LHC Machine Upgrade Overall

Frédérick Bordry

Fourth Common ATLAS CMS ElectronicS Workshop for LHC upgrades

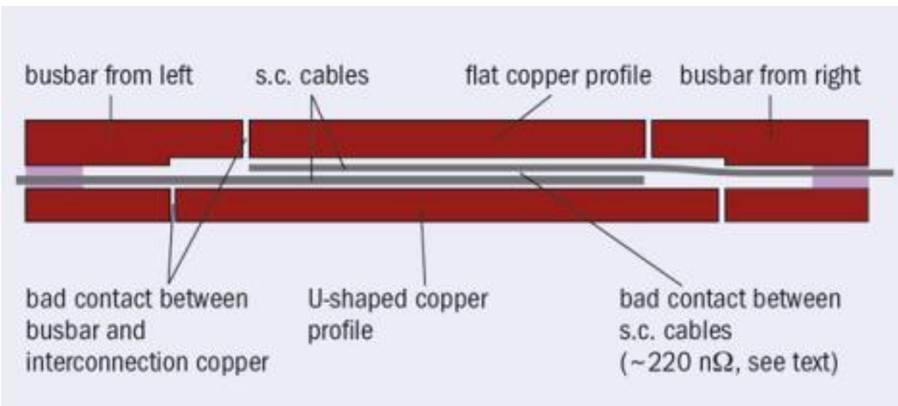
ACES2014 – 18th March 2014

Outline

- **LS1 status**
- **Run 2 (from LS1 to LS2), LS2 and Run 3**
- **HL-LHC project (LS3) : 3000 fb^{-1}**
- **LHC Roadmap up 2035**

Long Shutdown 1

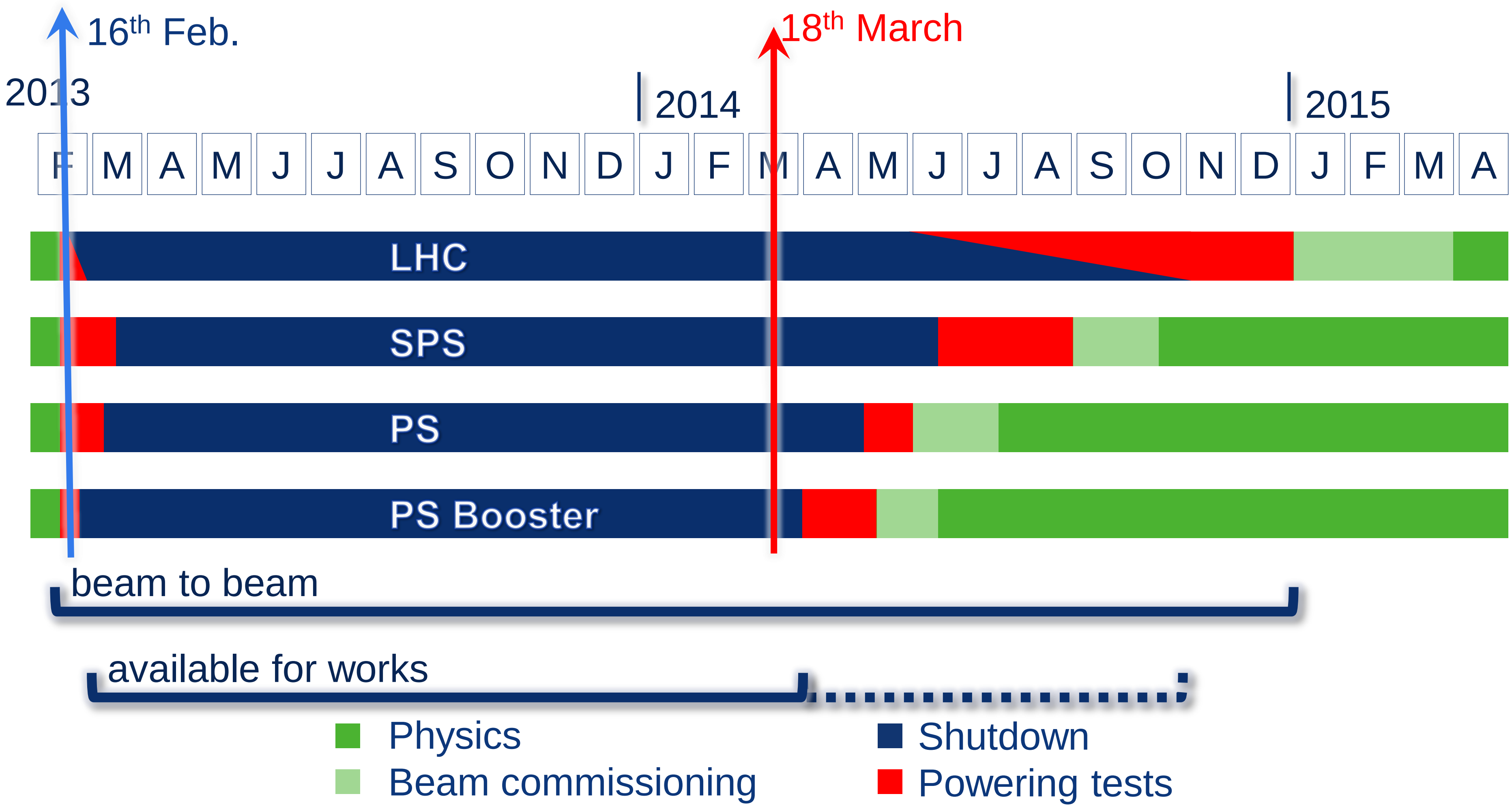
LS1 starts as the shutdown to repair the magnet interconnects to allow nominal current in the dipole and lattice quadrupole circuits of the LHC.



or shutdown which, in
repairs, maintenance,
nd cabling across the
x and the associated
experimental facilities.

All this in the shadow
interconnects.

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



The main 2013-14 LHC consolidations

Opening:100%
1695 Openings and final reclosures of the interconnections
Closure: 50%

100 % done
Complete reconstruction of ~~1500~~ of these splices
3000

98 % done
Consolidation of the 10170 13kA splices, installing 27 000 shunts

85 % done
Installation of 5000 consolidated electrical insulation systems

90 % done
300 000 electrical resistance measurements

75 % done
10170 orbital welding of stainless steel lines

18 000 electrical Quality Assurance tests
80 % done

10170 leak tightness tests
65 % done

3 quadrupole magnets to be replaced
Done

15 dipole magnets to be replaced
Done

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

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

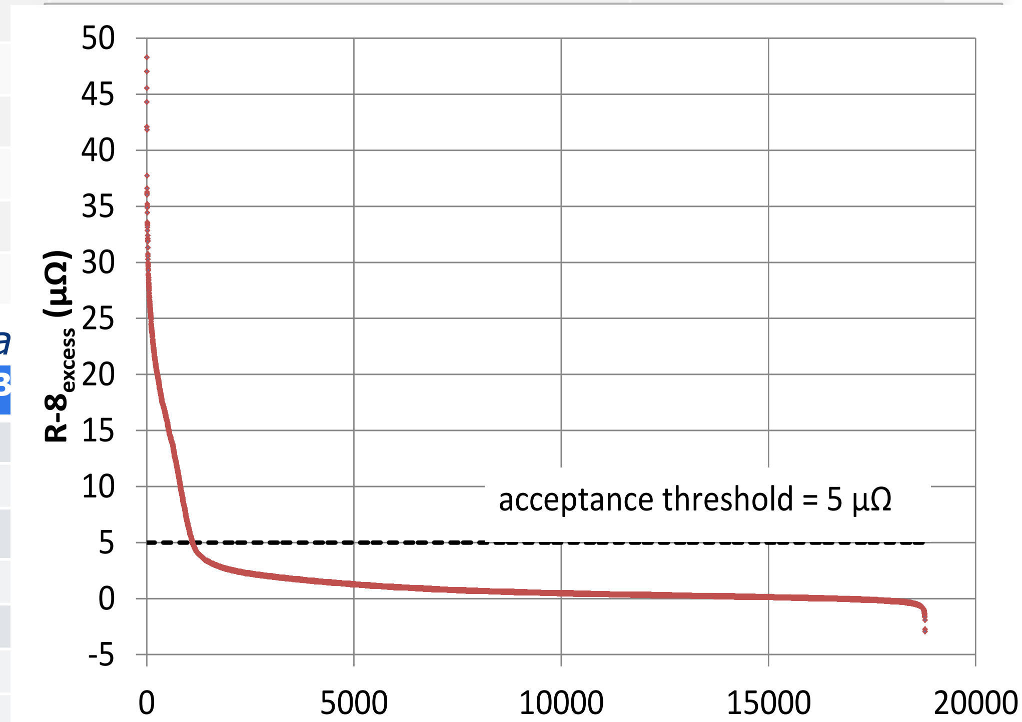

~10000 splices tested
~100 000 Electrical Measurements
End of Measurement
Campaign for Splice
produced before LS1
ELQC Team
~ 40 people
Visual inspection
Electrical Measurement

Top ten R-8 outliers

RB splice	R-8 (μΩ)	RQ splice	R-8 (μΩ)
QBBI.B24R7-M3-Ext-R	**77.5**	**QQBI.20L8-M1-Ext-L**	**116**
QQBI.9R4-M3-Ext-L	52.6	QBQI.27R1-M1-Int-L	54.8
QQBI.22L8-M3-Ext-L	52.6	QBBI.B18R2-M1-Int-L	52.5
QBBI.A14L8-M3-Int-R	49.9	QBBI.B25L8-M1-Int-R	51.4
QQBI.16R8-M3-Int-R	47.4		
QQBI.22R7-M3-Int-L	43.3		
QQBI.19L1-M3 Ext-L	41.8		
QBQI.32R7-M3-Int-L	41.6		
QBQI.31R6-M3-Ext-L	40.6		
QDQI.7R3-M3-Ext-L	39.2		

Highest R-8$_{excess}$ resistance va

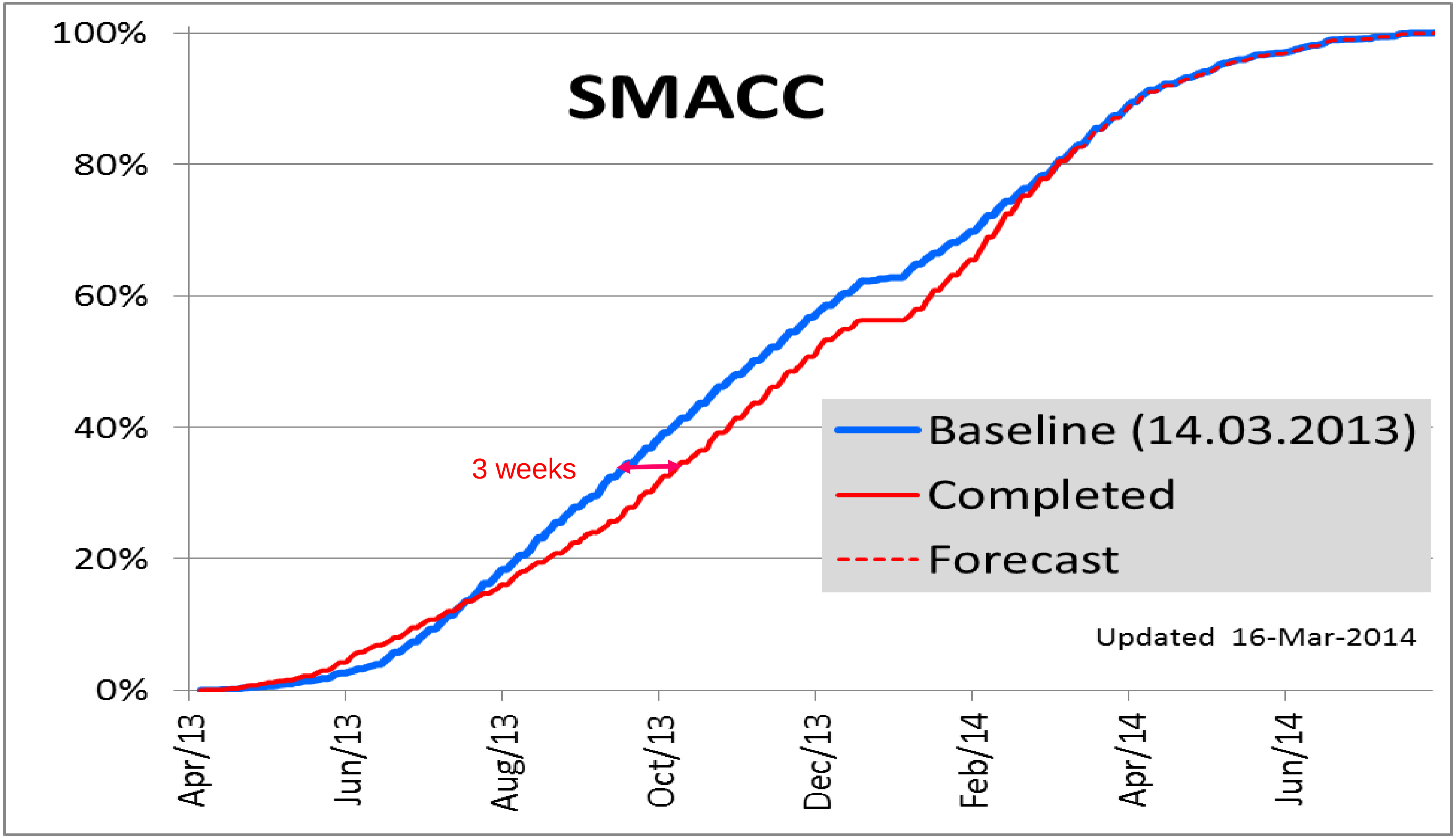
Sector	Max R-8$_{excess}$ RB
56	28.6
67	35.0
78	71.9
81	41.8
12	29.6
23	27.8
34	33.6
45	48.3



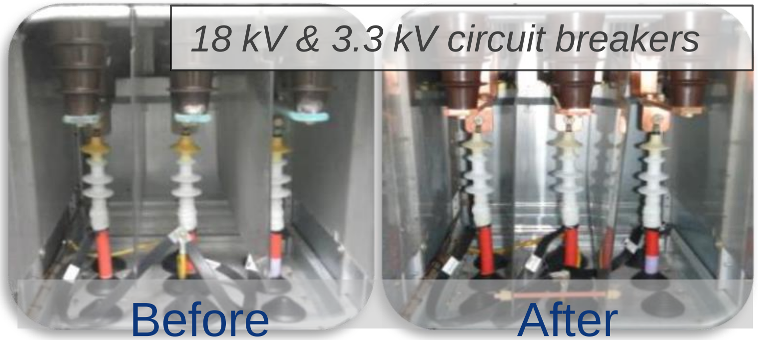
Excess resistance distribution sorted descending by resistance values. The two highest R-8 excess values of 106 μΩ and 72 μΩ are not shown.

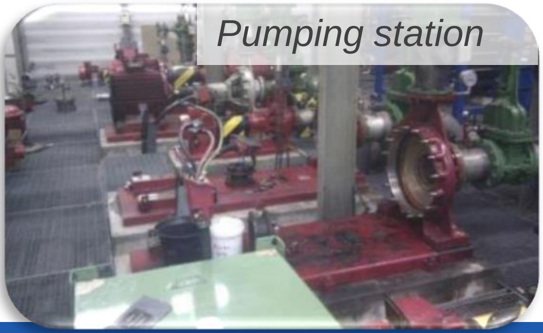
Courtesy of C. Scheuerlein

Superconducting Magnets And Circuits Consolidation Dashboards

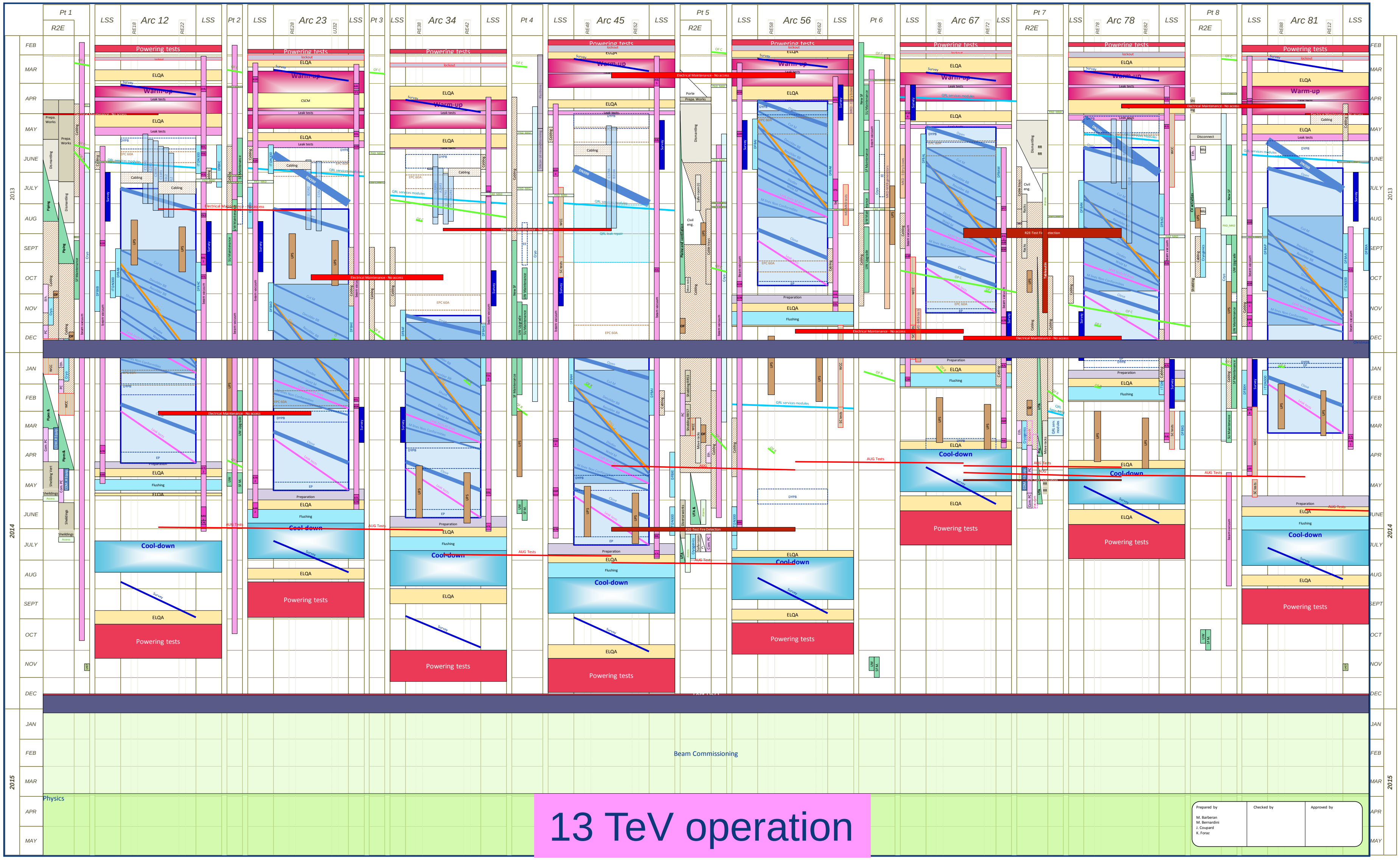


The other activities



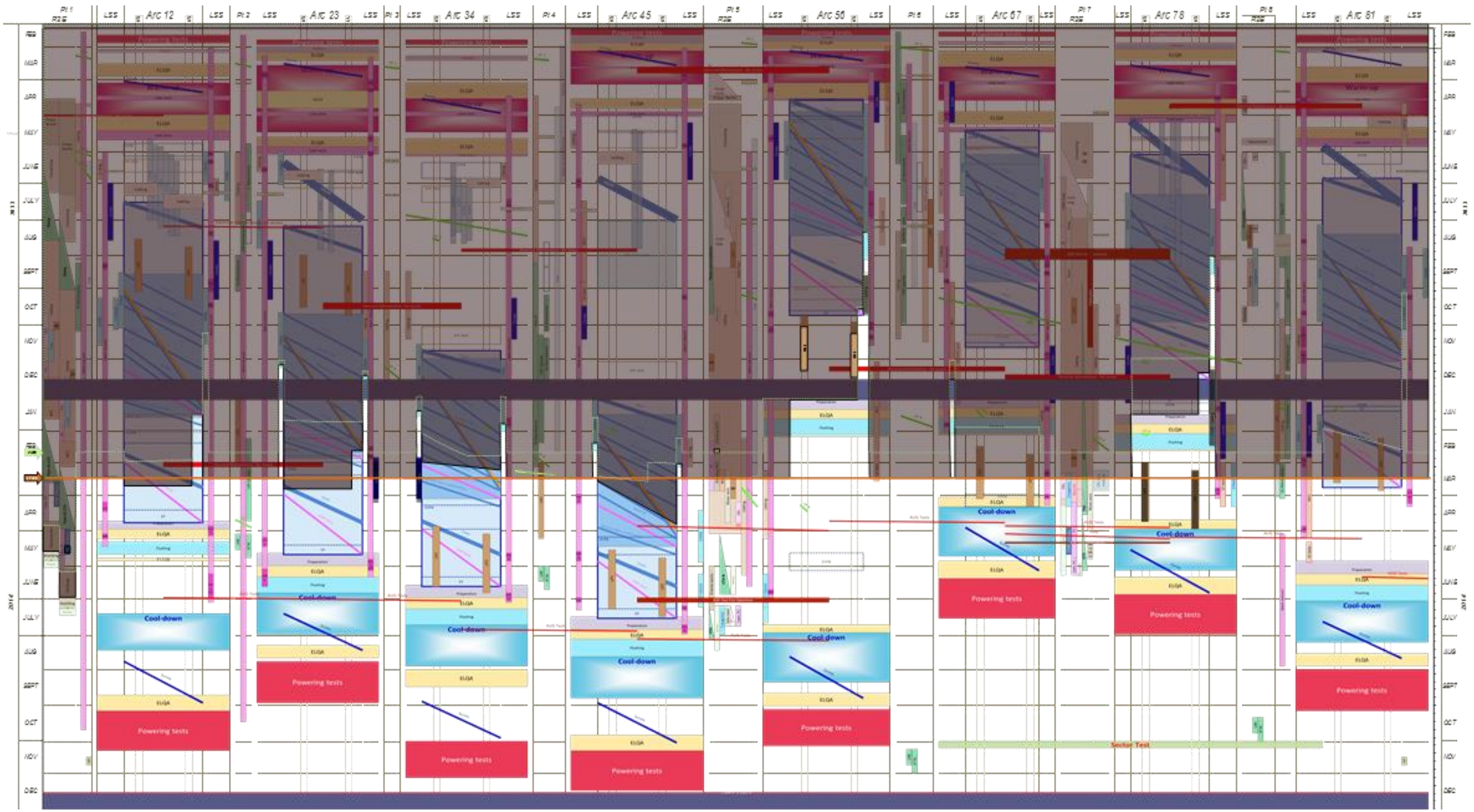


LS1: LHC schedule



LS 1

LHC injectors getting ready for hardware tests
LHC: all signals are green for beam on January 2015



LS1 status

LHC injectors getting ready for hardware tests
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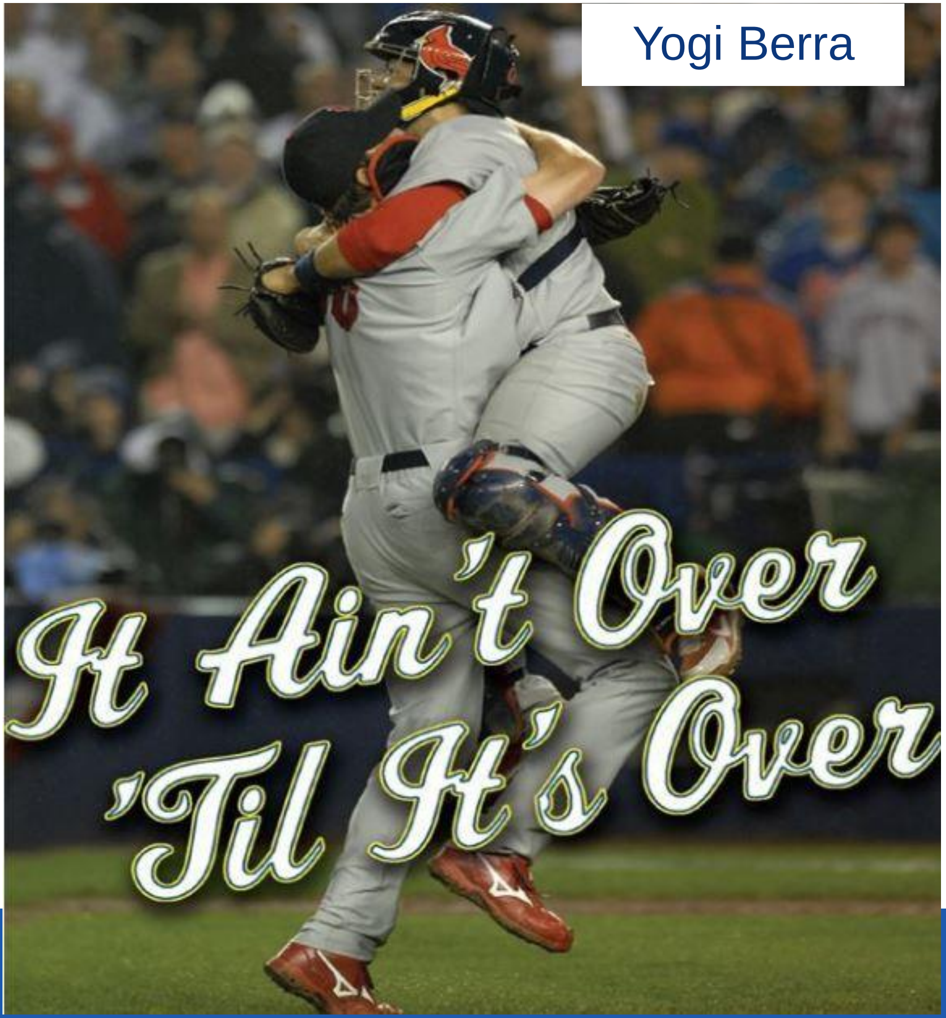
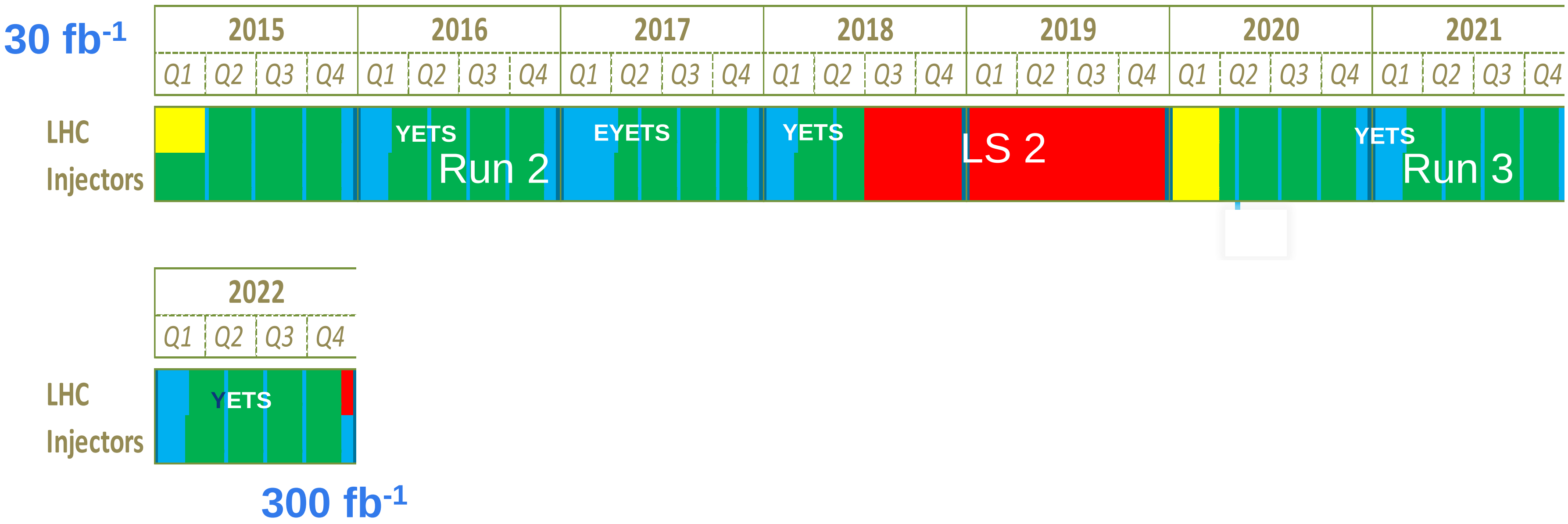


LHC schedule: Run2 and Run 3

LS2 starting in 2018 (July) => 18 months + 3 months BC
LS3 LHC: starting in 2023



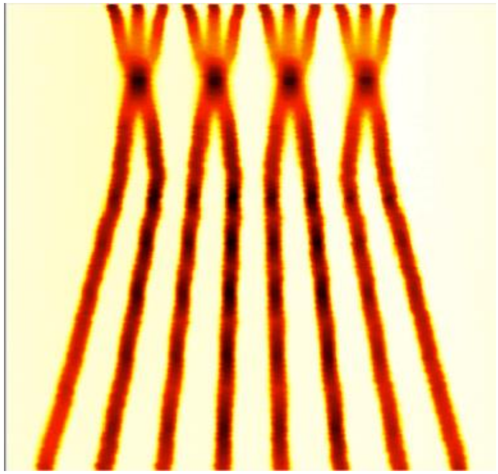
(Extended) Year End Technical Stop: (E)YETS

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

- **β^* ≤ 0.5m** (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	…

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

All numbers approximate

* different operational model – caveat - unproven

Courtesy Mike Lamont

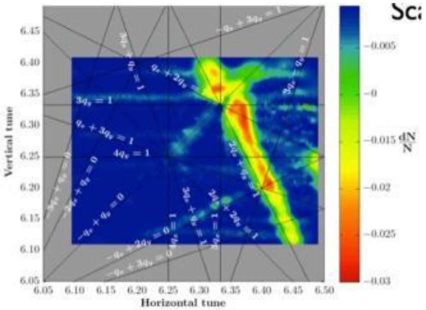
LS2 : (2018), LHC Injector Upgrades (LIU)

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

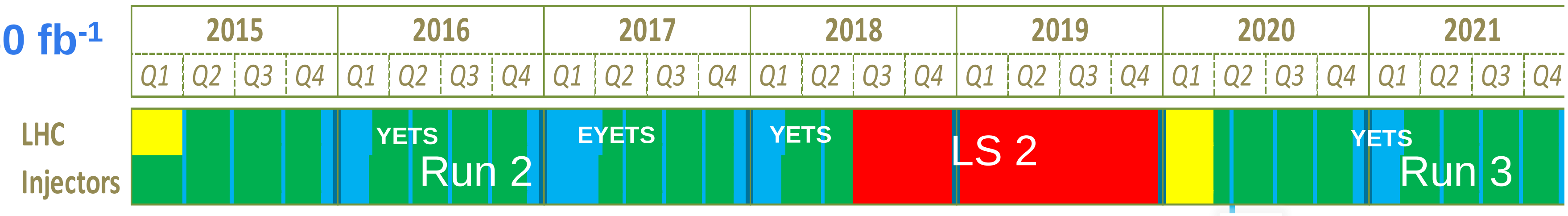
These are only the main modifications and this list is far from exhaustive
Project leadership: R. Garoby and M. Meddahi

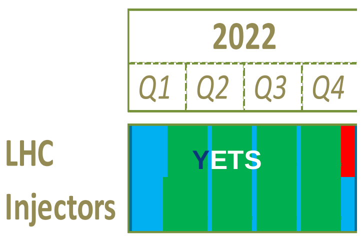
LHC schedule: LS3 2 and Run 3

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

30 fb^{-1}



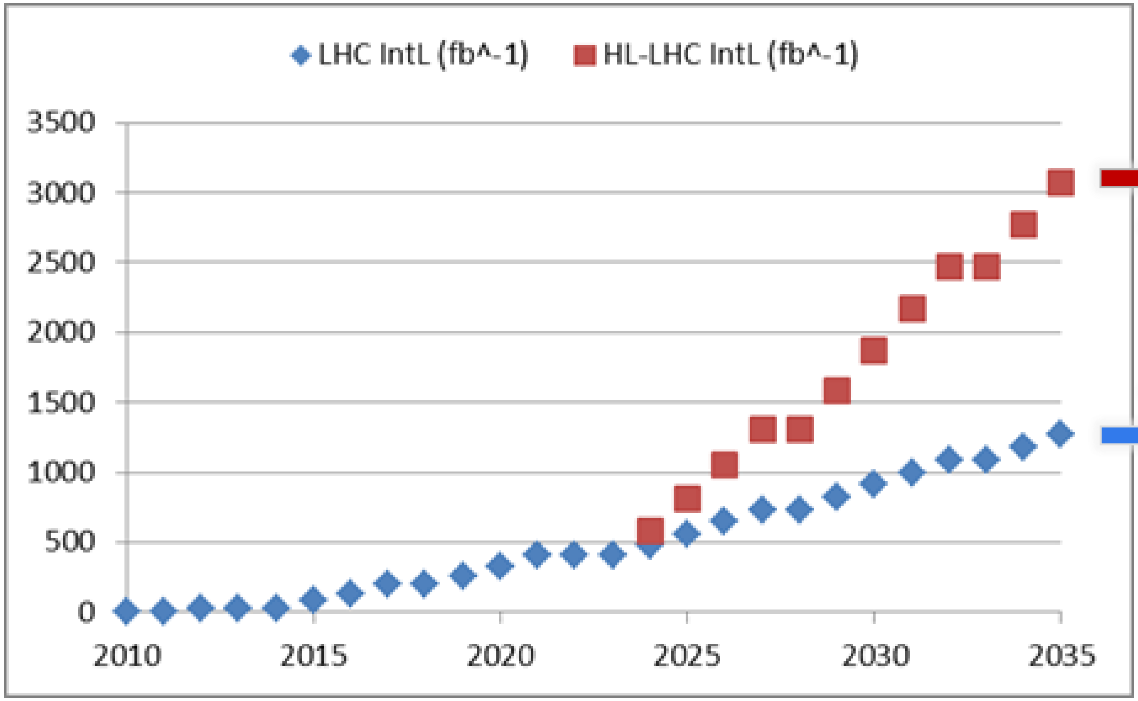


300 fb^{-1}

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

LS3 : HL-LHC installation

Why High-Luminosity LHC ? (LS3)



By implementing HL-LHC

Almost a factor 3

By continuous performance improvement and consolidation

Goal of HL-LHC project:

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

High Luminosity LHC

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.*

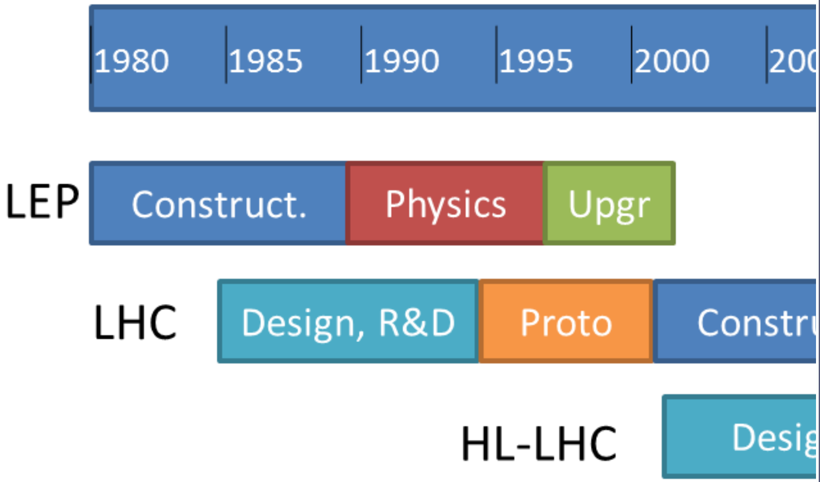
HL-LHC from a study to a PROJECT

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

including LHC injectors upgrade **LIU**

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

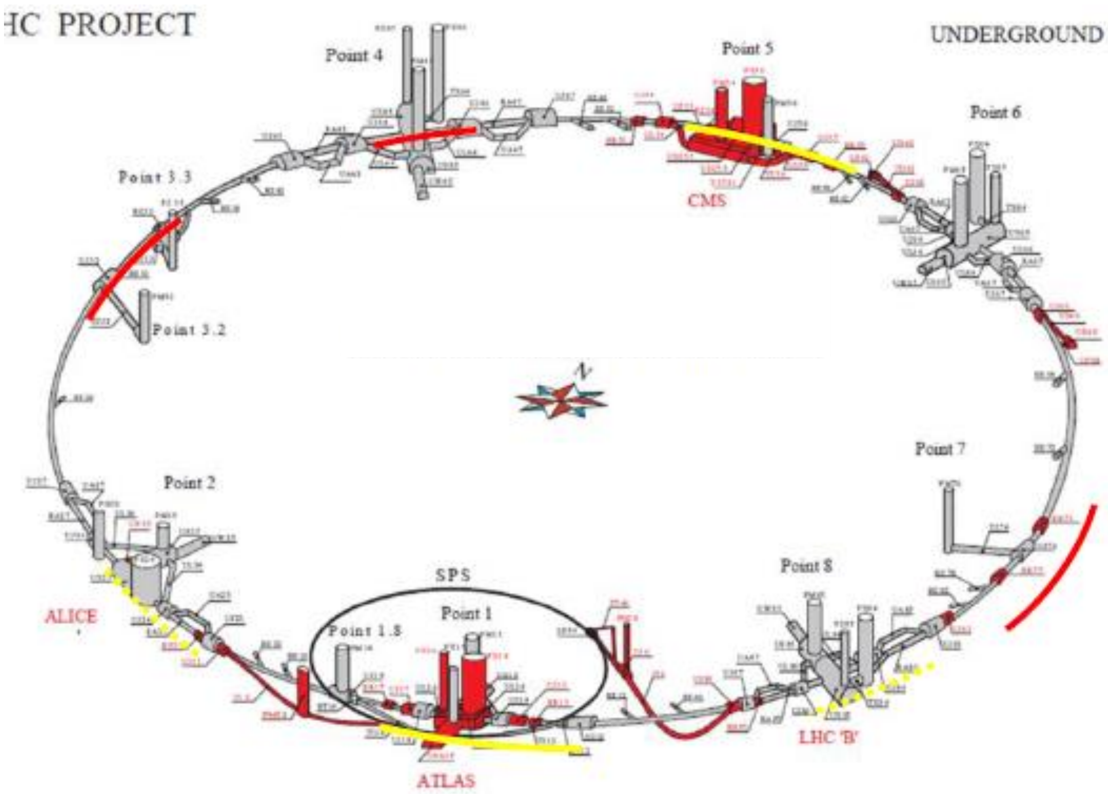
"…exploitation of the full pote
high-luminosity upgrade of th
=> High Lumi



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

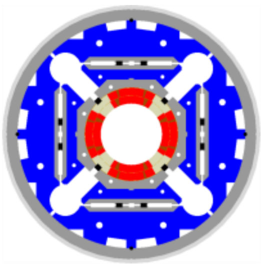
Project leadership: L. Rossi and O. Brüning

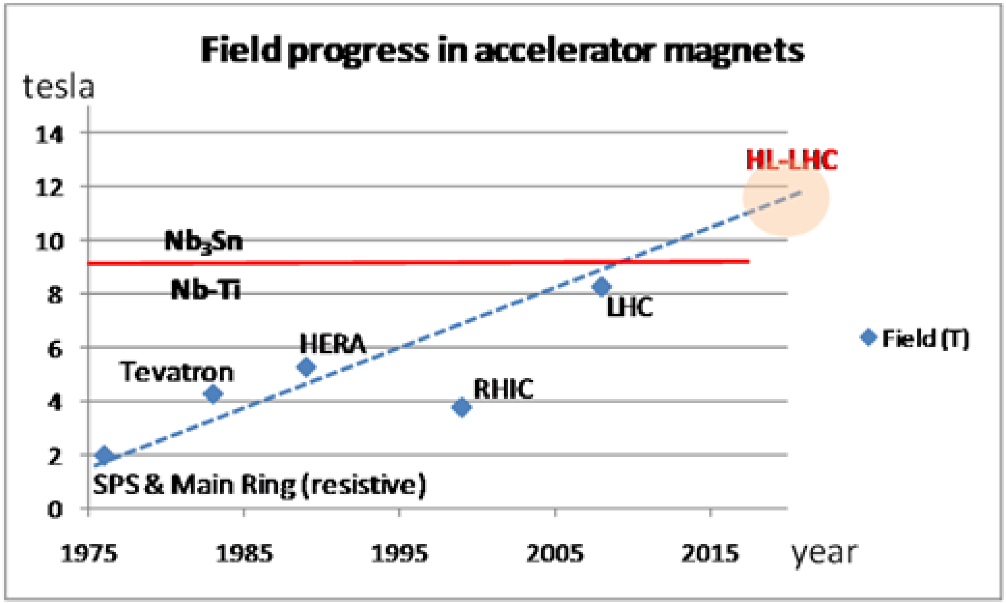
Squeezing the beams: High Field SC Magnets

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)





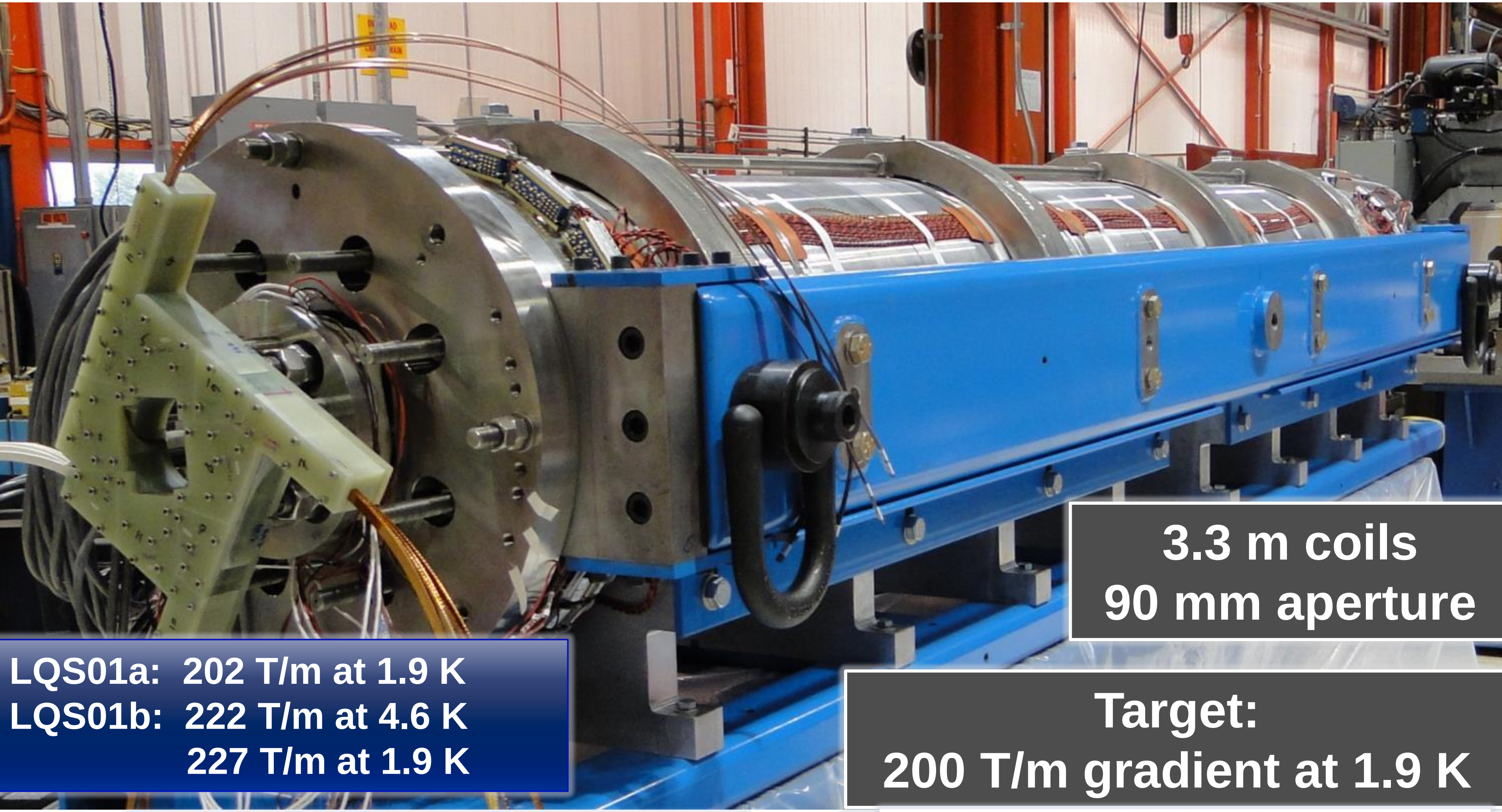
More focus strength,
β* as low as 15 cm (55 cm in LHC)
thanks to ATS** (Achromatic Telescopic Squeeze) **optics
In some scheme even β down to 7.5 cm are considered*

- 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)

Courtesy Lucio Rossi

LQS of LARP

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



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

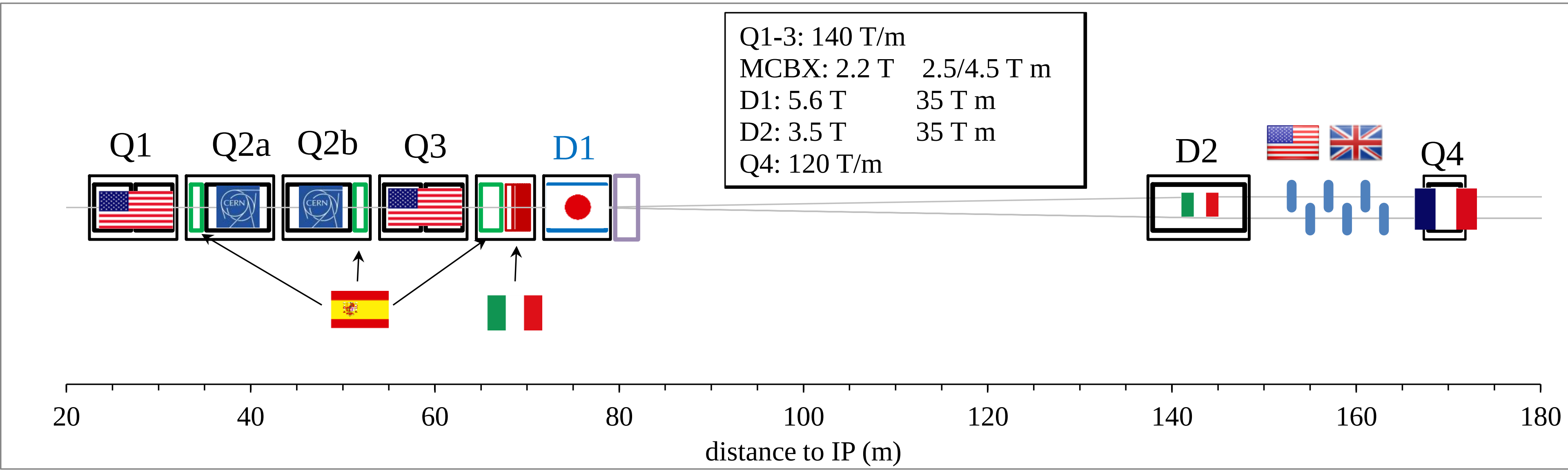
Target:
200 T/m gradient at 1.9 K

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

Setting up International collaboration

Baseline layout of HL-LHC IR region

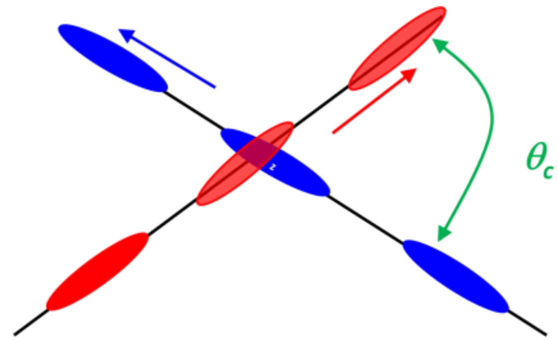


with national laboratories **but also involving industrial firms**

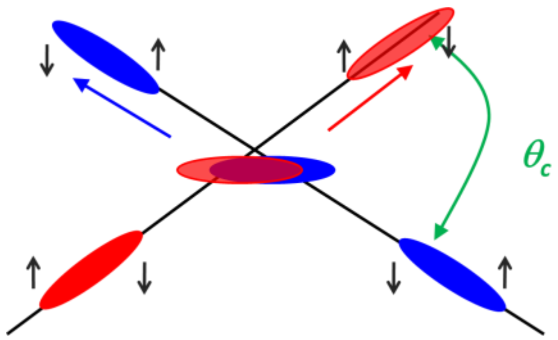
Crab Cavities, Increase "Head on"

Aim: reduce the effect of the crossing angle

Without crabbing



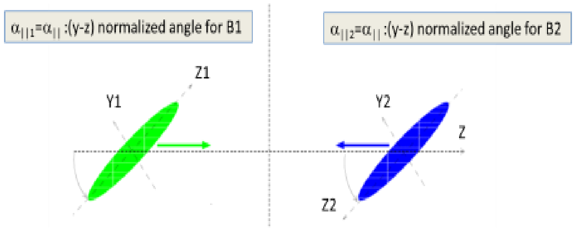
Without crabbing



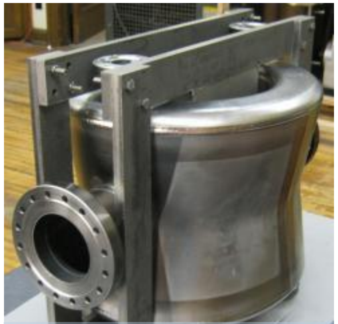
RF-Dipole Nb prototype

4-rod in SM18 for RF measurements

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

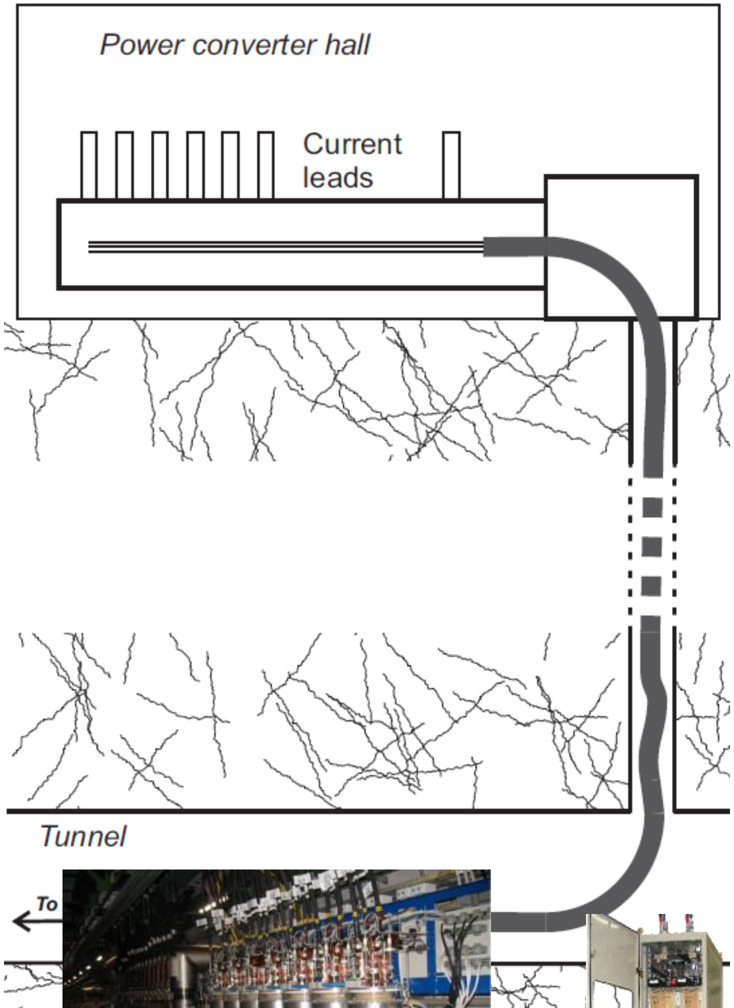


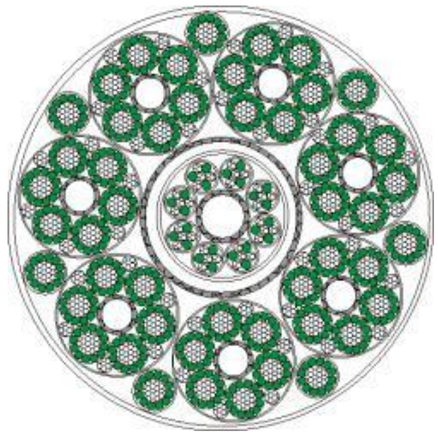
- 3 proto types available
- Cavity tests are on-going
- Test with beam in SPS foreseen in 2015-2016
- Beam test in LHC foreseen in 2017



DQWR prototype
17-Jan-2013

R2E: Removal of Power Converter (200kA-5 kV SC cable, 100 m height)





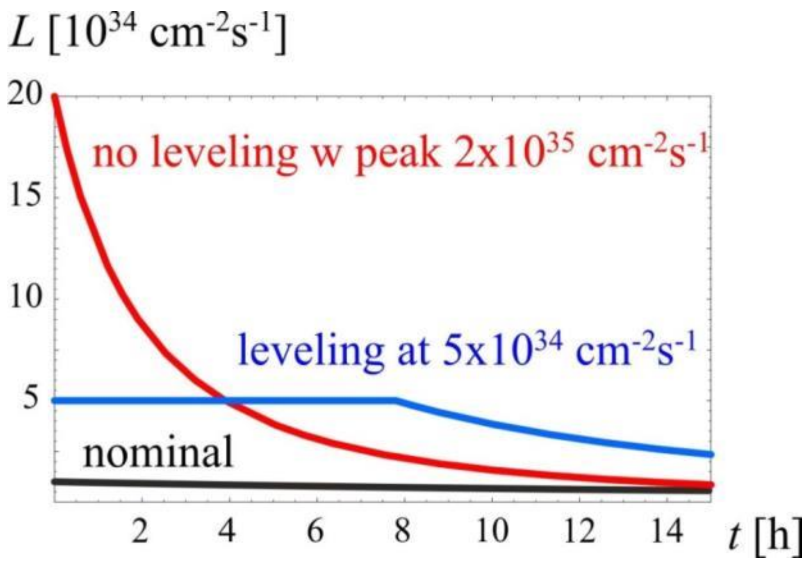
Φ = 62 mm

MgB_2
(or other HTS)

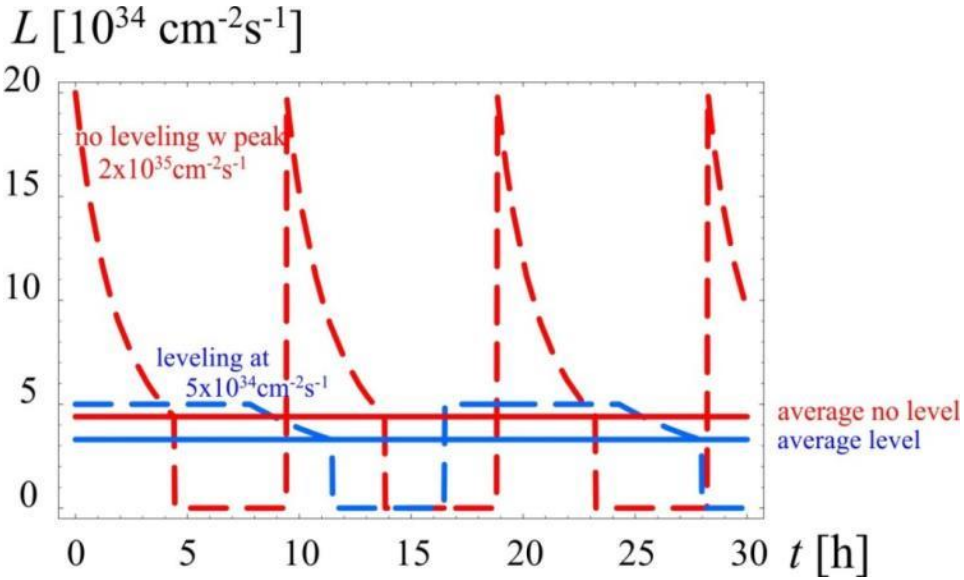
7 × 14 kA, 7 × 3 kA and 8 × 0.6 kA cables – Itot~120 kA @ 30 K

Also DFBs (current lead boxes) removed to surface
Final solution to R2E problem – in some points
Make room for shielding un-movable electronics
Make the maintenance and application of ALARA principle much easier and effective

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})*

Continuous global optimisation with LIU

	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

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
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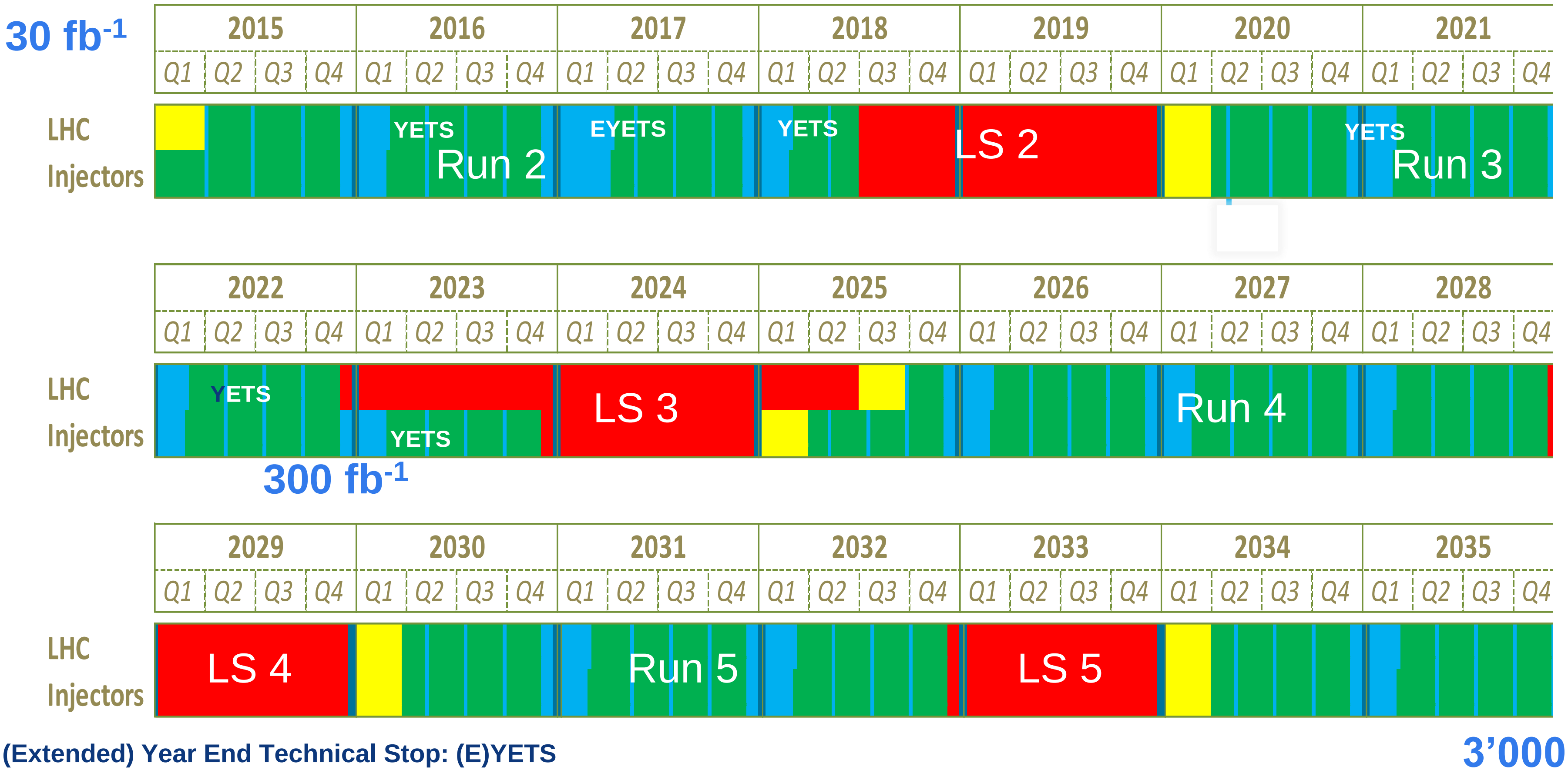

(Extended) Year End Technical Stop: (E)YETS

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

CERN

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