# CERN Report

Fabiola Gianotti, Plenary ECFA, CERN, 24/11/2016

# Outline

Some selected news since the July Plenary ECFA out of a large number of activities and accomplishments

- Scientific programme
- Geographical enlargement
- Toward an Alumni programme

# CERN scientific strategy: 3 main pillars

Full exploitation of the LHC:

- ❑ successful operation of the nominalLHC (Run 2, LS2, Run 3)
- ❑ construction and installation of LHC upgrades: LIU and HL-LHC

Scientific diversity programme serving a broad community:

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

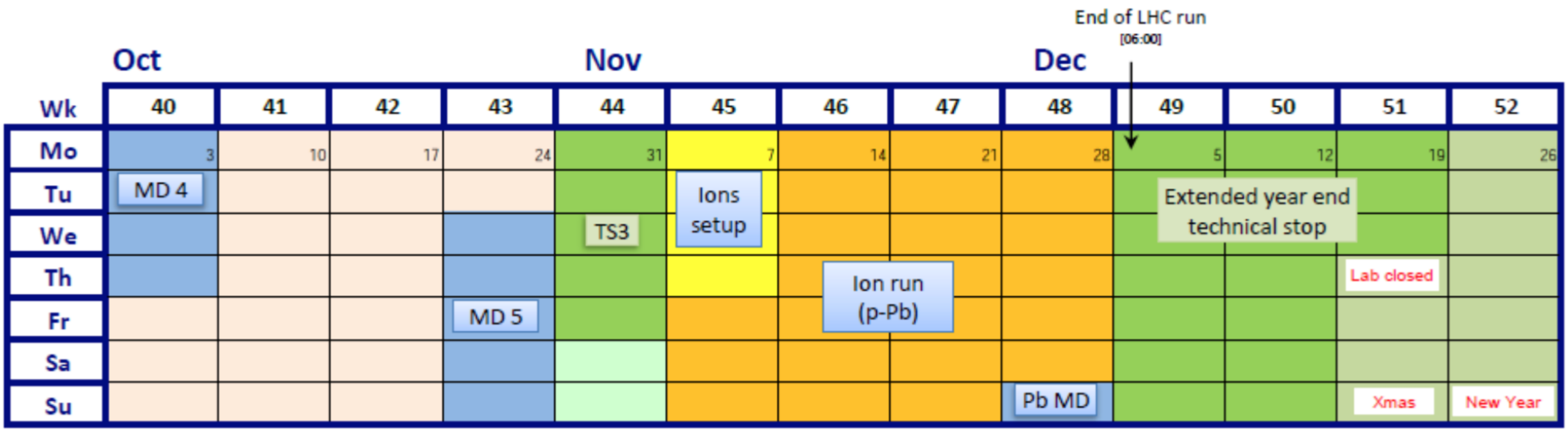
Preparation of CERN's future:

- ❑ 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 of diversity programme (new): "Physics Beyond Colliders" Study Group

Important milestone: update of the European Strategy for Particle Physics (ESPP): ~ 2019-2020

Here: one-two examples per topic

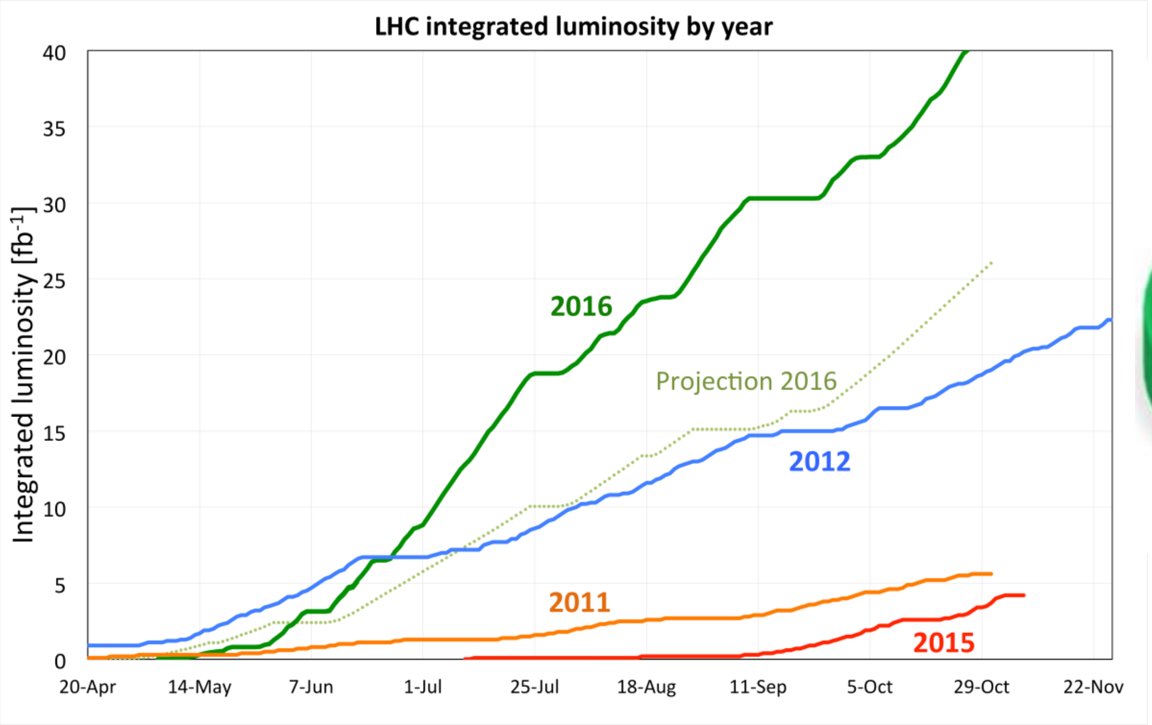
# Superb performance of the LHC in 2016

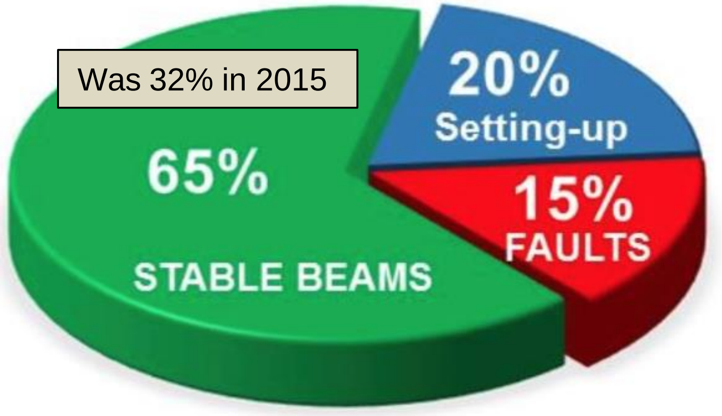



- ❑ proton run ended 25 October
- ❑ now Pb-p run until 4 December
- ❑ then 2 weeks of dipole training to 7 TeV (S34 and S45) before Christmas closure

# Superb performance of the LHC in 2016: pp run

- ❑ Achieved peak luminosity: ~ 1.4 x $10^{34}$ $cm^{-2}$ $s^{-1}$ → beyond design value
  Note: in spite of operation at 13 TeV and of beam intensity limitations from the SPS beam dump and one of the LHC injection kickers
- ❑ Total integrated luminosity in 2016: ~ 40 $fb^{-1}$ to ATLAS and CMS, 1.9 $fb^{-1}$ to LHCb

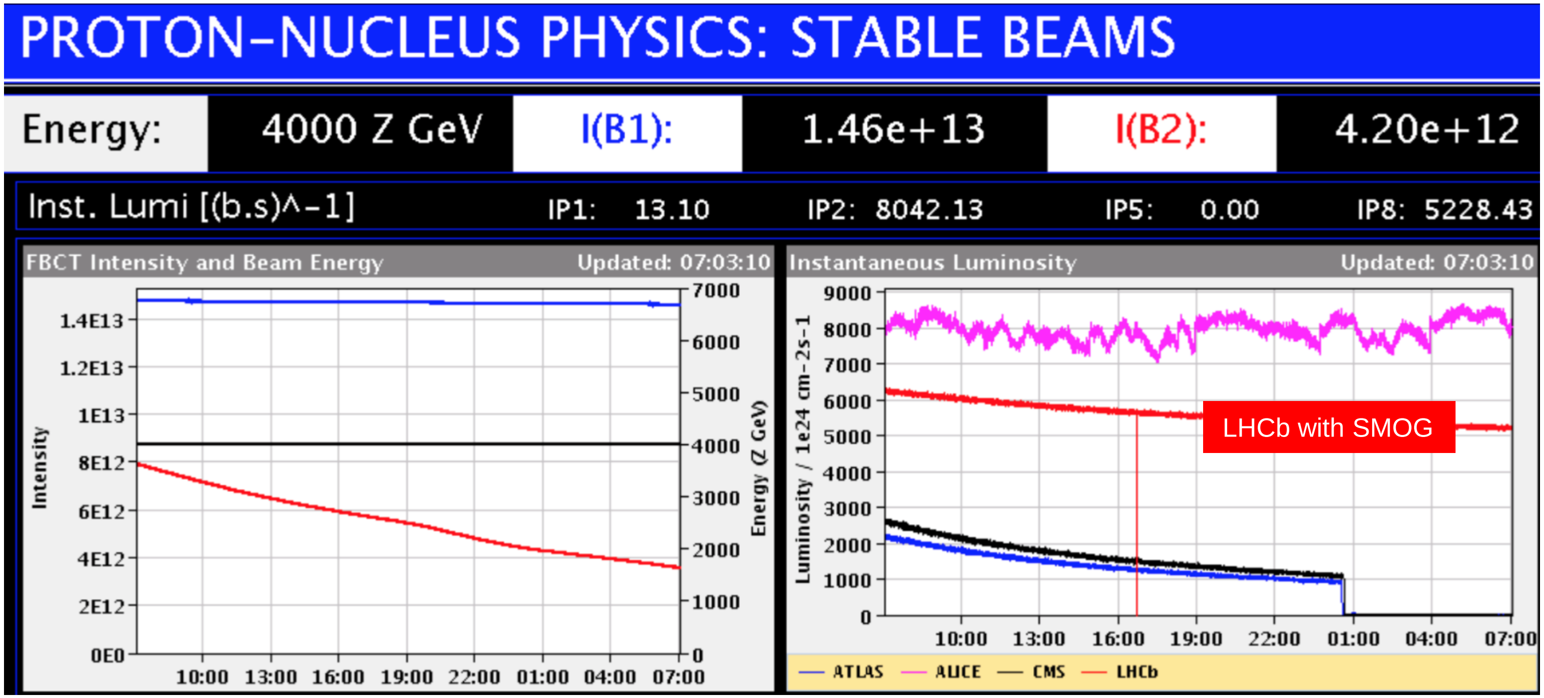



Experiments and computing also running very efficiently → many beautiful physics results produced quickly and presented at ICHEP 2016 in August in Chicago

# Superb performance of the LHC in 2016: p-Pb run

Part 1: 6-15 November:
E = 4 Z TeV (Z=1, 82) → $\sqrt{s_{NN}} \simeq 5$ TeV → as in 2013 p-Pb and 2015 Pb-Pb runs
Asked by ALICE for high-stat studies of collective effects (e.g. charm azimuth asymmetry) at low $p_T$
→ Goal was max lumi to ALICE: $L = 8 \times 10^{27}$ (separated beams in ATLAS and CMS to increase lifetime)



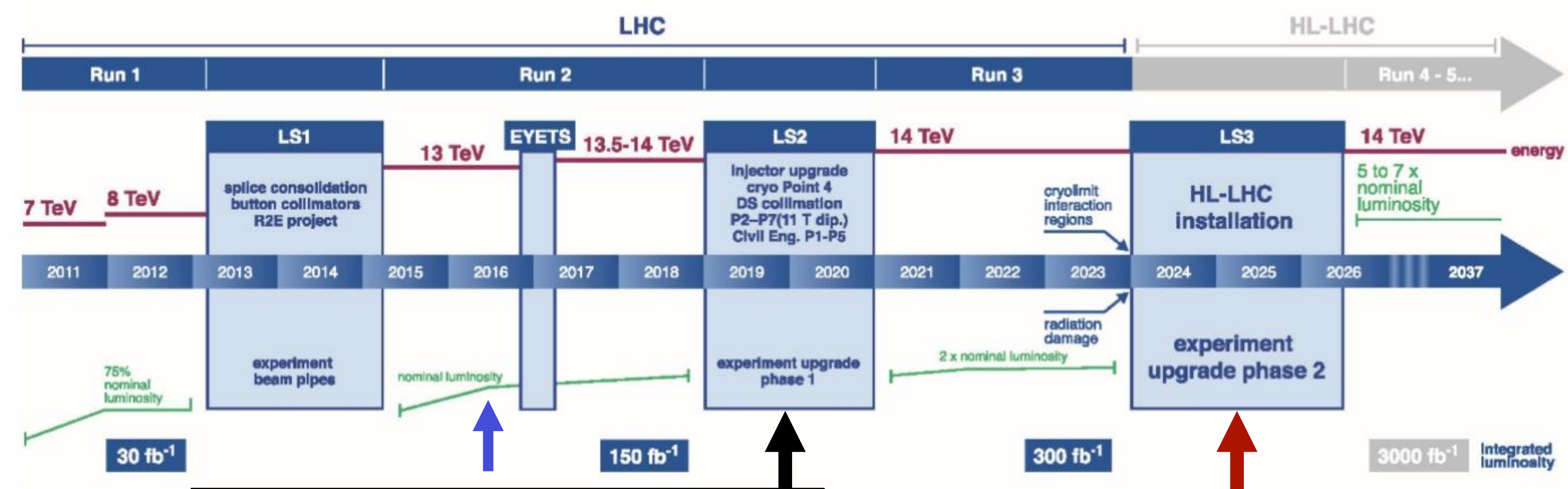

Higher intensity than expected from injectors, very long fills

Part 2: 16 November-4 December:
E = 6.5 Z TeV → $\sqrt{s_{NN}} \simeq 8.2$ TeV → max energy and luminosity
$L = 6 \times 10^{29}$ ATLAS and CMS → x 6 design value
> 65/nb to ATLAS and CMS, > 12/nb to ALICE and LHCb so far
Beam reversal p ↔ Pb tomorrow, e.g. for charmonium suppression studies in ALICE

# HL-LHC parameters, timeline and news

Nominal LHC: $\sqrt{s}$ = 14 TeV, L= $1 \times 10^{34}$ $cm^{-2}$ $s^{-1}$
Integrated luminosity to ATLAS and CMS: 300 $fb^{-1}$ by 2023 (end of Run-3)

**HL-LHC: $\sqrt{s}$ = 14 TeV, L= $5 \times 10^{34}$ $cm^{-2}$ $s^{-1}$ (levelled)**
**Integrated luminosity to ATLAS and CMS: 3000 $fb^{-1}$ by ~ 2035**

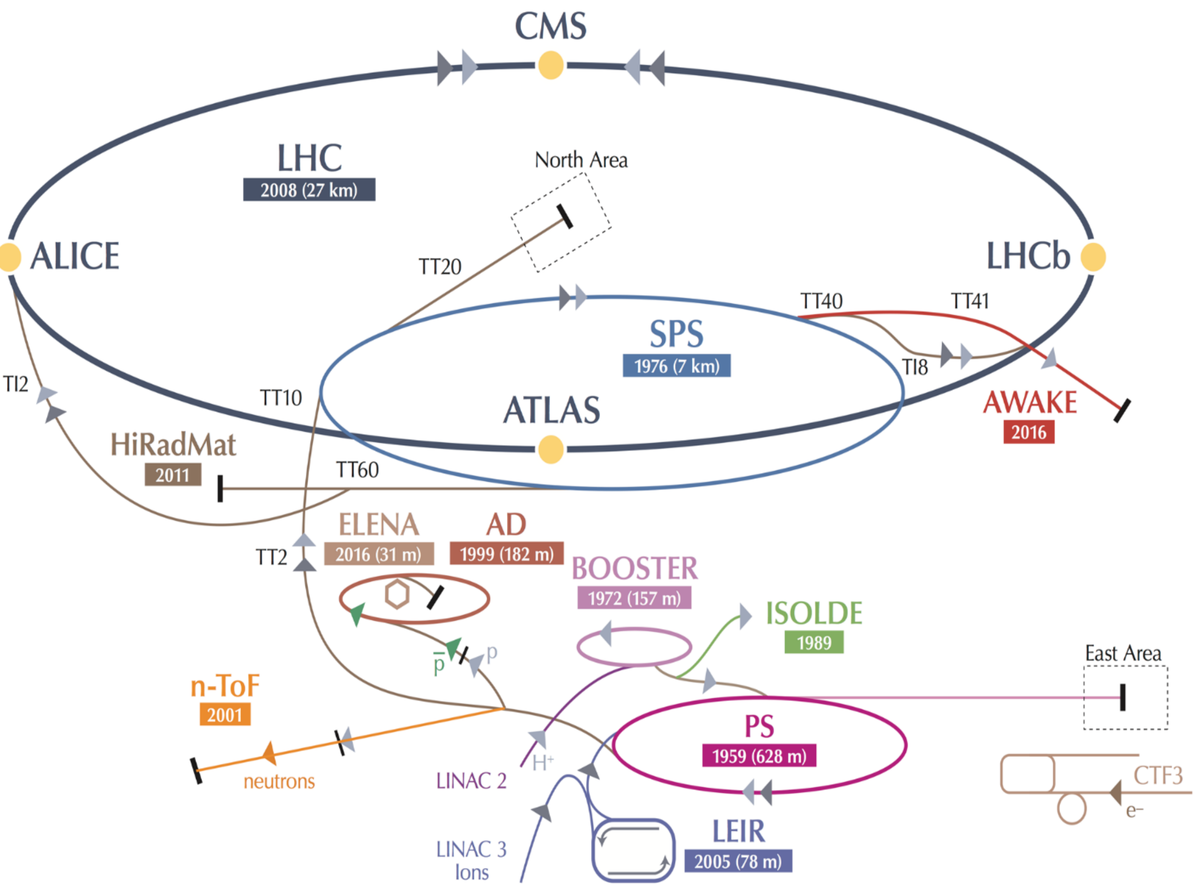



LS2 (2019-2020):
- ❑ LHC Injectors Upgrade (LIU)
- ❑ Phase-1 upgrade of LHC experiments

LS3 (2024-2026):
- ❑ **HL-LHC installation**
- ❑ Phase-2 upgrade of ATLAS and CMS

- ❑ LINAC4 reached design energy of 160 MeV end October
- ❑ September 2016: Council approved a credit facility with the European Investment Bank to address cash shortage in the peak years of HL-LHC construction (2018-2025)
- ❑ Very successful ECFA High-Luminosity LHC Experiments Workshop 3-6 Oct → report tomorrow
- ❑ 2nd LIU and HL-LHC Cost&Schedule Review 18-20 October

# CERN's scientific diversity programme




Exploits unique capabilities of CERN's accelerator complex; complementary to other efforts in the world.

~20 experiments, > 1200 physicists

**AD:** Antiproton Decelerator for antimatter studies

**AWAKE**: proton-induced plasma wakefield acceleration

**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**: heavy ions and neutrino targets

**NA62**: rare kaon decays

**NA63**: radiation processes in strong EM fields

**NA64**: search for dark photons

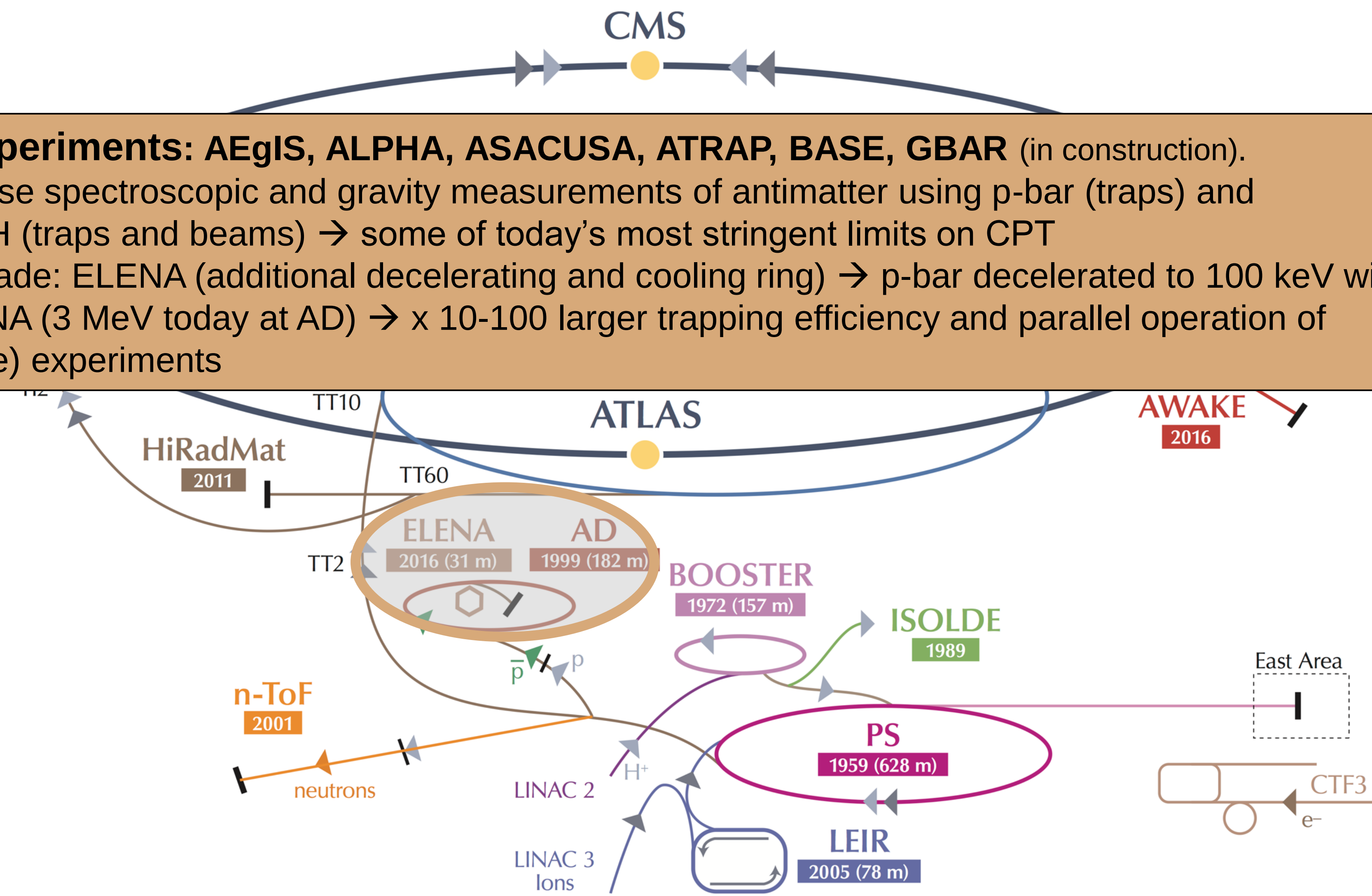
**Neutrino Platform:** **ν** detectors R&D for experiments in US, Japan

**n-TOF:** n-induced cross-sections

**UA9**: crystal collimation

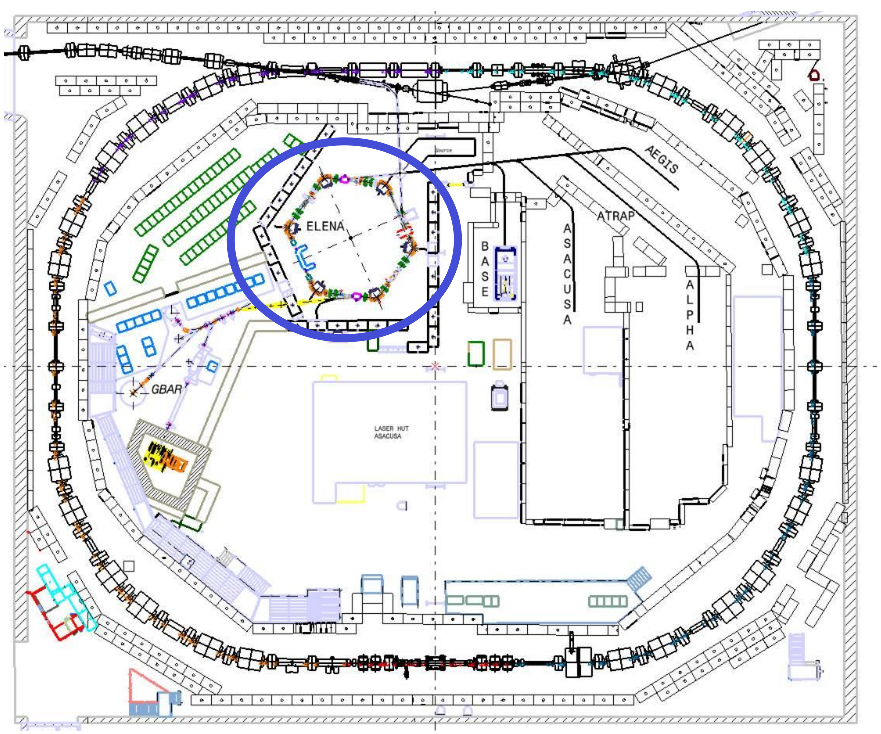
# Antiproton Decelerator and its upgrade (ELENA)

**6 experiments: AEgIS, ALPHA, ASACUSA, ATRAP, BASE, GBAR** (in construction).
Precise spectroscopic and gravity measurements of antimatter using p-bar (traps) and anti-H (traps and beams) → some of today's most stringent limits on CPT
Upgrade: ELENA (additional decelerating and cooling ring) → p-bar decelerated to 100 keV with ELENA (3 MeV today at AD) → x 10-100 larger trapping efficiency and parallel operation of (more) experiments



# Antiproton Decelerator and its upgrade (ELENA)

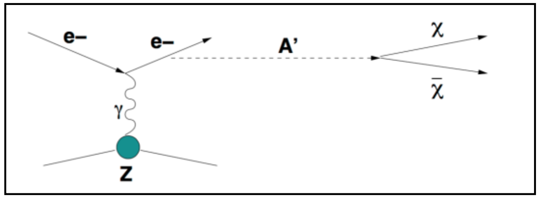
ELENA hardware and beam commissioning started

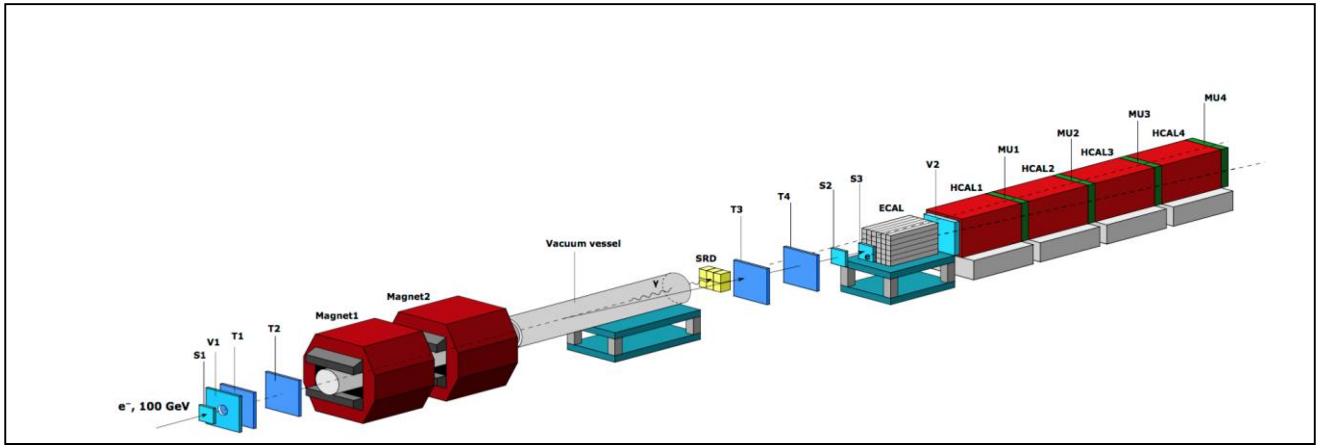


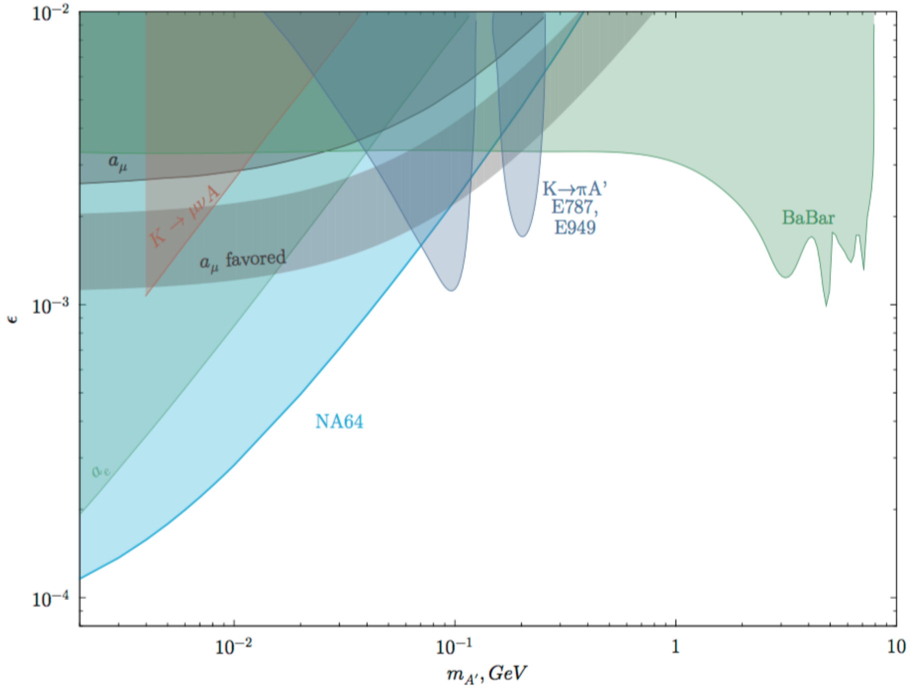

ELENA commissioning started.
Experiments will be connected in LS2

# First results of the NA64 experiment

Use 100 GeV $e^-$ from SPS to look for dark sector photons (A') decaying invisibly (e.g. into light dark-matter particles)




Preliminary results from 4 weeks of data-taking in 2016 (~ $3\times10^9$ $e^-$ on target)

$$-\frac{1}{2}\epsilon F_{\mu\nu} A'^{\mu\nu}$$

# "Physics Beyond Colliders" Study Group established in March 2016

**Mandate**
Explore opportunities offered by the (very rich) CERN accelerator complex to address outstanding questions in particle physics through projects:

- ❑ complementary to high-energy colliders (HL-LHC, HE-LHC, CLIC, FCC, etc.)
  → we know there is new physics, we don't know where it is → we need to be as broad as possible in our exploratory approach

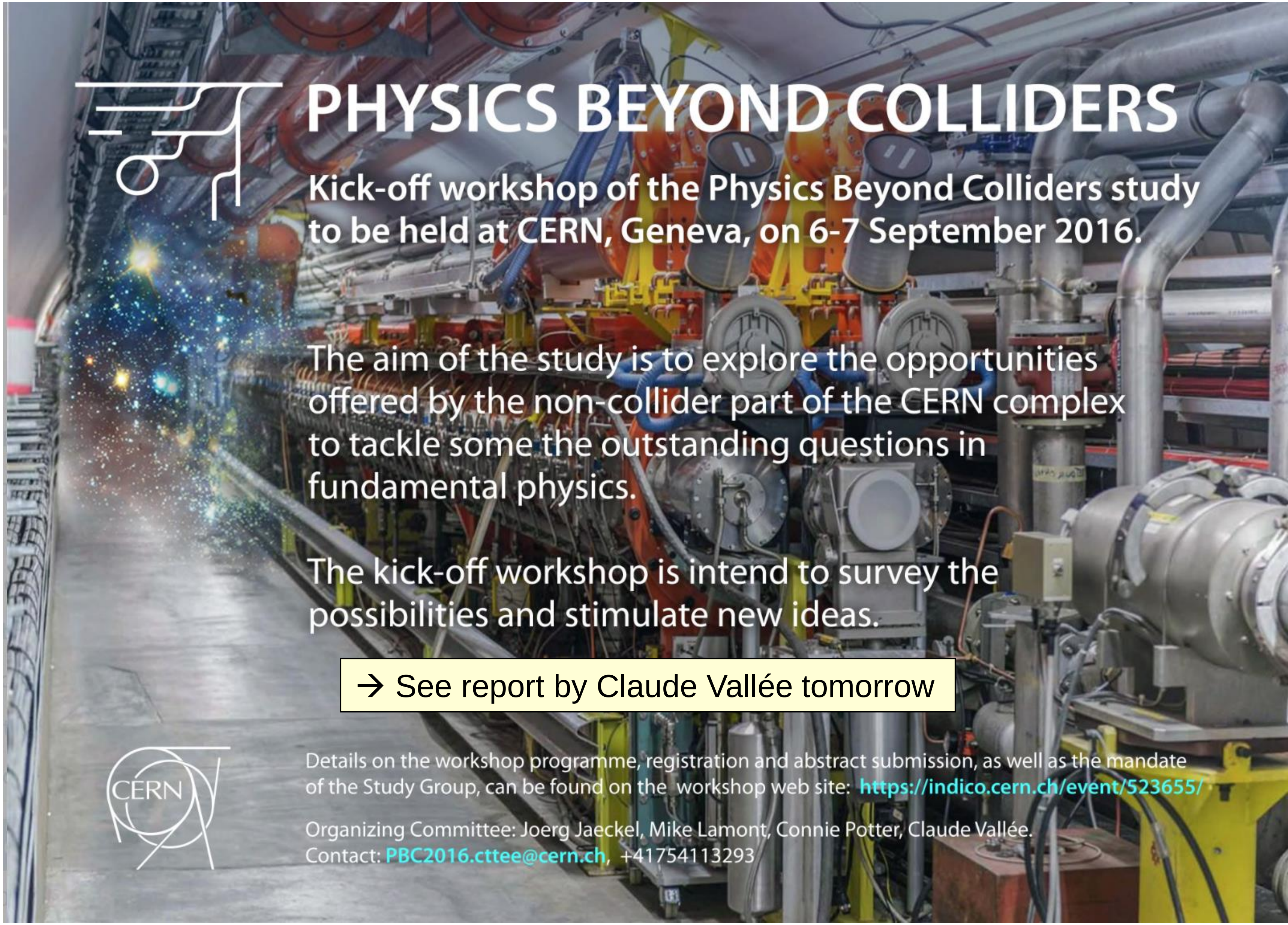
- ❑ exploiting the unique capabilities of CERN accelerator complex and infrastructure and complementary to other efforts in the world:
  → optimise the resources of the discipline globally

Report by end 2018 → in time for update of European Strategy

Goal is also to enrich and diversify CERN's future scientific programme.
Study Group will involve interested worldwide community, and create synergies with other laboratories and institutions in Europe (and beyond).

Overall coordinators: Joerg Jaeckel (Heidelberg; theory), Mike Lamont (CERN; accelerator), Claude Vallée (CPPM and DESY; experimental physics)

# 6-7 September 2016: kick-off meeting




→ See report by Claude Vallée tomorrow

# Geographical enlargement

CERN geographical enlargement approved by Council in June 2010.

"Main goal: adapting Membership policy to increasing globalisation of science and to the needs for global financing of future particle physics projects"

**Since 2010**

2 New Member States:
Israel (2014)
Romania (2016, which joined with pre-2010 accession rules)

2 Associate Member States in pre-stage to Membership:
Serbia (2012), Cyprus (2016)

3 Associate Member States:
Pakistan (2015), Turkey (2015), Ukraine (2016)
Soon India (agreement signed on 21 October, now waiting for final ratification)

Romania's flag-raising ceremony, 5/9/2016

Countries with applications in progress (at different level of advancement):
Slovenia, Russia, Brazil, Lithuania, Croatia, Ireland

Observers to Council (status now phasing out for countries):
India, Japan, Russia, USA, EU, JINR, UNESCO

In addition: ~50 ICA with Non-Member States; many MoU of countries with experiments/projects

**Goals include:**

- Offer opportunity to former CERN personnel (staff, fellows, associates, users, …) to stay connected and engaged with CERN, through strong links and involvement in a variety of CERN-related activities
- Create a community and network of "ambassadors" propagating the core values of CERN: importance of fundamental research, peaceful collaboration, open science, impact on society (in particular though Alumni's (successful!) careers in various fields)
- Provide help and guidance to the younger generations, in particular young people looking for jobs outside research.

**Project team in place**: collecting requirements, defining content of the programme, developing tools (software, database, web-based platform), etc.

**Kick-off event** likely in January 2018 (to be able to offer visits to underground installations)

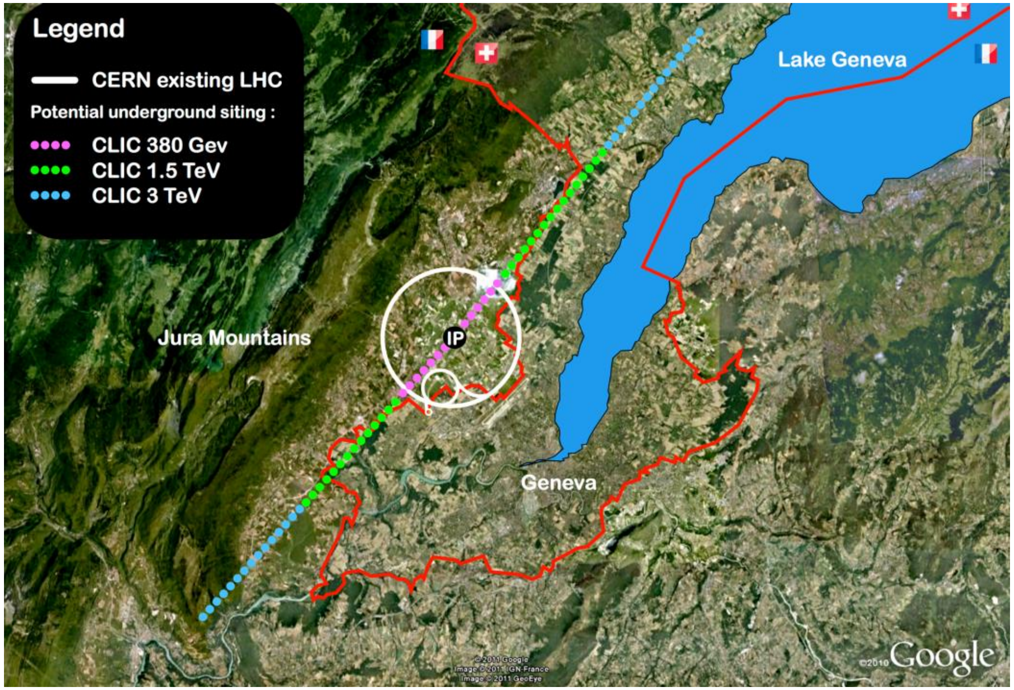

THANK YOU!
LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
ALICE
CMS
LHC 27 km

EXTRA

# Compact Linear Collider (CLIC)

Linear $e^+e^-$ collider $\sqrt{s}$ up to 3 TeV

100 MV/m accelerating gradient needed for compact (~50 km) machine
→ based on normal-conducting accelerating structures and a two-beam acceleration scheme




- ❑ Direct discovery potential and precise measurements of new particles (couplings to Z/γ*) up to m~ 1.5 TeV
- ❑ Indirect sensitivity to E scales Λ ~ O(100) TeV
- ❑ Measurements of “heavy” Higgs couplings: ttH to ~ 4%, HH ~ 10%

| **Parameter** | **Unit** | **380 GeV** | **3 TeV** |
|---|---|---|---|
| Centre-of-mass energy | TeV | 0.38 | 3 |
| Total luminosity | $10^{34}cm^{-2}s^{-1}$ | 1.5 | 5.9 |
| Luminosity above 99% of $\sqrt{s}$ | $10^{34}cm^{-2}s^{-1}$ | 0.9 | 2.0 |
| Repetition frequency | Hz | 50 | 50 |
| Number of bunches per train | | 352 | 312 |
| Bunch separation | ns | 0.5 | 0.5 |
| Acceleration gradient | MV/m | 72 | 100 |

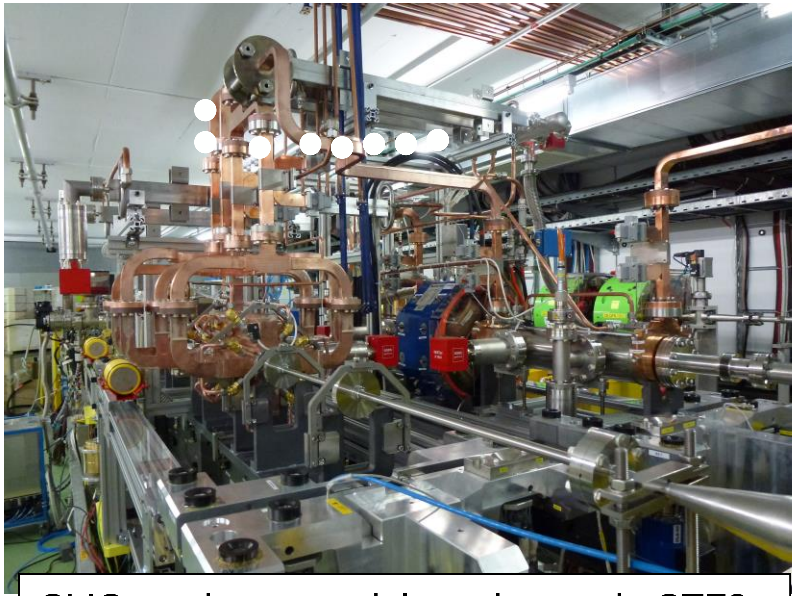
Most recent operating scenario: start at $\sqrt{s}$=380 GeV for H and top physics

# CLIC

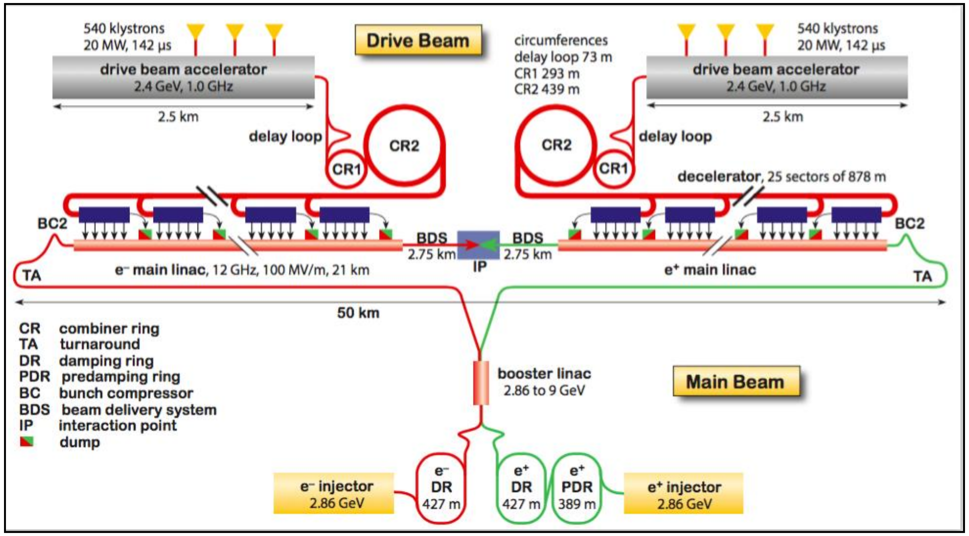
CDR completed end 2012 → for ES update:
- ❑ develop plan for staged implementation
- ❑ complete key R&D studies
- ❑ review cost and schedule

Challenges:
- ❑ minimise RF breakdown rate in cavities
- ❑ efficient RF power transfer from drive to main beam
- ❑ reduce power consumption (600 MW at 3 TeV)
- ❑ nm size beams, final focus
- ❑ huge beamstrahlung in detectors

CTF3 facility: testing two-beam acceleration concept: efficient power transfer from high-intensity low-E "drive" beam to the accelerating structure of the main ("probe") beam.
→ to be completed in 2016



CLIC two-beam module under test in CTF3




CLIC construction could technically start ~2025, duration ~6 years for $\sqrt{s}$ ~ 380 GeV (11 km Linac)
→ physics could start by ~2035

# Future Circular Colliders (FCC)

Conceptual design study of a ~100 km ring:

- ❑ pp collider (FCC-hh): ultimate goal → defines infrastructure requirements

  $\sqrt{s}$ ~ 100 TeV, L~2x$10^{35}$; 4 IP, ~20 $ab^{-1}$/expt

- ❑ $e^+e^-$ collider (FCC-ee): possible first step

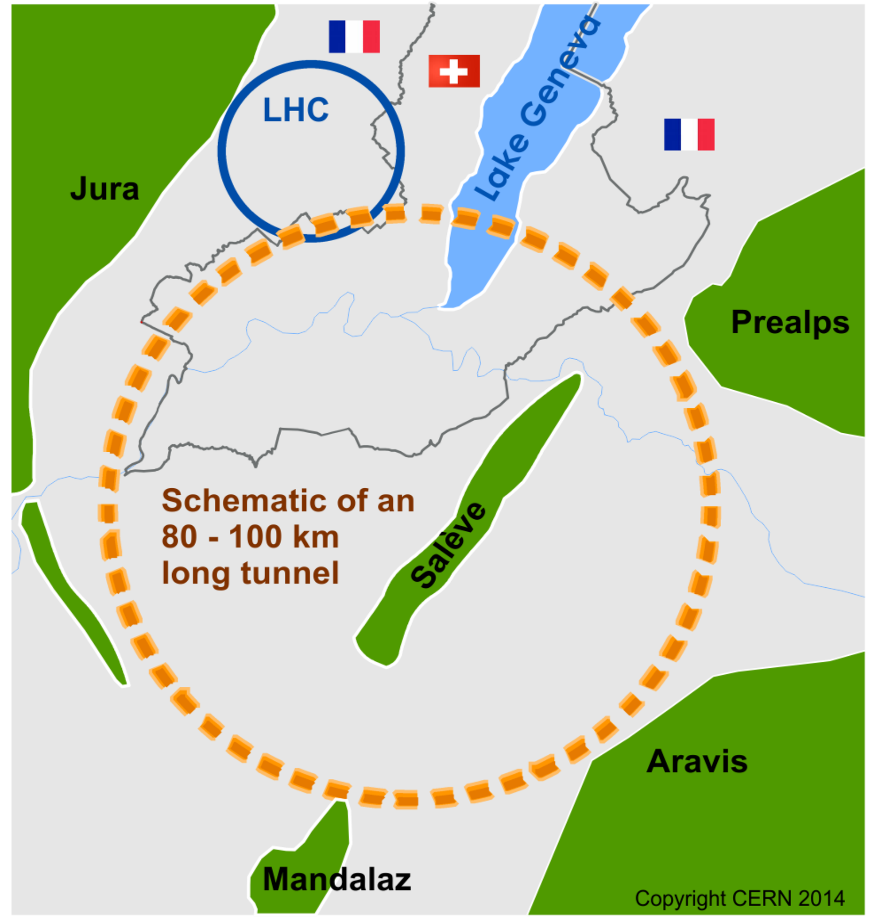
  $\sqrt{s}$ = 90-350 GeV, L~200-2 x $10^{34}$; 2 IP

- ❑ pe collider (FCC-he): option

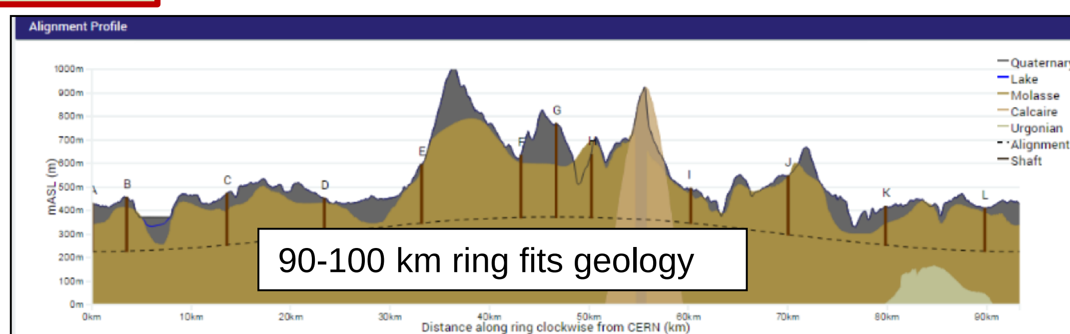
  $\sqrt{s}$ ~ 3.5 TeV, L~$10^{34}$

**Goal: CDR in time for next ES**

Also part of the study: HE-LHC**:** FCC-hh dipole technology (~16 T) in LHC tunnel → $\sqrt{s}$ ~ 30 TeV




Machine studies are site-neutral. However, FCC at CERN would greatly benefit from existing laboratory infrastructure and accelerator complex



# FCC

FCC-hh: ~100 TeV pp collider is expected to:

- ❑ explore directly the 10-50 TeV E-scale
- ❑ conclusive exploration of EWSB dynamics
- ❑ say the final word about heavy WIMP dark matter

The two machines are complementary and synergetic

FCC-ee: 90-350 GeV

- ❑ measure many Higgs couplings to few permill
- ❑ indirect sensitivity to E-scale up to O(100 TeV) by improving by ~20-200 times the precision of EW parameters measurements, $\Delta M_W < 1$ MeV, $\Delta m_{top} \sim 10$ MeV

Many huge technological, design and operational challenges: e.g. ~16 T $Nb_3Sn$ magnets

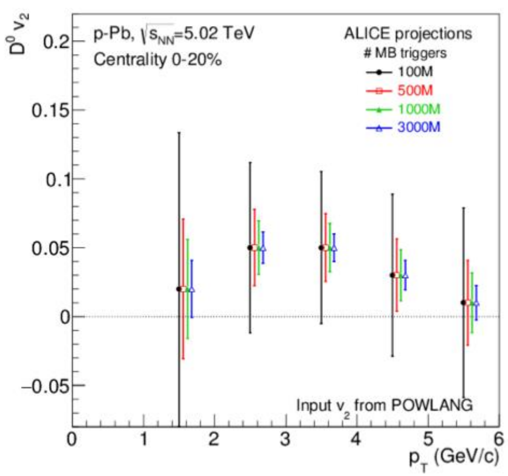
“Natural” continuation of LHC and HL-LHC programmes: step-wise approach, each step deployed and operated in a (big) accelerator:

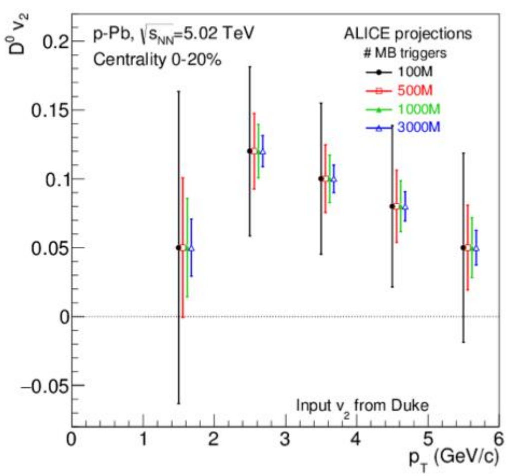
- ❑ LHC: Nb Ti technology: 8.3 T
- ❑ HL-LHC: $Nb_3Sn$ technology
  (11 T dipoles in IR7, 12-13 T peak field low-$\beta$ quads in IR1, IR5)

End 2015: $Nb_3Sn$ dipole (1.8 m) reached 11.3 T (> nominal) w/o quenches
March 2016: $Nb_3Sn$ quadrupole (1.5 m long, aperture =150 mm) reached 18 kA (nominal: 16.5 kA). 2 coils from CERN + 2 coils from US

# Charm $v_2$

- $v_2$: quantifies azimuthal asymmetry
  - second-order Fourier harmonics of azimuthal distribution
- observation of $v_2 \neq 0$ would provide crucial indication of medium effects
- expected uncertainties in ALICE corresponding to two pA energy loss models
  - as a function of minimum-bias statistics at 5 TeV

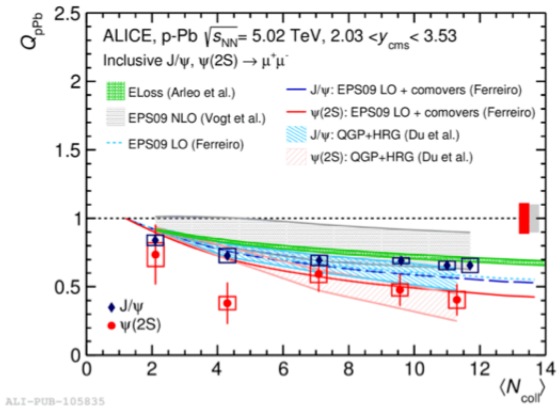


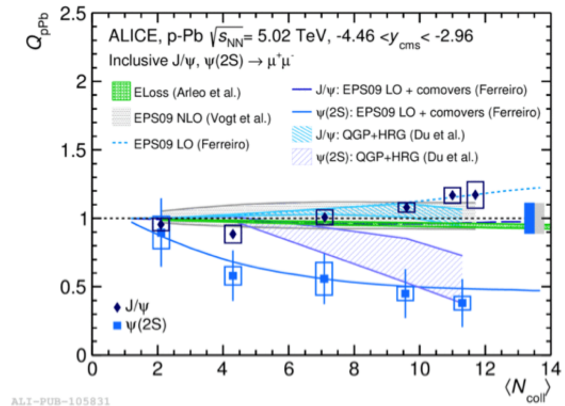
# Charmonia in p-Pb, Pb-p

## Final-state effects in Pb-going direction?

**p-going**




**Pb-going**




- p-Pb : moderate suppression of charmonium production at low $p_T$ (~ shadowing)
- Pb-p : no suppression for J/ψ, but ψ(2S) appears to be suppressed, multiplicity dependence?
- Run 1: ~ 5/nb per beam orientation → Run 2: ~ 15/nb per beam orientation at 8 TeV

→ Pb-p run is very important for ALICE and LHCb, but scheduling is at risk…

- – it was decided to start with p-Pb, in order to facilitate LHCf run
- – beam orientation irrelevant for ATLAS and CMS
- – beam orientation same for ALICE and LHCb