LHC & Future High-Energy Circular Colliders

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JUAS 2016– European Scientific Institute – Archamps

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Outline

- **LHC recall in few slides**

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

- **High Luminosity LHC project** ⇒ **3'000 fb^{-1}**

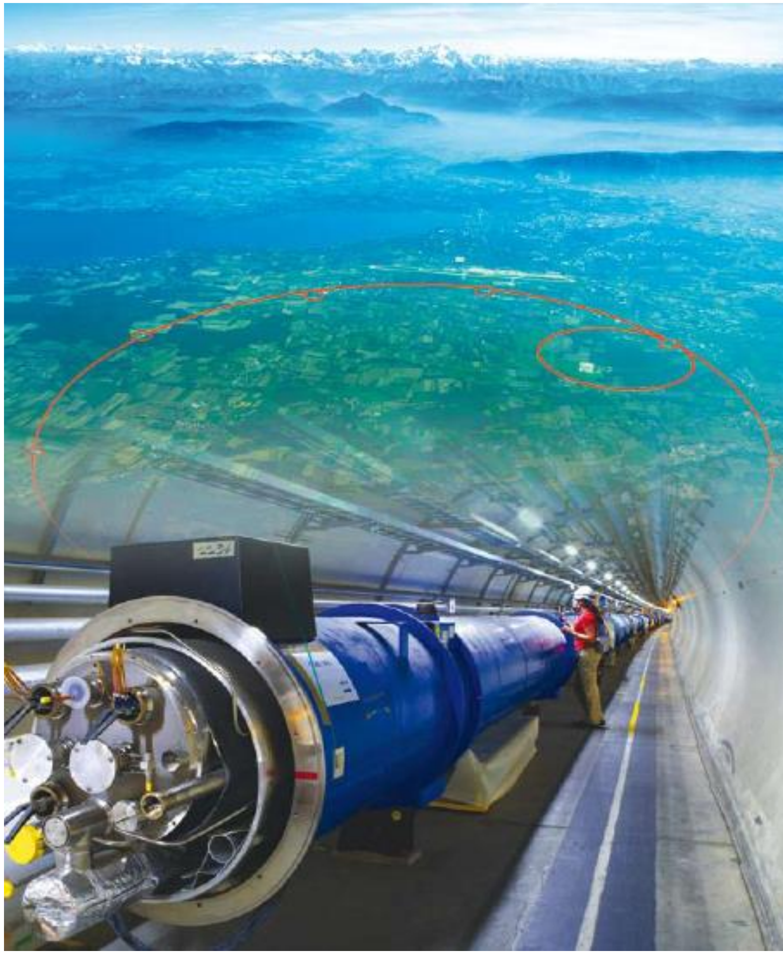
- **Post-LHC machines:**
  World studies
  Future Circular Colliders ⇒ ***towards 100 TeV***

- **Conclusion**

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
2010-2035 : Physics exploitation

LHC:
technological challenges

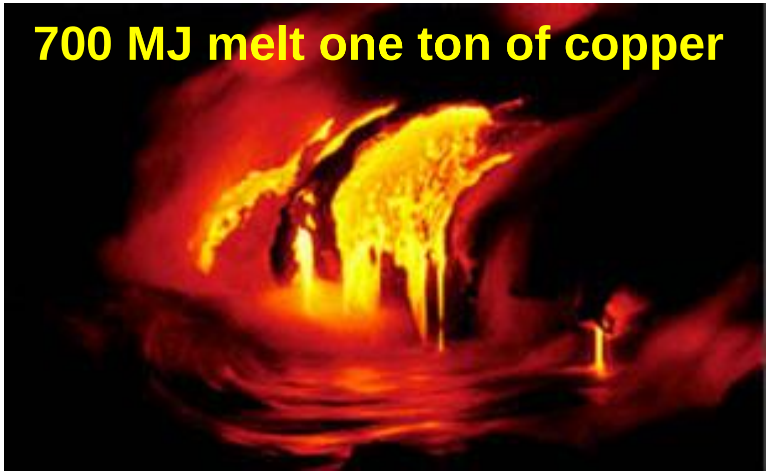
The specifications of many systems were over the state of the art.
Long R&D programs with many institutes and industries worldwide.

- **The highest field accelerator magnets: 8.3 T** (1232 dipole magnets of 15 m)
- **The largest superconducting magnet system** (~10'000 magnets)
- **The largest 1.9 K cryogenics installation** (superfluid helium, 150 tons of LHe to cool down 37'000 tons)
- **Ultra-high cryogenic vacuum for the particle beams** (10^{-13} atm, ten times lower than on the Moon)
- **The highest currents controlled with high precision** (up to 13 kA)
- **The highest precision ever demanded from the power converters** (ppm level)
- **A sophisticated and ultra-reliable magnet quench protection system**
  (Energy stored in the magnet system: ~10 Gjoule, in the beams > 700 MJ)

Energy management challenges

Energy stored in the magnet system: ~10 GJoule

Energy stored in the two beams: 720 MJ *[6 10^{14} protons (1 ng of H+) at 7 TeV]*



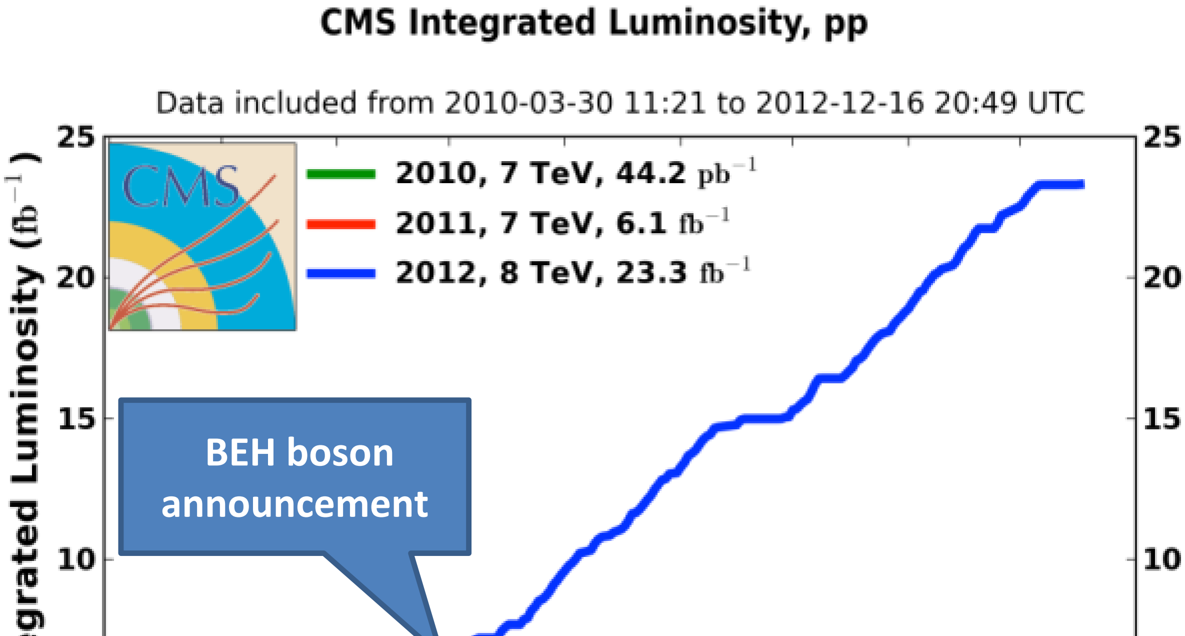
700 MJoule dissipated in 88 μs

700.106 / 88.106 ≅ 8 TW

World Electrical Installed Capacity ≅ 3.8 TW

1 electron volt = 1,602× 10^{-19} joule

LHC 2010-2012: a rich harvest of collisions



Σ ~30 fb^{-1}

~ 2 10^{15} collisions

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

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

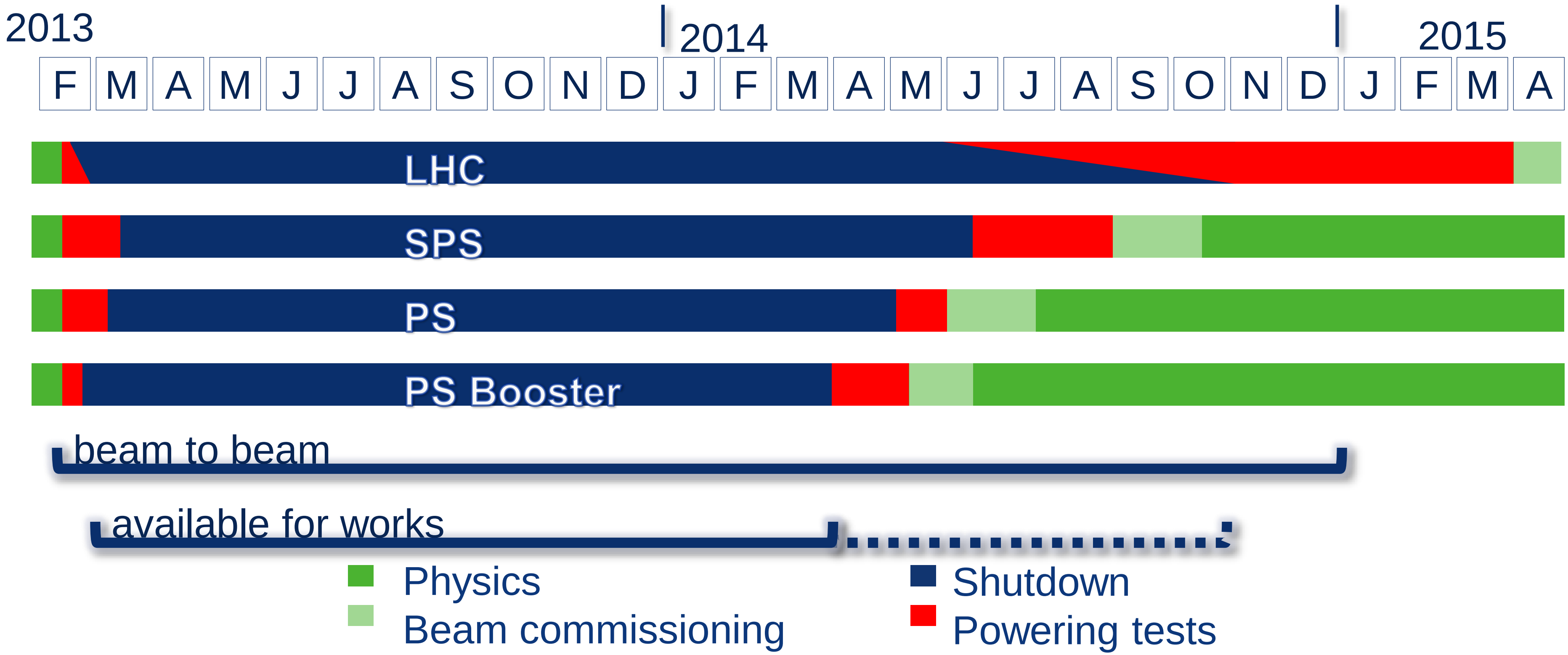
2012: **23.3 fb^{-1}**
8 TeV CoM
… production

3.5 TeV and 4 TeV in 2012
Up to 1380 bunches
with1.5 10^{11} protons

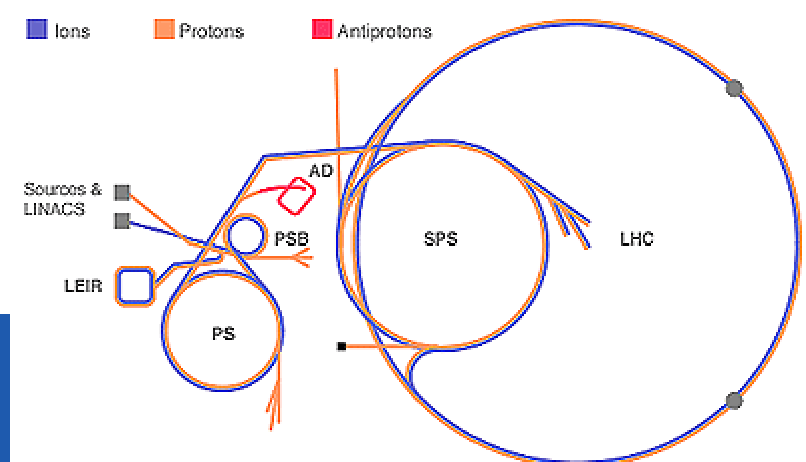
Nobel Prize in Physics 2013

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider".*

Long Shutdown LS1 from Feb. 2013 to Mar. 2015



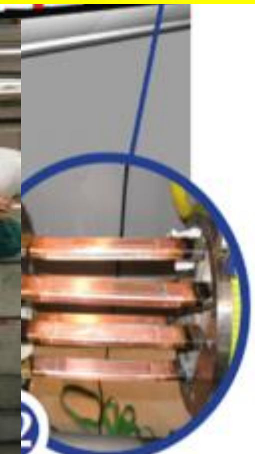
- **Prepare the LHC for Operation at Nominal Energy**
- **Consolidate and Upgrade the LHC and Injector performance**
- **Major Maintenance Programme**



The main 2013-14 LHC consolidations

SMACC project : Closure of the last interconnection – 18.06.2014

18 000 electrical
Quality Assurance tests



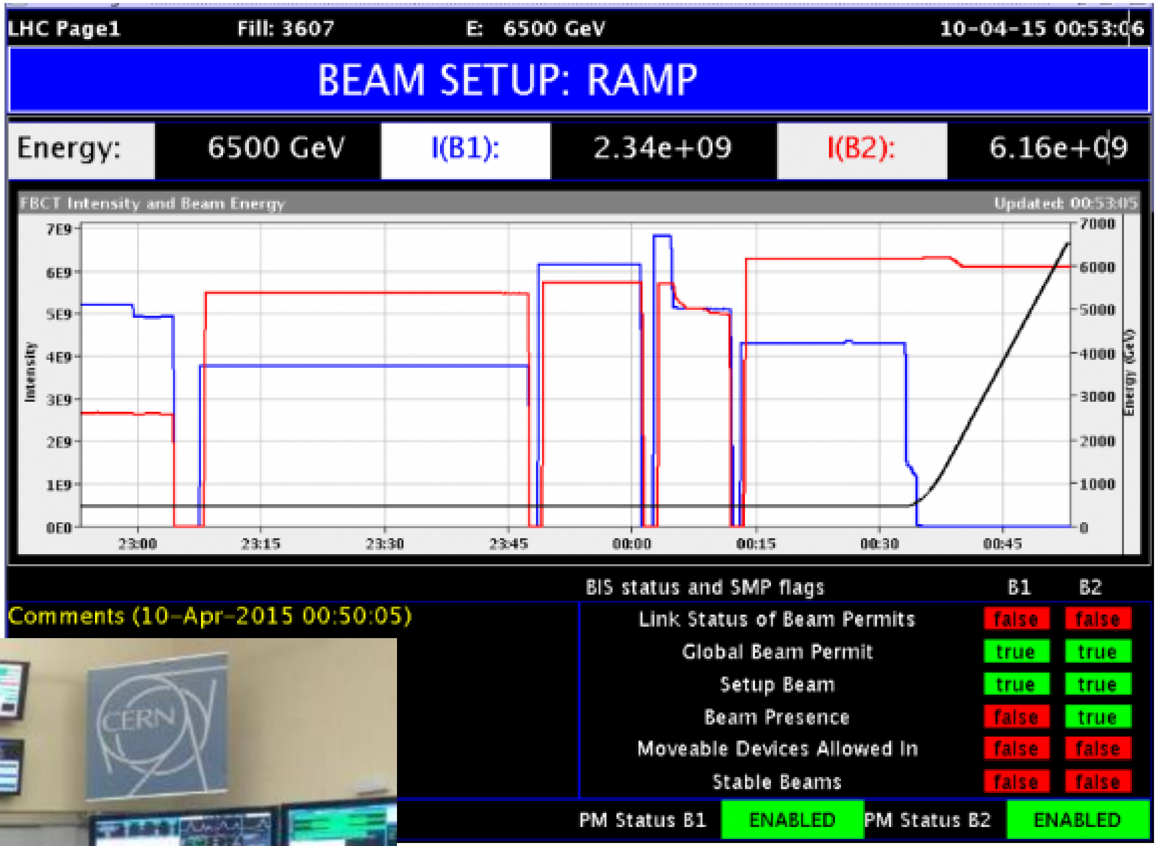
nsolidation of the
kA circuits in the 16
in electrical feed-
oxes

First circulating beams in LHC on Easter Sunday

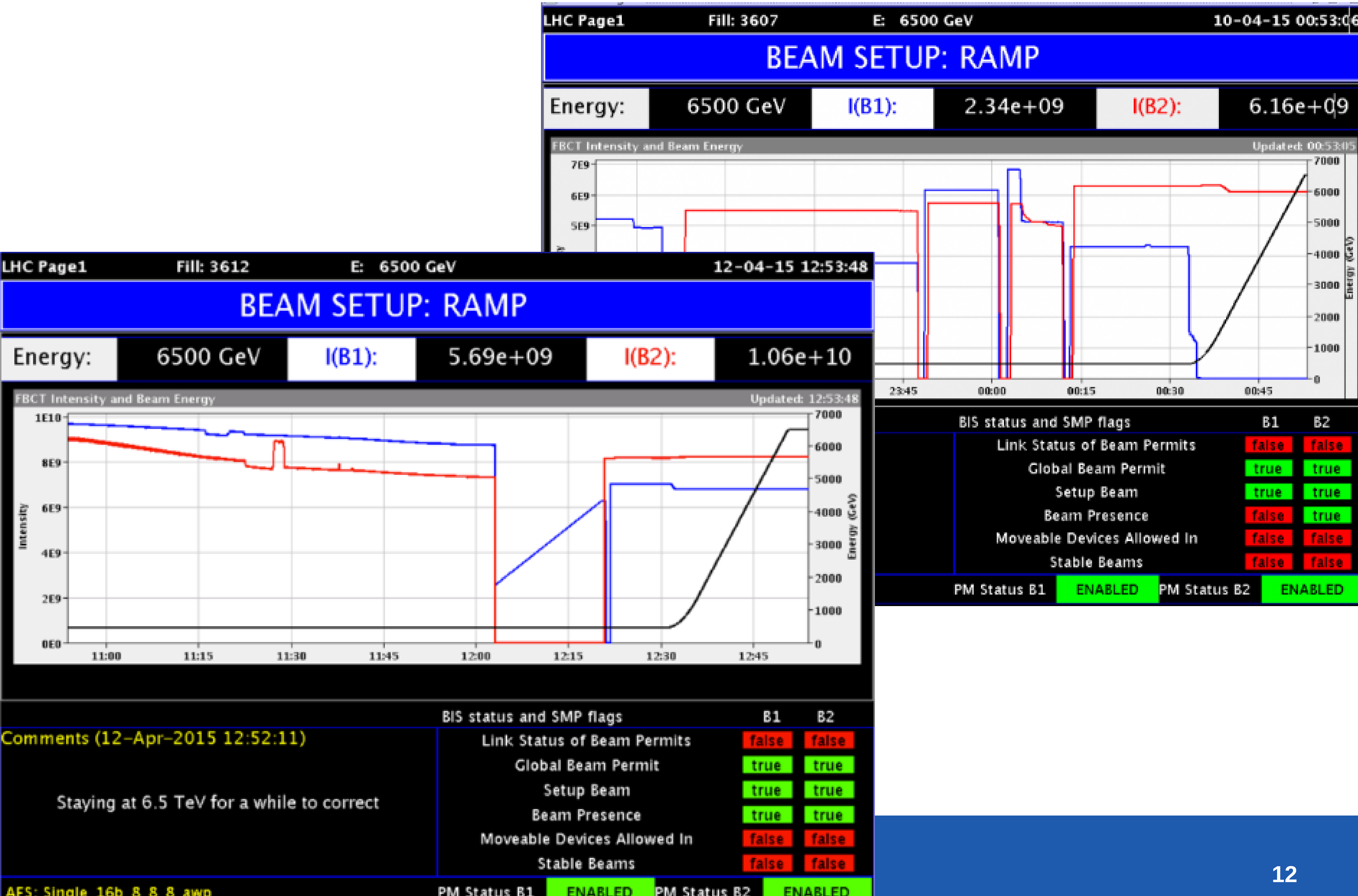
5th April 2015




First beam at 6.5 TeV! (10th April)

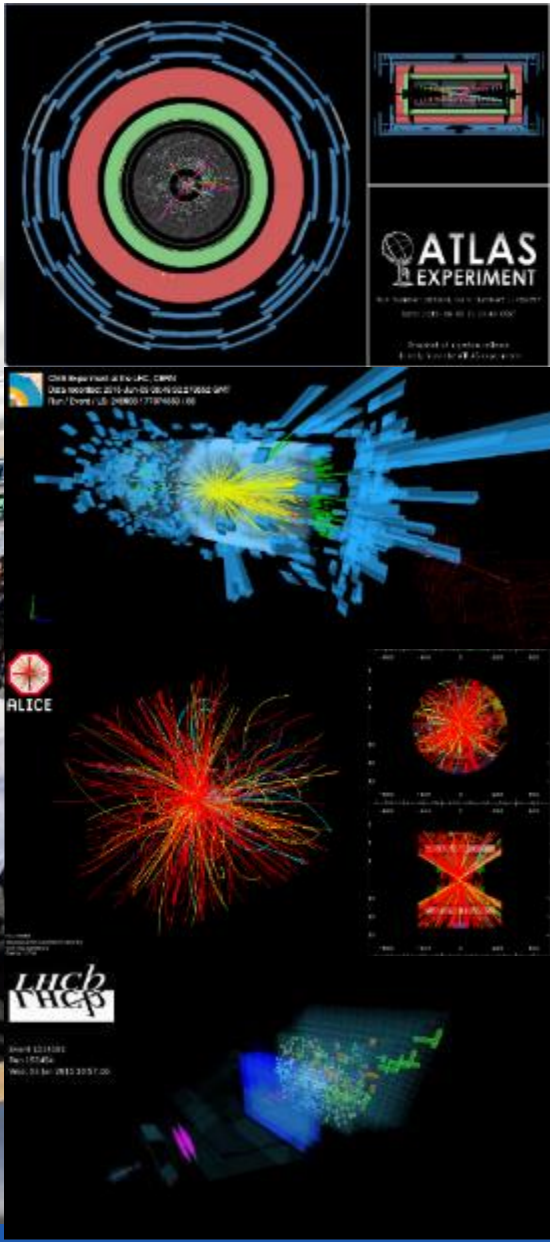


First beamS at 6.5 TeV! (12th April)



LHC experiments are back in business at a new record energy 13 TeV

3rd June 2015



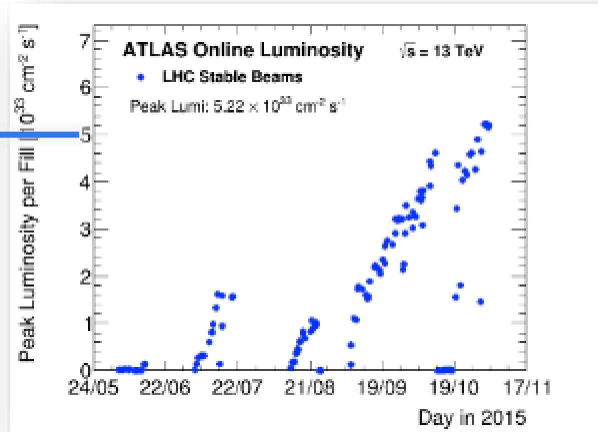
2015 LHC Luminosity

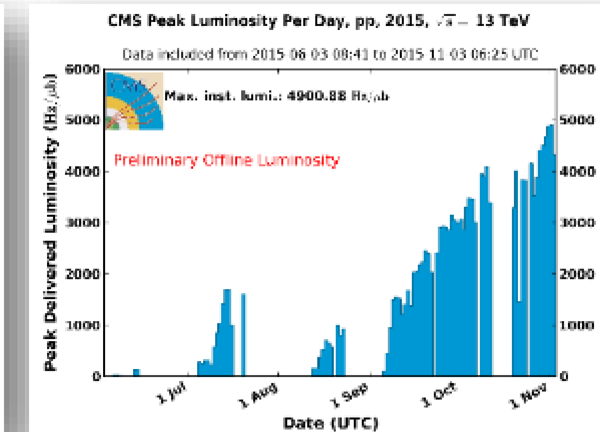
ATLAS | CMS

Peak

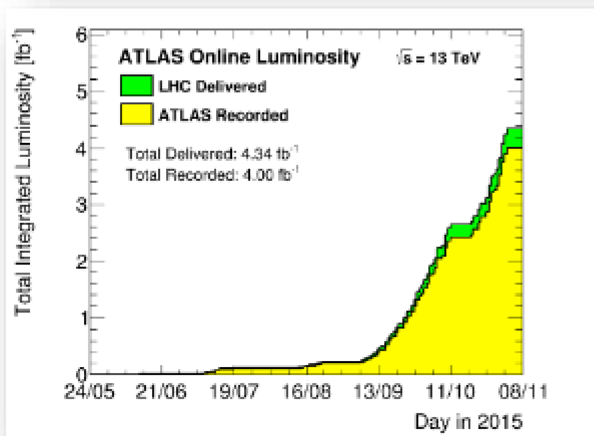
5×10^{33} cm^{-1} s^{-1}

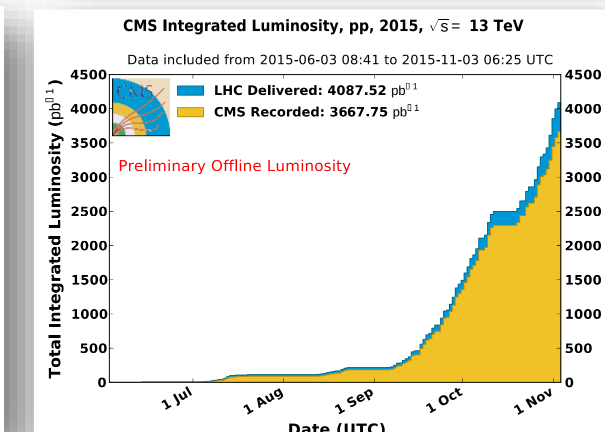
Design 10^{34} cm^{-1} s^{-1}





Integrated





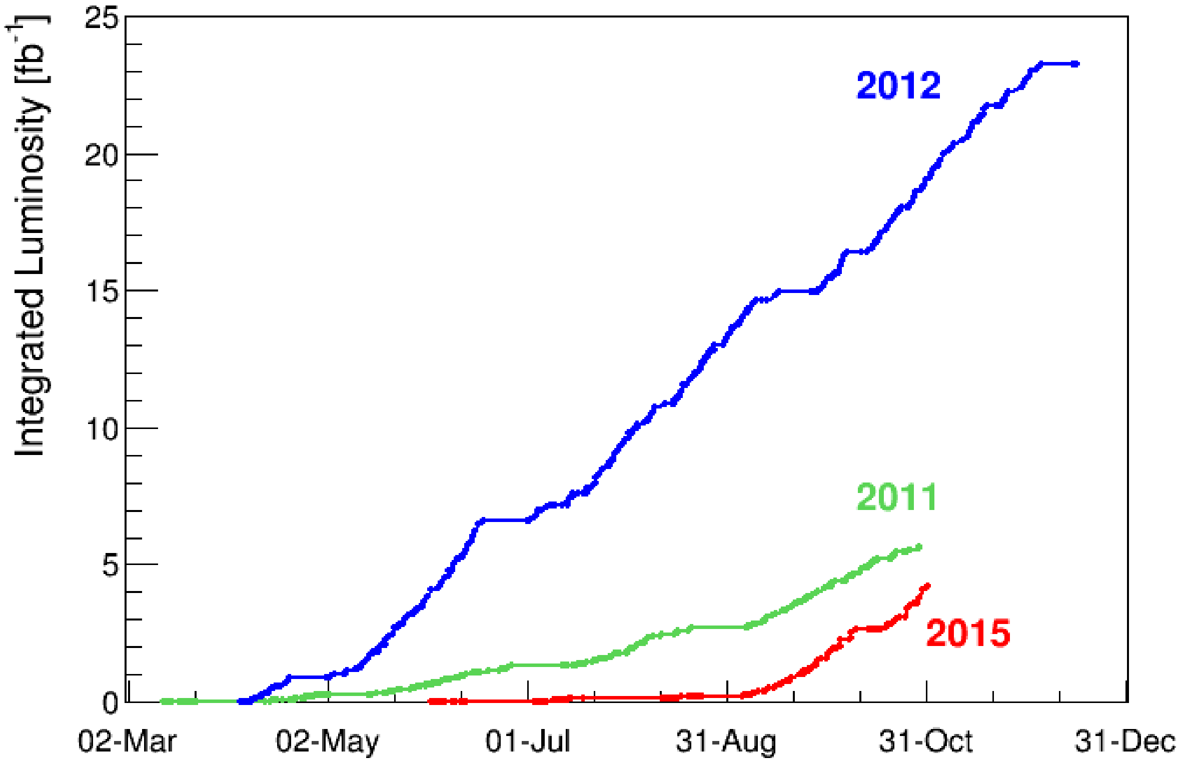
2015 LHC Integrated Luminosity

- The initial projections of integrated luminosity for 2015 were ~ 8-10 fb^{-1}.
- Achieved ~ 4.3 fb^{-1}.
- Slope at the end of the run better than in 2011, and close to 2012 slope

(last week of operation > 1 fb^{-1})

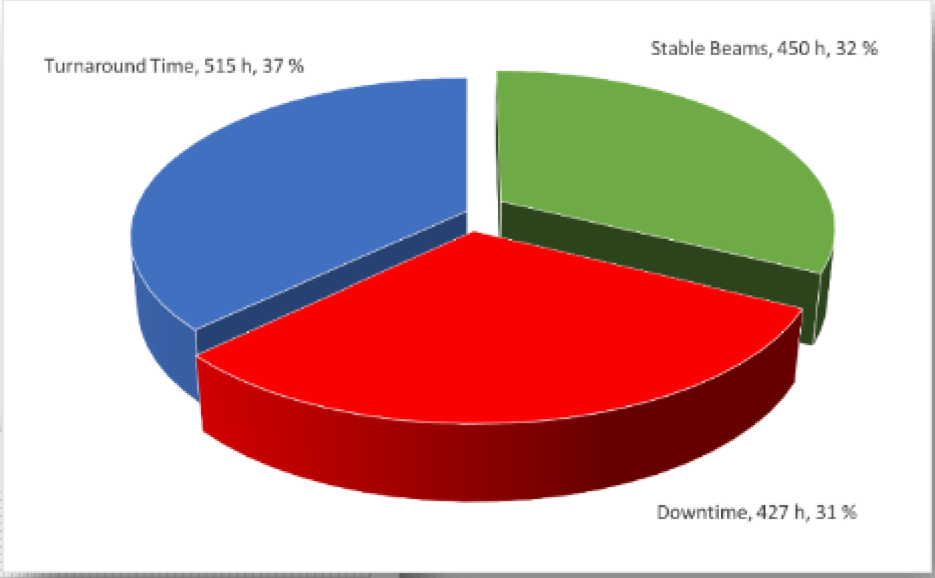
The main reasons for the lower value:

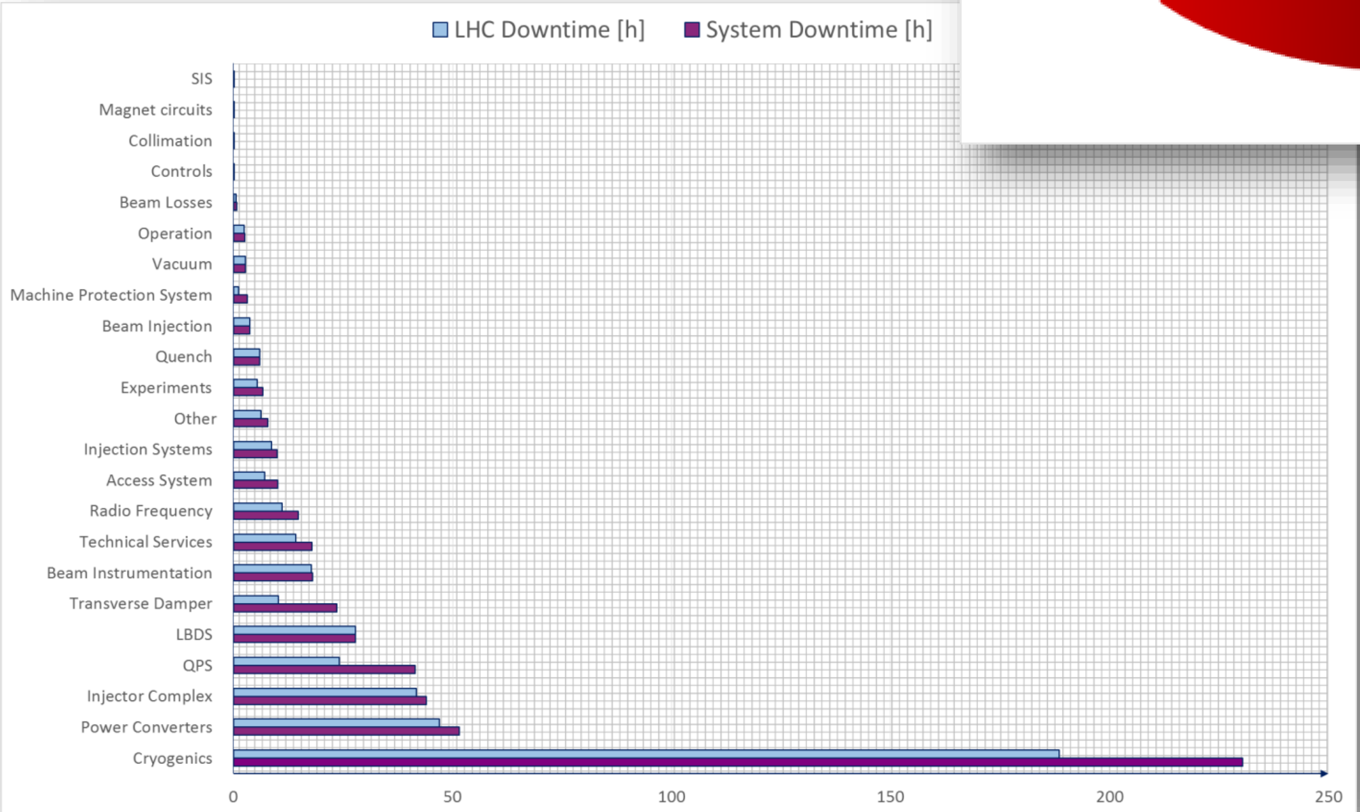
- Start-up delays (~ 4 weeks),
- Availability issues (radiation failures on the quench protection tunnel electronics; solved after TS2),
- Electron clouds mitigation



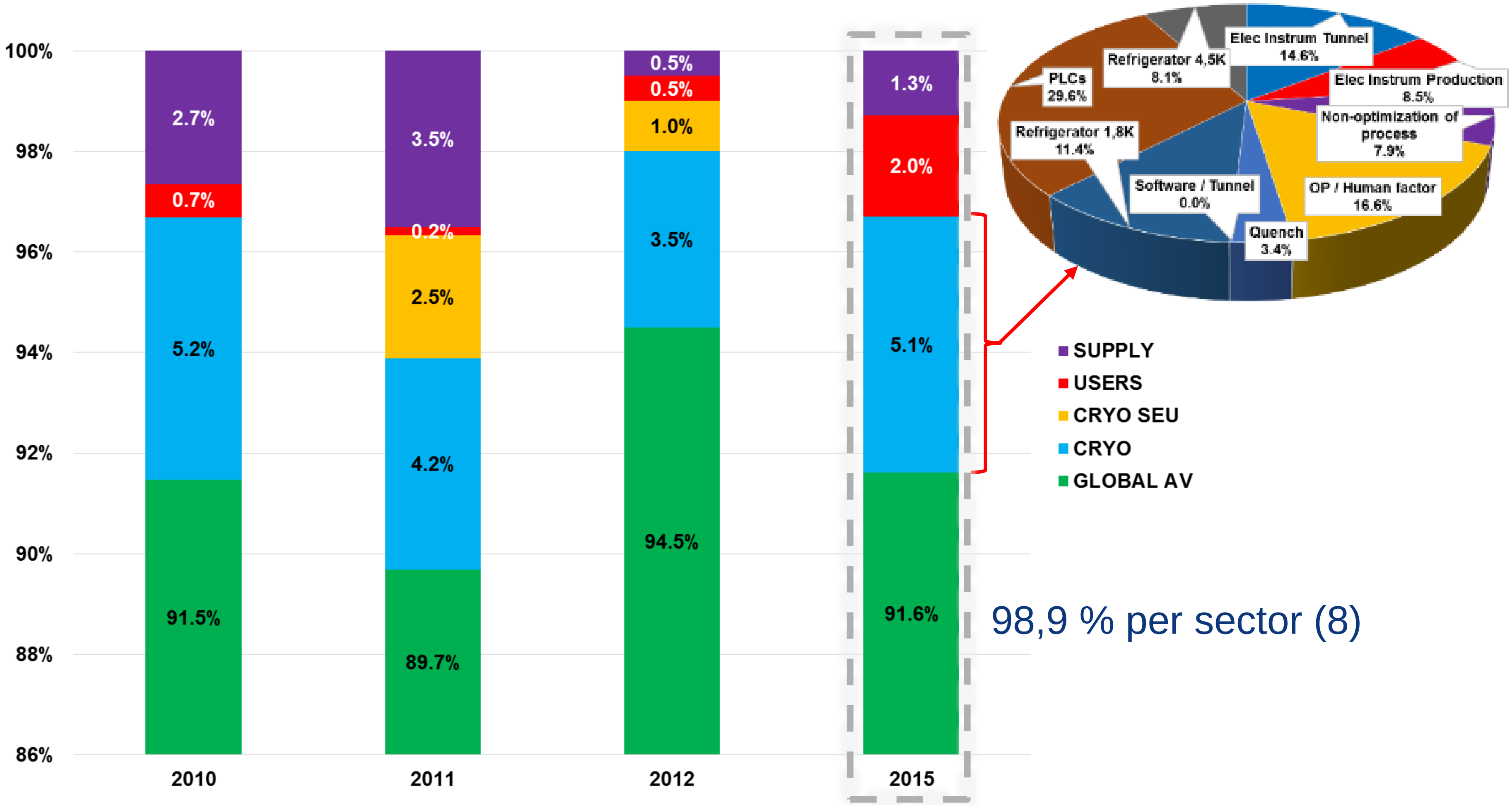
2015 LHC Machine availability

Statistics for 25 ns run from September 7th to November 3rd



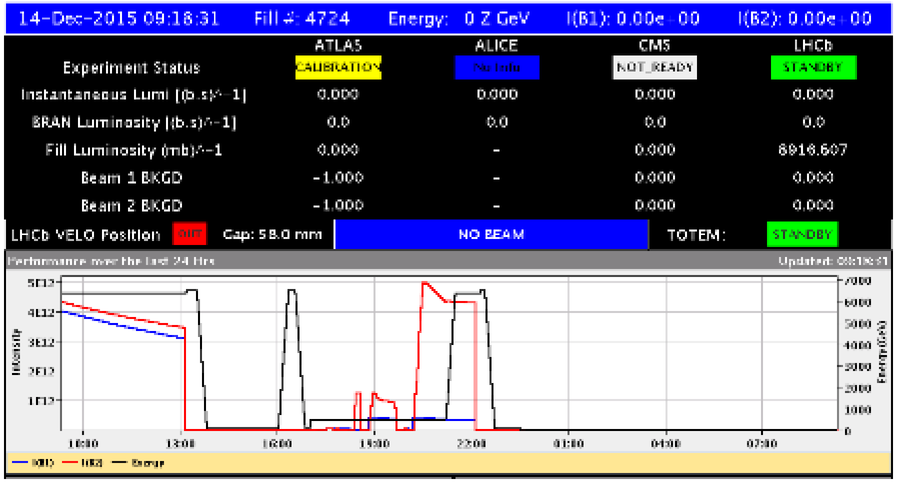


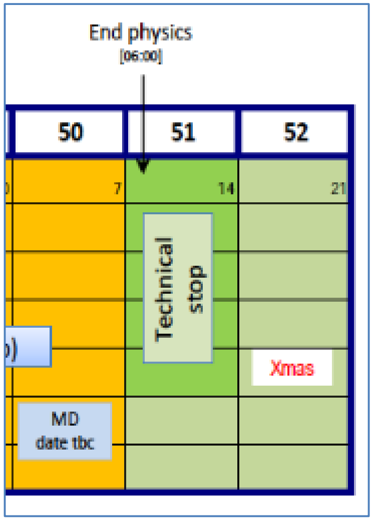
LHC cryogenic availability

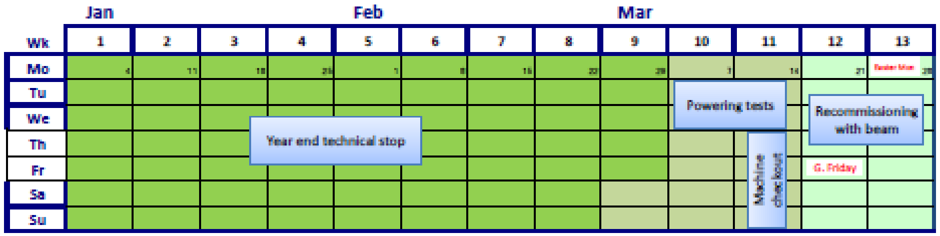


98,9 % per sector (8)

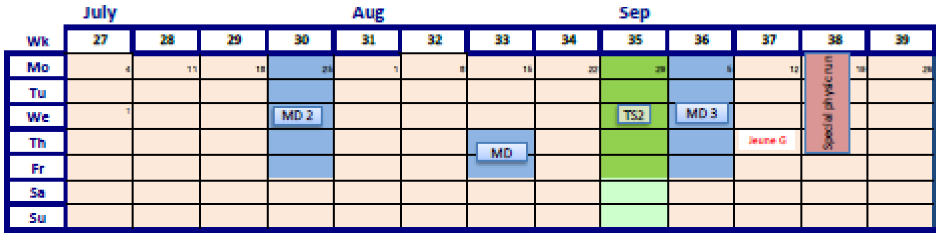
Technical stop and YETS (Year End Technical Stop)



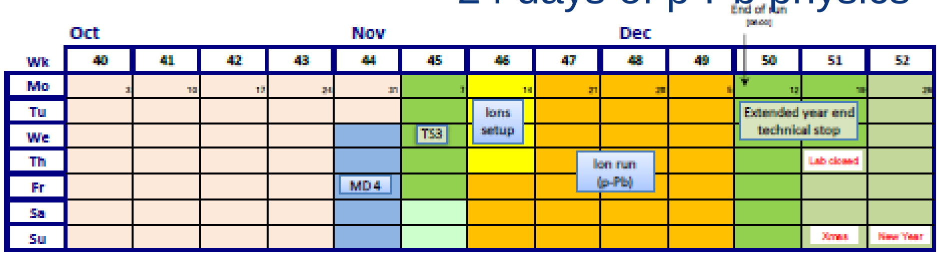




160 days of p-p physics and 9 days special runs



24 days of p-Pb physics



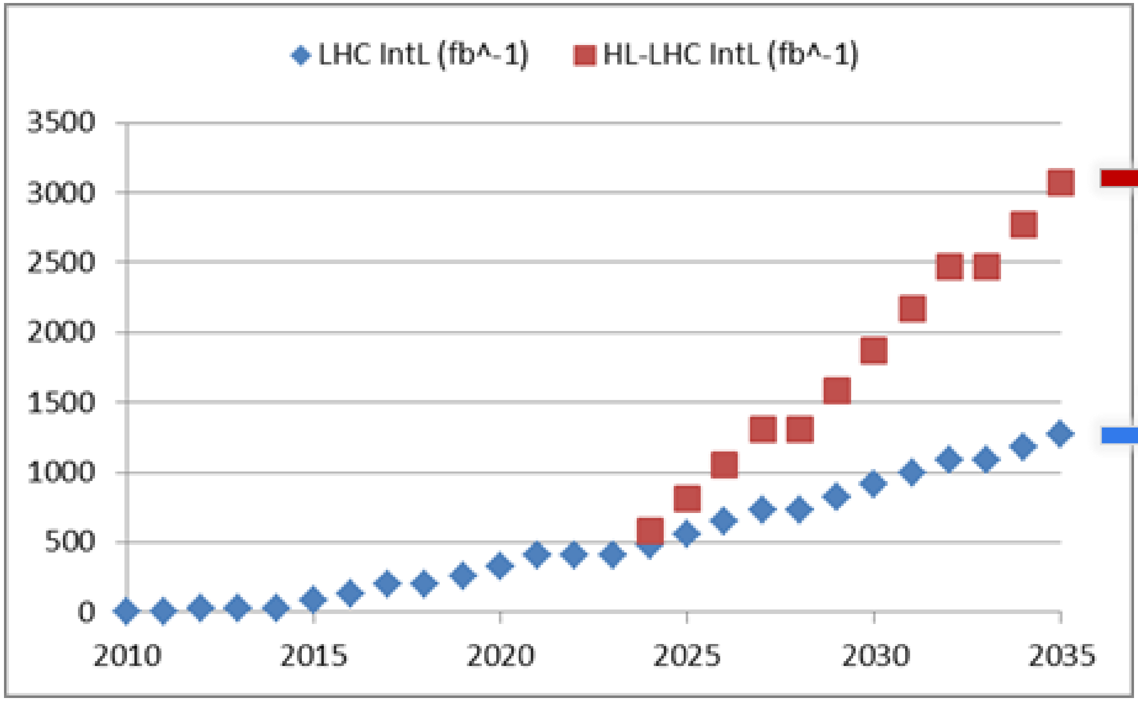
LHC goal for Run 2 and 3

Integrated luminosity goal:

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

~ 300 fb^{-1} before LS3

Why High-Luminosity LHC ? (LS3)



By implementing HL-LHC

Almost a factor 3

By continuous performance improvement and consolidation

Around 300 fb^{-1} the present Inner Triplet magnets reach the end of their useful life (due to radiation damage) and must be replaced.

Goal of HL-LHC project:

- 250 – 300 fb^{-1} per year
- **3000 fb^{-1} in about 10 years**

European Strategy
for Particle Physics

The European Strategy for Particle Physics
Update 2013

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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.***

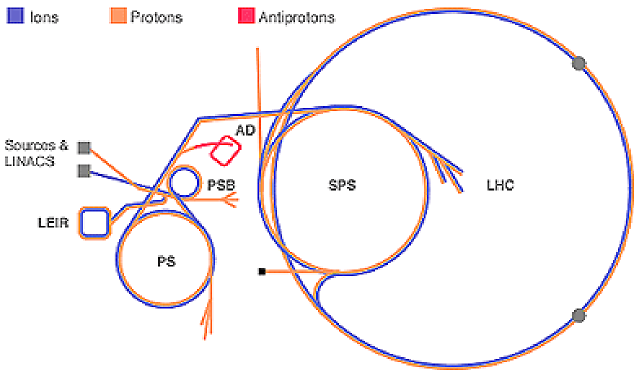
HL-LHC from a study to a PROJECT

300 fb^{-1} → 3000 fb^{-1}

including LHC injectors upgrade **LIU**

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

Goals and means of the LHC Injectors Upgrade: 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…)

Courtesy of Malika Meddahi

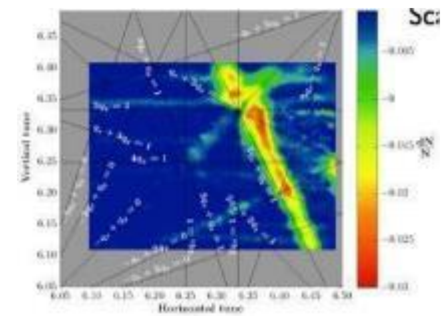
LS2 : (2019-2020), LHC Injector Upgrades (LIU)

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:

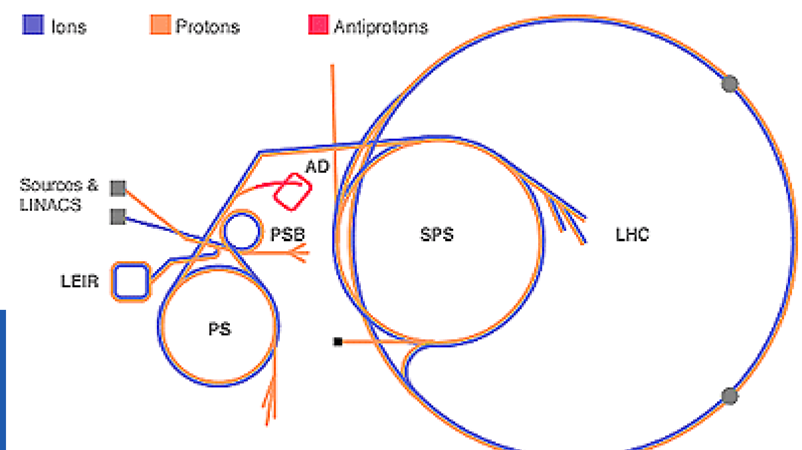
- Increase of injection energy from 1.4 GeV to 2 GeV to increase PS space charge threshold
- Transverse resonance compensation
- New RF Longitudinal feedback system
- New RF beam manipulation scheme to increase beam brightness



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



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 2035-37**

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 μ ~ **140 (~ 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

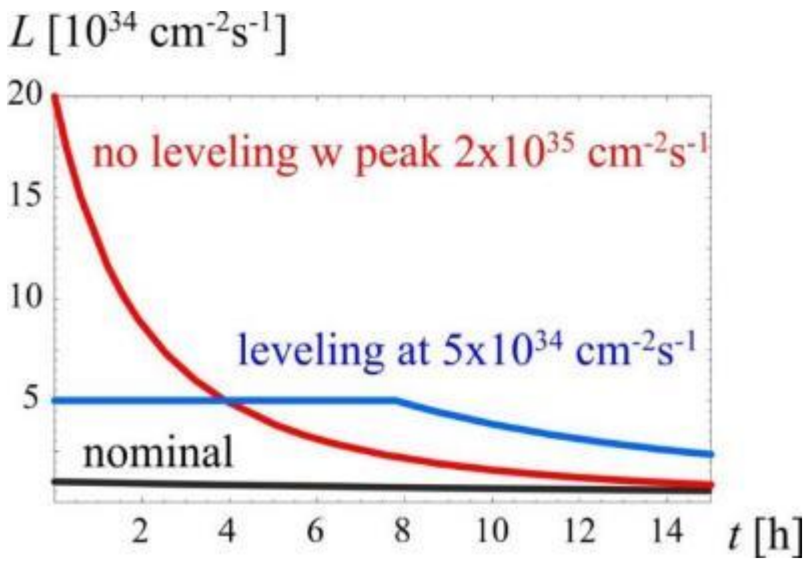
LHC Upgrade Goals: Performance optimization

Luminosity recipe :

$$L = \frac{n_b \times N_1 \times N_2 \times \gamma \times f_{rev}}{4\pi \times \beta^* \times \varepsilon_n} \times F(\phi, \beta^*, \varepsilon, \sigma_s)$$

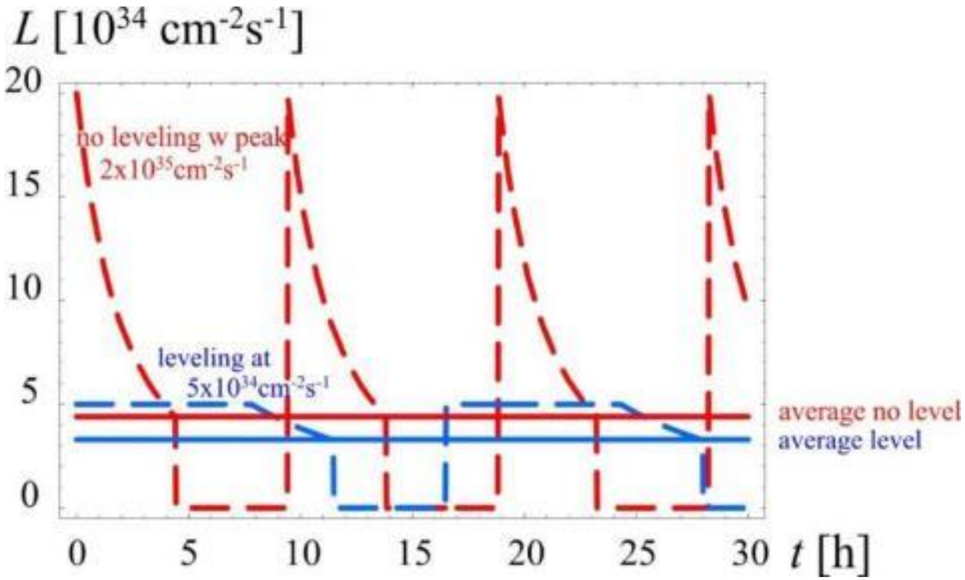
- ➔ 1) maximize bunch intensities ➔ Injector complex
- ➔ 2) minimize the beam emittance LIU ⬄ IBS
- ➔ 3) minimize beam size (constant beam power); ➔ triplet aperture
- ➔ 4) maximize number of bunches (beam power); ➔ 25ns
- ➔ 5) compensate for 'F'; ➔ Crab Cavities
- ➔ 6) Improve machine 'Efficiency' ➔ minimize number of unscheduled beam aborts

Luminosity Levelling, a key to success

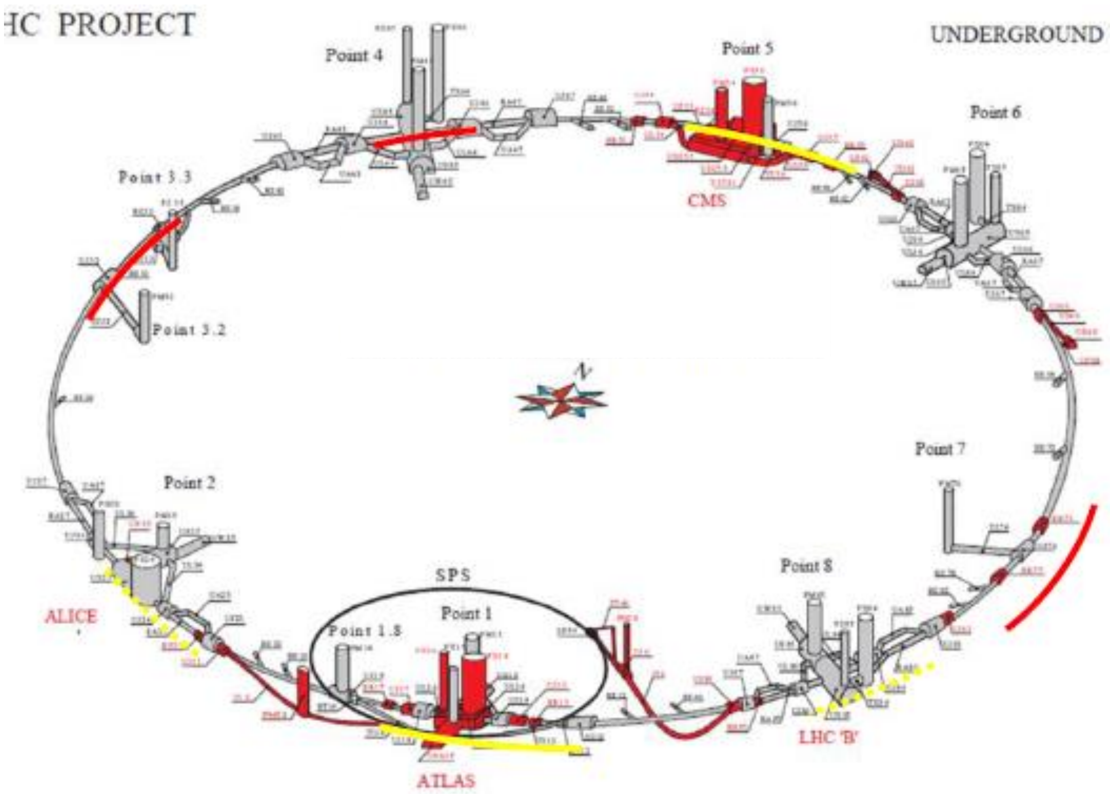


- High peak luminosity
- Minimize pile-up in experiments and provide “constant” luminosity

- Obtain about 3 - 4 fb^{-1}/day (40% stable beams)
- About 250 to 300 fb^{-1}/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

Squeezing the beams: High Field SC Magnets

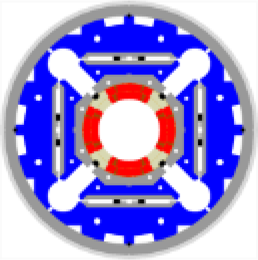
Quads for the inner triplet

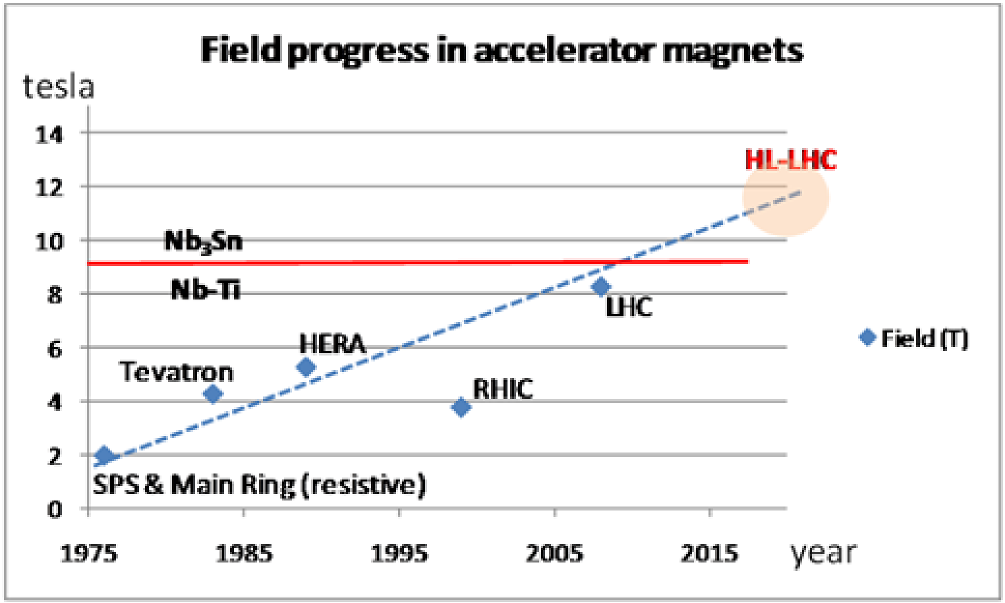
Decision 2012 for low-β quads

Aperture ∅ 150 mm – 140 T/m

(B_{peak} ≈12.3 T)

(LHC: 8 T, 70 mm)





More focus strength,

β* as low as 15 cm (55 cm in LHC)

thanks to ATS** (Achromatic Telescopic Squeeze)* ***optics

In some scheme even β down to 7.5 cm are considered*

- Dipoles for beam recombination/separation capable of 6-8 T with 150-180 mm aperture (LHC: 1.8 T, 70 mm)
- Dipoles 11 T for extra collimators

Squeezing the beams: High Field SC Magnets

Quads for the inner triplet

Decision 2012 for low-β quads

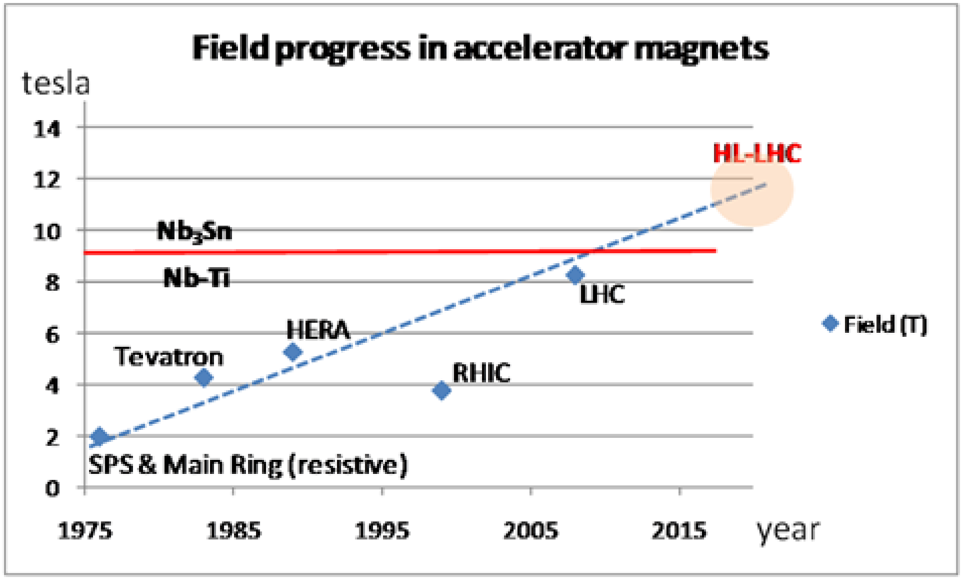
Aperture ∅ 150 mm – 140 T/m

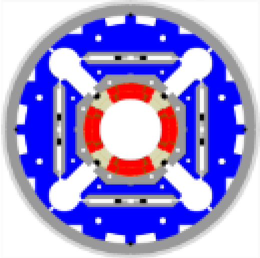
(B_{peak} ≈12.3 T)

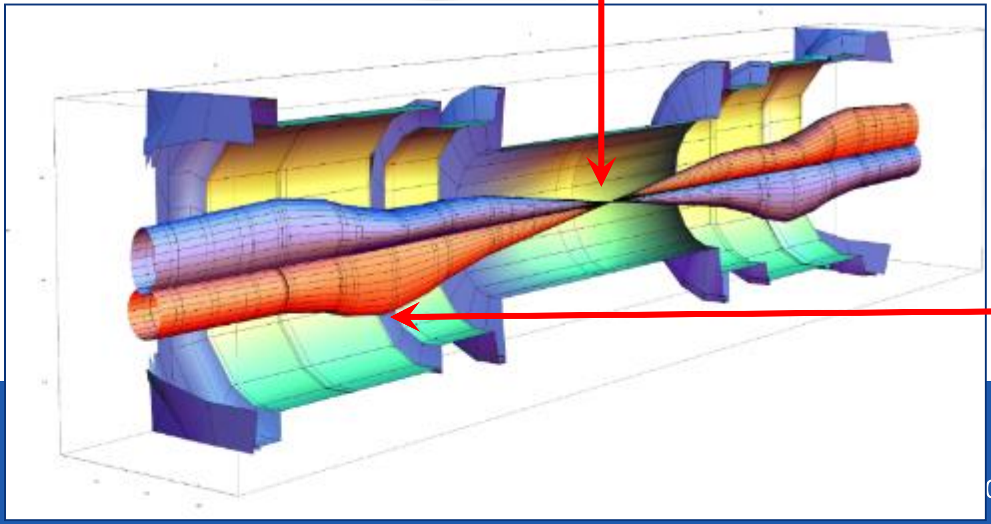
operational field, designed for 13.5 T

=> Nb_3Sn technology

(LHC: 8 T, 70 mm)







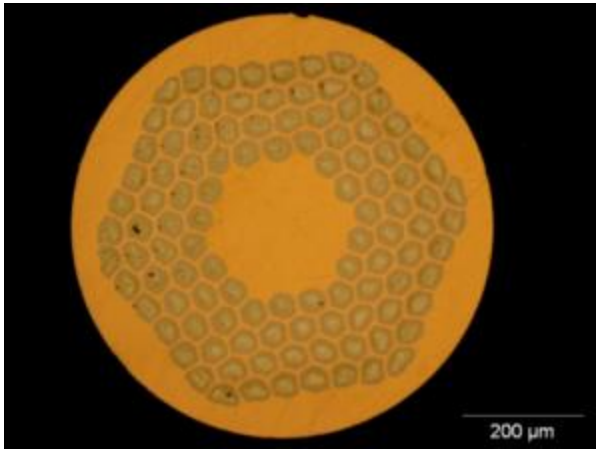
	$\beta_{triplet}$	Sigma triplet	β*	Sigma*
Nominal	~4.5 km	1.5 mm	55 cm	17 um
HL-LHC	~20 km	2.6 mm	15 cm	7 um

The « new » material : Nb_3Sn

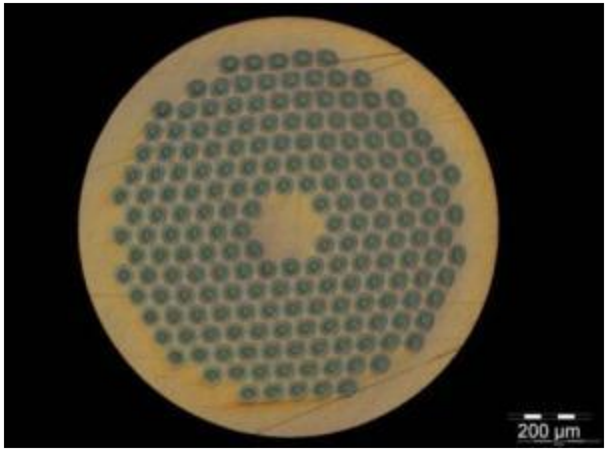
- Recent 23.4 T (1 GHz) NMR Magnet for spectroscopy in Nb_3Sn (and Nb-Ti).
- 15-20 tons/year for NMR and HF solenoids. Experimental MRI is taking off
- ITER: 500 tons in 2010-2015!

  It is comparable to LHC *(1200 tons of Nb-Ti but HL-LHC will require only 20 tons of Nb_3Sn)*

- HEP ITD (Internal Tin Diffusion):
  - High Jc., 3xJc ITER
  - Large filament (50 µm), large coupling current...
  - Cost is 5 times LHC Nb-Ti



0.7 mm, 108/127 stack RRP from **Oxford OST**

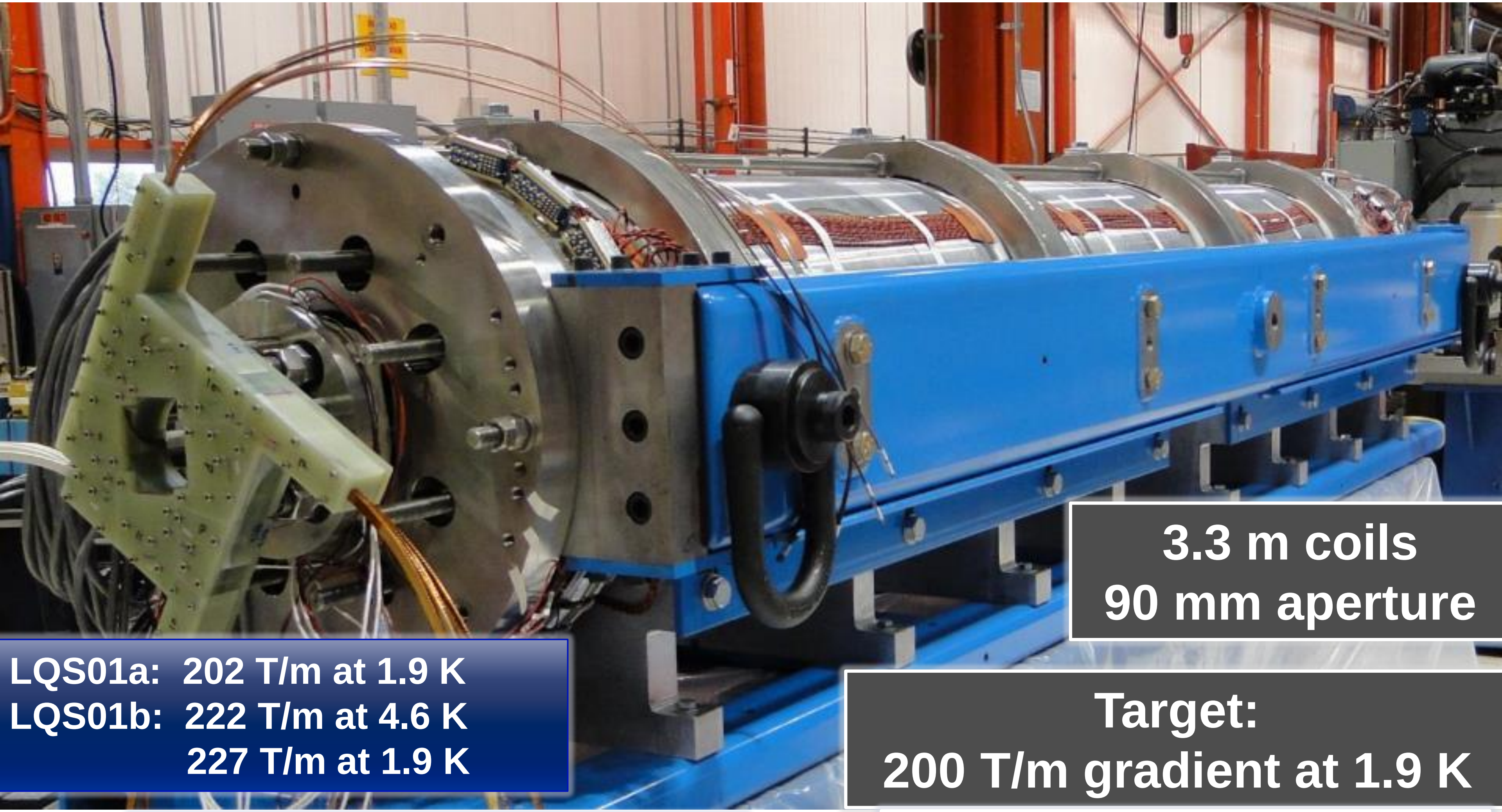


1 mm, 192 tubes PIT from **Bruker EAS**

LQS of LARP

Courtesy: G. Ambrosio FNAL and G. Sabbi , LBNL

LARP



3.3 m coils
90 mm aperture

Target:
200 T/m gradient at 1.9 K

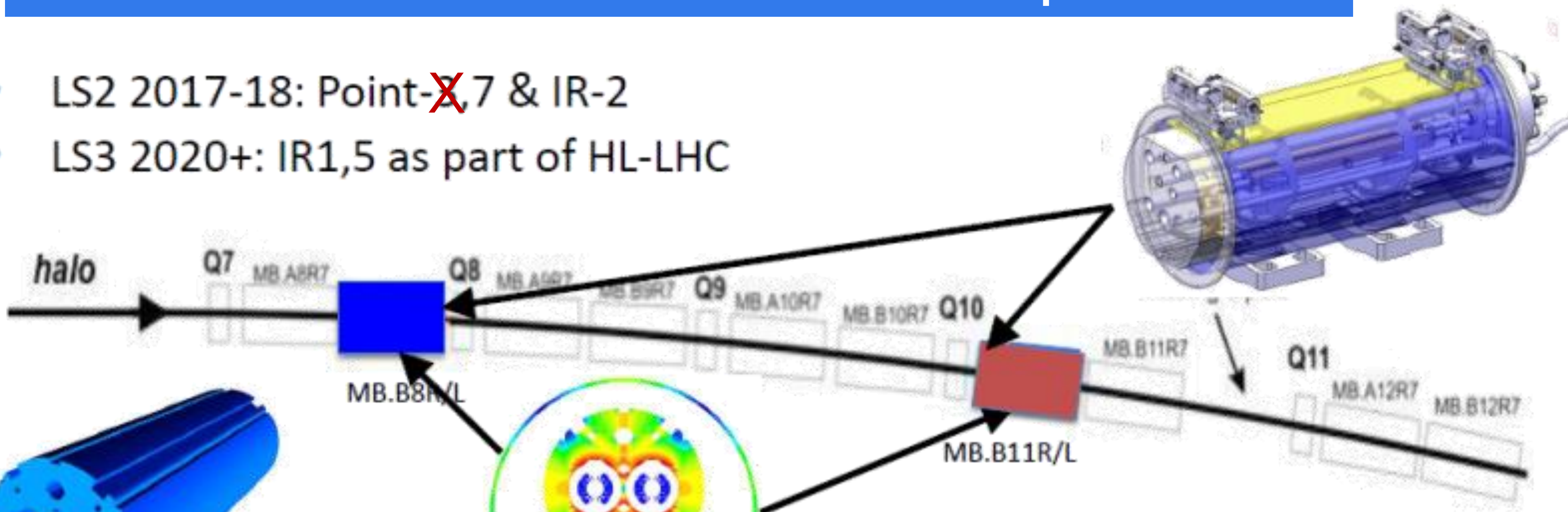
LQS01a: 202 T/m at 1.9 K
LQS01b: 222 T/m at 4.6 K
227 T/m at 1.9 K

LQS02: 198 T/m at 4.6 K 150 A/s
208 T/m at 1.9 K 150 A/s
limited by one coil

LQS03: 208 T/m at 4.6 K
210 T/m at 1.9 K
1st quench: 86% s.s. limit

LS2 : collimators and 11T Dipole

- LS2 2017-18: Point-X,7 & IR-2
- LS3 2020+: IR1,5 as part of HL-LHC

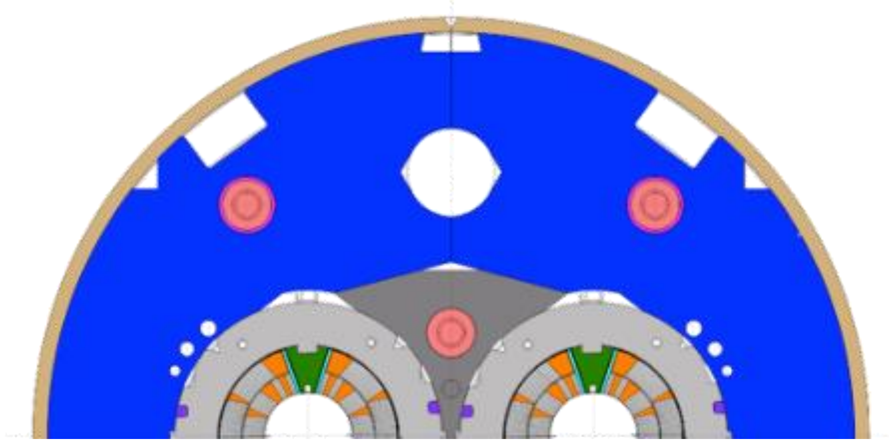


$\int BdL$ = 119.2 Tm @ I_{nom} = 11.85 kA
in series with MB with 20 % margin

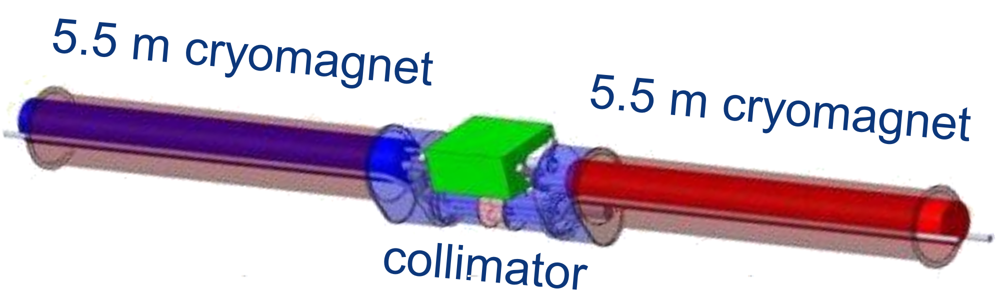
LS2: 12 coldmass + 2 spares = 14 CM
LS3: 8 coldmass + 2 spares = 10 CM
Total 24 CM

LS2: 24 coldmass + 4 spares = 28 CM
LS3: 16 coldmass + 4 spares = 20 CM
Total 48 CM

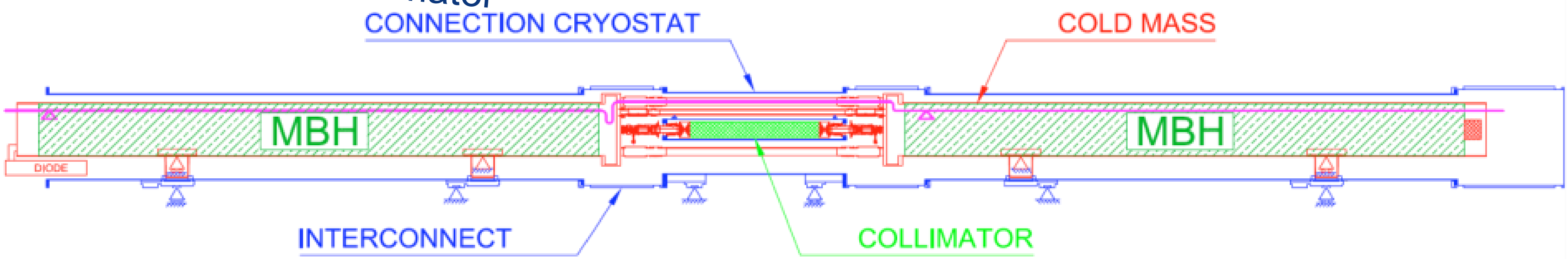
11 T dipole program (Nb_3Sn)



Aperture	(mm)	60
Field	(T)	10.8
Current	(A)	11850
Temperature	(K)	1.9
Peak field	(T)	11.35

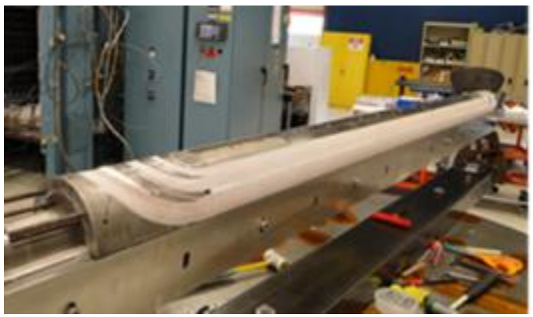


Cryo-unit design with integrated collimator



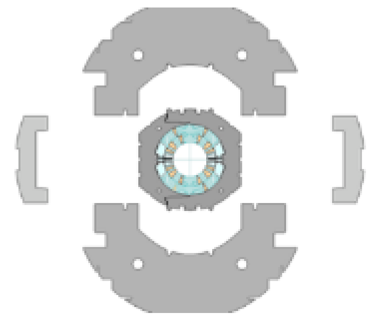
FNAL: MBHSP01 – 1-in-1 Demonstrator (2 m)

40-strand cable fabricated using FNAL cabling machine



Coil fabrication

Collared coil assembly



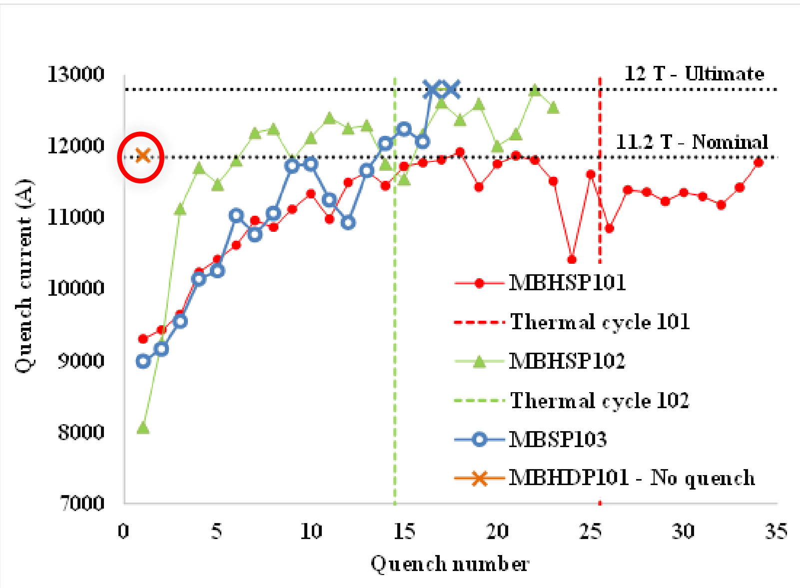
Cold mass assembly

MBHSP02 passed 11 T field during training at 1.9 K with I = 12080A on 5th March 2013!

Fermilab

11 T Dipole for HL-LHC (Dispersion suppressor collimation)
First assembly in Two-In-One magnet of short coils (1.8 m)
Nb3Sn technology

Single apertures n. 102 & 103 reached 12 T after some training that started at ~ 9 T.



- Cold powering test started on Wednesday 9th December : Result in red
- No quench up to 11.3 T, above nominal! Test stopped because of quen connection (**NOT in the magnet**). Magnet is warming up, fix clamp, tes

HL-LHC Upgrade Ingredients: Crab Cavities

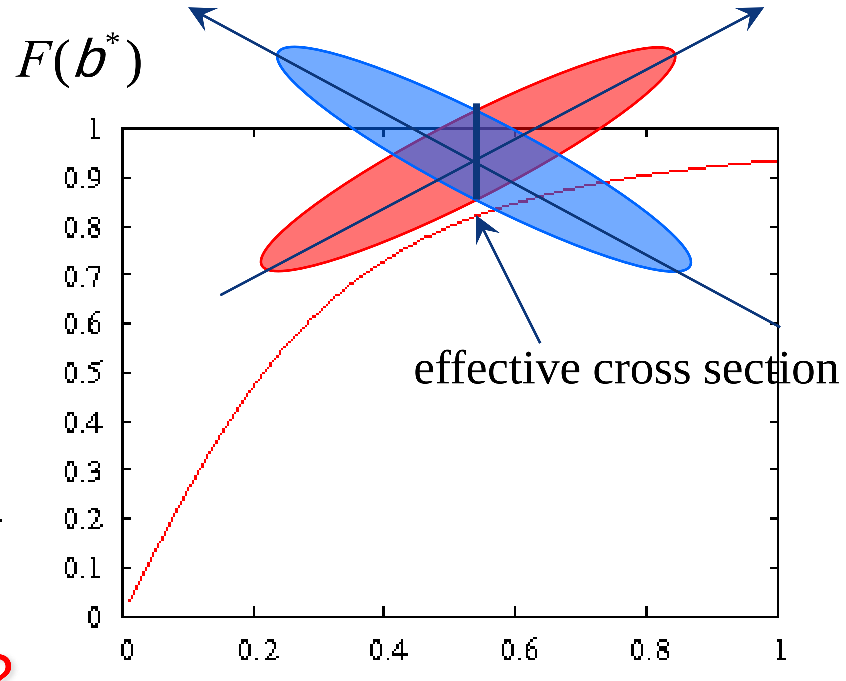
Geometric Luminosity Reduction Factor:

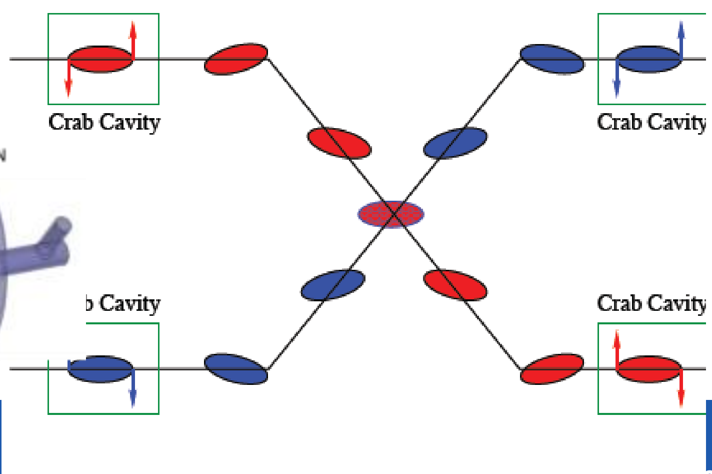
Crab Cavities:

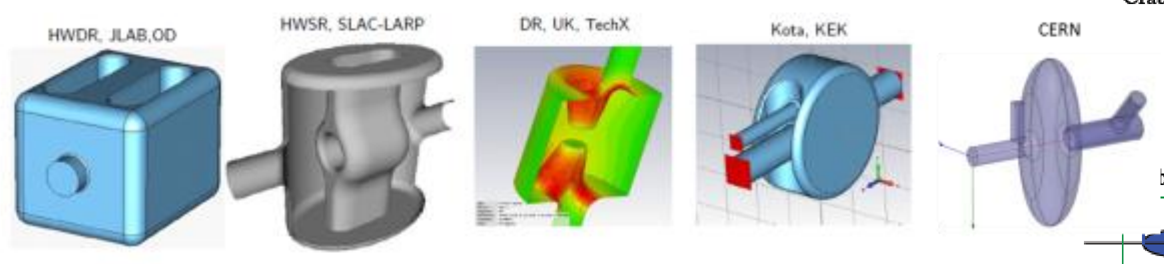
- Reduces the effect of geometrical reduction factor
- Independent for each IP

$$F = \frac{1}{\sqrt{1+\Theta^2}}; \quad \Theta \equiv \frac{\theta_c \sigma_z}{2\sigma_x}$$

- Noise from cavities to beam?!?
- Challenging space constraints



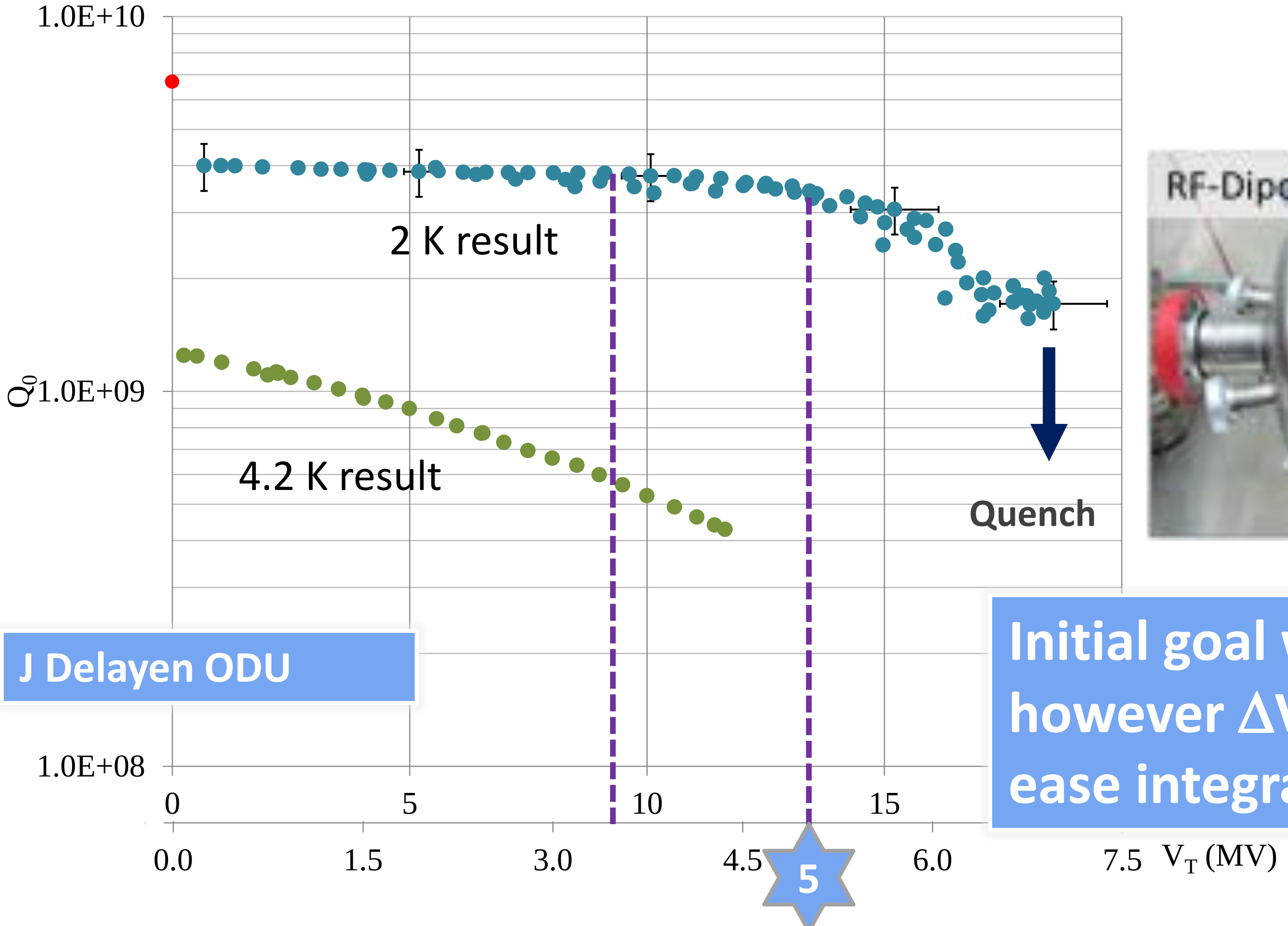




Compact cavities aiming at small footprint & 400 MHz, ~5 MV/cavity

Excellent first results: e.g. RF dipole > 5 MV

¼ w and 4-rods also tested (1.5 MV)



J Delayen ODU

Initial goal was 3.5 MV however ΔV > 5-6 MV would ease integration

Baseline parameters of HL for reaching 250 -300 fb^{-1}/year

25 ns is the option

However:
50 ns should be kept as alive and possible because we DO NOT have enough experience on the actual limit *(e-clouds, I_{beam})*

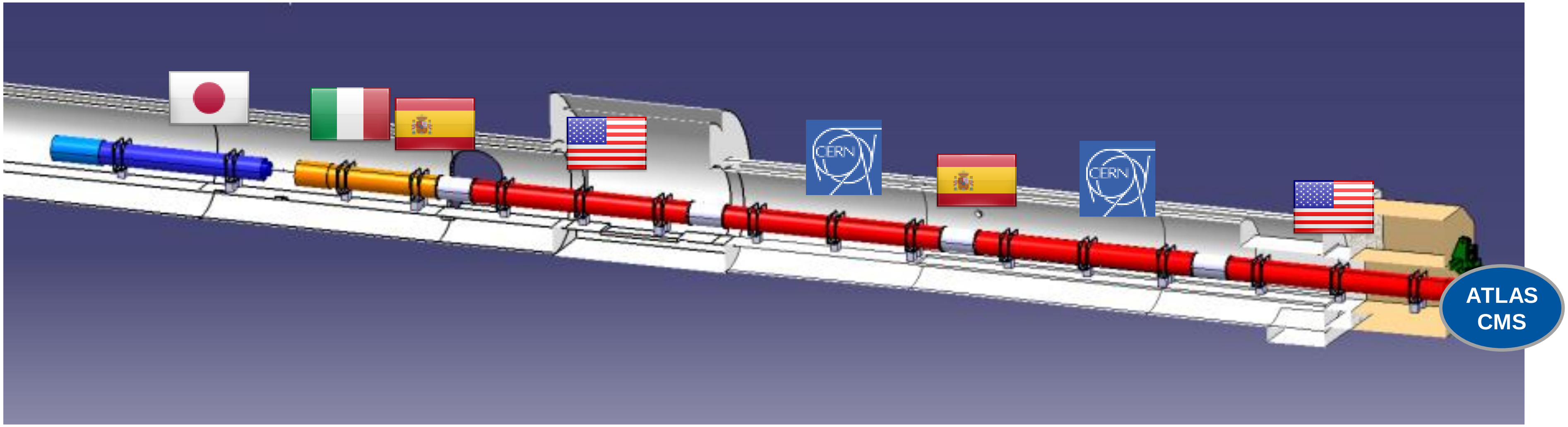
	25 ns	50 ns
# Bunches	2808	1404
p/bunch [10^{11}]	**2.0 (1.01 A)**	**3.3 (0.83 A)**
ε_L [eV.s]	2.5	2.5
σ_z [cm]	7.5	7.5
$\sigma_{\delta p/p}$ [10^{-3}]	0.1	0.1
$\gamma\varepsilon_{x,y}$ [μm]	**2.5**	**3.0**
β* [cm] (baseline)	15	15
X-angle [μrad]	**590 (12.5 σ)**	**590 (11.4 σ)**
Loss factor	0.30	0.33
Peak lumi [10^{34}]	6.0	7.4
Virtual lumi [10^{34}]	20.0	22.7
$T_{leveling}$ [h] @ 5E34	**7.8**	**6.8**
#Pile up @5E34	123	247

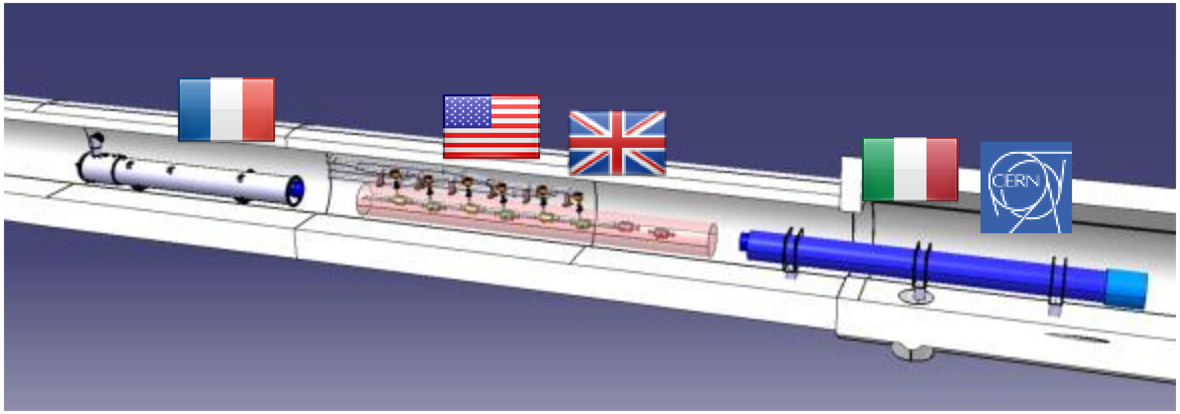
Continuous global optimisation with LIU

Courtesy Oliver Brüning

In-kind contributions and collaborations for design, prototypes, production and tests

Discussions are ongoing with other countries, e.g Canada,…





Q1-Q3 : R&D, Design, Prototypes and in-kind **USA**
D1 : R&D, Design, Prototypes and in-kind **JP**
MCBX : Design and Prototype **ES**
HO Correctors: Design and Prototypes **IT**
Q4 : Design and Prototype **FR**

CC : R&D, Design and in-kind **USA**

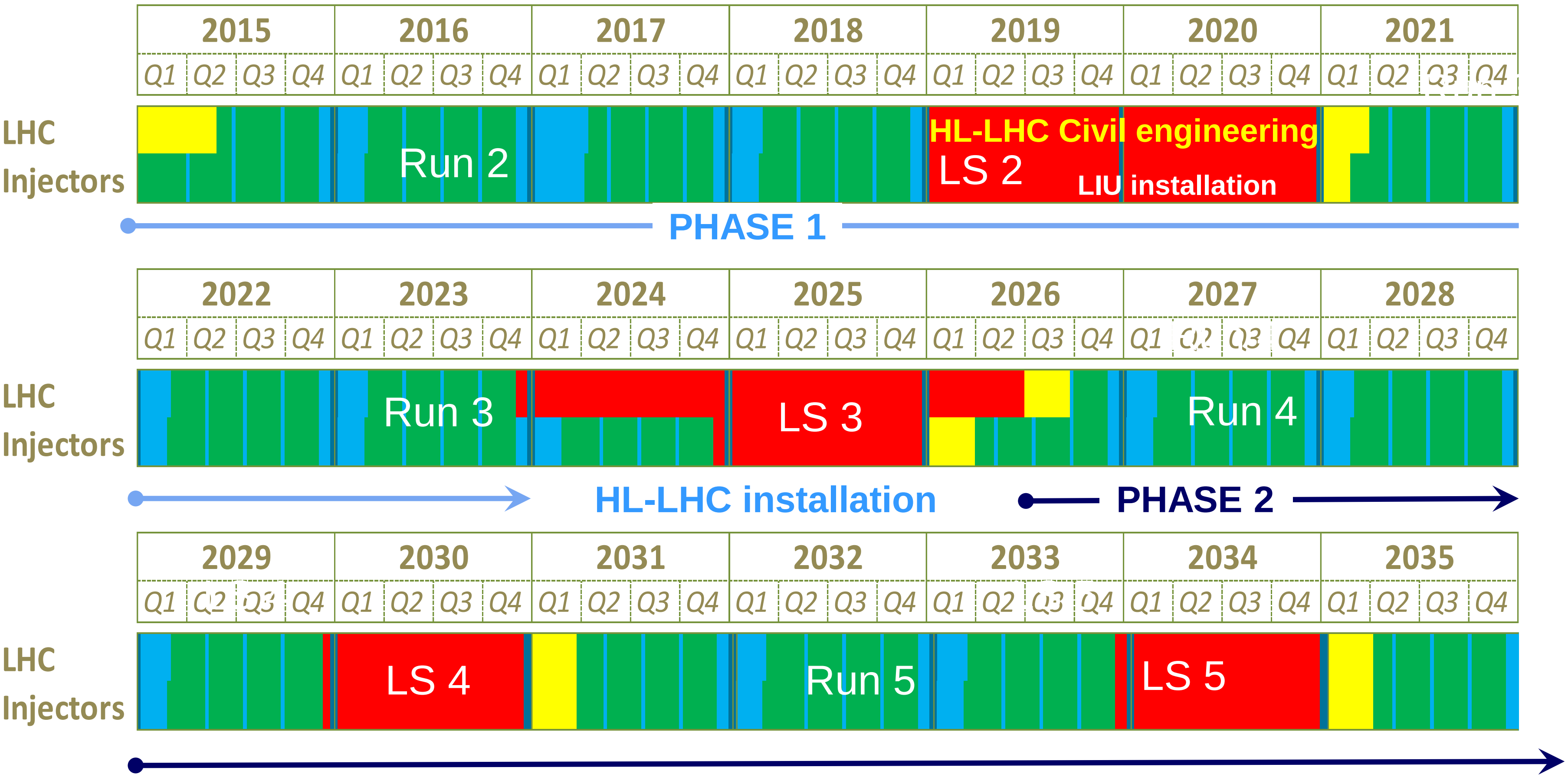
CC : R&D and Design **UK**

High Luminosity LHC

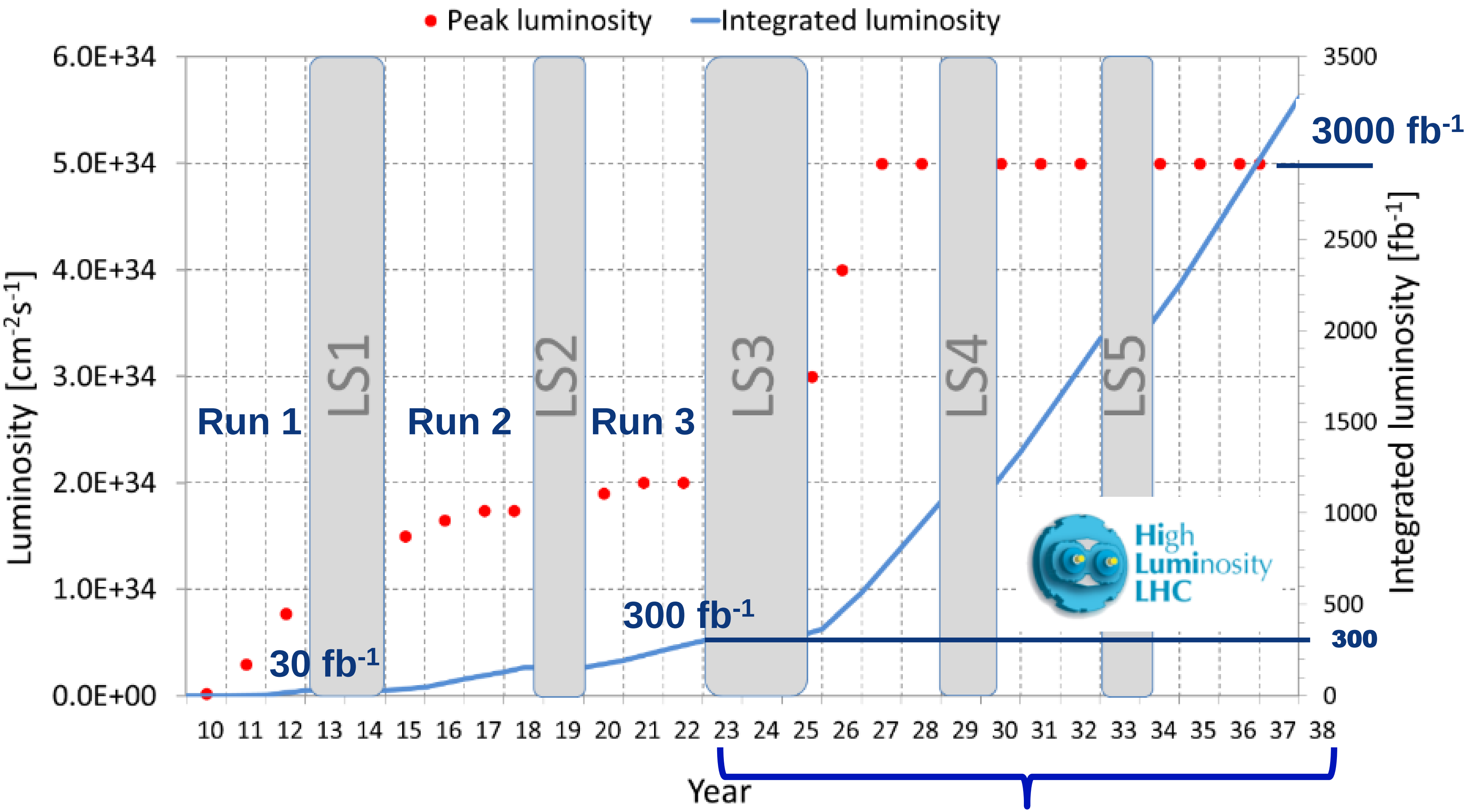
High Luminosity LHC Participants

LHC roadmap: according to MTP 2016-2020

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

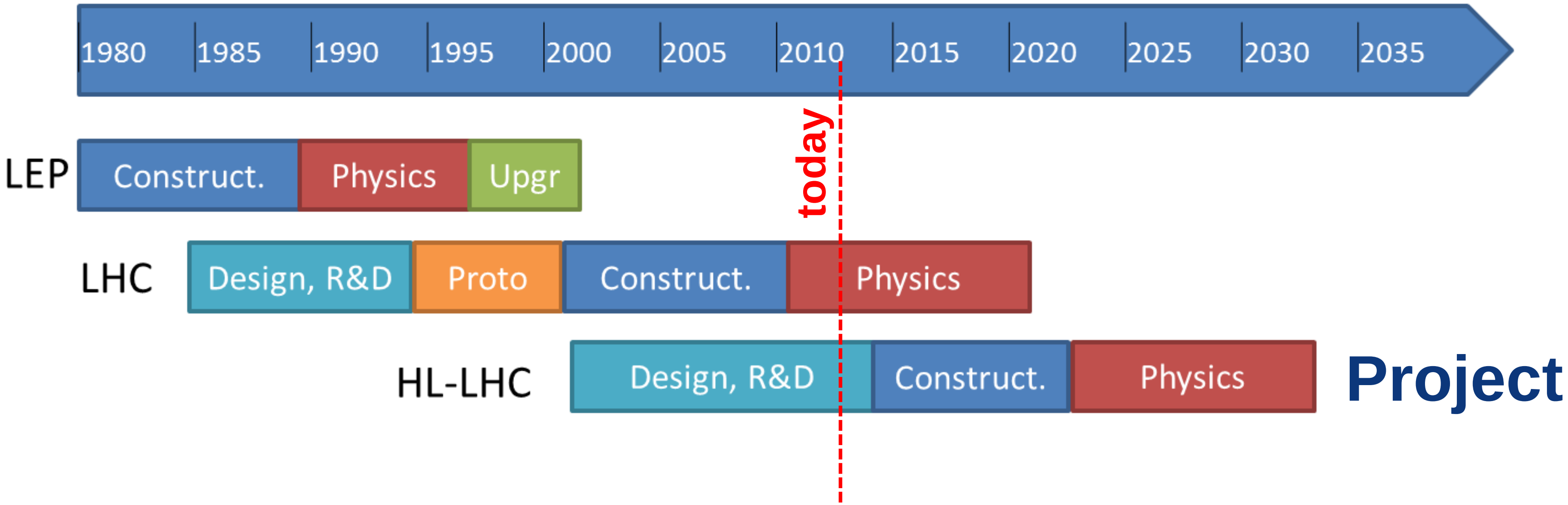


LHC roadmap: **Goal of 3'000 fb^{-1}** by mid 2030ies



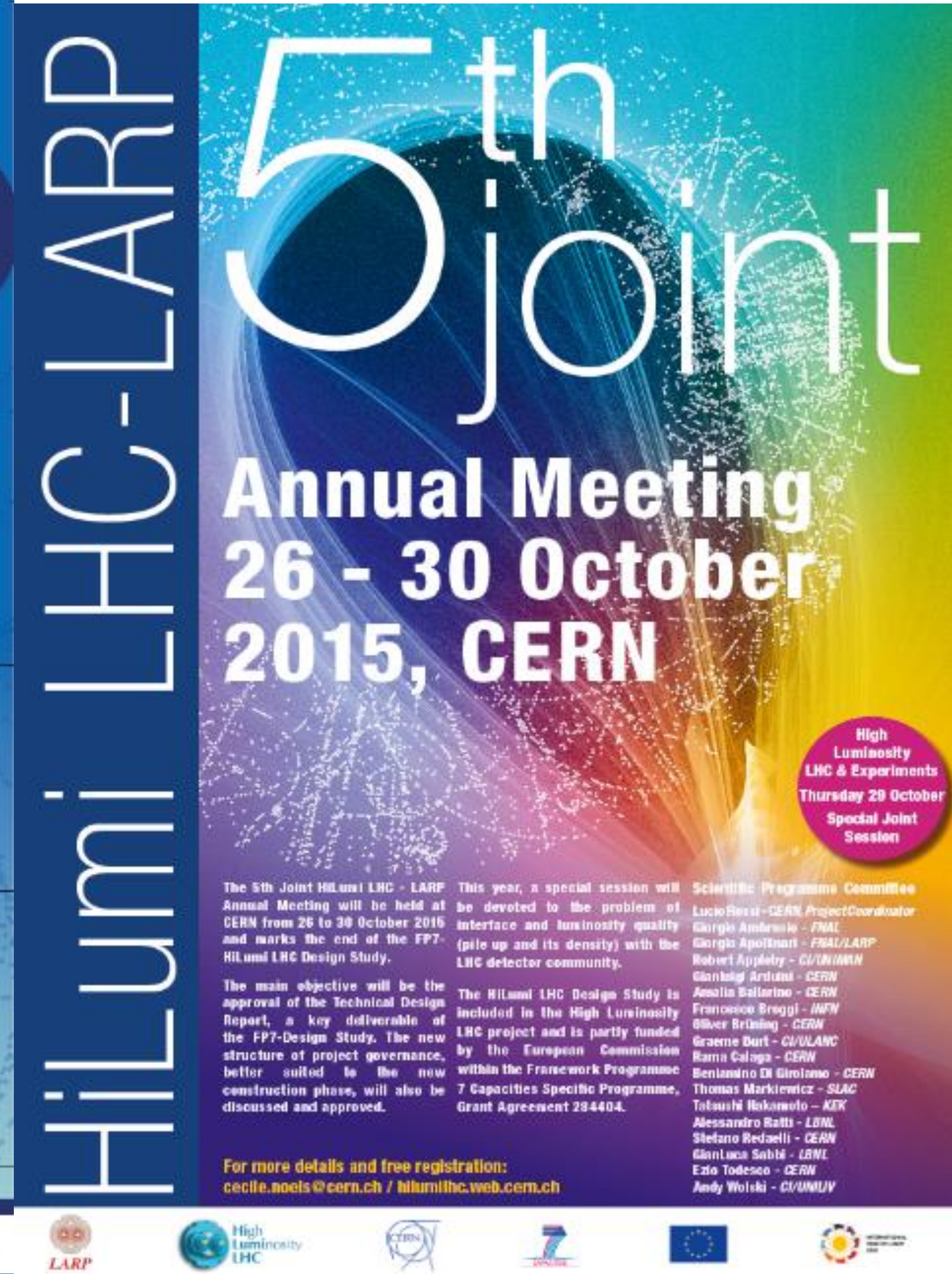
High Luminosity project (HL-LHC)

"…exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors…"
=> High Luminosity LHC project



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

http://cern.ch/hilumilhc



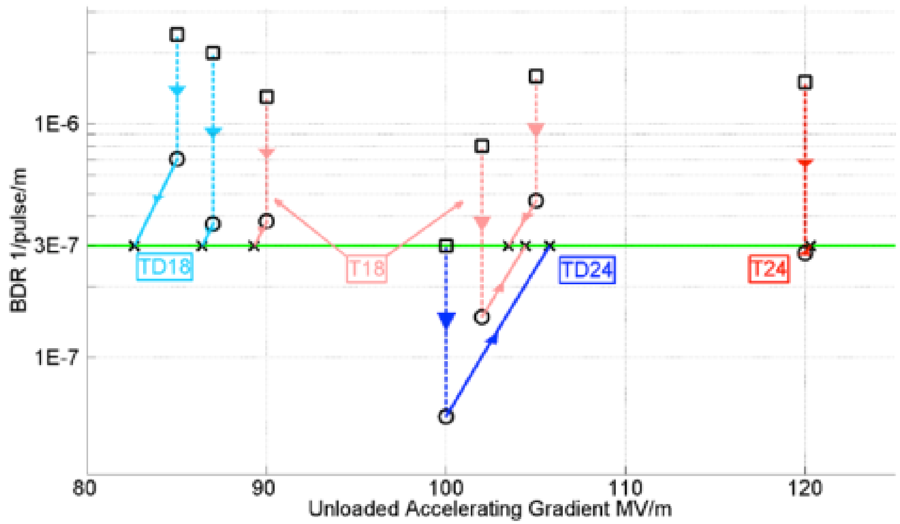
http://cern.ch/hilumilhc

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

d) *CERN should undertake design studies for accelerator projects in a global context,*

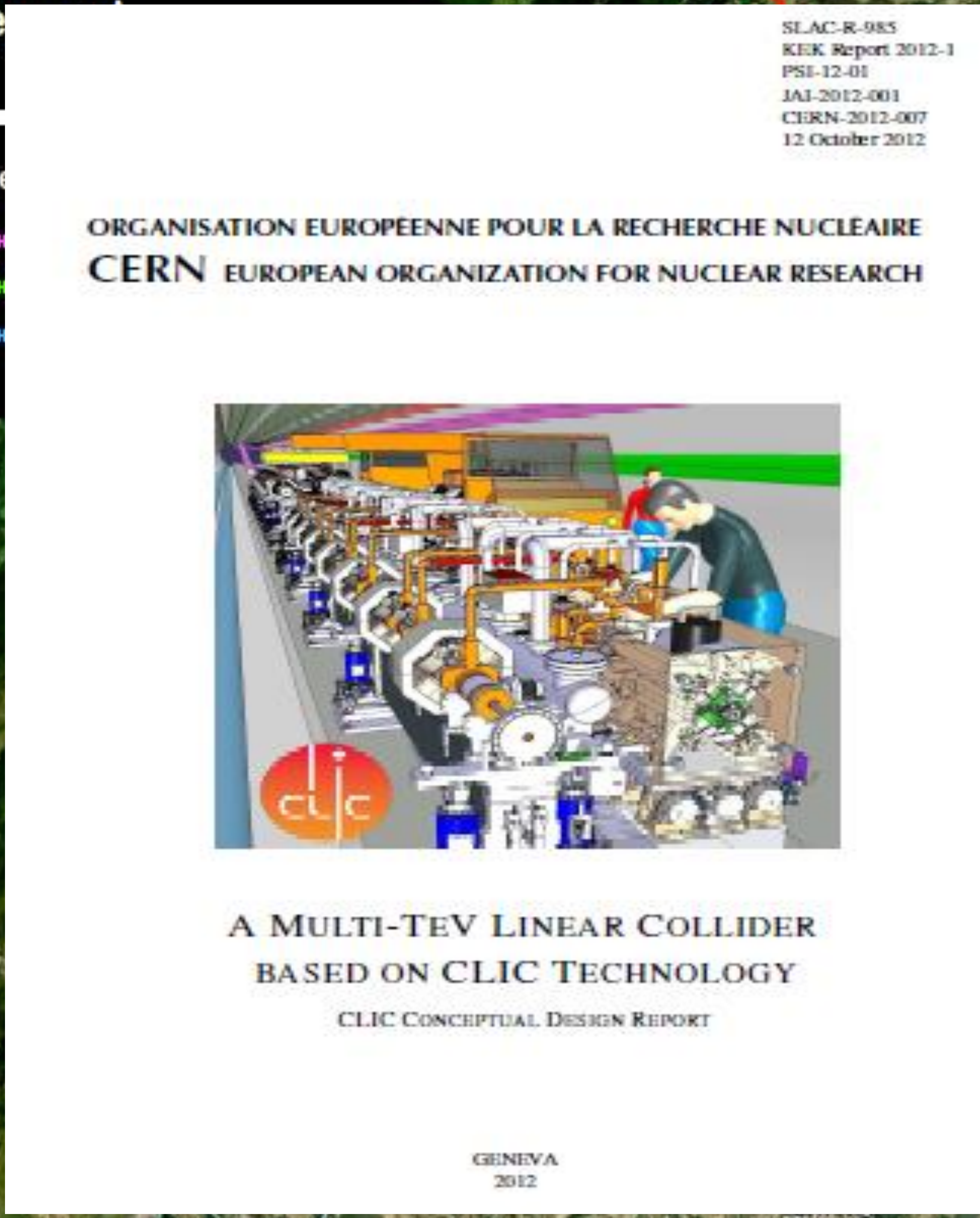
*with emphasis on **proton-proton and electron-positron high-energy frontier machines**. These design studies should be coupled to a vigorous accelerator **R&D programme**, including **high-field magnets and high-gradient accelerating structures**, **in collaboration with national institutes, laboratories and universities worldwide.***

HGA



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

CLIC Multi-TeV Linear Collider


SLAC-R-985
KEK Report 2012-1
PSI-12-01
JAI-2012-001
CERN-2012-007
12 October 2012

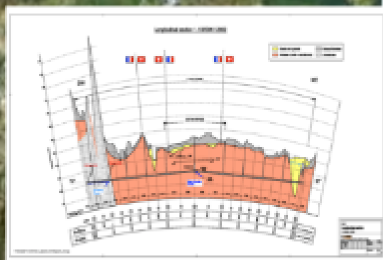
ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

A MULTI-TEV LINEAR COLLIDER BASED ON CLIC TECHNOLOGY

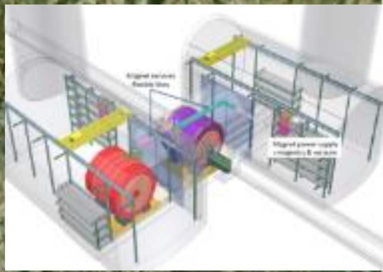
CLIC CONCEPTUAL DESIGN REPORT

GENEVA
2012

Lake Geneva



Tunnel implementations (laser straight)

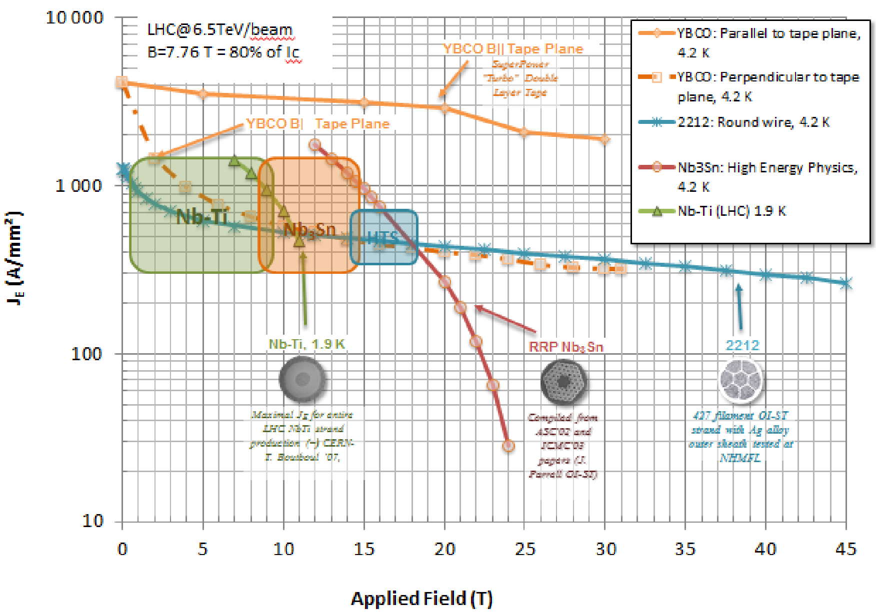


Central MDI & Interaction Region

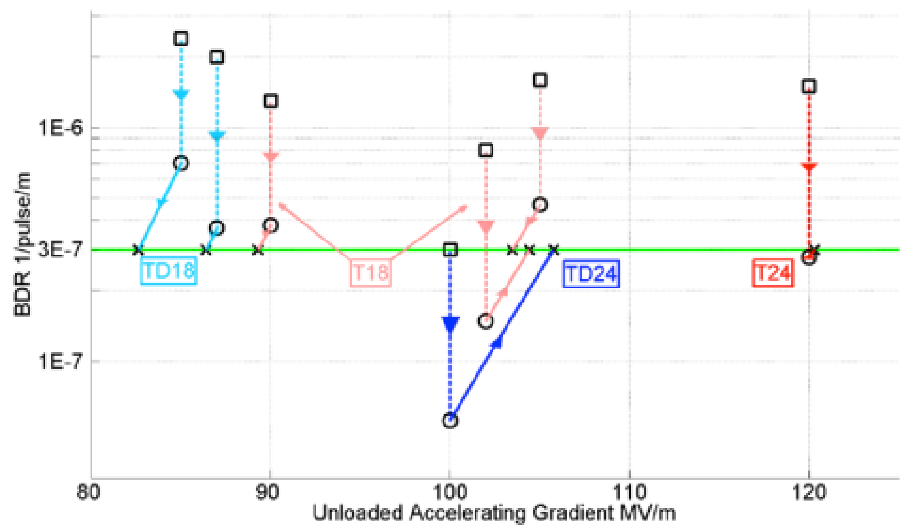
“to propose an ambitious **post-LHC accelerator project at CERN** by the time of the next Strategy update”

d) 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

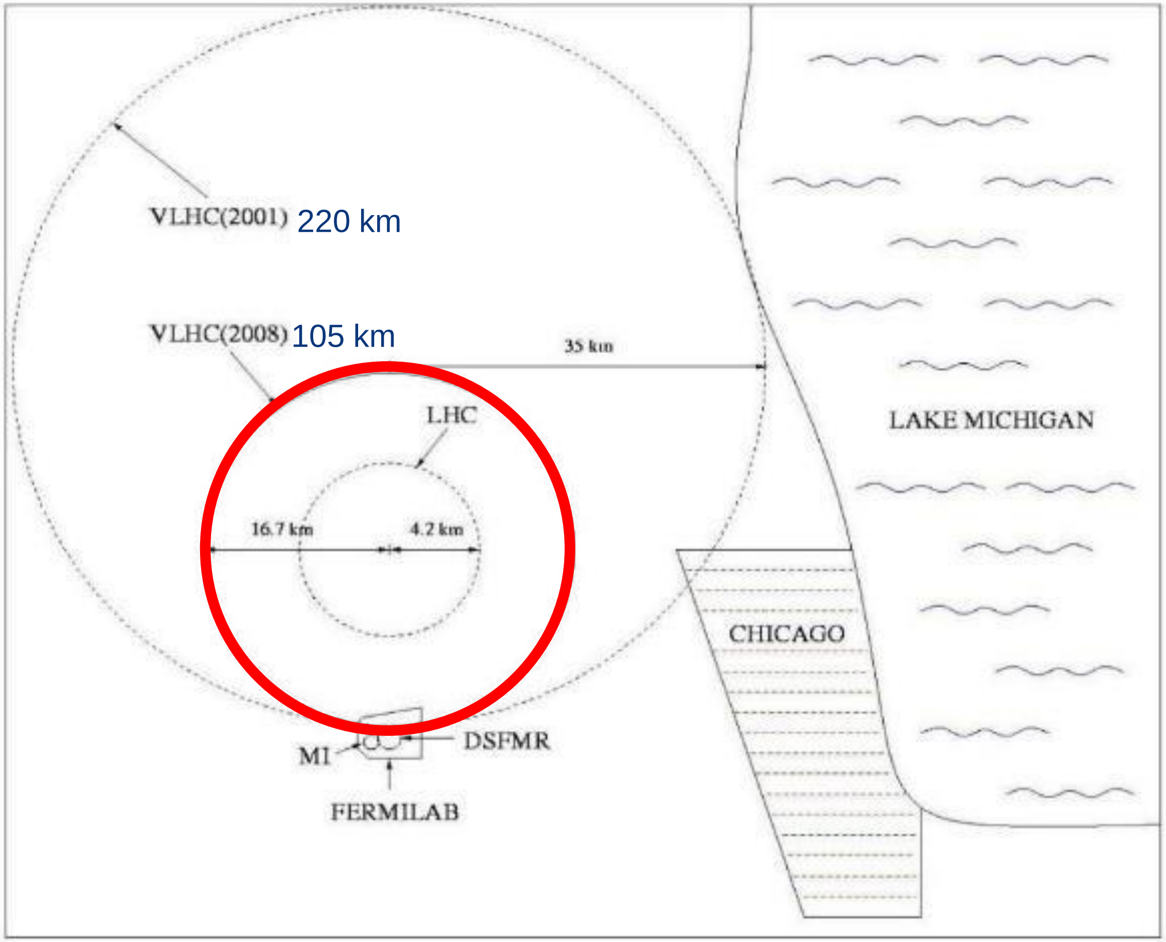


HGA



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

105 km tunnel near FNAL

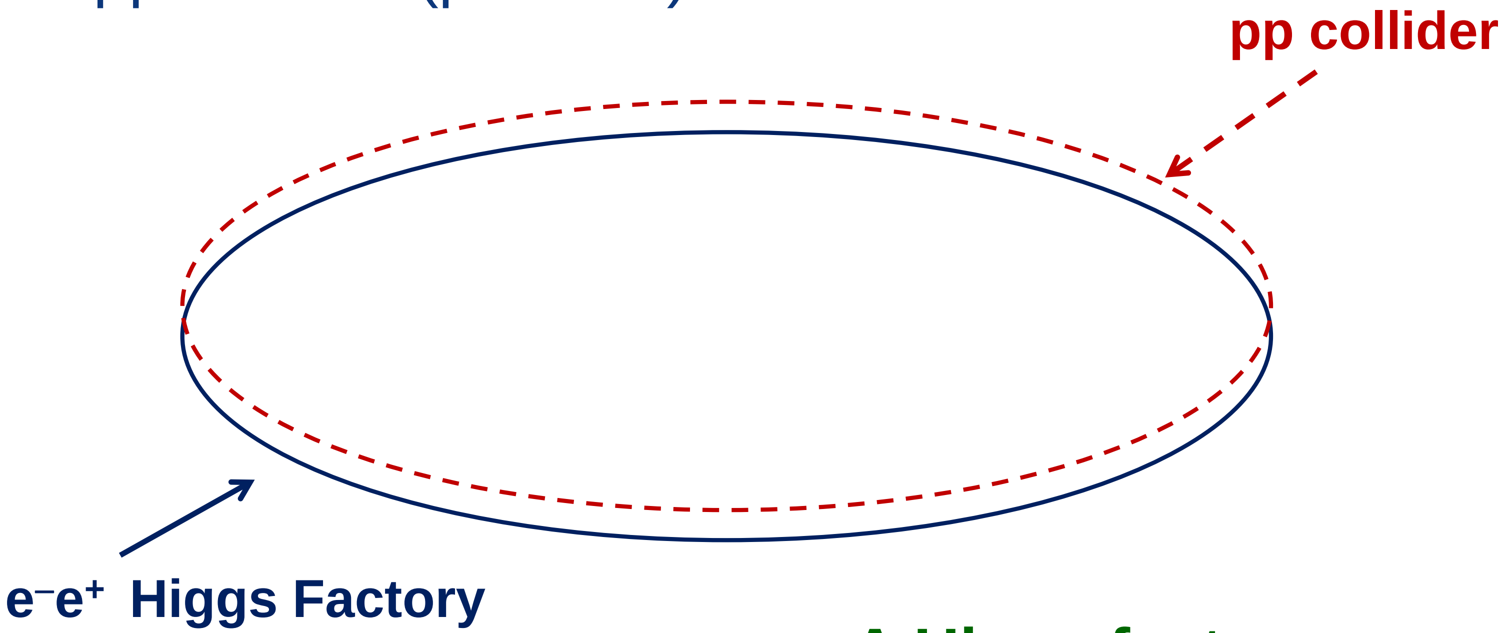


H. Piekarz, "… and … path to the future of high energy particle physics," JINST 4, P08007 (2009)


80 km ring in KEK area
12.7 km
KEK
Mt Tsukuba
筑波山
Tsutsujigaoka
つつじヶ丘
Miyawaki
宮脇
Mt Fuji
富士山
Ishioka
City Office
Makabe Branch
City Office
Chiyoda Branch
市役所千代田庁舎
City Office
Niihari Branch
フラワーパーク
筑波国際CC
筑波東急GC
千代田PA
Toyosato
Map data ©2012 Google, ZENRIN

Introduction — What is a (CEPC + SppC) ?
Chinese project

- Circular Electron Positron Collider (phase I) +
  Super pp Collider (phase II) in the same tunnel



A Higgs factory +
A machine of discovery

CEPC basic parameter:

- Beam energy ~120 GeV.
- Synchrotron radiation power ~50 MW.
- 50/70 km in circumference.

SppC basic parameter:

- Beam energy ~50-70 TeV.
- 50/70 km in circumference.
- Needs B_{max} ~20T.

The circumference of CEPC is determined by that of the SppC, which is determined by the final energy of proton beam and the achievable dipole field strength.

2013-10-18 6th TLEP workshop

中國科學院高能物理研究所
Institute of High Energy Physics 4

CEPC+SppC

Where(if in China):
For example, Qin-Huang-Dao

CEPC+SppC

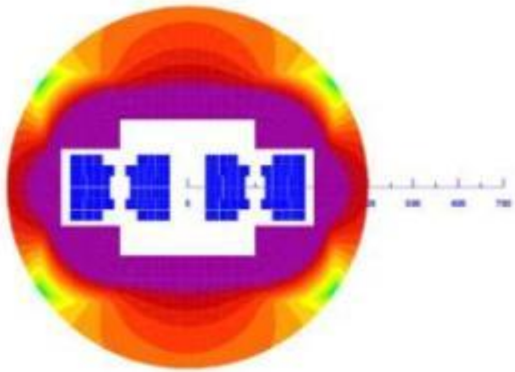
When(**dream**):

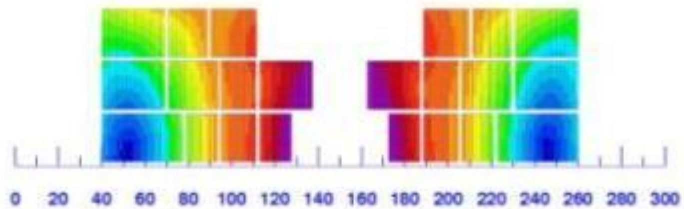
- CPEC
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-15
    - R&D: 2015-2020
    - Engineering Design: 2015-2020
  - **Construction: 2021-2027**
  - **Data taking: 2028-2035**
- SppC
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-2020
    - R&D: 2020-2030
    - Engineering Design: 2030-2035
  - **Construction: 2035-2042**
  - **Data taking: 2042 -**

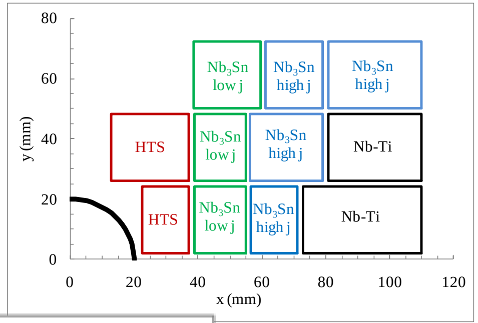
International Workshop on Future High Energy Circular Colliders (December 2013) (IHEP, Beijing)

Courtesy of Prof. Yifang Wang (IHEP)

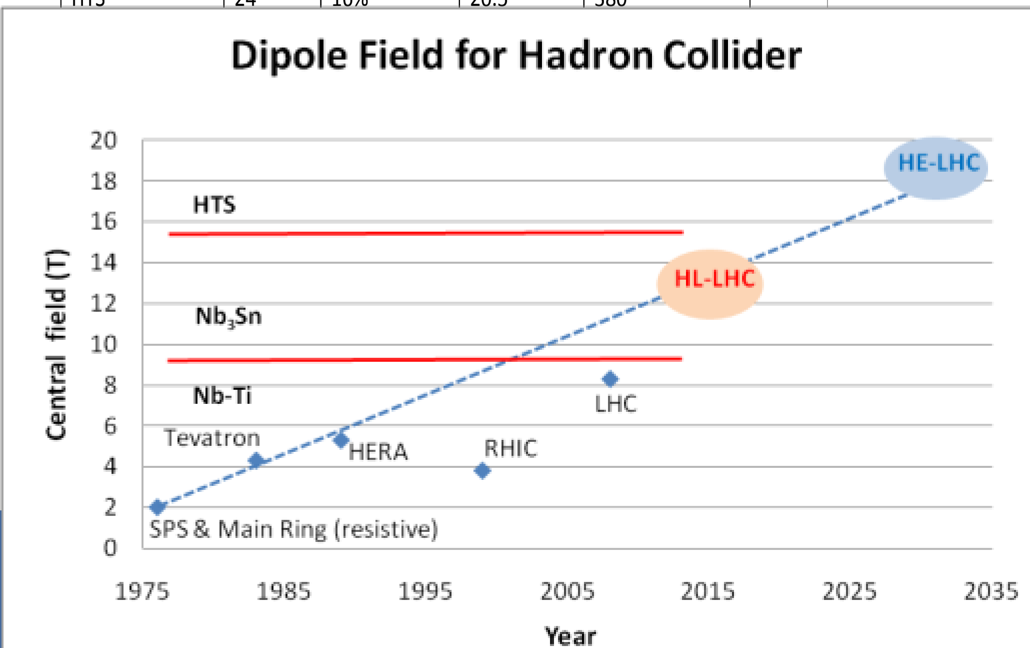
Malta Workshop: **HE-LHC @ 33 TeV c.o.m.**
14-16 October 2010







Material	N. turns	Coil fraction	Peak field	$J_{overall}$ (A/mm^2)
Nb-Ti	41	27%	8	380
Nb3Sn (high Jc)	55	37%	13	380
Nb3Sn (Low Jc)	30	20%	15	190
HTS	24	16%	20.5	380



Magnet design (20 T): very challenging but not impossible.

300 mm inter-beam

Multiple powering in the same magnet (and more sectioning for energy)

Work for 4 years to assess HTS for 2X20T to open the way to 16.5 T/beam .

Otherwise limit field to 15.5 T for 2x13 TeV

Higher INJ energy is desirable (2xSPS)

ng the beam screen at 60 K.

ks to dumping time.

IC. Reaching 2x10^{34} appears reasonable.

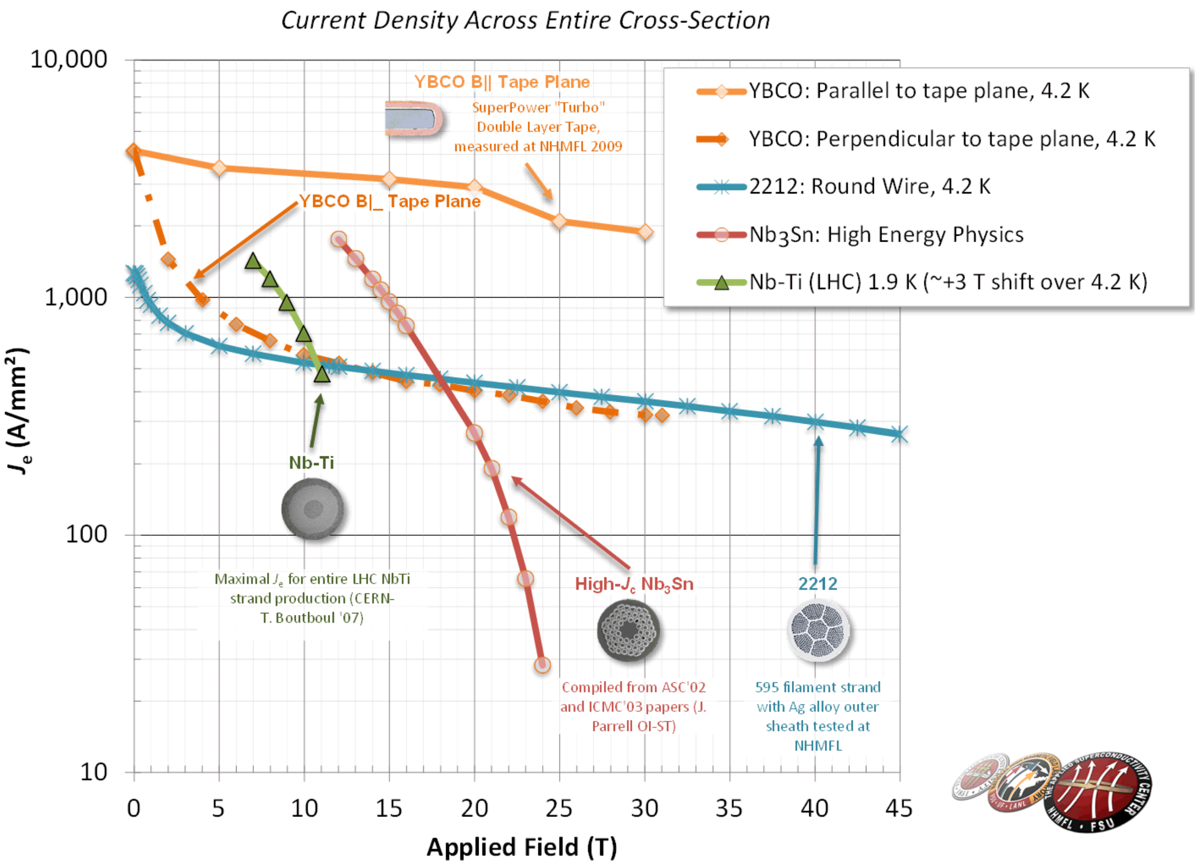
s beam handling for INJ & beam dump:

nake twice more room for LHC kickers.

HE-LHC main parameters

parameter	LHC	HL-LHC	HE-LHC
c.m. energy [TeV]	14		33
circumference *C* [km]	26.7		26.7
dipole field [T]	8.33		20
dipole coil aperture [mm]	56		40
beam half aperture [cm]	~2		1.3
injection energy [TeV]	0.45		>1.0
no. of bunches	2808		2808
bunch population N_b [10^{11}]	1.15	2.2	0.94
init. tr. norm. emittance [μm]	3.75	2.5	1.38
init. longit. emittance [eVs]	2.5		3.8
no. IPs contributing to ΔQ	3	2	2
max. total b-b tune shift ΔQ	0.01	0.015	0.01
beam current [A]	0.584	1.12	0.478
rms bunch length [cm]	7.55		7.55
IP beta function [m]	0.55	0.15	0.35
rms IP spot size [μm]	16.7	7.1 (min.)	5.2

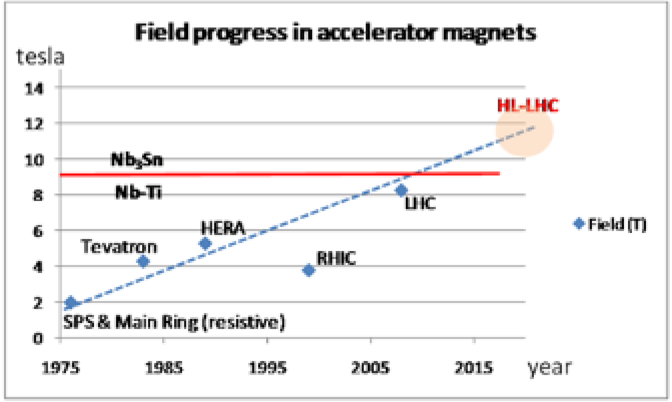
Superconductors:
from materials to applications



Superconductors as seen by the eye of an engineer

The grand challenge of today is to develop the technology of **high-field superconductors**
(field quality,…)

LTS (NbTi ; Nb_3Sn)



NbTi mature but limited to 9T

Is Nb_3Sn mature ? Yes, and no

performance of Nb_3Sn wires has seen a great boost in the past decade (factor 3 in J_C w/r to ITER)

However, Nb_3Sn magnets were never built nor operated in accelerators. Manufacturing, quench, training, protection, strain tolerance, field quality are the focus today to make this new technology a reality

Solid and aggressive R&D in HFM (High Field Magnet) for accelerators must be intensified

From Luca Bottura

HTS

Can HTS displace LTS ? Not today

Much needs to be done to bring this technology to a point where it can be sold as "mature"

Materials have potential that can be exploited

- OPHT for BSCCO-2212
- Thicker layer for YBCO tapes
- The Holy Grail of a round YBCO wire

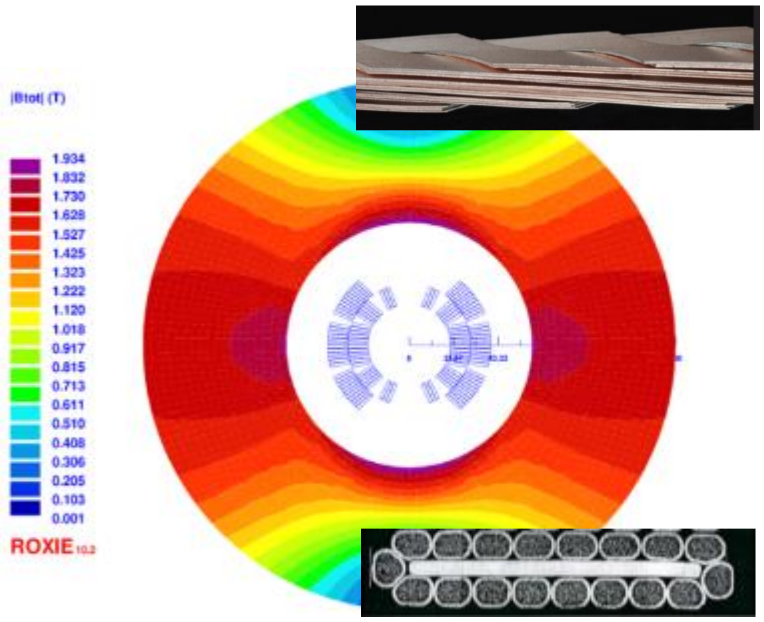
Production quantities, homogeneity and cost need to evolve

Step-up application demands, from self-field (SC-link is an ideal test-bed) to high-field accelerator magnets (feasibility)

From Luca Bottura

Program Eucard2 on HTS

EuCARD2: Develop 10 kA class HTS accelerator cable using Bi-2212 and YBCO. Test stability, magnetization, and strain tolerance



WP10: a 5 T, 40 mm bore HTS dipole

Future Circular Collider

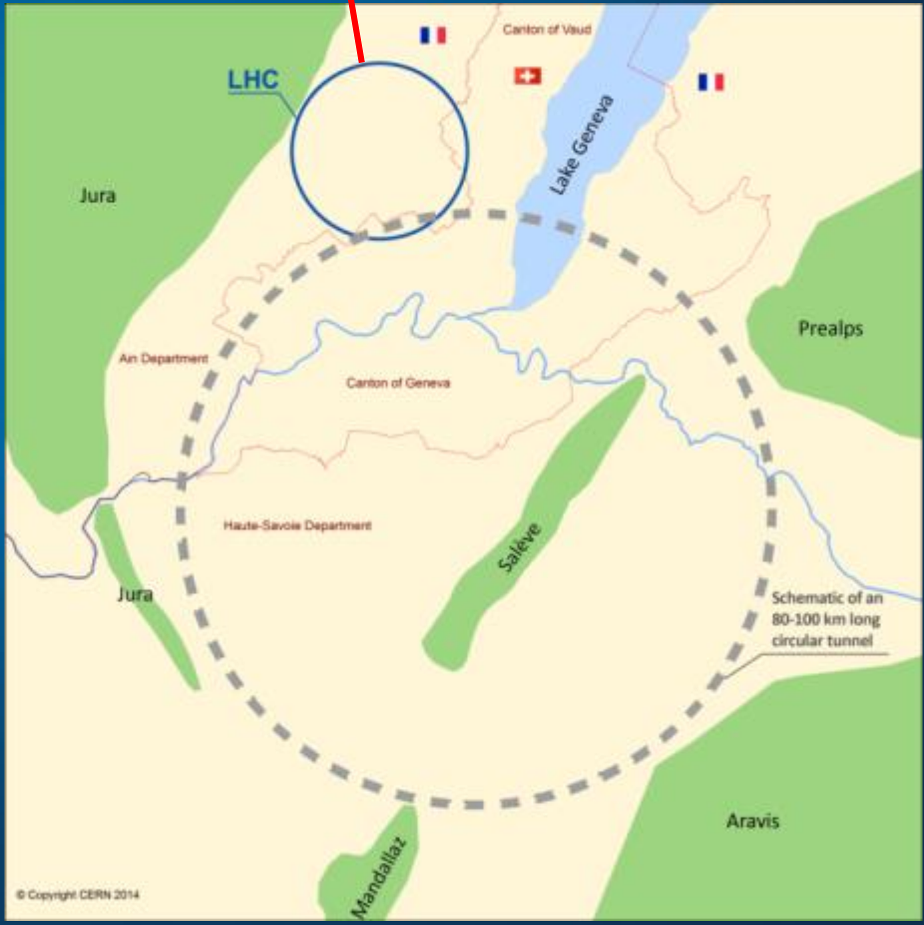
FCC hh ee he

CERN

First studies on a new 80 km tunnel in the Geneva area

High Energy-LHC :33 TeV with 20T magnets

- **42 TeV** with **8.3 T** using present LHC dipoles
- **80 TeV** with **16 T** based on Nb_3Sn dipoles
- **100 TeV** with **20 T** based on HTS dipoles



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

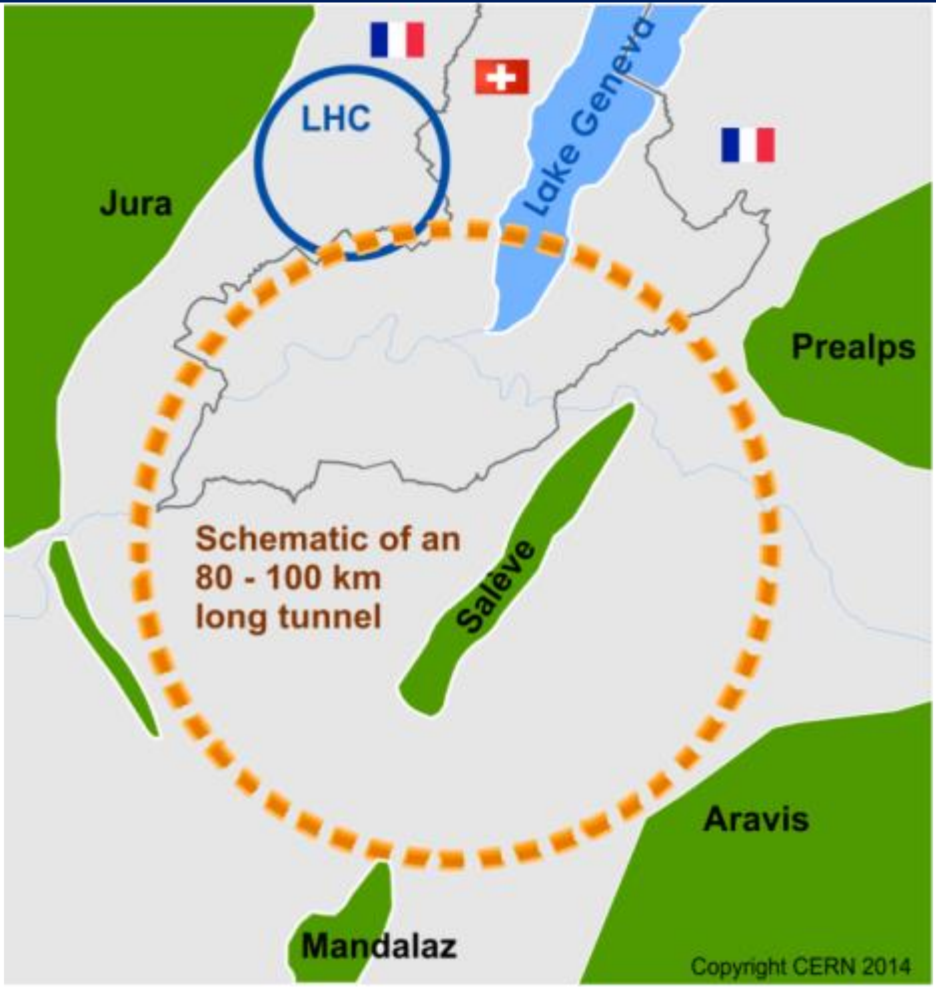
Forming an international collaboration to study:

- ***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


Future Circular Collider Study
Kick-off Meeting
12-15 February 2014,
University of Geneva,
Switzerland
LOCAL ORGANIZING COMMITTEE
University of Geneva
C. Blanchard, A. Blondel,
C. Doglioni, G. Iacobucci,
M. Koratzinos
CERN
M. Benedikt, E. Delucinge,
J. Gutleber, D. Hudson,
C. Potter, F. Zimmermann
SCIENTIFIC ORGANIZING
COMMITTEE
FCC Coordination Group
A. Ball, M. Benedikt, A. Blondel,
F. Bordry, L. Bottura, O. Brüning,
P. Collier, J. Ellis, F. Gianotti,
B. Goddard, P. Janot, E. Jensen,
J. M. Jimenez, M. Klein, P. Lebrun,
M. Mangano, D. Schulte,
F. Sonnemann, L. Tavian,
J. Wenninger, F. Zimmermann
UNIVERSITÉ
DE GENÈVE
EuCARD
ECFA
http://indico.cern.ch/
e/fcc-kickoff


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)
E. Delucinge (CERN)
J. Ellis (King's College)
A. Blondel (U. Geneva)
F. Gianotti (CERN)
B. Goddard (CERN)
S. Gourlay (LBNL)
C. Grojean (ICREA)
J. Gutleber (CERN)
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P. Janot (CERN)
E. Jensen (CERN)
J.M. Jimenez (CERN)
M. Klute (MIT)
A. Lankford (UC Irvine)
D. Larbalestier (NHFML)
P. Lebrun (CERN)
L.K. Len (DOE)
E. Levichev (BINP)
M. D'Onofrio (U. Liverpool)
M. Klein (U. Liverpool)
J. Lykken (FNAL)
M. Mangano (CERN)
A. Patwa (DOE)
R. Sundrum (U. Maryland)
S. Nagaitsev (FNAL)
T. Ogitsu (KEK)
K. Oide (KEK)
E. Palmieri (INFN-LNL)
F. Perez (ALBA-CELLS)
C. Potter (CERN)
Q. Qin (IHEP)
B. Rimmer (JLAB)
T. Roser (BNL)
L. Rossi (CERN)
D. Schulte (CERN)
M. Seidel (PSI)
A. Seryi (JAI)
Shufang Su (Arizona)
B. Strauss (DOE)
S. Strauss
M. Syphers (MSU-FNAL)
L. Tavian (CERN)
E. Todesco (CERN)
R. Van Kooten (U. Indiana)
P. Vedrine (CEA)
J. Wenninger (CERN)
U. Wienands (SLAC)
F. Zimmermann (CERN)
CERN
FCC
U.S. DEPARTMENT OF ENERGY
Office of Science
Further information and registration
http://cern.ch/fccw2015
EuCARD

FCC Week 2016

Rome, 11-15 April 2016

SAPIENZA UNIVERSITÀ DI ROMA

INFN Istituto Nazionale di Fisica Nucleare Sezione di Roma

INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati

ROMA TRE UNIVERSITÀ DEGLI STUDI

CERN

FCC-hh Key Parameters

Parameter	FCC-hh	LHC
Energy [TeV]	**100 c.m.**	**14 c.m.**
Dipole field [T]	**16**	**8.33**
# IP	2 main, +2	4
Luminosity/IP_{main} [$cm^{-2}s^{-1}$]	5-10 x 10^{34}	1 x 10^{34}
Energy/beam [GJ]	**8.4**	**0.39**
Synchr. rad. [W/m/apert.]	28.4	0.17
Bunch spacing [ns]	25 (5)	25

Preliminary, subject to evolution

discharge 330 μs ⇒ 24 TW

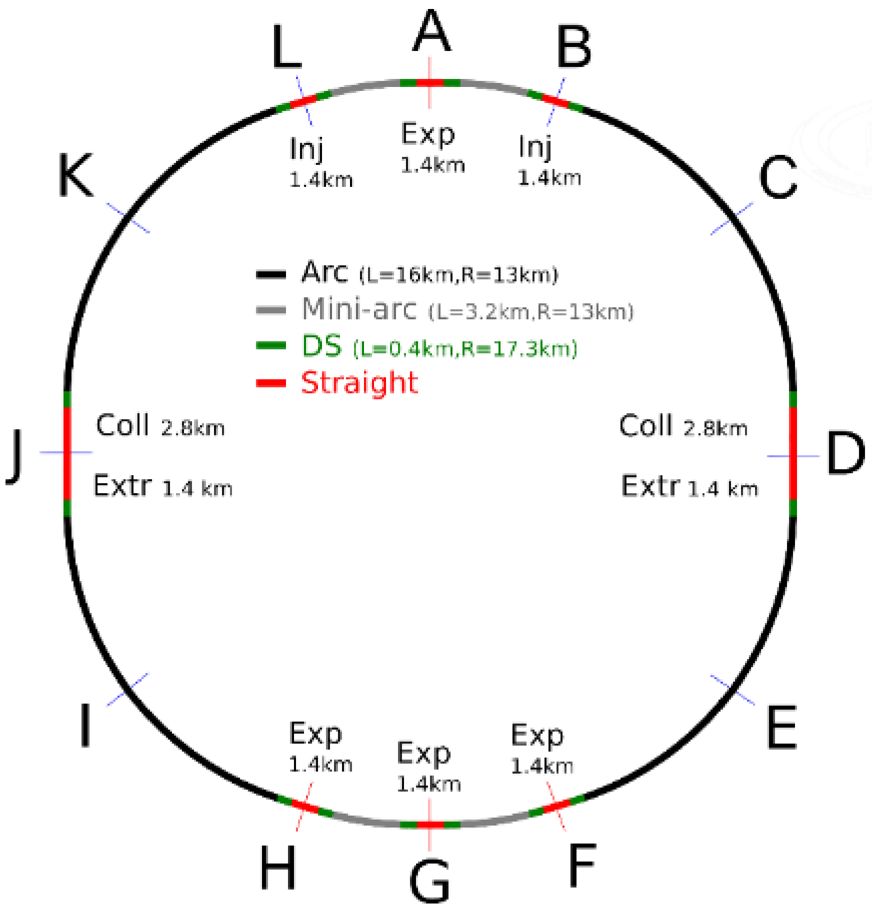
FCC-ee Key Parameters

Parameter	FCC-ee			LEP2
Energy/beam [GeV]	45	120	175	105
Bunches/beam	16700	1360	98	4
Beam current [mA]	1450	30	6.6	3
Luminosity/IP x 10^{34} $cm^{-2}s^{-1}$	28	6	1.8	0.0012
Energy loss/turn [GeV]	0.03	1.67	7.55	3.34
Synchr. Power [MW]	**100**			**22**
RF Voltage [GV]	2.5	5.5	11	3.5

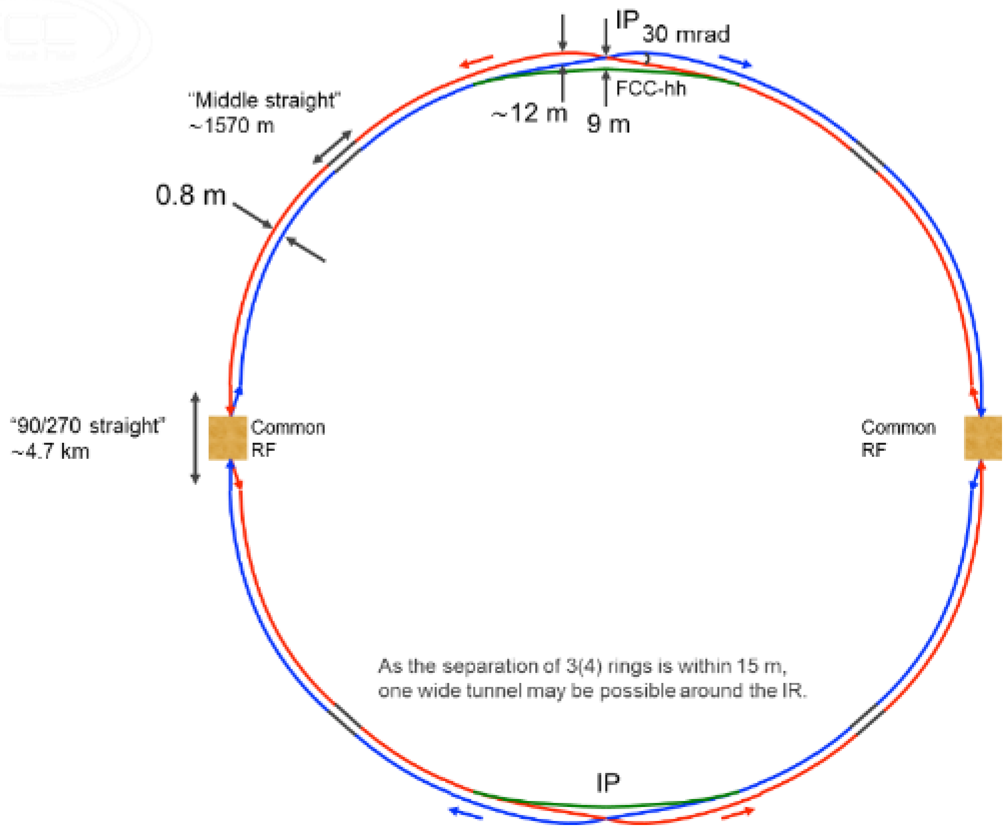
Preliminary, subject to evolution

22 MW at LEP2

FCC-hh



FCC-ee 1, FCC-ee 2, FCC-hh and FCC-ee booster



Key Technologies and Challenges

- 16T superconducting magnets
- Superconducting RF cavities
- RF power sources
- Affordable & reliable cryogenics

- Reliability & availability concepts
- Stored Energy in the beams

  8.4 GJ / beam ; discharge 330 μs ⇒ 24 TW
- Tunnel Geology

Layout Studies

ARUP

Alignment | **Shaft Tools**

Choose alignment option: 93km quasi-circular

Tunnel depth at centre: 286mASL

Gradient Parameters

- Azimuth (°): -15
- Slope Angle x-x(%): 3
- Slope Angle y-y(%): 0

CALCULATE

Alignment centre

X: 2498923 Y: 1106695

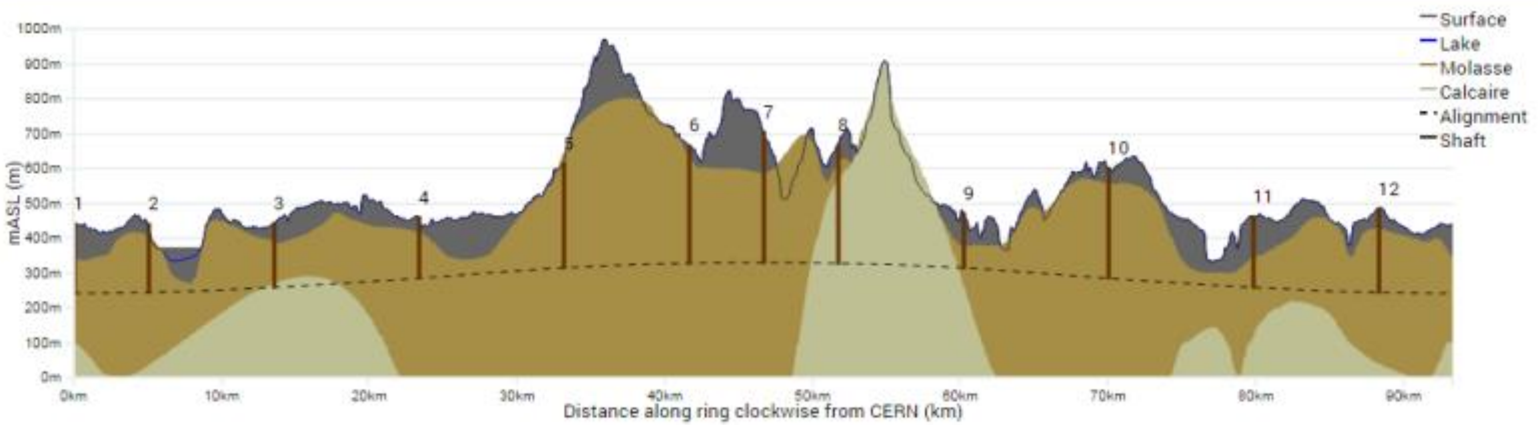
LHC Intersection	IP 1	IP 2
Angle	1°	-1°
Depth	542m	542m

Alignment Location

Geology Intersected by Shafts | **Shaft Depths**

Shaft	Shaft Depth (m)				Geology (m)		
	Actual	Min	Mean	Max	Moraine	Molasse	Calcaire
1	200	195	197	200	92	108	0
2	196	143	181	211	34	162	0
3	183	175	184	194	53	121	9
4	174	146	166	178	44	130	0
5	299	286	311	350	0	325	0
6	336	325	339	350	35	302	0
7	374	349	377	412	119	256	0
8	337	318	341	366	44	56	237
9	155	131	145	167	94	61	0
10	315	305	320	336	46	269	0
11	203	199	202	204	122	81	0
12	239	229	238	243	58	181	0
Total	3014	2801	3001	3211	741	2052	247

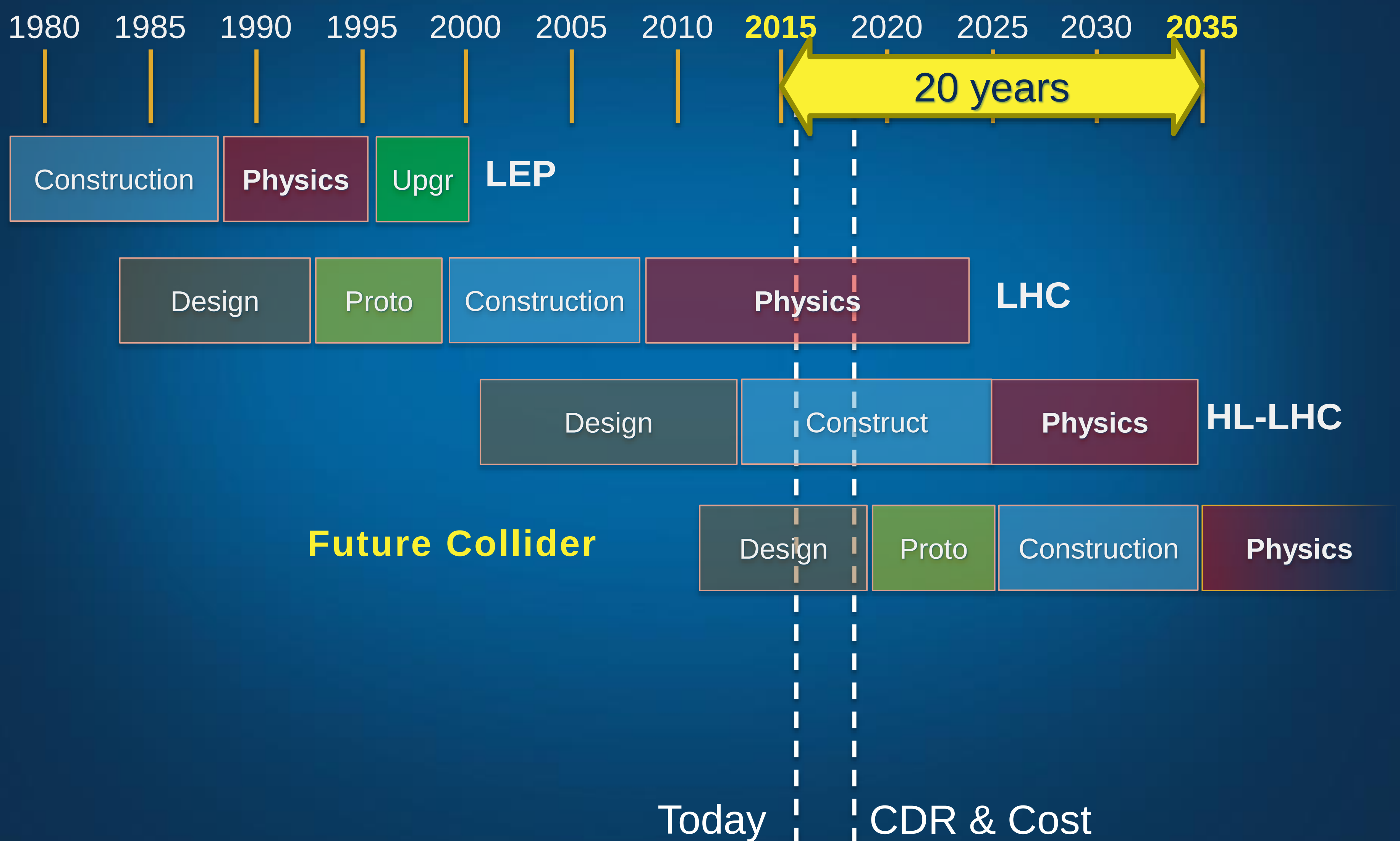
Alignment Profile



Collaboration Status (11/2015)

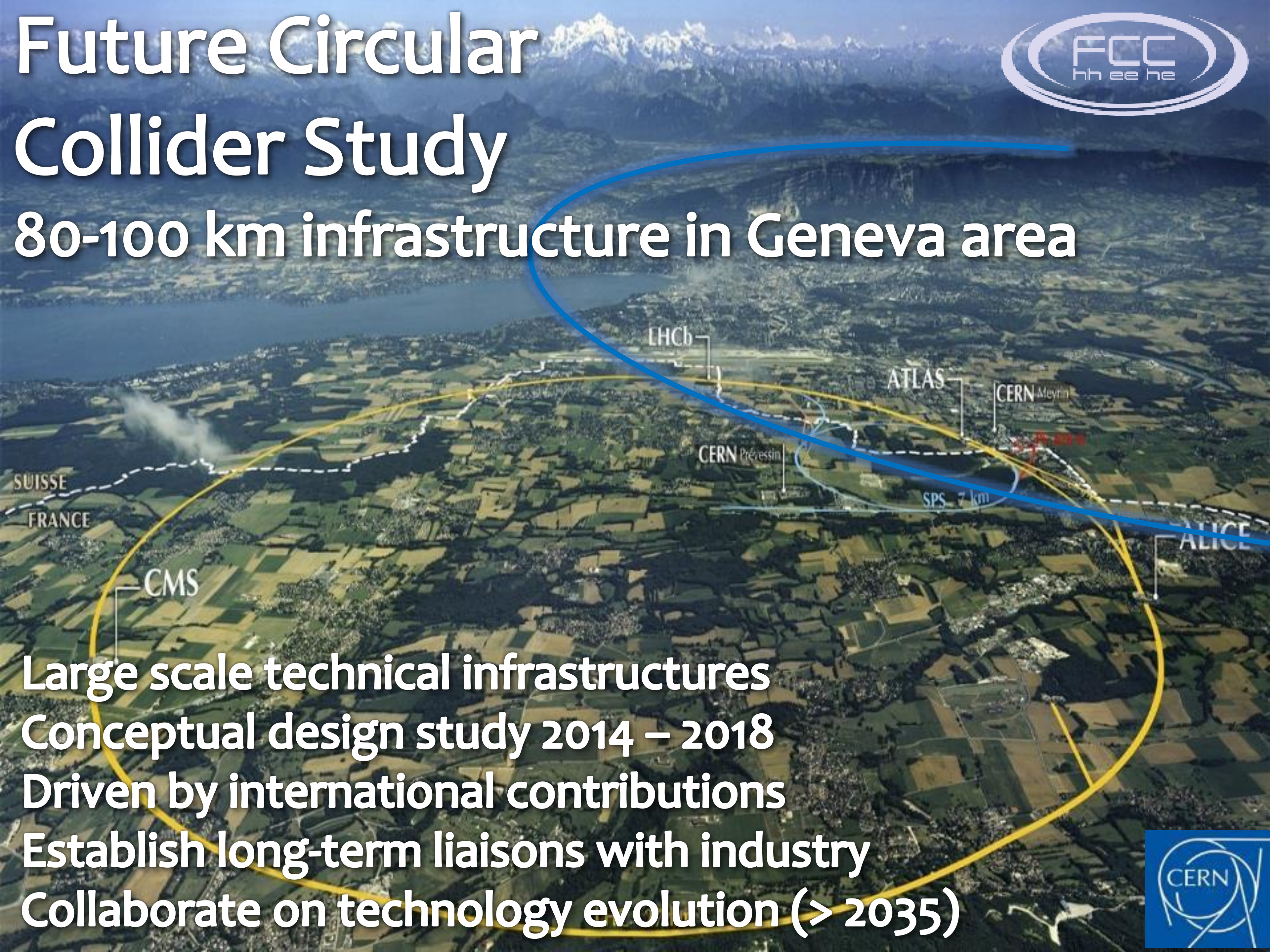
- 67 Institutes (research centers & universities)
- European Commission
- 26 countries

CERN Circular Collider Timescale



Future Circular Collider Study

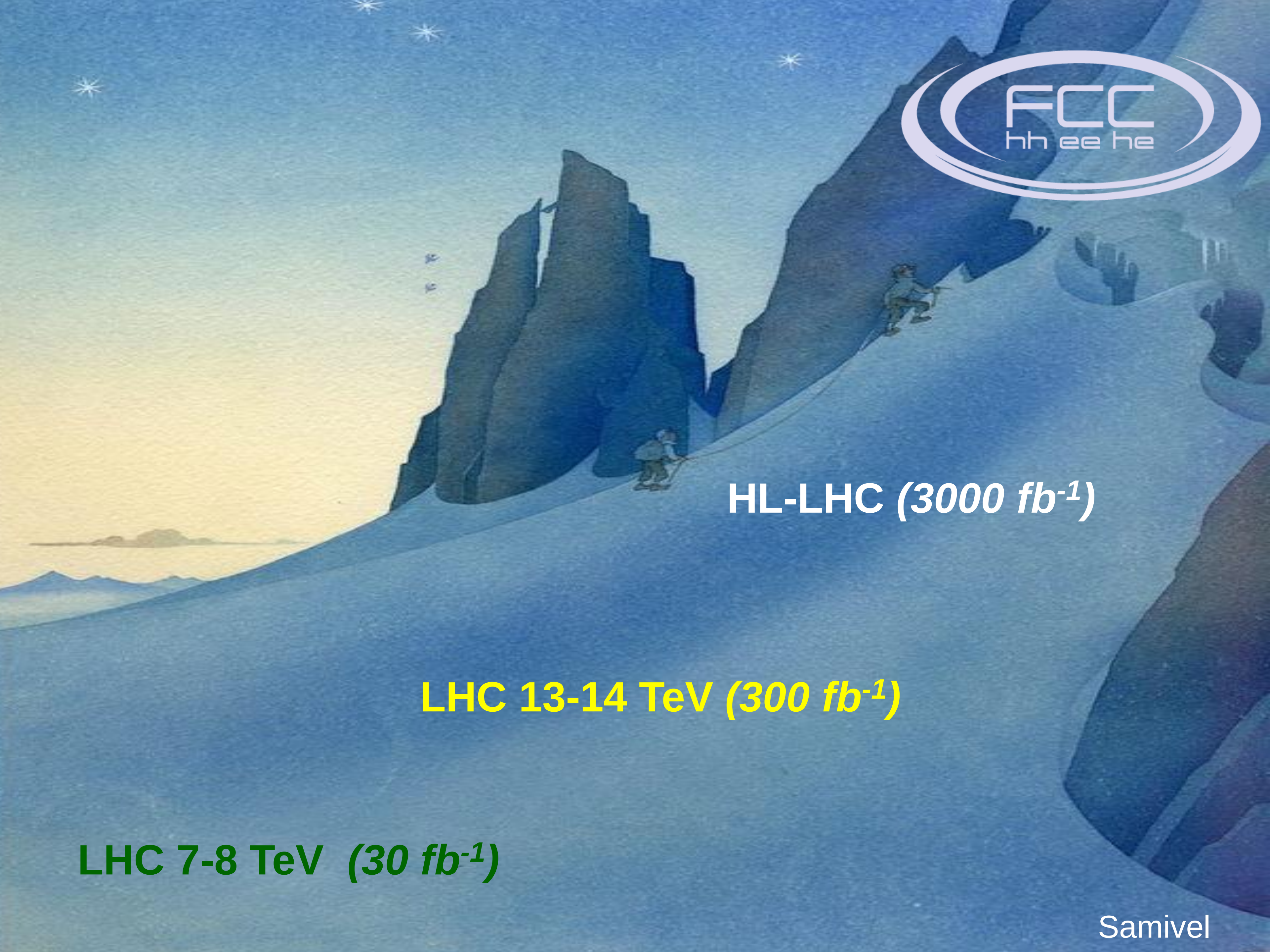
80-100 km infrastructure in Geneva area



Large scale technical infrastructures
Conceptual design study 2014 – 2018
Driven by international contributions
Establish long-term liaisons with industry
Collaborate on technology evolution (> 2035)

Conclusion

- **CERN is presently exploiting the physics potential of the LHC**
- **After the long shutdown LS1 the LHC operates at 13 TeV (2015) and later to study when to increase towards 14 TeV (2016-2023).**
  => Goal 300 fb^{-1}
- **The high luminosity project HL-LHC will allow to collect ten times more data (2026 - 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**


FCC
hh ee he
HL-LHC *(3000 fb^{-1})*
LHC 13-14 TeV *(300 fb^{-1})*
LHC 7-8 TeV *(30 fb^{-1})*
Samivel

Thanks for your attention

"The task of the mind is to produce future"
Paul Valéry

www.cern.ch