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LHC status & prospects

Dr. Frédérick Bordry

Large Hadron Collider Physics (LHCP) conference

New York - 2nd June 2014

Outline

- **LHC recall and Run 1**
- **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}**

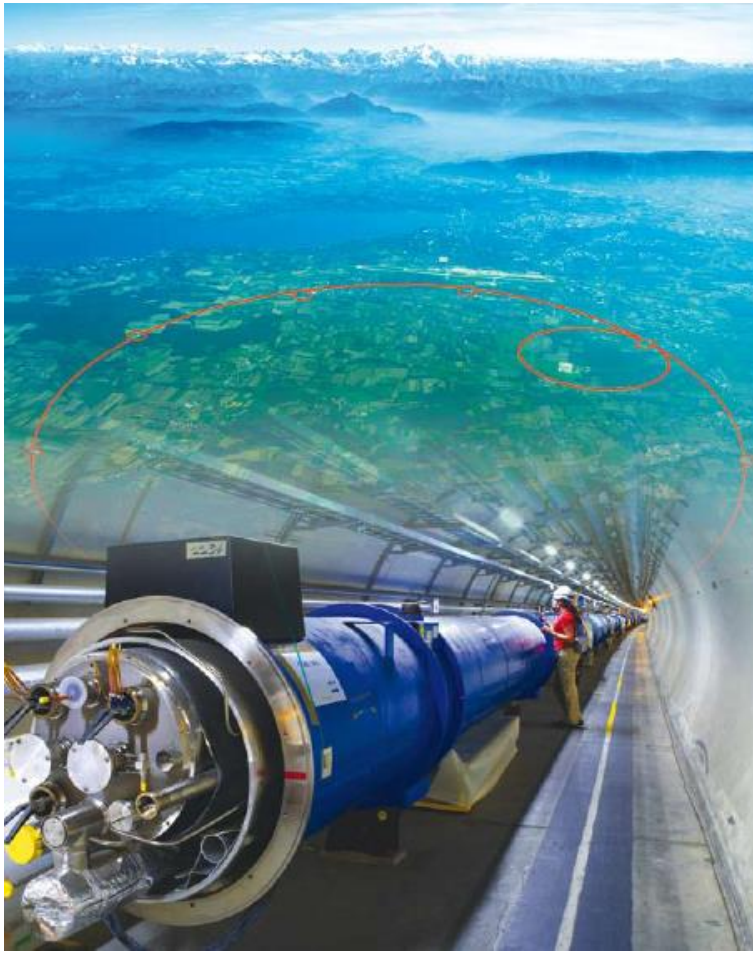
- **Post-LHC machine**

LHC (Large Hadron Collider)

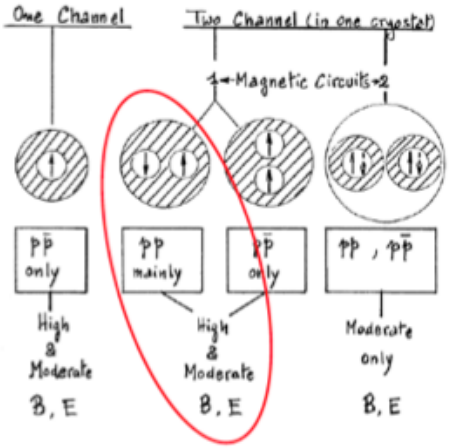
14 TeV proton-proton accelerator-collider built in the LEP tunnel

Lead-Lead (Lead-proton) collisions

1983	**:**	**First studies for the LHC project**
1988	**:**	**First magnet model (feasibility)**
1994	**:**	**Approval 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**



ECFA-CERN workshop



June 1994
first full scale prototype dipole

1994 project approved by council (1-in-2)

June 2007 First sector cold

April 2008
Last dipole down

9T- 1m single bore

25 years

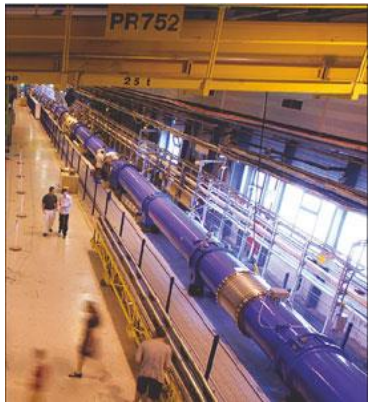
Main contracts signed

83 84 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10

Decision for Nb-Ti

9T -10 m prototype

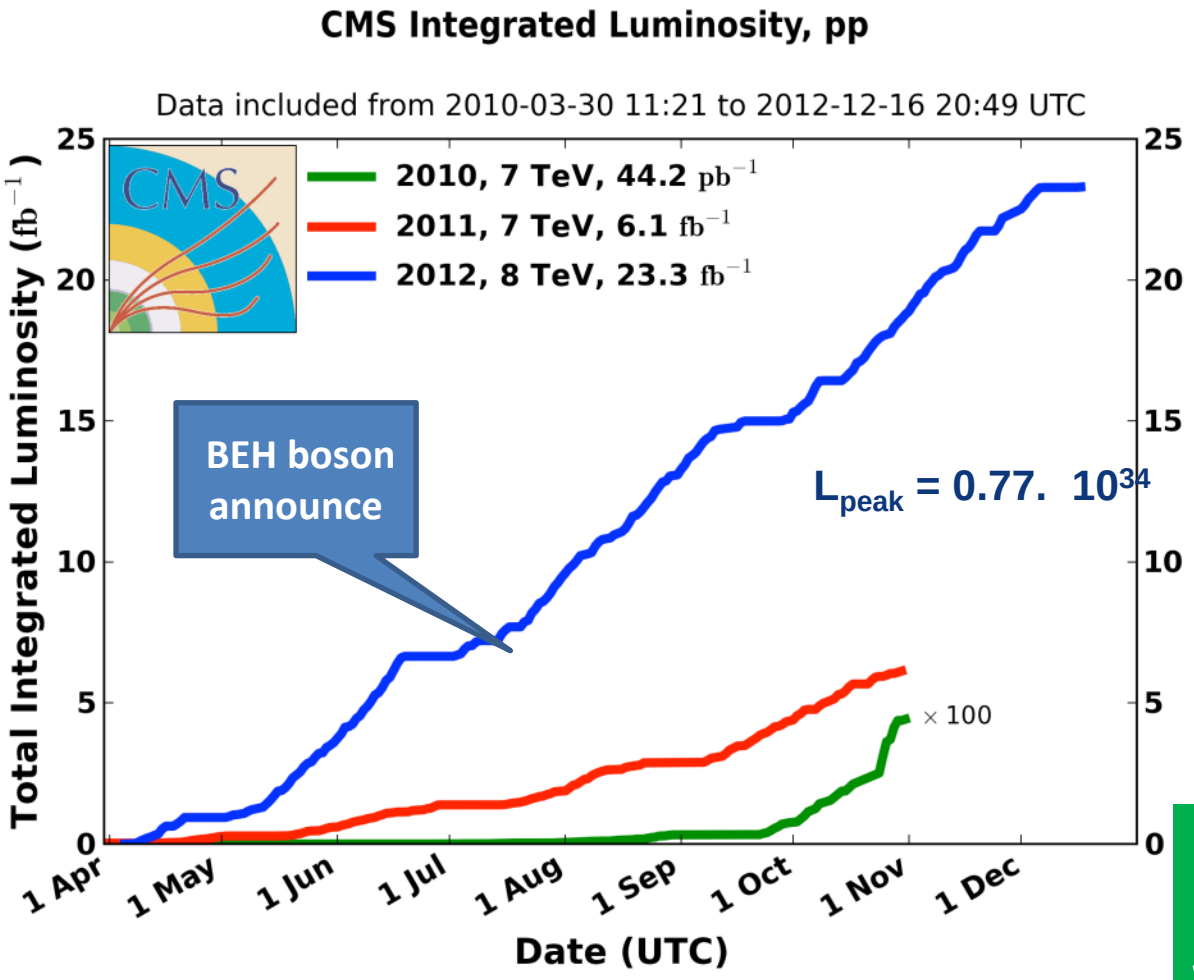
2002 String 2



November 2006
1232 delivered

September 10, 2008
First beams around

2010-2012 (Run 1): LHC integrated luminosity



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

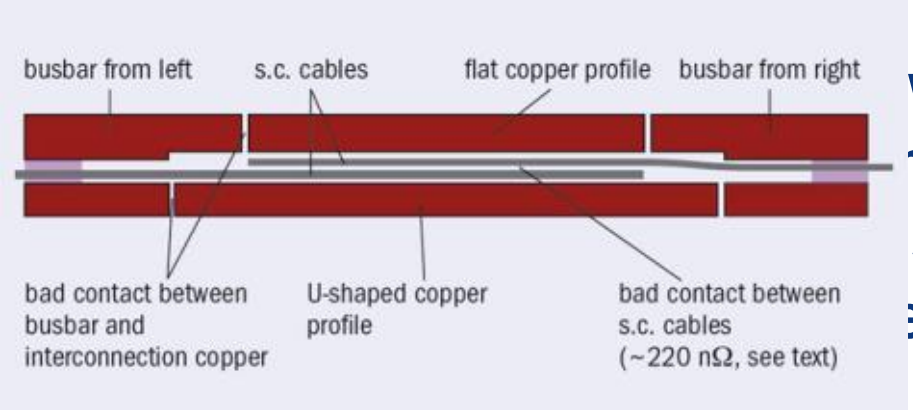
2011: **6.1 fb^{-1}**
7 TeV CoM
… exploring limits

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

7 TeV and 8 TeV in 2012
Up to 1380 bunches
with1.5 10^{11} protons

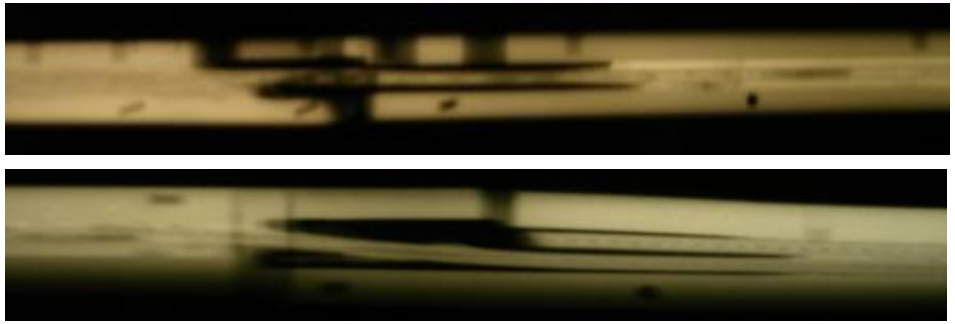
Long Shutdown 1

LS1 starts as the shutdown to repair the magnet interconnects to allow nominal current in the dipole and lattice quadrupole circuits of the LHC.

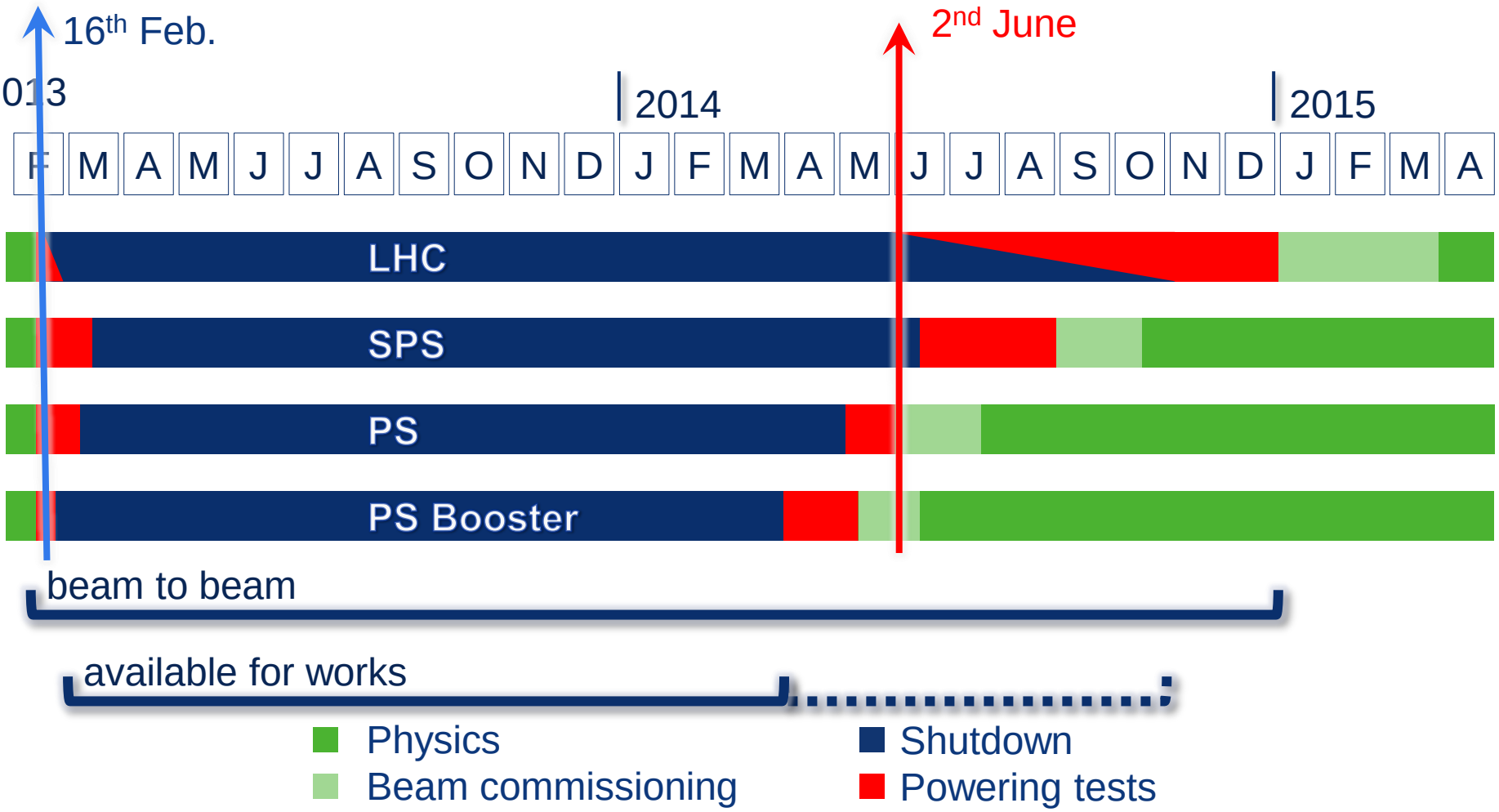


wn which, in addition, ntenance, consolidation, s the whole accelerator experimental facilities.

All this in the shadow interconnects.



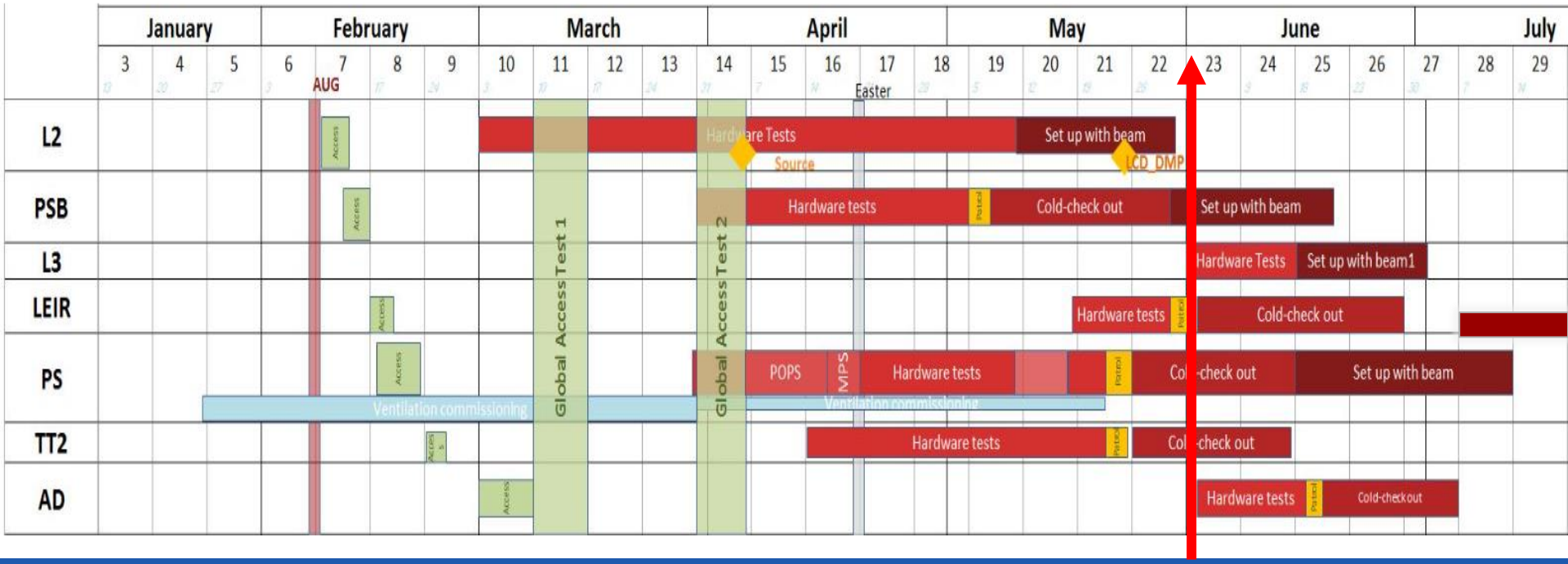
LS 1 from 16th Feb. 2013 to Dec. 2014



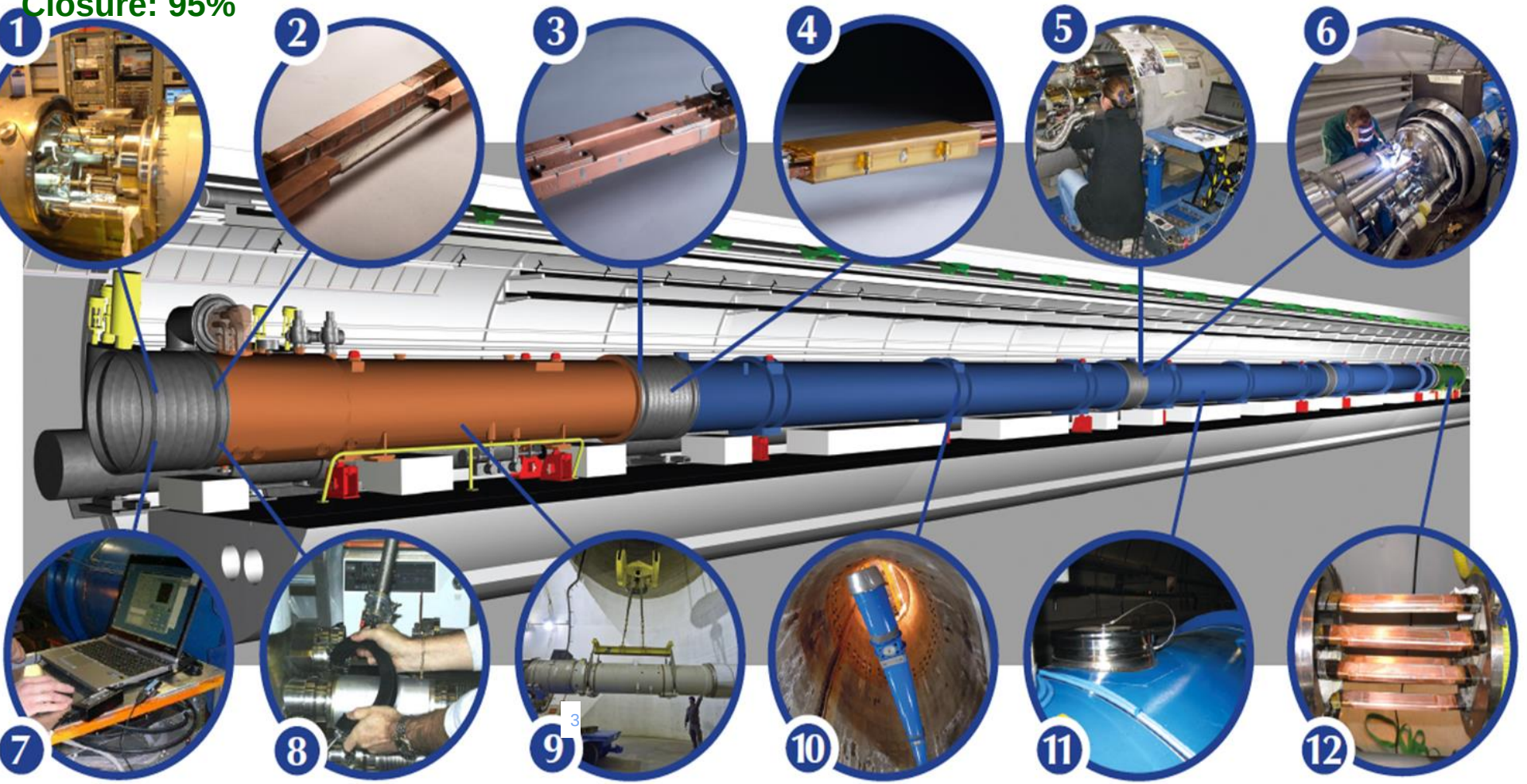
LHC Injectors start-up

LHC-injectors … getting ready for beams

- PSB &PS : hardware tests started in April
- Cold check-out phases well advanced
- SPS: powering tests will start by end of June



The main 2013-14 LHC consolidations



Opening:100%
1695 Openings and final reclosures of the interconnections

Closure: 95%

1

100 % done
Complete reconstruction of 3000 of these splices

2

100 % done
Consolidation of the 10170 13kA splices, installing 27 000 shunts

3

100 % done
Installation of 5000 consolidated electrical insulation systems

4

100 % done
300 000 electrical resistance measurements

5

100 % done
10170 orbital welding of stainless steel lines

6

7

80 % done
18 000 electrical Quality Assurance tests

8

80 % done
10170 leak tightness tests

9

3 quadrupole magnets to be replaced

Done

10

15 dipole magnets to be replaced

Done

11

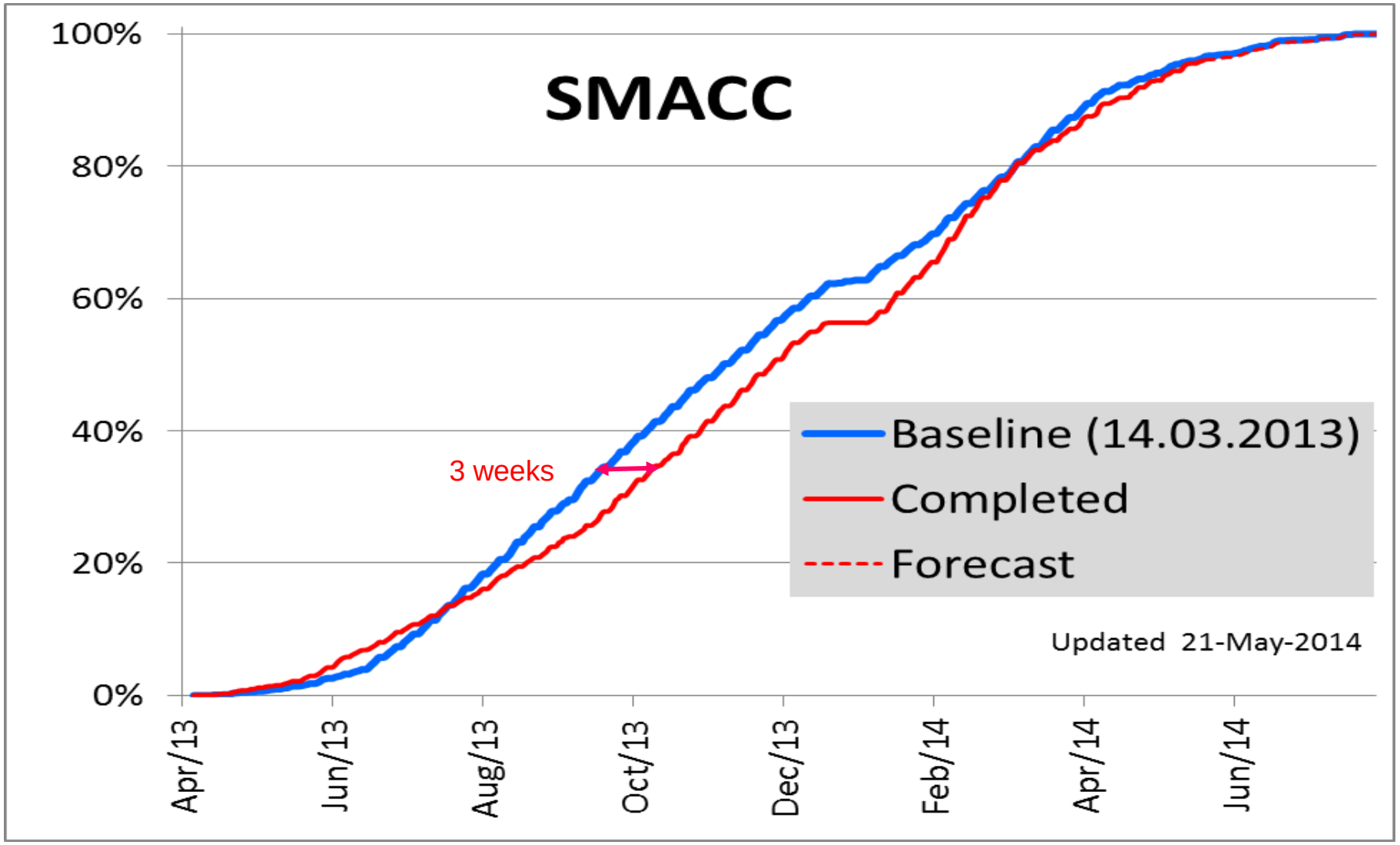
100 % done
Installation of 612 pressure relief devices to bring the total to 1344

12

90 % done
Consolidation of the 13 kA circuits in the 16 main electrical feed-boxes


SHUNTS
CERN
FINISH
SMACC PROJECT
30/04/2014

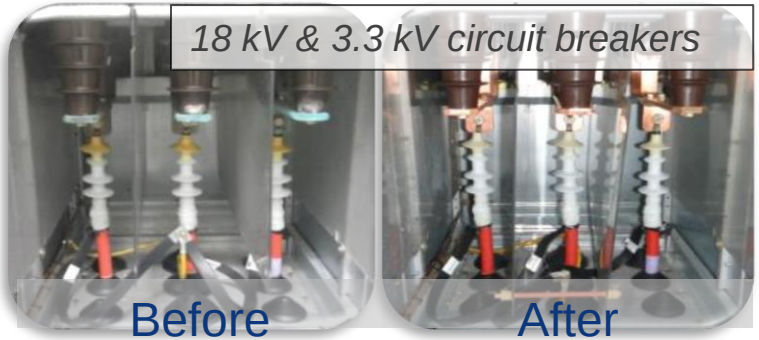
Superconducting Magnets And Circuits Consolidation Dashboards



The other activities


Vacuum


UPS-RE82




Cryo plant


P7 enclosure

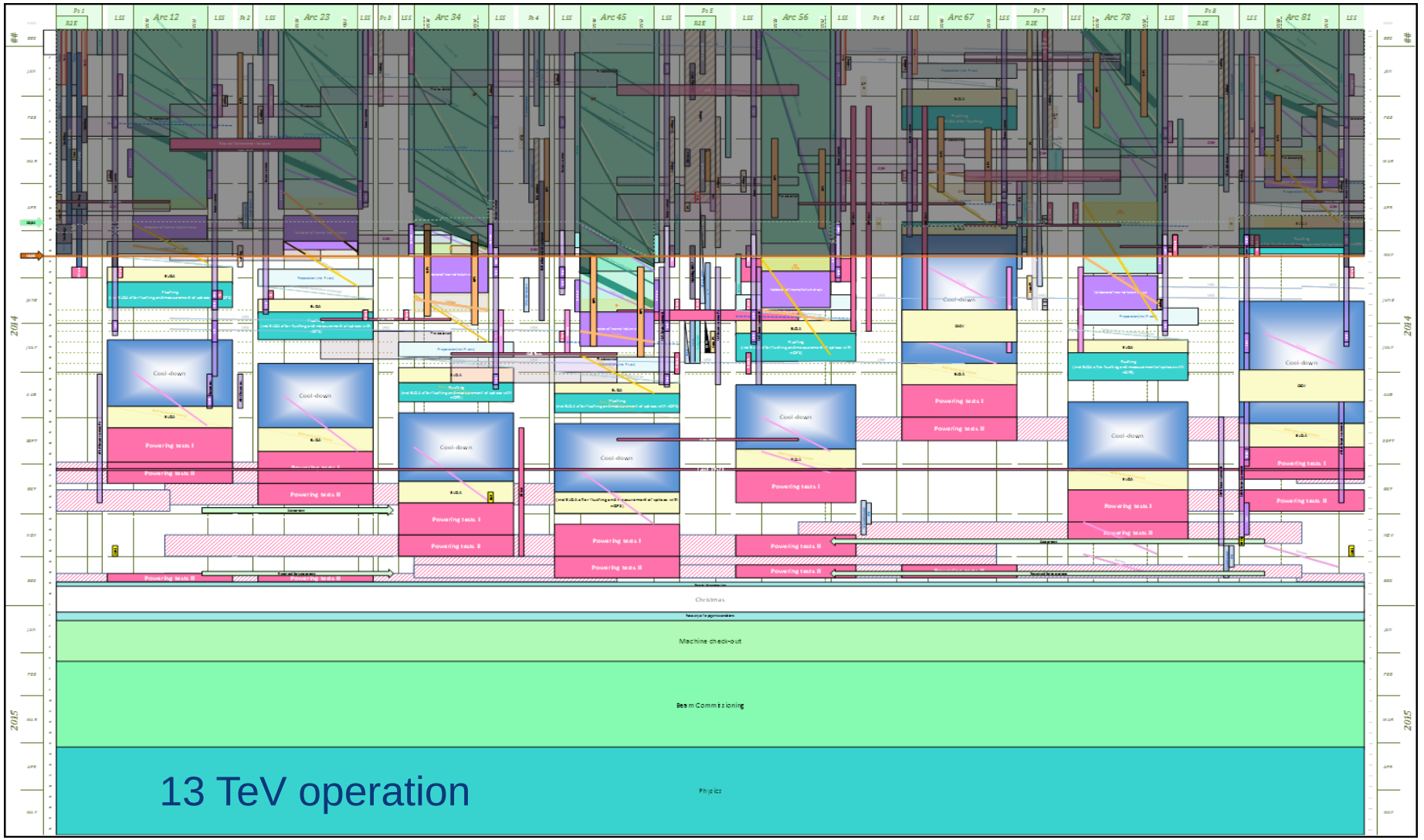

Pumping station


Helium spill test


ACS transport

Courtesy of Katy Foraz

LS 1: LHC status



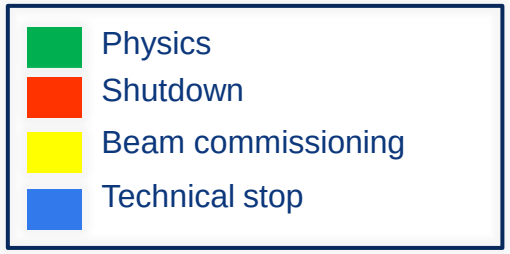
LS1 status

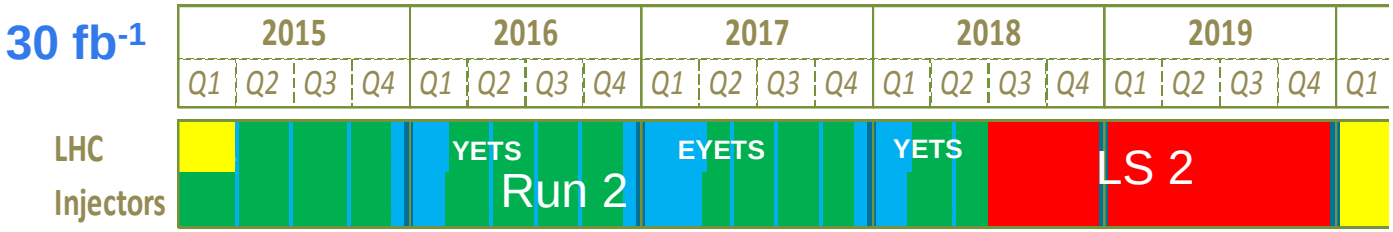
LHC injectors getting ready for beams

LHC: all signals are green for beam on January 2015

LHC schedule: Run2 and LS2

LS2 starting in 2018 (July) => 18 months + 3 months BC





(Extended) Year End Technical Stop: (E)YETS

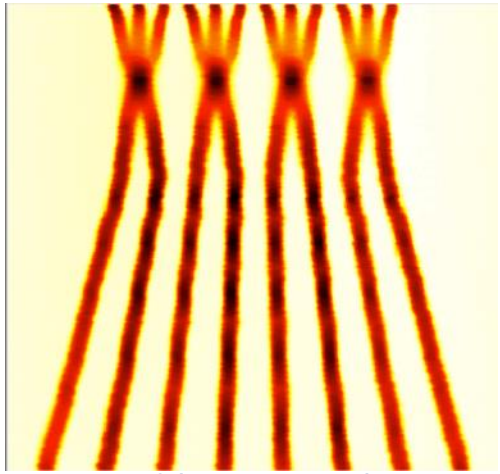
Run 2:
Start with 13 TeV
and later decision towards 14 TeV
according to magnet training

Expectations after Long Shutdown 1 (2015)

- Collisions at least at **13 TeV** c.m.
- **25 ns** bunch spacing

  Using new injector beam production scheme (BCMS), resulting in brighter beams.

Batch Compression and Merging and splitting (BCMS)



Courtesy of the LIU-PS project team

- **$\beta^* \leq 0.5$m** (was 0.6 m in 2012)
- Other conditions:
  - Similar turn around time
  - Similar machine availability
- Expected maximum luminosity: **1.6×10^{34} cm^{-2} s^{-1}** ± 20%
  - Limited by inner triplet heat load limit, due to collisions debris

	Number of bunches	Intensity per bunch	Transverse emittance	Peak luminosity	Pile up	Int. yearly luminosity
25 ns BCMS	**2508**	**1.15×10^{11}**	**1.9 µm**	**1.6×10^{34} cm^{-2}s^{-1}**	**~43**	**~42 fb^{-1}**

Potential performance

	Number of bunches	Ib LHC [1e11]	Collimator scenario	Emit LHC (SPS) [um]	Peak Lumi [cm^{-2}s^{-1}]	~Pile-up	Int. Lumi [fb^{-1}]
25 ns	2760	1.15	S1	3.5 (2.8)	9.2e33	21	24
25 ns low emit	***2508***	***1.15***	***S4***	***1.9 (1.4)***	***1.6e34***	***43***	***42***
50 ns	1380	1.6	S1	2.3 (1.7)	1.7e34 levelling 0.9e34	76 levelling 40	~45*
50 ns low emit	1260	1.6	S4	1.6 (1.2)	2.2e34	108	…

- **13 TeV**
- **1.1 ns bunch length**
- **150 days proton physics, HF = 0.2**

All numbers approximate

* different operational model – caveat - unproven

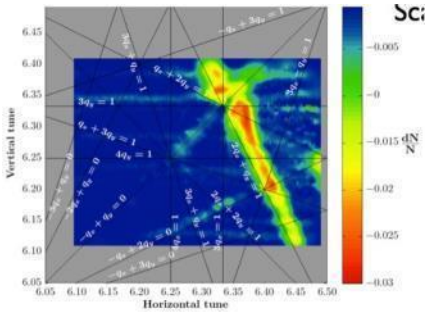
LS2 : (mid 2018-2019), LHC Injector Upgrades (LIU)

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

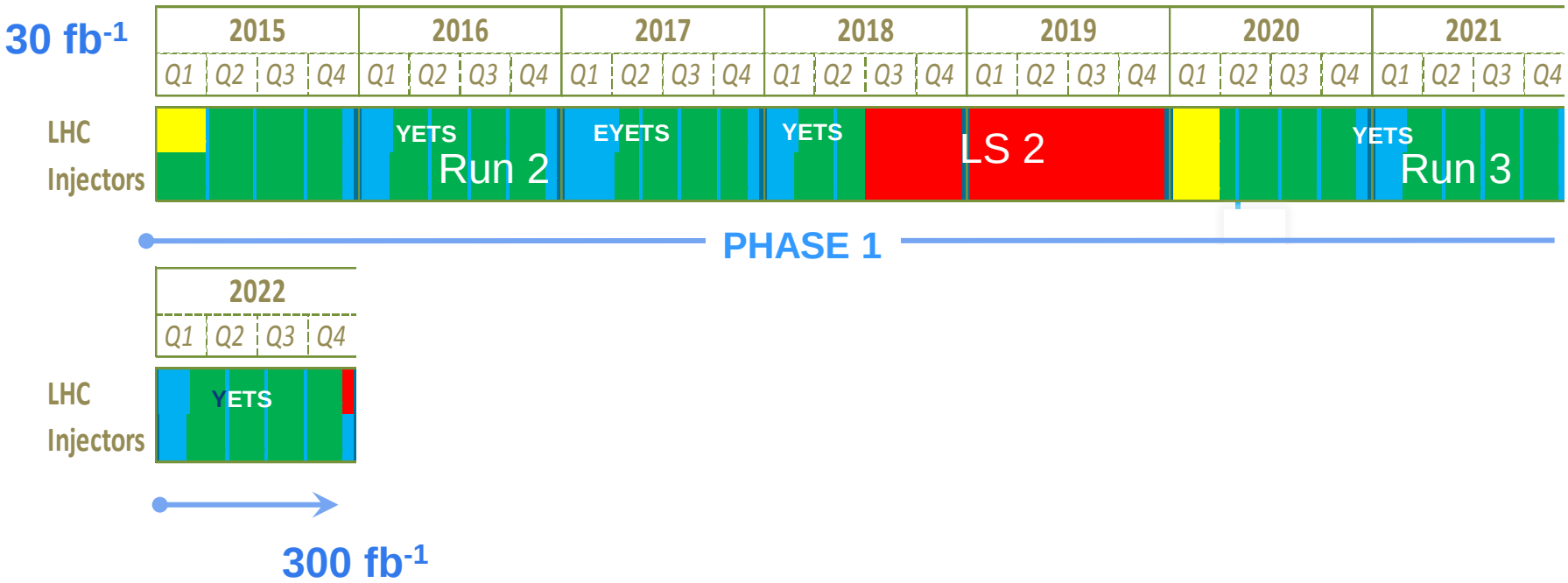
Project leadership: R. Garoby and M. Meddahi

LHC schedule: LS3 ? and Run 3

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

Physics
Shutdown
Beam commissioning
Technical stop

(Extended) Year End Technical Stop: (E)YETS



LS3 : HL-LHC installation

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.*

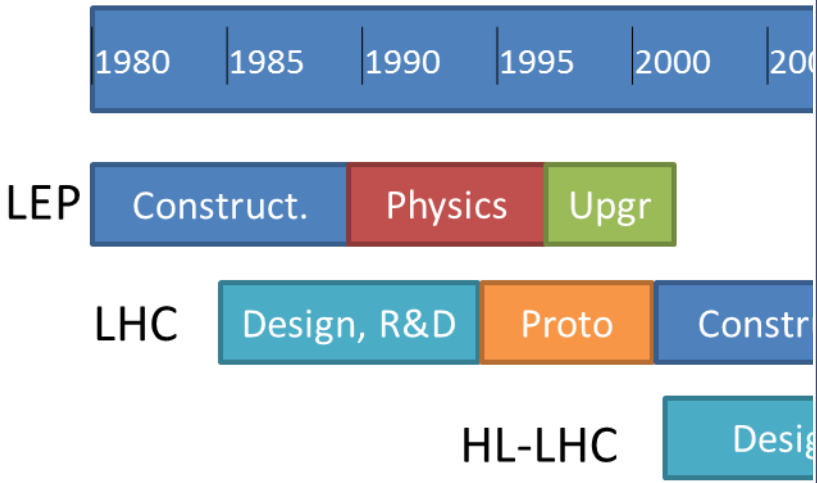
HL-LHC from a study to a PROJECT

300 fb^{-1} → 3000 fb^{-1}

including LHC injectors upgrade **LIU**

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

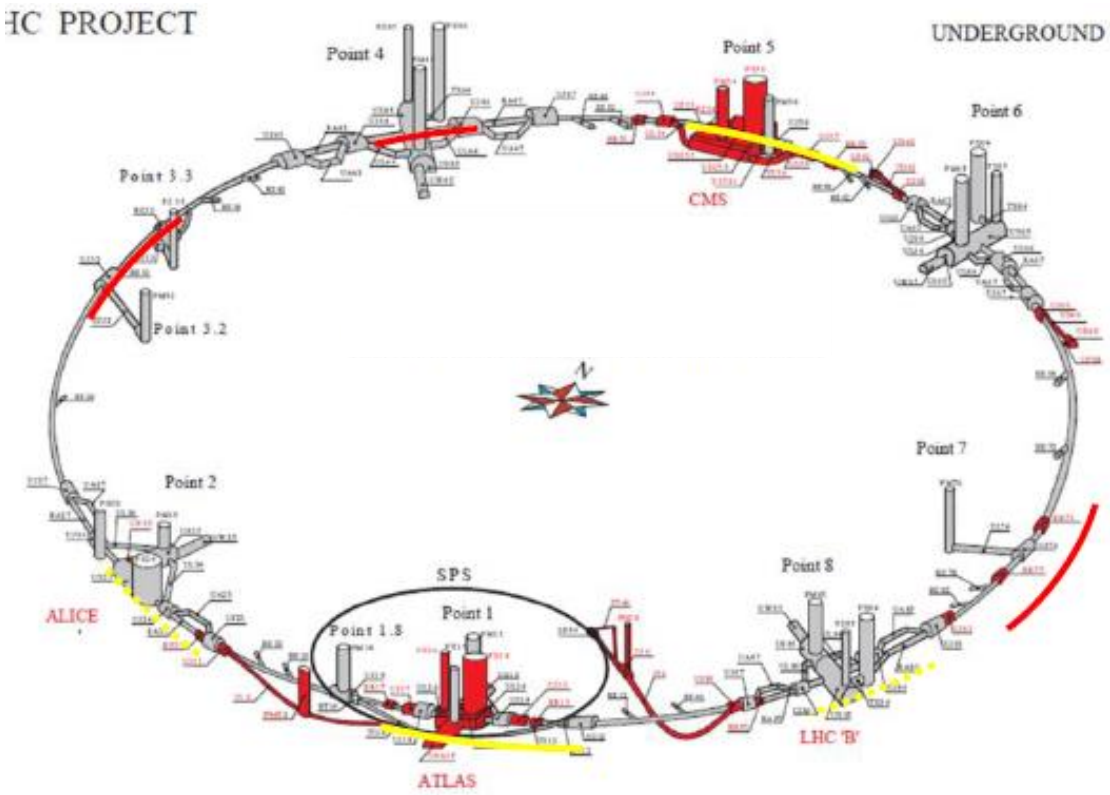
"…exploitation of the full pote
high-luminosity upgrade of th
=> High Lumi



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

http://cern.ch/hilumilhc

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 leadership: L. Rossi and O. Brüning

Squeezing the beams: High Field SC Magnets

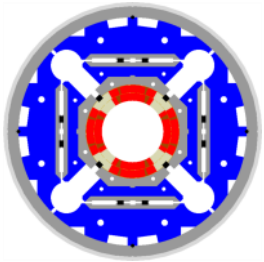
Quads for the inner triplet

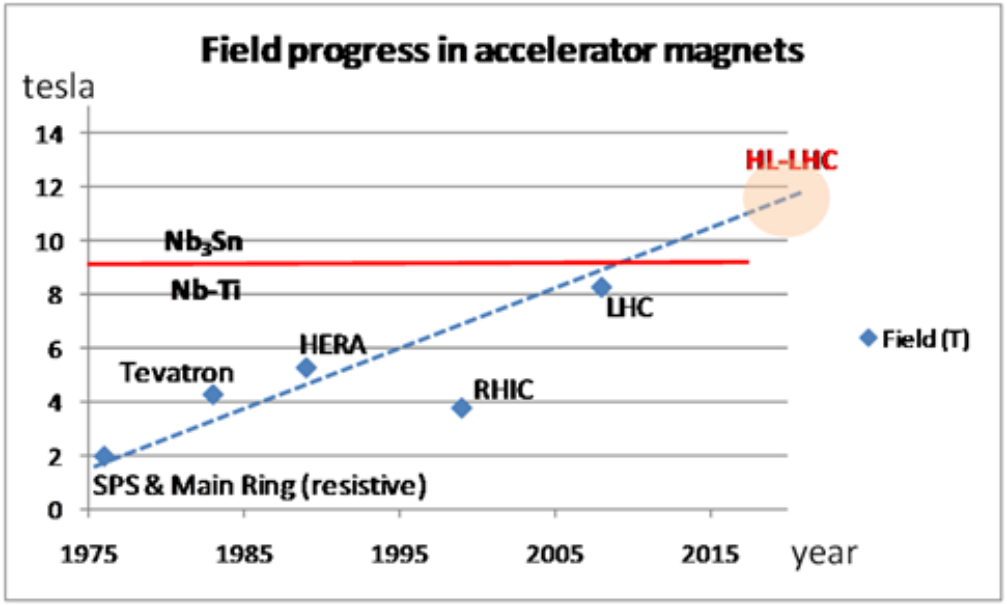
Decision 2012 for low-β quads

Aperture ∅ 150 mm – 140 T/m

(B_{peak} ≈12.3 T)

(LHC: 8 T, 70 mm)





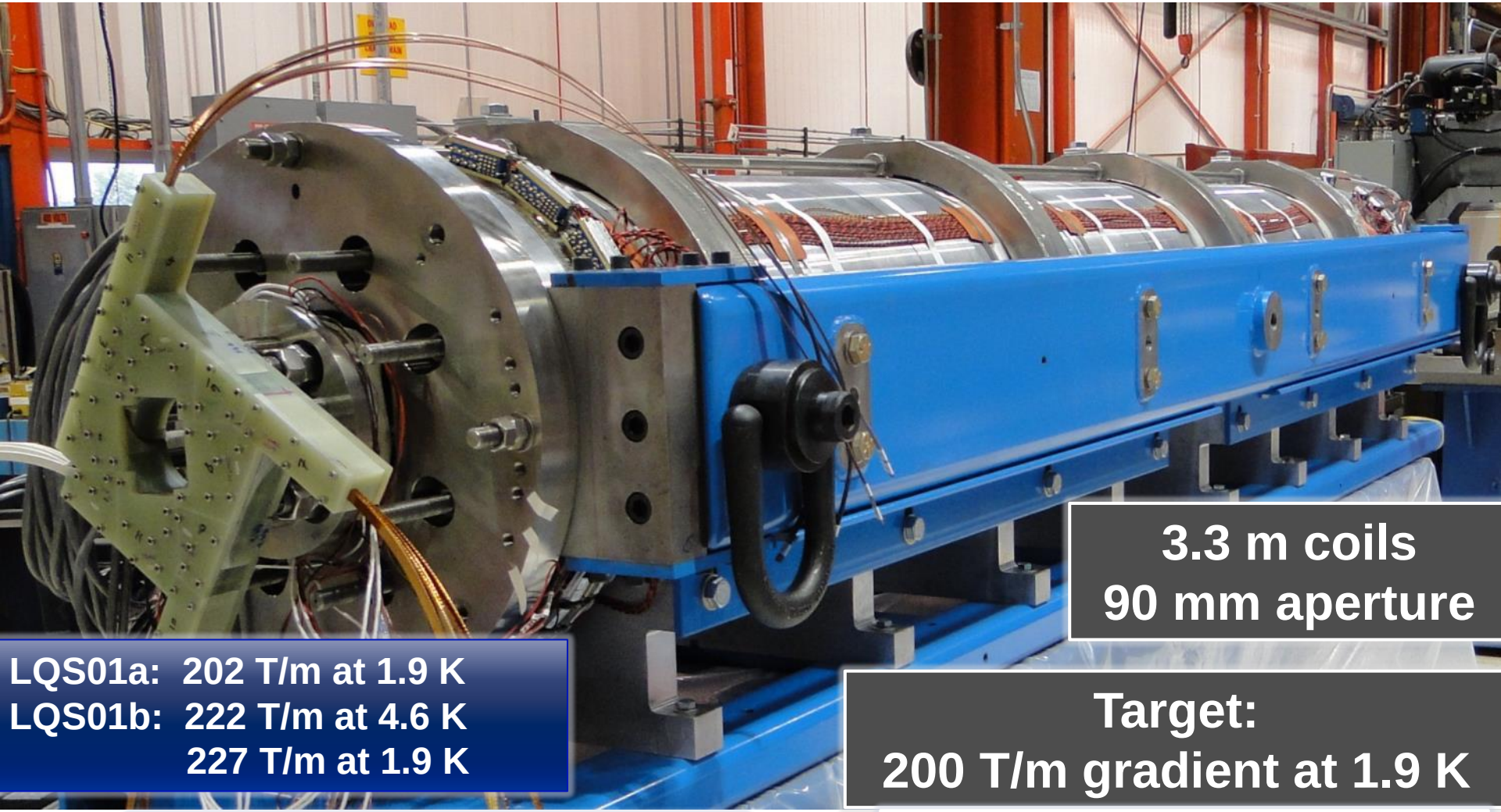
More focus strength,
β* as low as 15 cm (55 cm in LHC)
thanks to ATS** (Achromatic Telescopic Squeeze) **optics
In some scheme even β down to 7.5 cm are considered*

- Dipoles 11 T for LS2
- Dipoles for beam recombination/separation capable of 6-8 T with 150-180 mm aperture (LHC: 1.8 T, 70 mm)

LQS of LARP

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

LARP



3.3 m coils
90 mm aperture

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

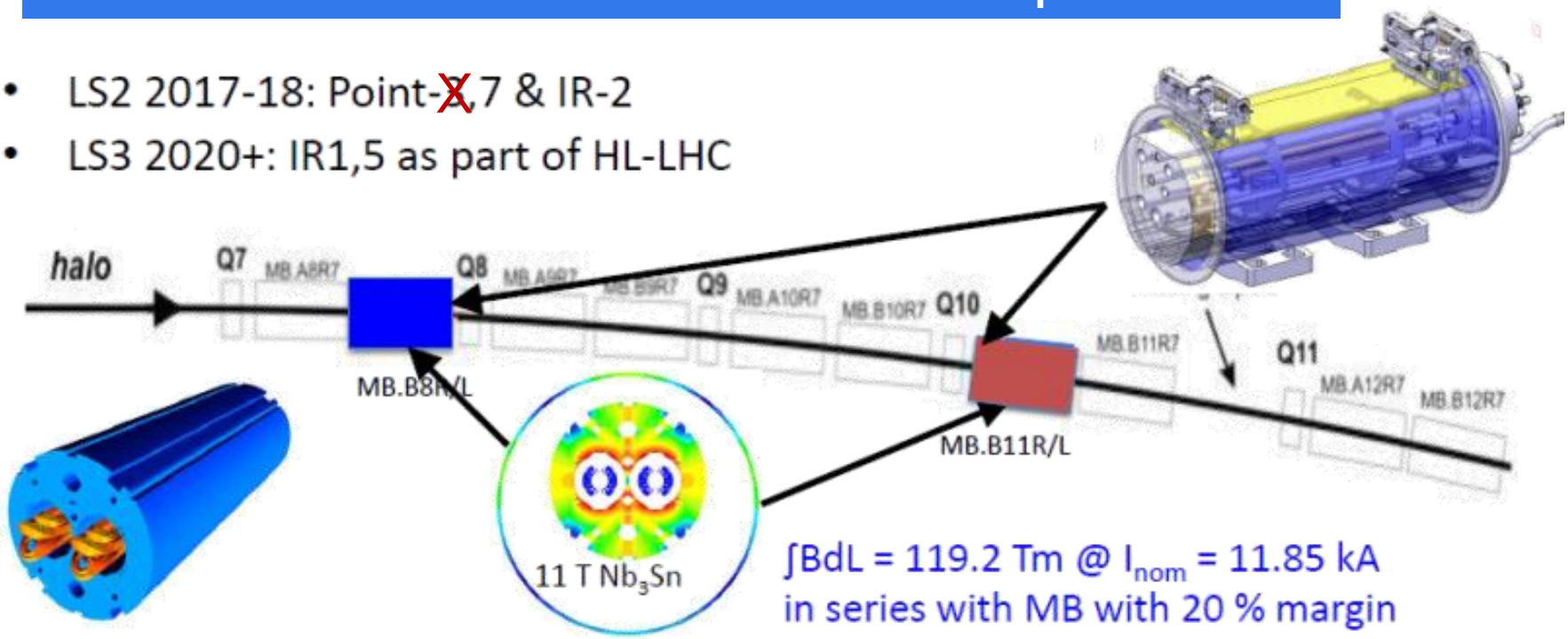
Target:
200 T/m gradient at 1.9 K

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-~~2~~,7 & IR-2
- LS3 2020+: IR1,5 as part of HL-LHC



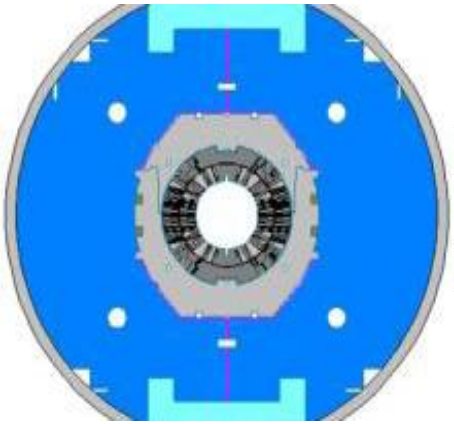
$\int BdL = 119.2$ Tm @ $I_{nom} = 11.85$ kA
in series with MB with 20 % margin

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

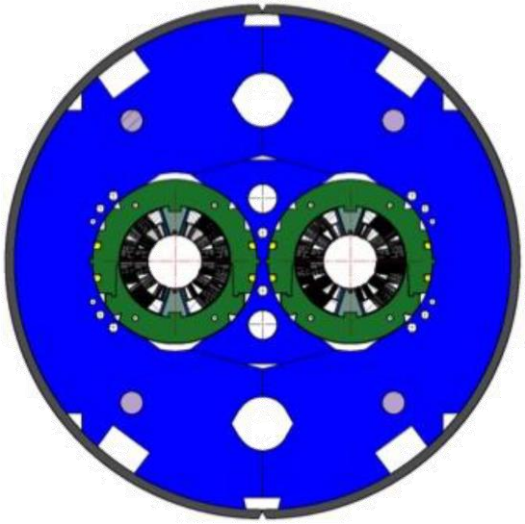
LS2: 24 coldmass + 4 spares = 28 CM
LS3: 16 coldmass + 4 spares = 20 CM
Total 48 CM

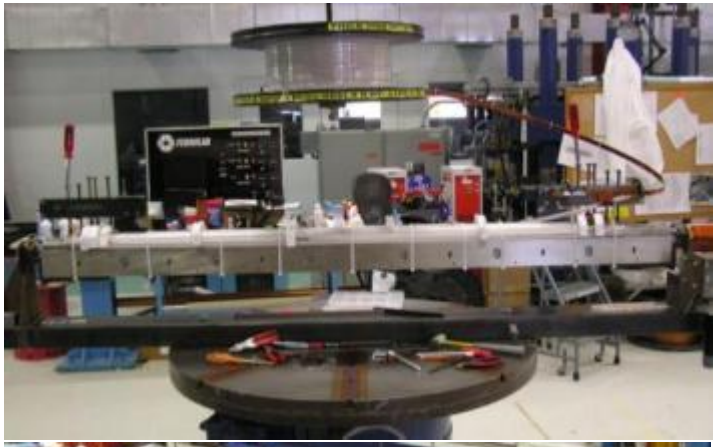
Nb_3Sn 11T Dipole R&D

Single aperture model



Twin aperture model

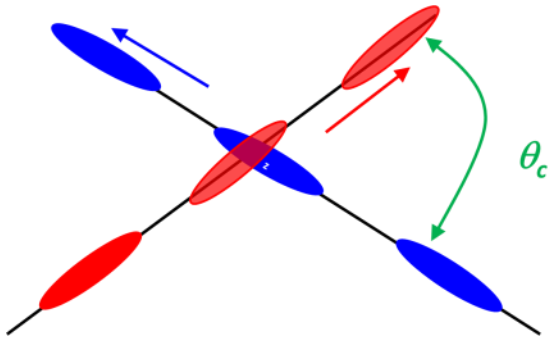




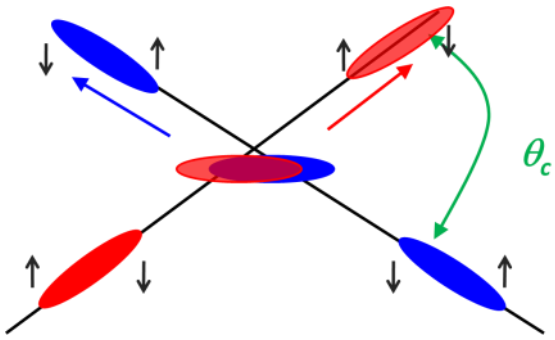
Crab Cavities, Increase “Head on”

Aim: reduce the effect of the crossing angle

Without crabbing

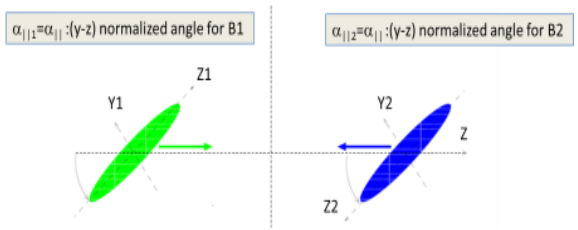


Without crabbing

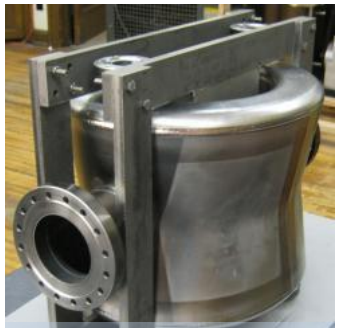



RF-Dipole Nb prototype

New crossing strategy under study to soften the pile-up density:
some new schemas have interesting potential as “crab-kissing”, to be discussed with all experiments

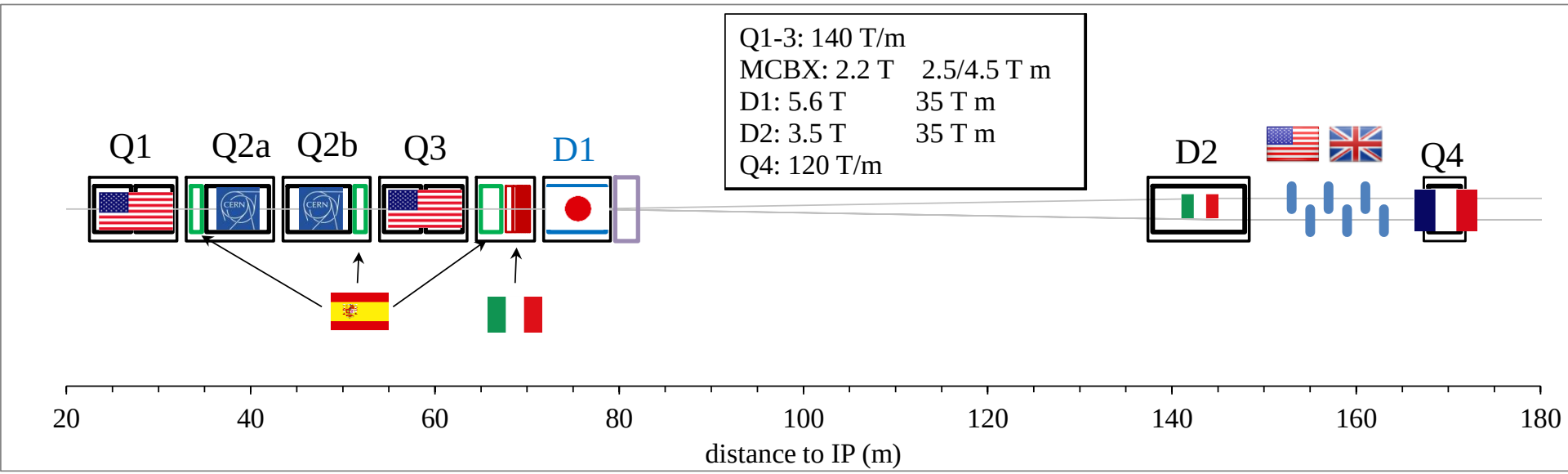


- 3 proto types available
- Cavity tests are on-going
- Test with beam in SPS foreseen in 2015-2016
- Beam test in LHC foreseen in 2017


DQWR prototype
17-Jan-2013

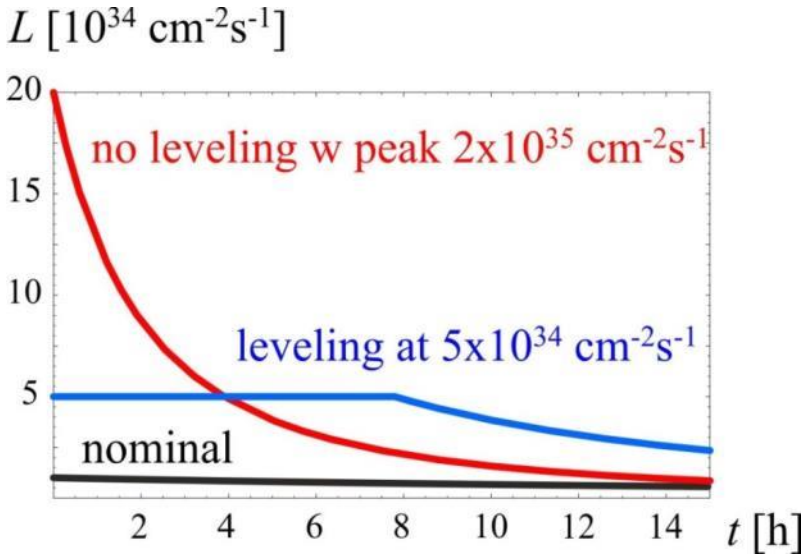
Setting up International collaboration

Baseline layout of HL-LHC IR region



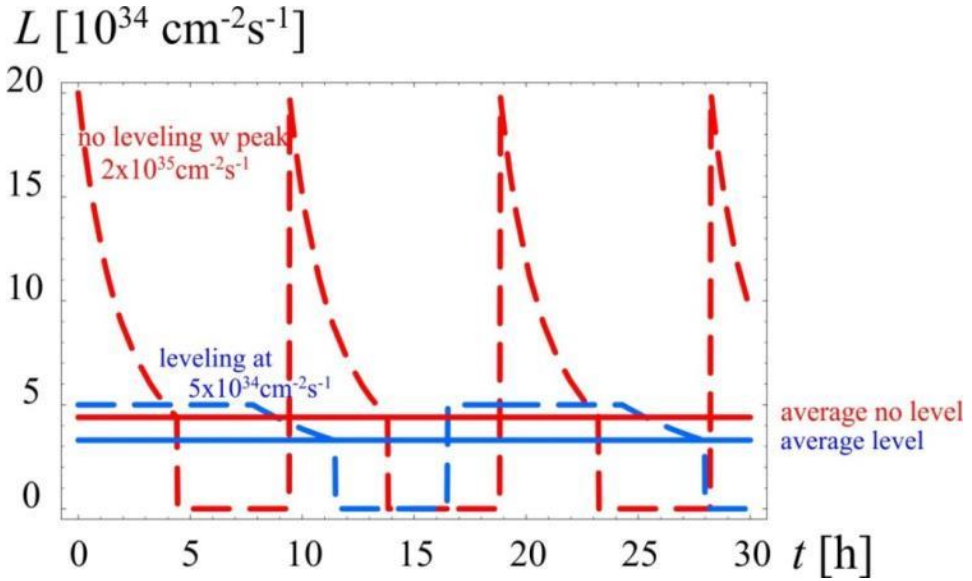
with national laboratories **but also involving industrial firms**

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



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

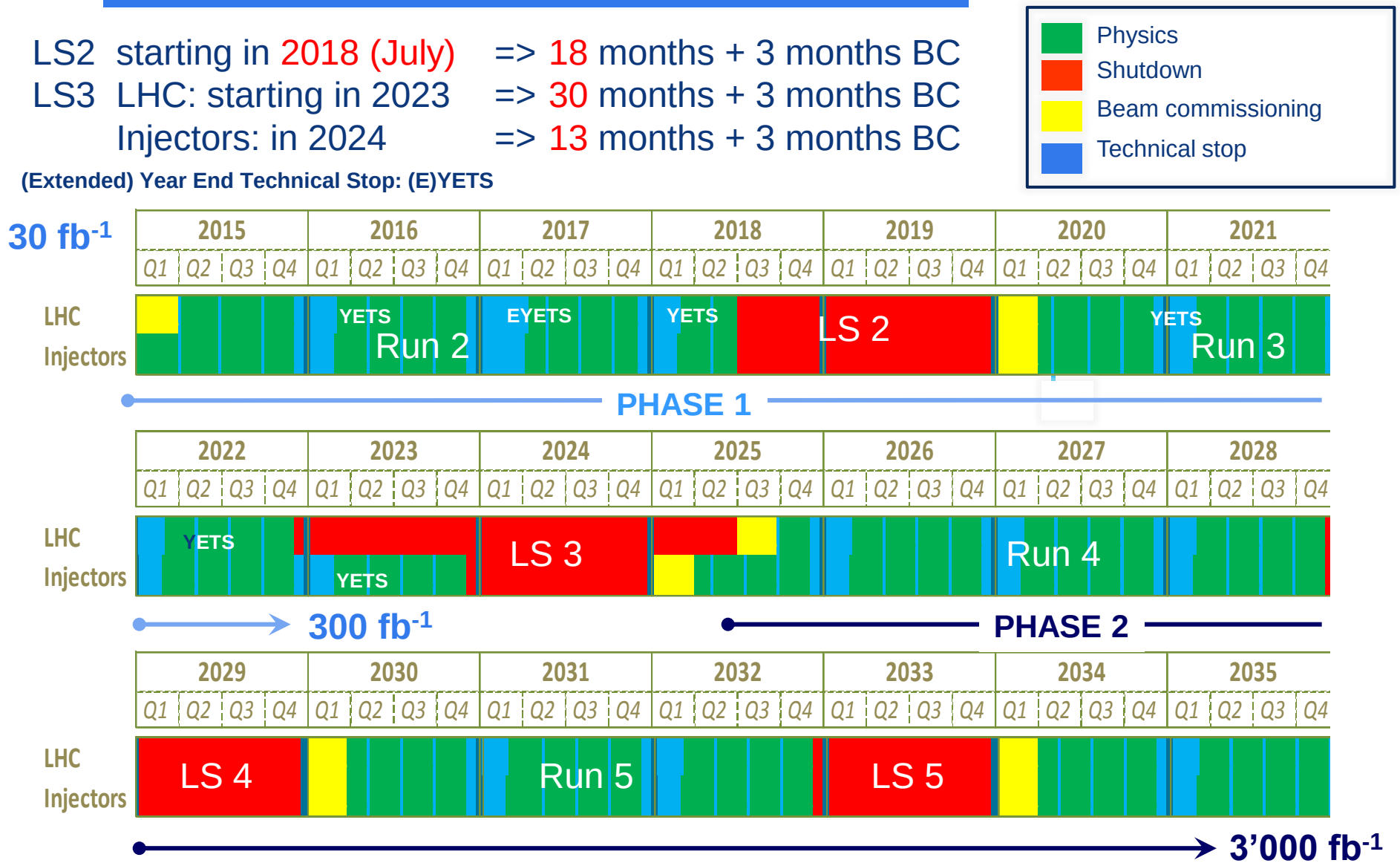
Continuous global optimisation with LIU

Courtesy Oliver Brüning

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

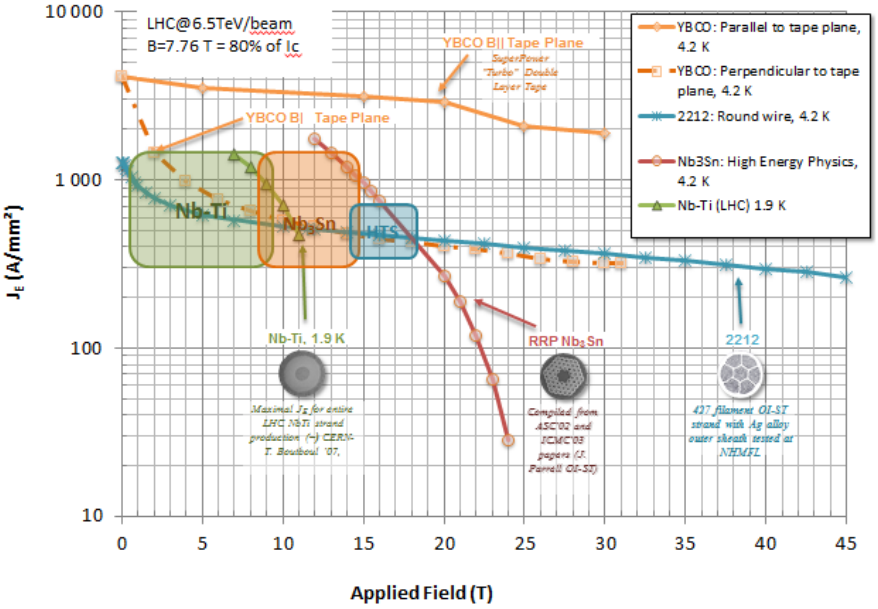


LHC schedule approved by CERN management and LHC experiments spokespersons and technical coordinators (December 2013)

“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.***

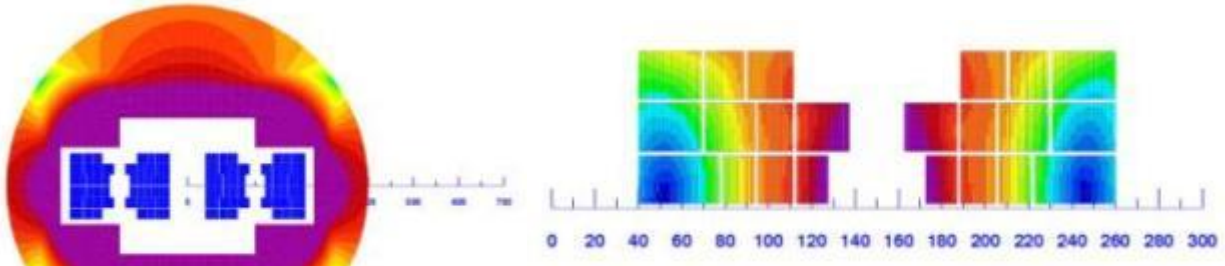
HFM - FCC



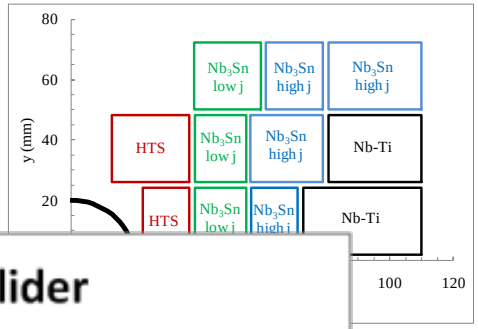
HGA - CLIC

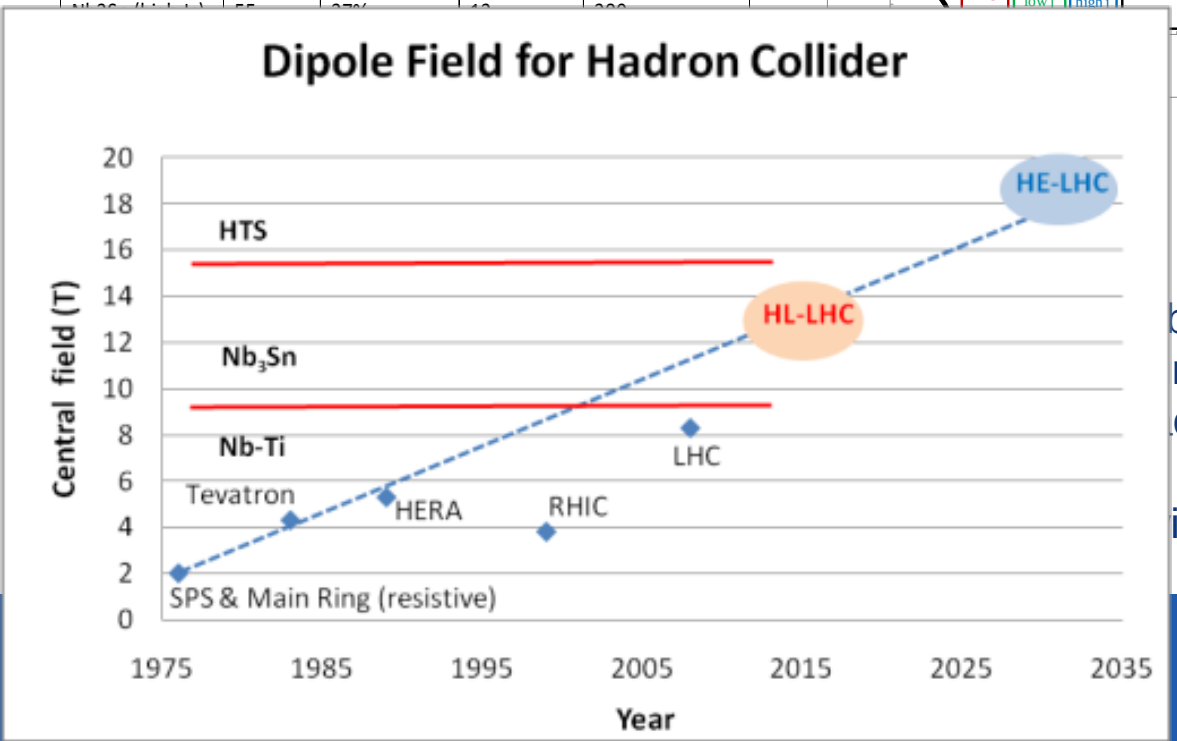
Malta Workshop: **HE-LHC @ 33 TeV c.o.m.**

14-16 October 2010



Material	N. turns	Coil fraction	Peak field	$J_{overall}$ (A/mm^2)
Nb-Ti	41	27%	8	380





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)

beam screen at 60 K.

mping time.

ching 2x10^{34} appears reasonable.

handling for INJ & beam dump:

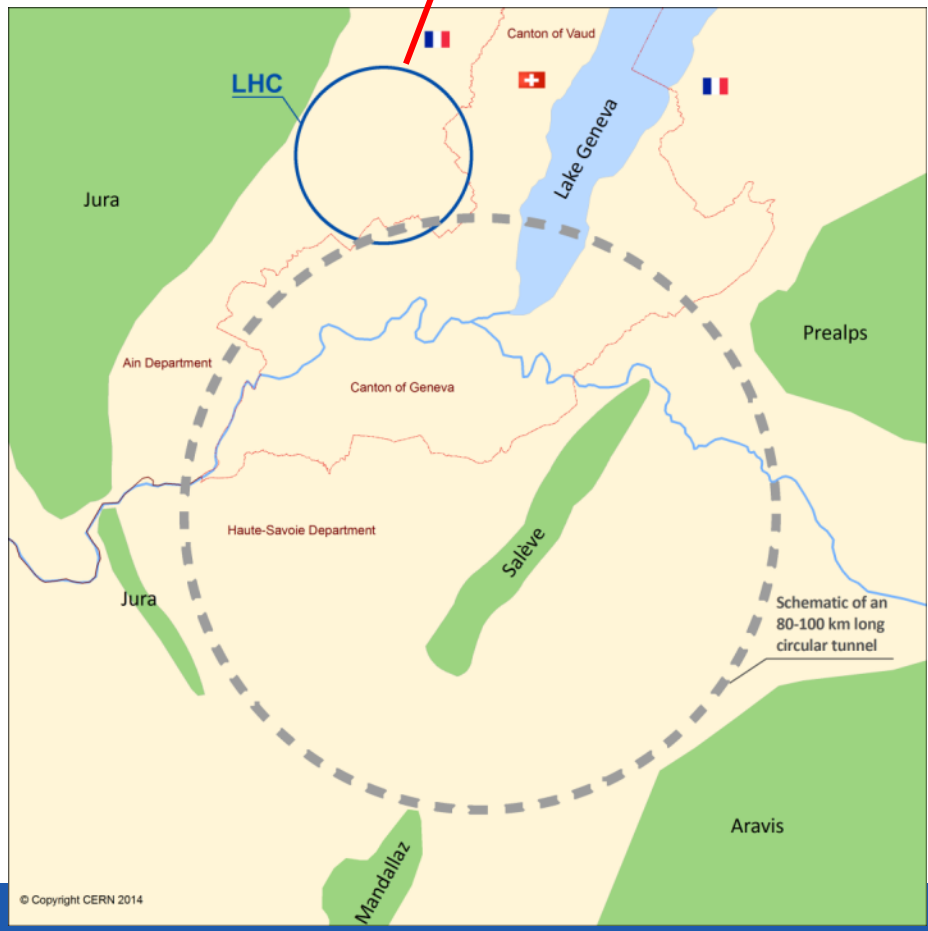
ice more room for LHC kickers.

"High Energy LHC"

HE-LHC :33 TeV with 20T magnets

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

- **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**

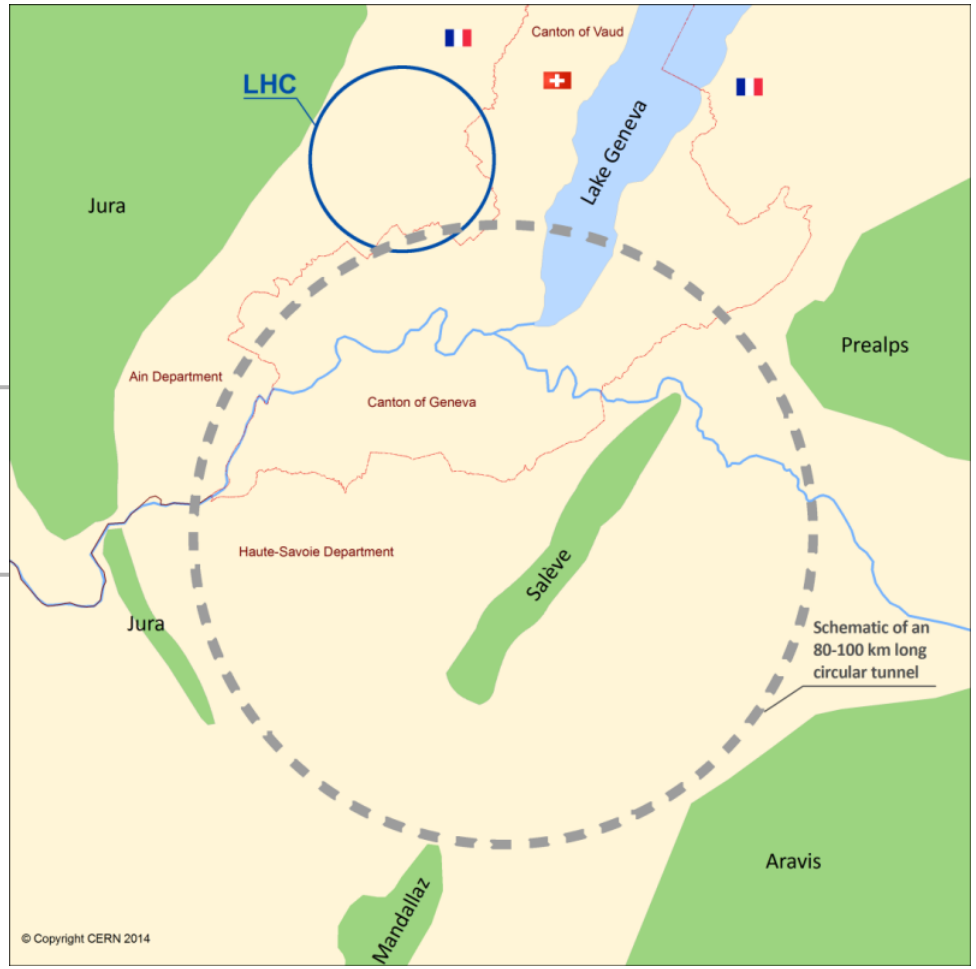


80-100 km tunnel infrastructure in Geneva area – design driven by pp-collider requirements (FCC-hh)

with possibility of e+-e- (FCC-ee) and p-e (FCC-he)

FCC (Future Circular Colliders)
CDR and cost review for the next ESU *(2018-2019)*
(including injectors)

16 T ⇒ 100 TeV in 100 km
20 T ⇒ 100 TeV in 80 km



Future Circular Collider Study
Kick-off Meeting

12-15 February 2014,
University of Geneva,
Switzerland

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CERN
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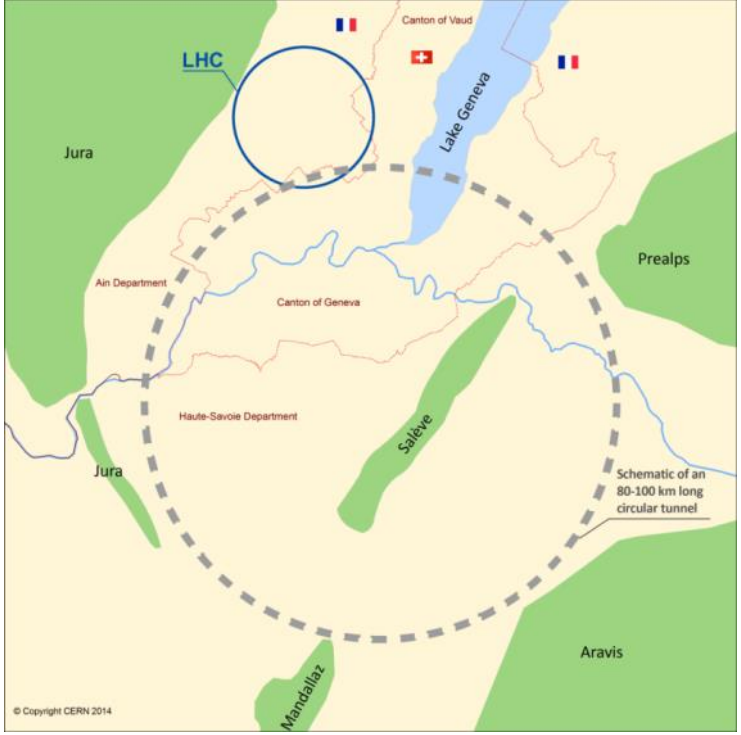
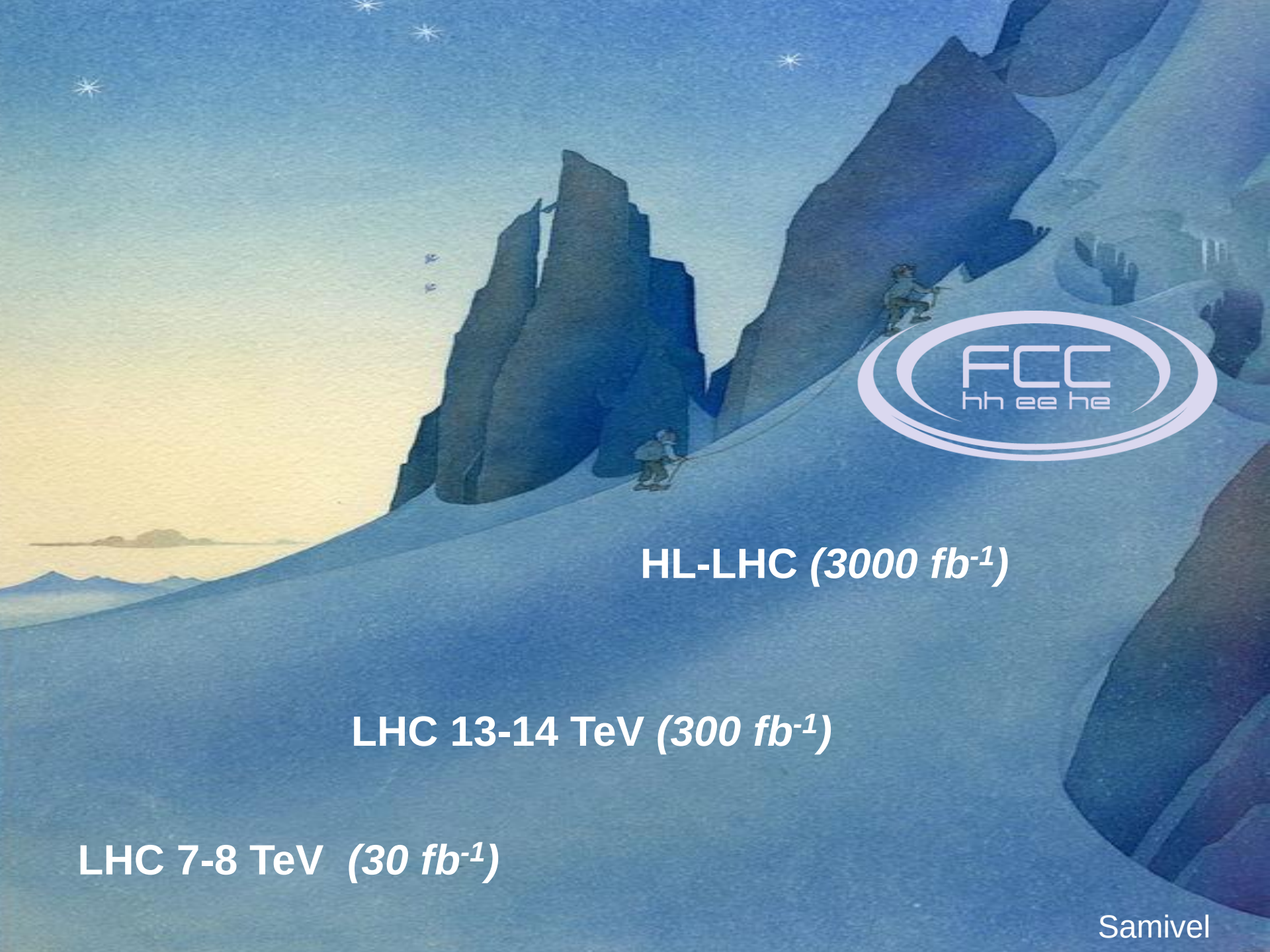
UNIVERSITÉ DE GENÈVE EuCARD² ECFA http://indico.cern.ch/e/fcc-kickoff



http://indico.cern.ch/e/fcc-kickoff

FCC hh ee he


FCC
hh ee he
HL-LHC (3000 fb-1)
LHC 13-14 TeV (300 fb-1)
LHC 7-8 TeV (30 fb-1)

Samivel

www.cern.ch