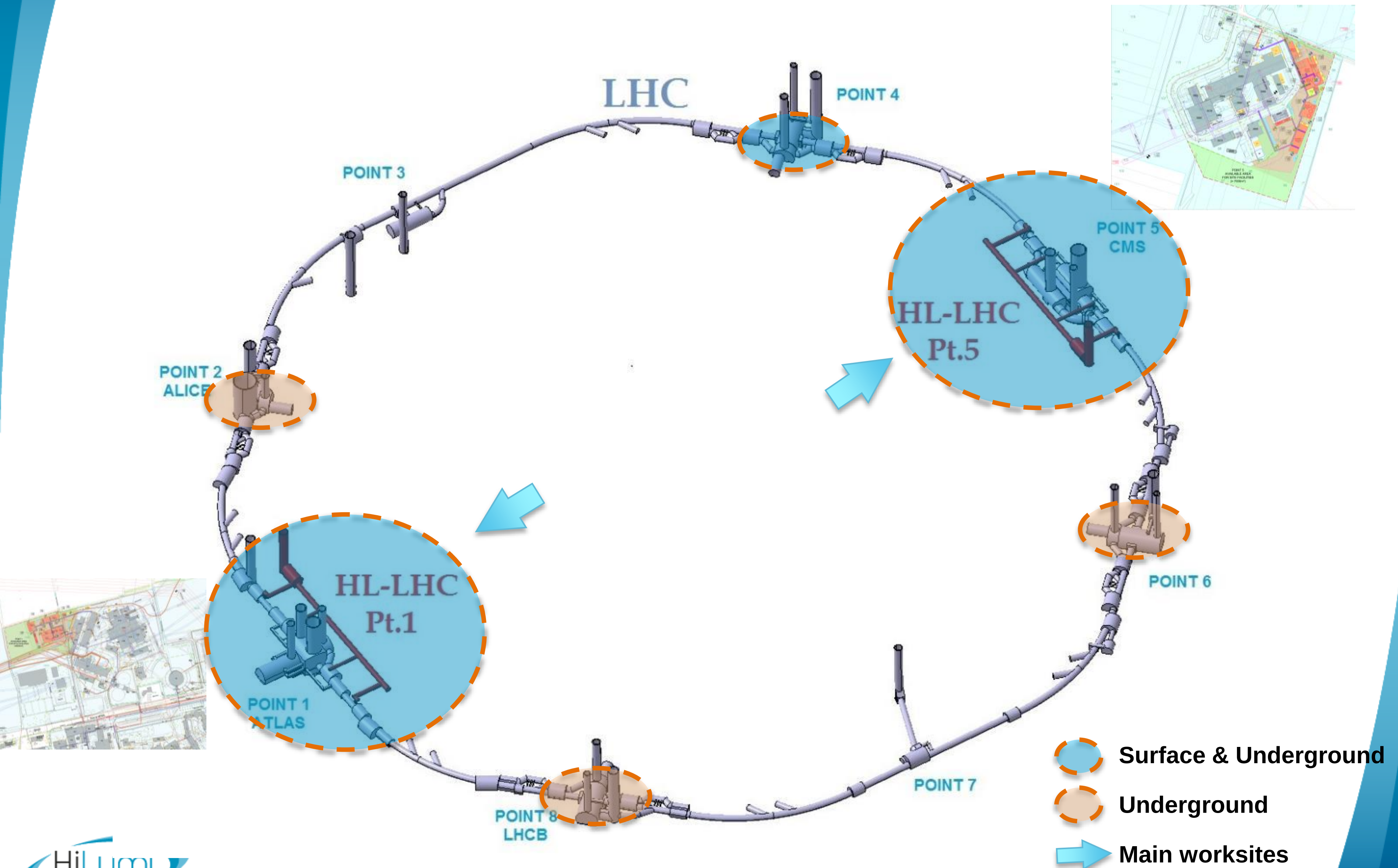
PRESENTE ….

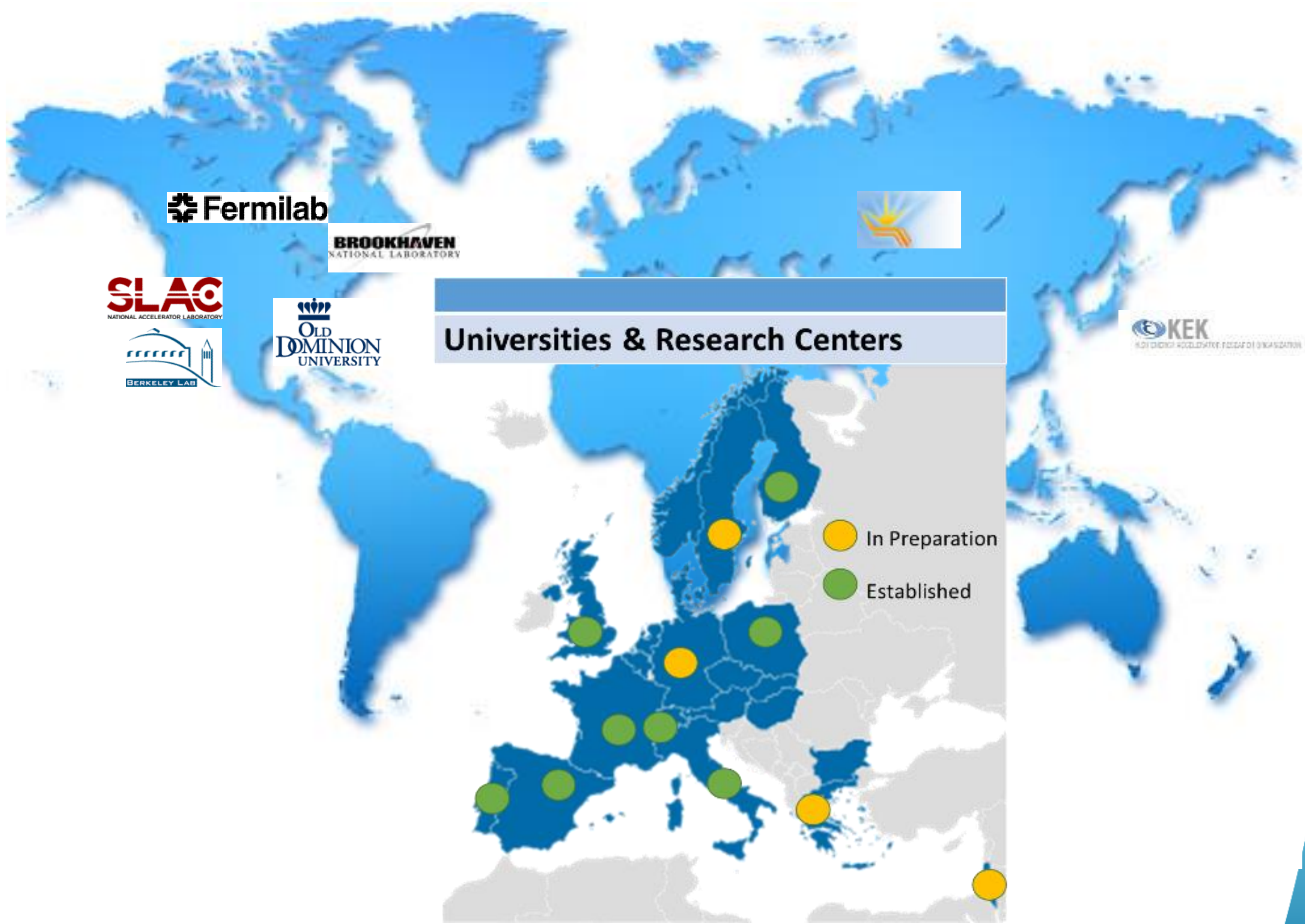
¿¿Presente??

Unas pinceladas sobre HL-LHC

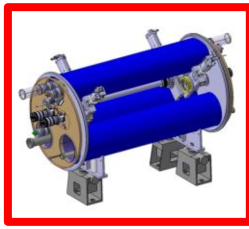


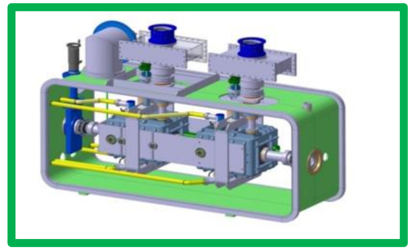
Many points around the ring

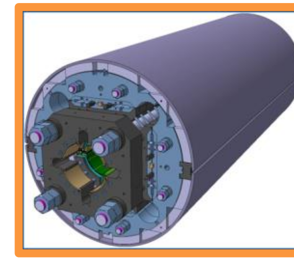


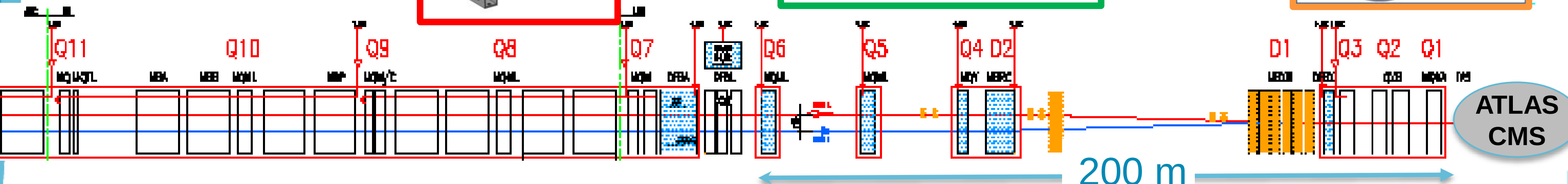

Fermilab
BROOKHAVEN
NATIONAL LABORATORY
SLAC
NATIONAL ACCELERATOR LABORATORY
BERKELEY LAB
OLD DOMINION UNIVERSITY
KEK
Universities & Research Centers
In Preparation
Established

The largest HEP accelerator in construction









Dispersion Suppressor (DS)

Modifications

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

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

Matching Section (MS)

Complete change and new lay-out

1. TAN
2. D2
3. CC
4. Q4
5. All correctors
6. Q5
7. New MQ in P6
8. New collimators

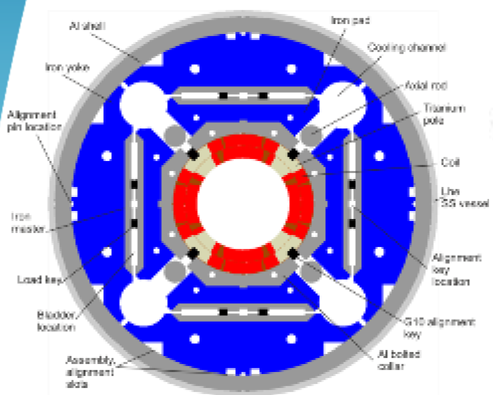
Interaction Region (ITR)

Complete change and new lay-out

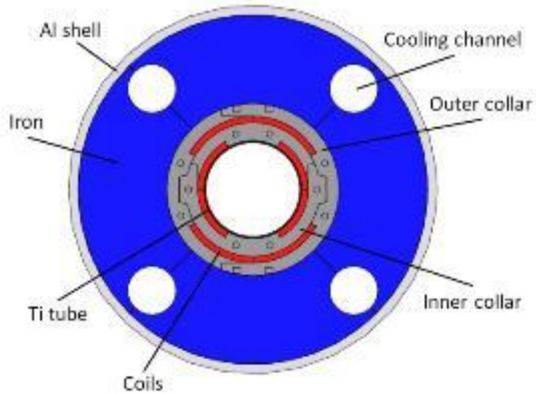
1. TAXS
2. Q1-Q2-Q3
3. D1
4. All correctors
5. Heavy shielding (W)

> 1.2 km of LHC

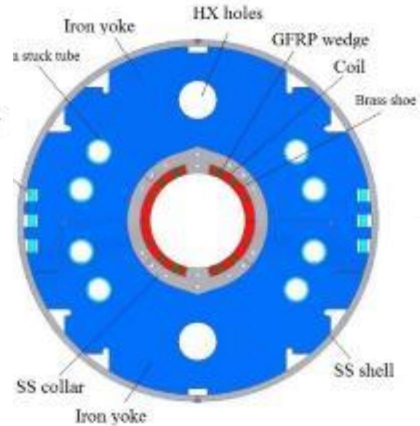
HiLumi LHC magnet zoo



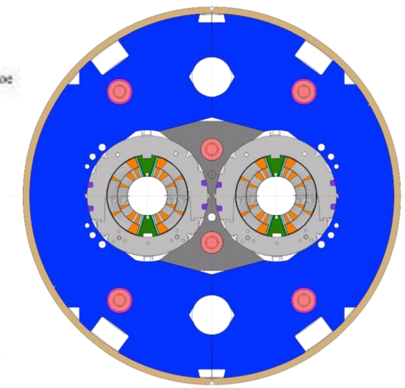
Triplet QXF (LARP and CERN)



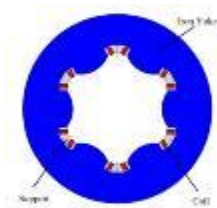
Orbit corrector (CIEMAT)



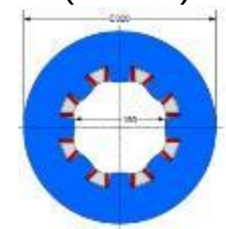
Separation dipole D1 (KEK)



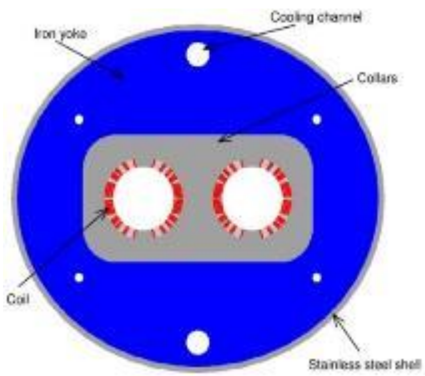
11 T dipole (CERN)



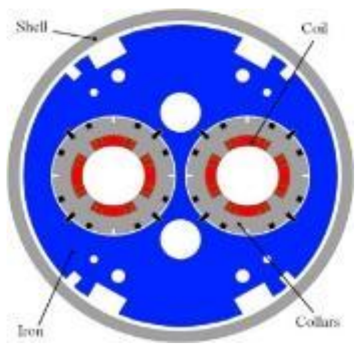
Sextupole (INFN)



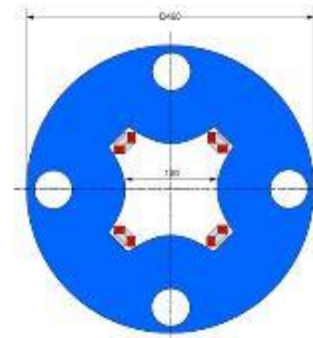
Octupole (INFN)



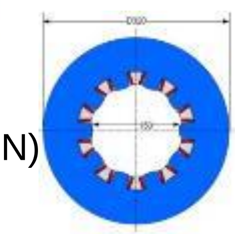
Recombination dipole D2
(INFN design)



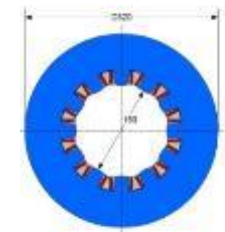
Q4 (CEA)



Skew quadrupole (INFN)



Decapole (INFN)

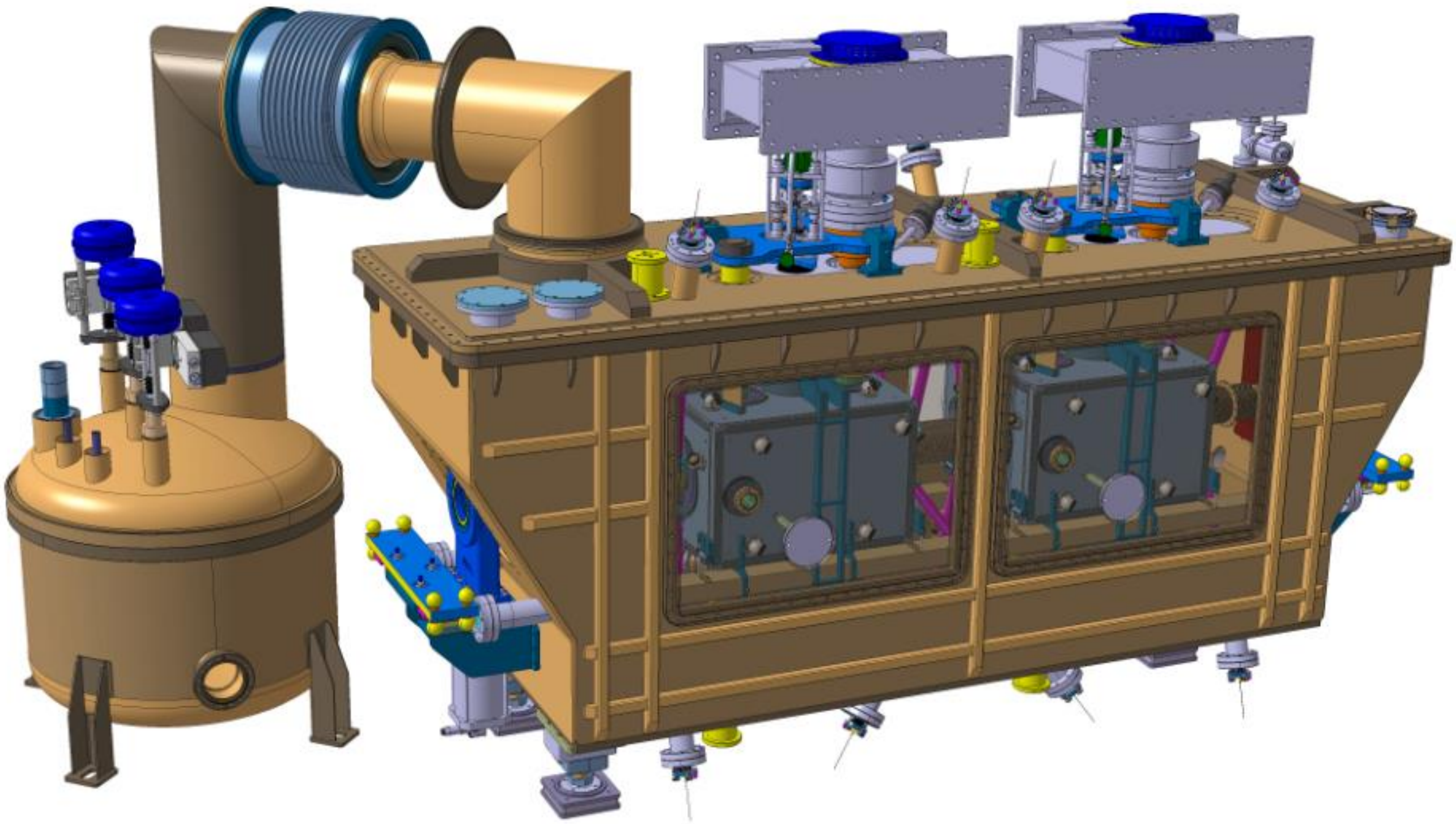


Dodecapole (INFN

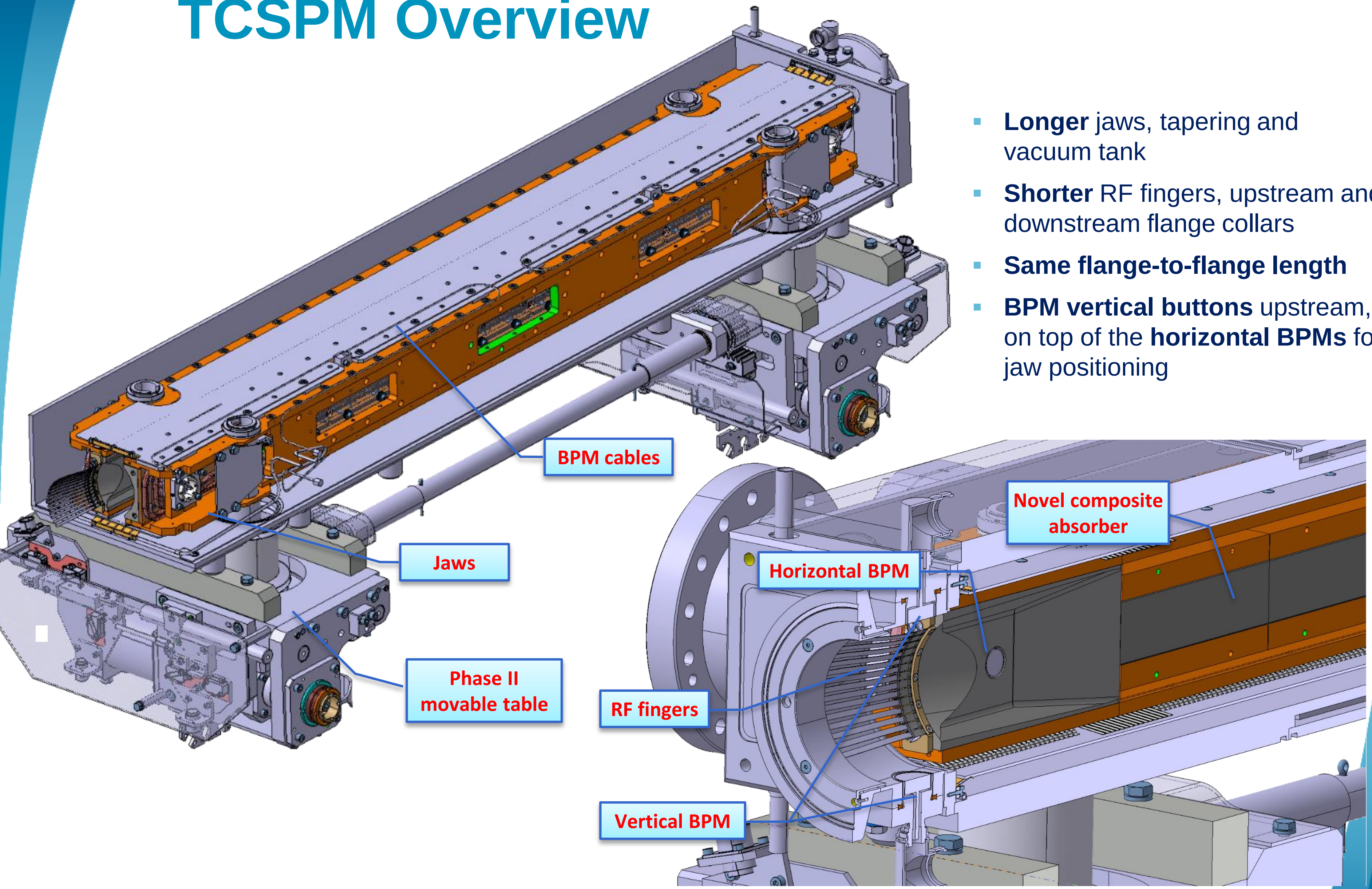
Overall, about 150 magnets are needed

SPS Cryomodule:
Include 2 identical cavities

Double Quarter

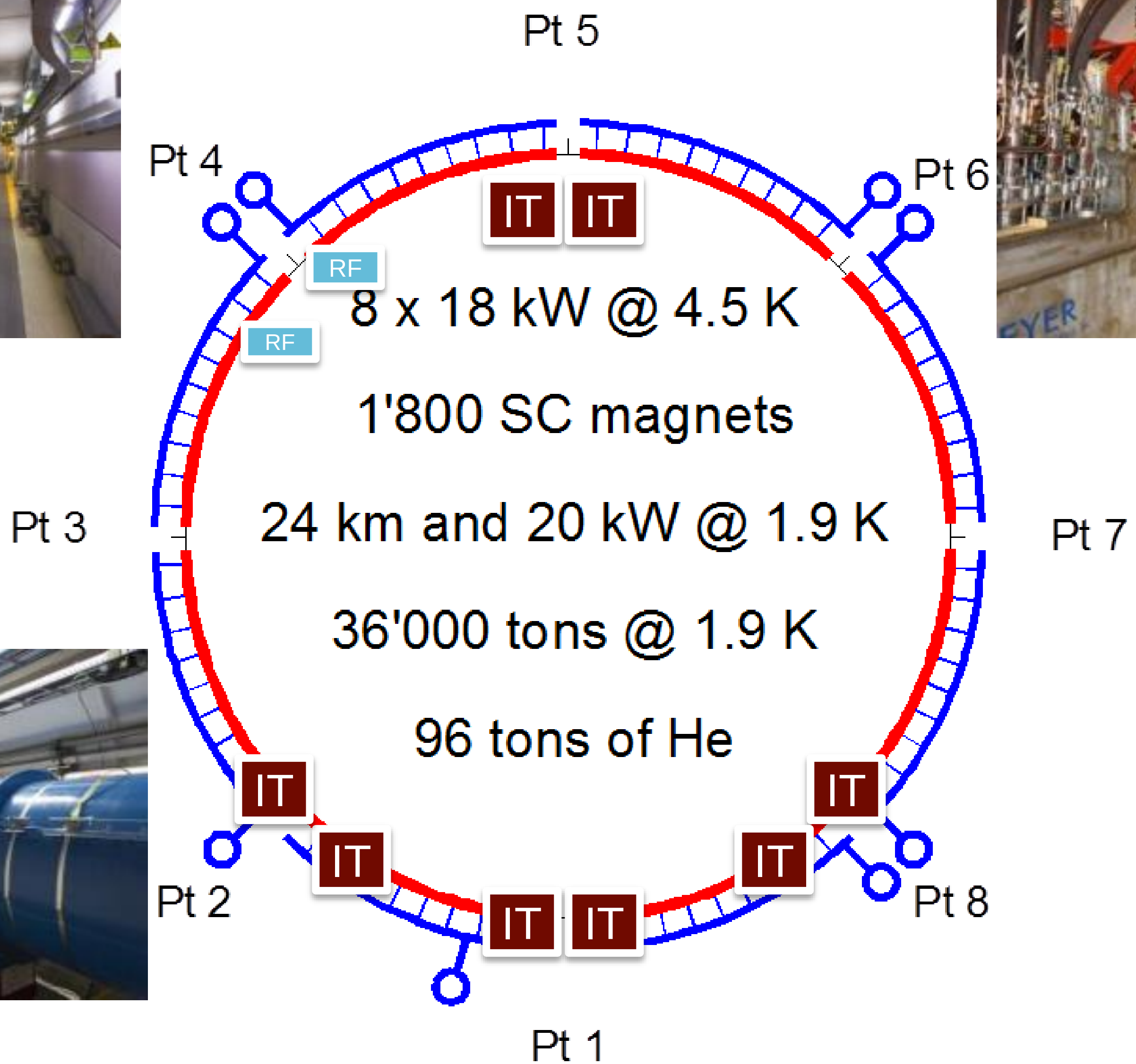


TCSPM Overview



- **Longer** jaws, tapering and vacuum tank
- **Shorter** RF fingers, upstream and downstream flange collars
- **Same flange-to-flange length**
- **BPM vertical buttons** upstream, on top of the **horizontal BPMs** for jaw positioning

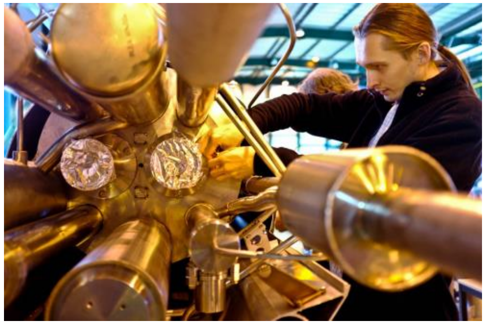
Eliminating Technical bottlenecks

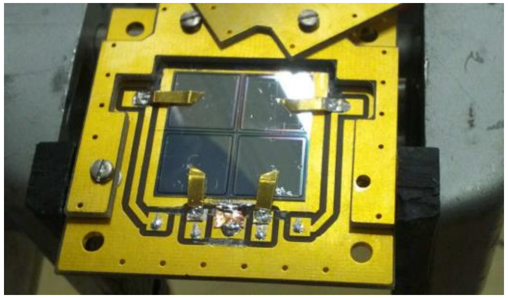


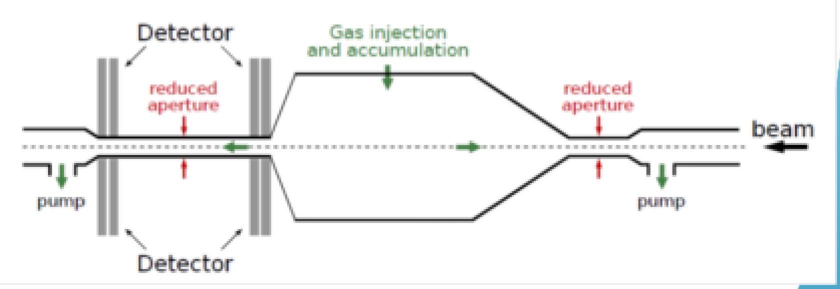
Cryogenic plant

Beam diagnostic improvement

- Cryogenic BLMs & Radiation Hard Electronics
  - Cryogenic BLMs
  - Radiation hard electronics
- Fast WireScanners
- Insertion Region BPMs
  - Cold directional couplers
  - Tungsten shielded cold directional couplers
  - Warm directional couplers
  - High precision electronics for insertion region BPMs
- Luminosity Monitors
- Diagnostics for Crab Cavities
- Upgrade to Synchrotron Light Monitors
  - Upgrade to existing monitor
  - New light source
  - Halo diagnostics
- Beam Gas Vertex Detector
  - Final Implementation
- Long-Range Beam-Beam Compensator
  - Prototype
  - Final Implementation

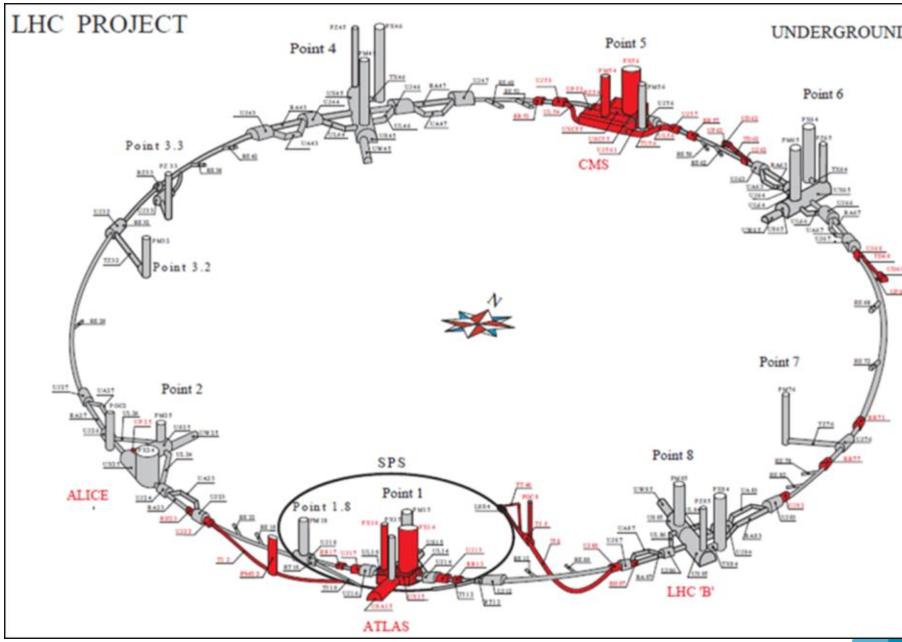






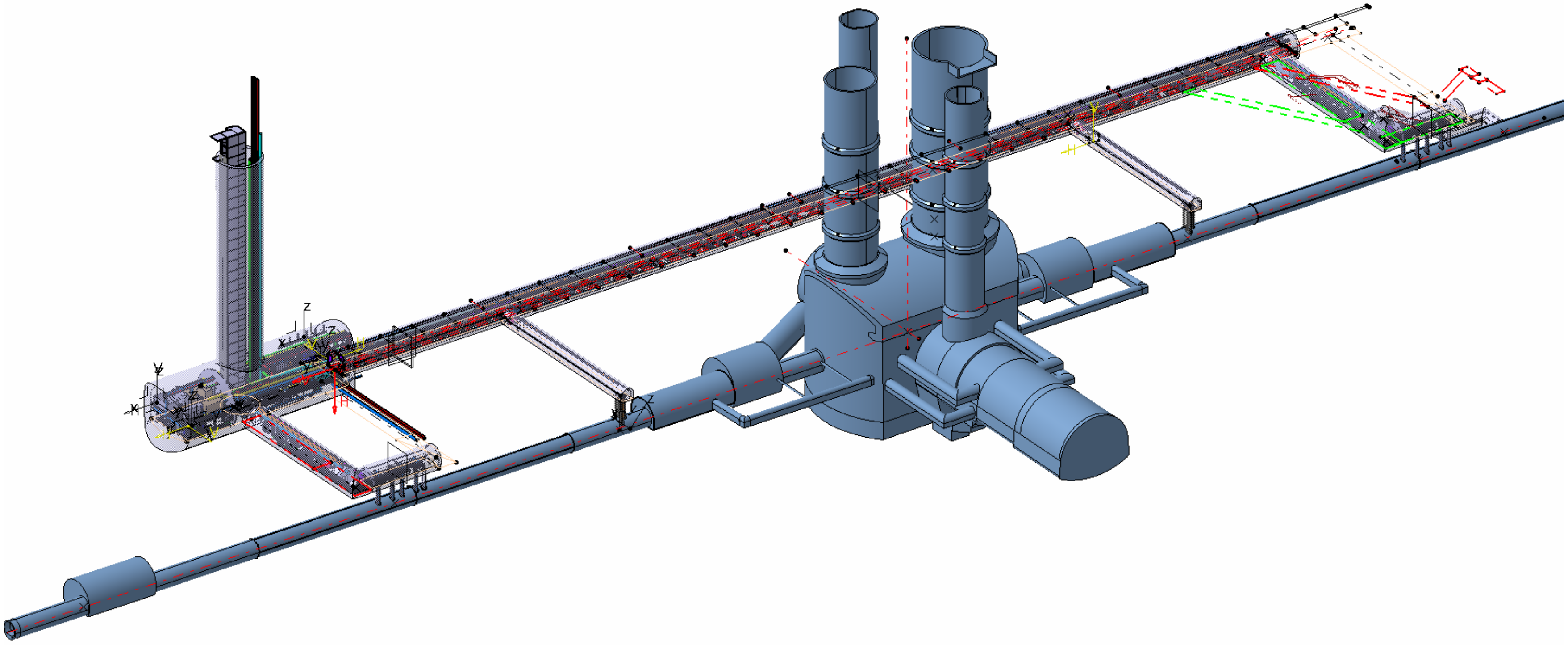
And many other improvements

- **Machine protection:** improved robustness to mis-injected beams, to kickers sparks will be required. The kicker system, collimation and TDI, is the main shield against severe beam induced damage.
- **Quench Protection System** of SC magnets to remake a 20 years old design.
- **Remote manipulation:** the level of activation around 2020 requires development of special equipment to allow replacing/servicing collimators, magnets, vacuum components etc., according to ALARA principle. Remote manipulation, enhanced reality and supervision is the key to minimizing the radiation doses sustained during interventions.



- **Vacuum** …

Point 1 Civil Engineering underground



Y si el futuro es la física de partículas sin aceleradores….

Gracias a todos los que trabajan y aportan su granito de arena para resolver los misterios que nos entornan

Gracias a aquellos que contribuyen para que nuestro trabajo sea posible

Gracias a todos los que son curiosos y despiertan la curiosidad en los que les rodean