

Status of LHC machine and plans

Frédéric Bordry

LHCC

22nd February 2017



LHC: Q4 2016

	July				Aug				Sep				
Wk	27	28	29	30	31	32	33	34	35	36	37	38	39
Mo	4	11	18	25	1	8	15	22	29	5	12	19	26
Tu								MD 2					
We											TS2		
Th				MD 1						Jeune G			
Fr								beta* 2.5 km dev.					
Sa													
Su				beta* 2.5 km dev.						MD 3			

	Oct			Nov				Dec					
Wk	40	41	42	43	44	45	46	47	48	49	50	51	52
Mo	3	10	17	24	31	7	14	21	28	5	12	19	26
Tu	MD 4					ions setup							
We					TS3								
Th								ion run (p-Pb)				Lab closed	
Fr				MD 5									
Sa													
Su									Pb MD			Xmas	New Year

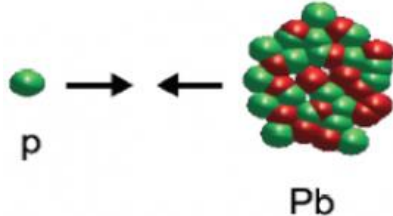
LHCC

End of LHC run [06:00]

- Proton-lead run at $\sqrt{s_{NN}}$ of 5 and 8 TeV
- 2 weeks dipole training (2 sectors) before Christmas



LHC: proton-Pb run 2016



Nov					Dec				
44	45	46	47	48	49	50	51	52	
31	7	14	21	28	5	12	19	26	
TS3	ions setup				Extended year end technical stop				
		ion run (p-Pb)					Lab closed		
				Pb MD			Xmas	New Year	

End of LHC run [06:00] ↓

- Experiments requested very different conditions (energy, luminosity) for p-Pb run
- Highly optimised plan devised to attempt to satisfy all requests (possibly with some compromises)
 - Endorsed by LHC Experiments Committee in May

Part 1: planned for 6-15 November

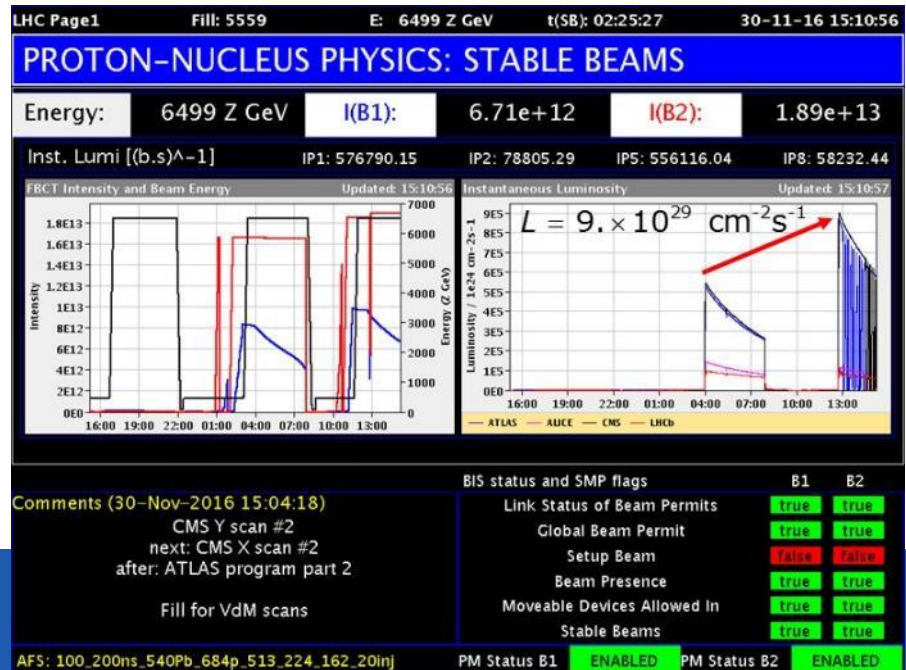
- ▶ $E = 4 Z \text{ TeV}$ ($Z=1, 82$) $\Rightarrow \sqrt{s_{NN}} = 5.02 \text{ TeV}$, as in 2013 p-Pb and 2015 Pb-Pb and reference p-p runs
- ▶ Priority ALICE: $L \approx 8 \times 10^{27}$ for $\approx 130 \text{ h}$ (minimum-bias data-taking)

Part 2: planned for 16 Nov-5 Dec

- ▶ $E = 6.5 Z \text{ TeV} \Rightarrow \sqrt{s_{NN}} = 8.16 \text{ TeV}$, max energy and luminosity
- ▶ **Goals: 100/nb to ATLAS and CMS, $\approx 20/\text{nb}$ to ALICE and LHCb**
- ▶ Beam reversal $p \leftrightarrow \text{Pb}$ (new set-up and validation) half-way for LHCb and ALICE
- ▶ Short run for LHCf

LHC Goals of p-Pb run surpassed

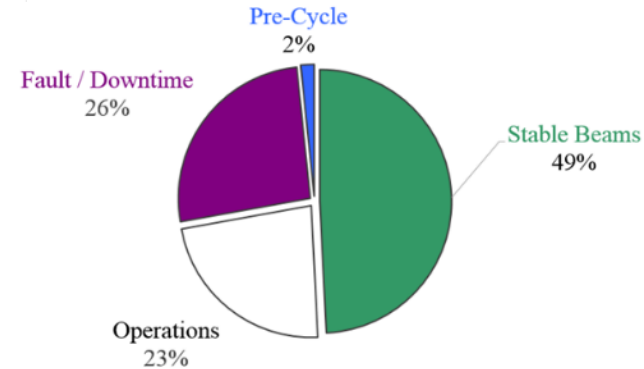
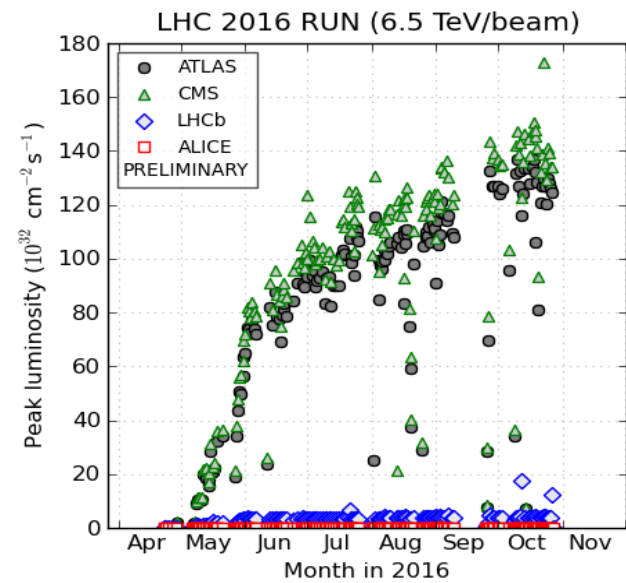
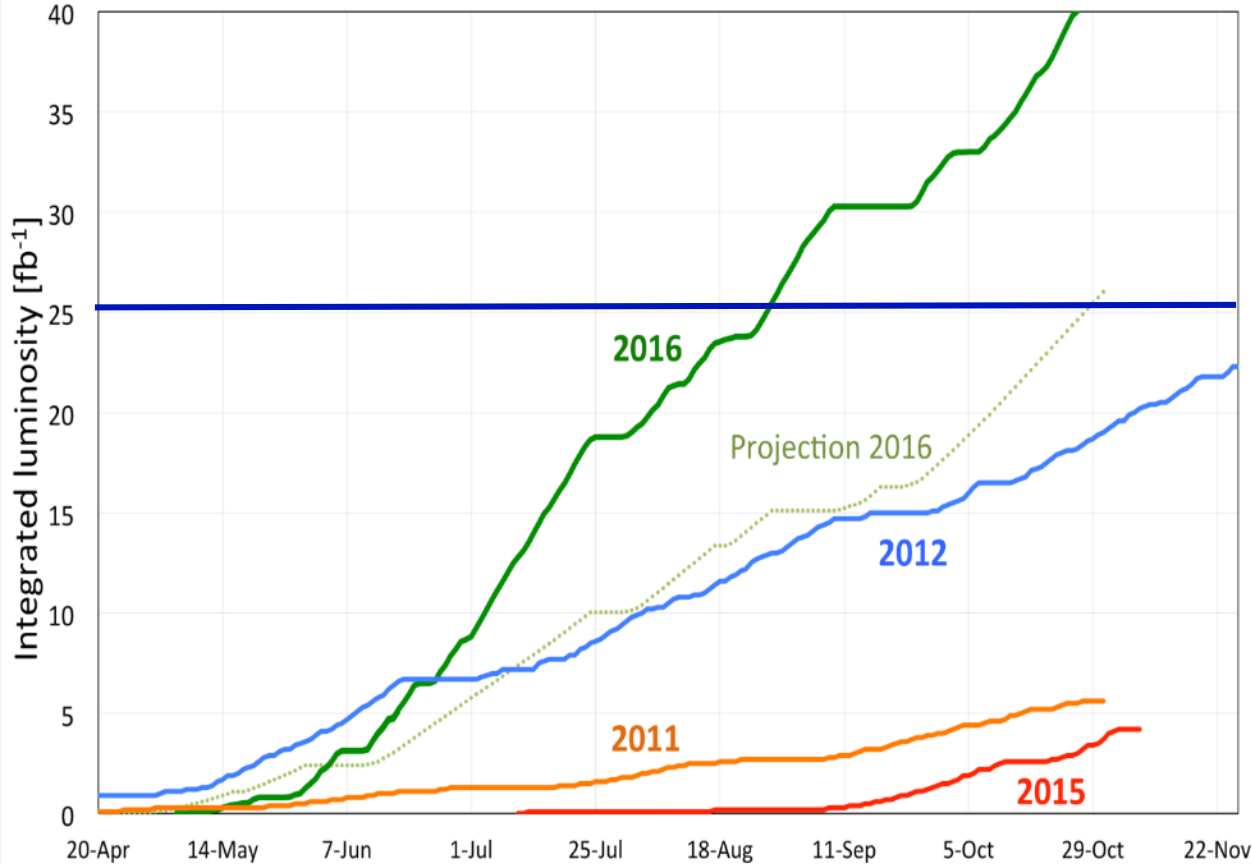
Configuration		Goal	Achieved
5 TeV p-Pb ($E_{\text{beam}}=4 \text{ Z TeV}$)	ALICE	700×10^6 min bias events	780×10^6
8 TeV p-Pb ($E_{\text{beam}}=6.5 \text{ Z TeV}$)	ATLAS - CMS	50 nb^{-1}	$69.5 - 65.5 \text{ nb}^{-1}$
	LHCb - ALICE	10 nb^{-1}	$14 - 13 \text{ nb}^{-1}$
	LHCf	9-12 h at $10^{28} \text{ cm}^{-2}\text{s}^{-1}$	9.5 h
8 TeV Pb-p ($E_{\text{beam}}=6.5 \text{ Z TeV}$)	ATLAS - CMS	50 nb^{-1}	$124 - 118 \text{ nb}^{-1}$
	ALICE - LHCb	10 nb^{-1}	$25 - 19 \text{ nb}^{-1}$



2016 LHC : Production year

Peak luminosity > $1.4 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
 OVER 25 fb^{-1} in both ATLAS and CMS

LHC integrated luminosity by year



≈153 days physics ≈3738.7 hours

	Duration [h]
Stable Beams	1839.5
Fault / Downtime	980.0
Operations	857.9
Pre-Cycle	61.3



LHC Limitations

SPS beam-dump

Nb of bunches per injection limited to 96
Total number of bunches: 2200

LHC Injection kickers

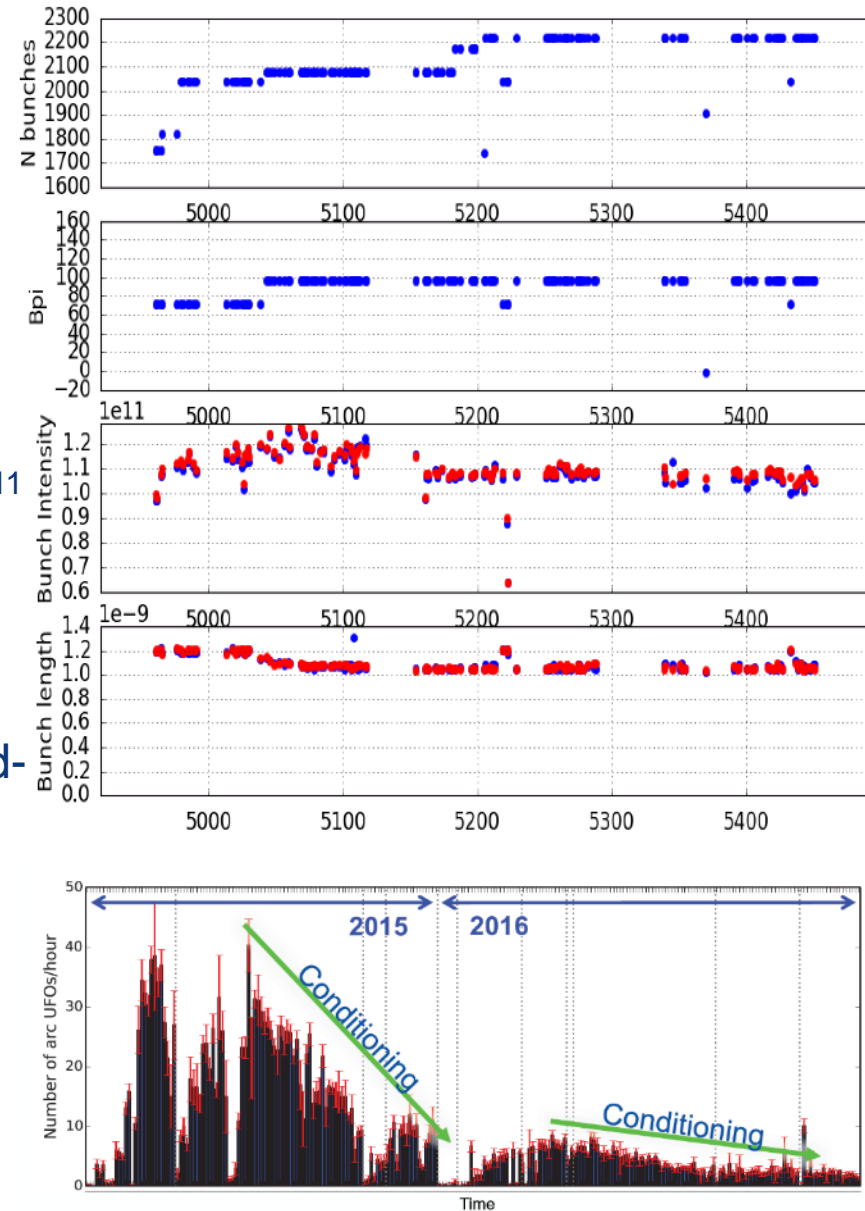
Outgassing from ceramic
Bunch population limited to around 1.1×10^{11}

Electron cloud

Still significant heat-load within cryogenic limits
Dynamics – well handled by cryogenics feed-forward – no impact on operations in the present conditions

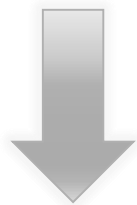
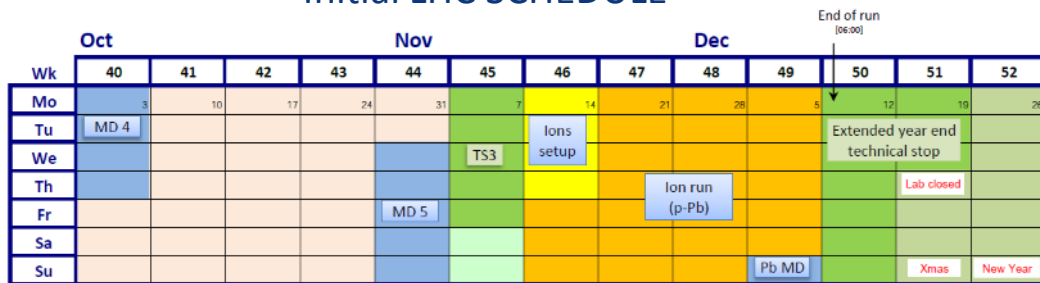
UFOs

Frequency has happily conditioned down



LHC: new schedule approved on 31st August

Initial LHC SCHEDULE

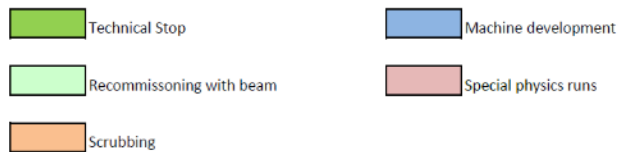


New Schedule



LHC Proton Run 2016 was reduced by one week: one week investment for energy increase

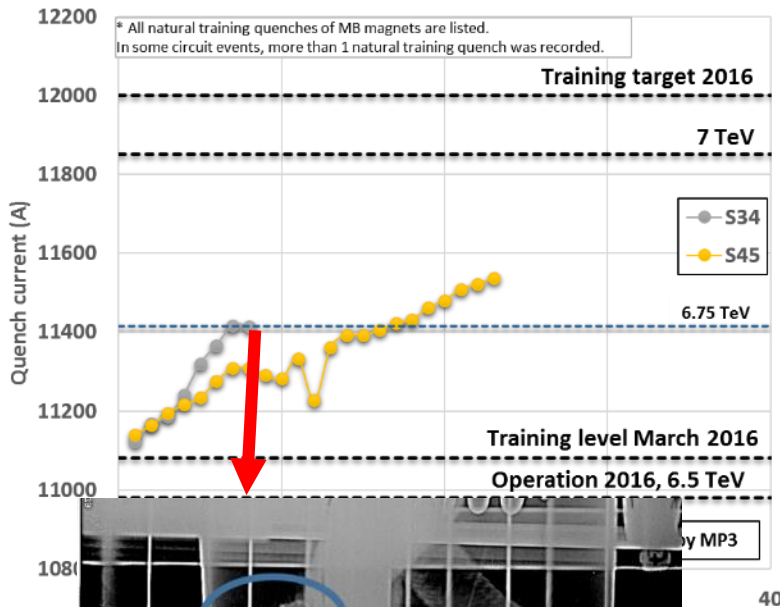
The restart date in 2017 is unchanged



Training of 2 sectors towards 7 TeV (max 2 weeks; finally 10 days)

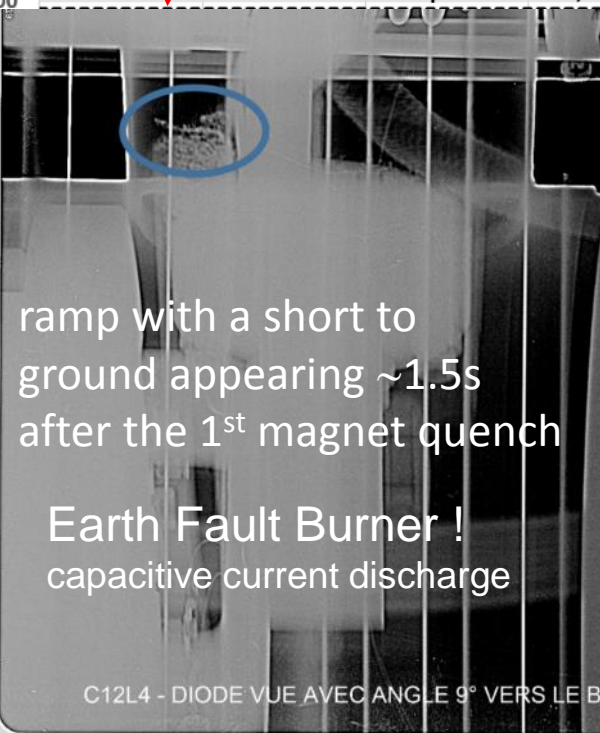
MB Training campaign 2016, December 5 - 14

Training of magnets in S34 and S45 in 2016 *

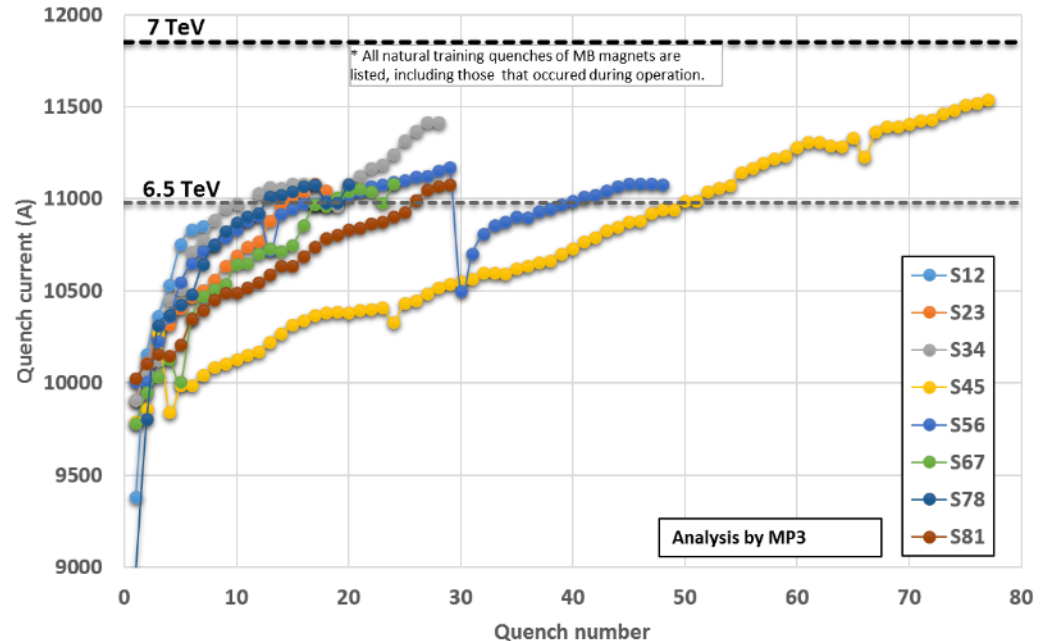


ramp with a short to ground appearing ~1.5s after the 1st magnet quench

Earth Fault Burner !
capacitive current discharge

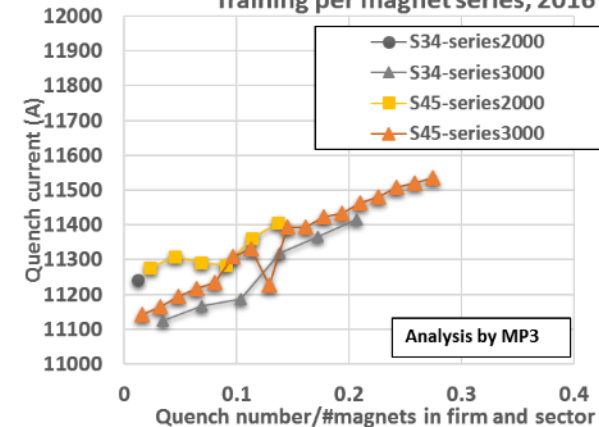


All main dipole training quenches in the LHC since 2008*



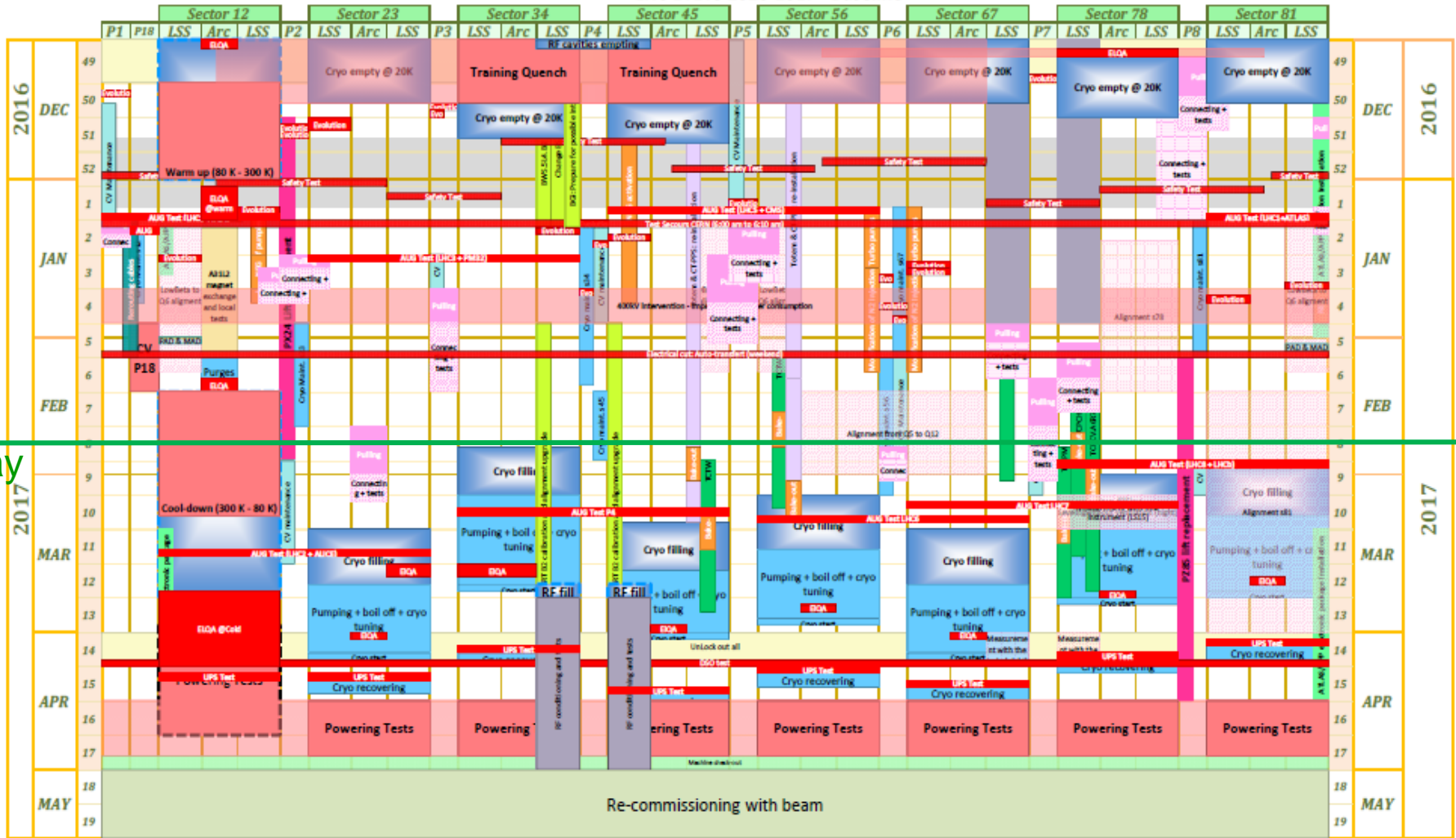
	Training quenches December 2016		
	Series 1000	Series 2000	Series 3000
RB.A34	1	1	6
RB.A45	0	6	17
total	1	7	23

Training per magnet series, 2016



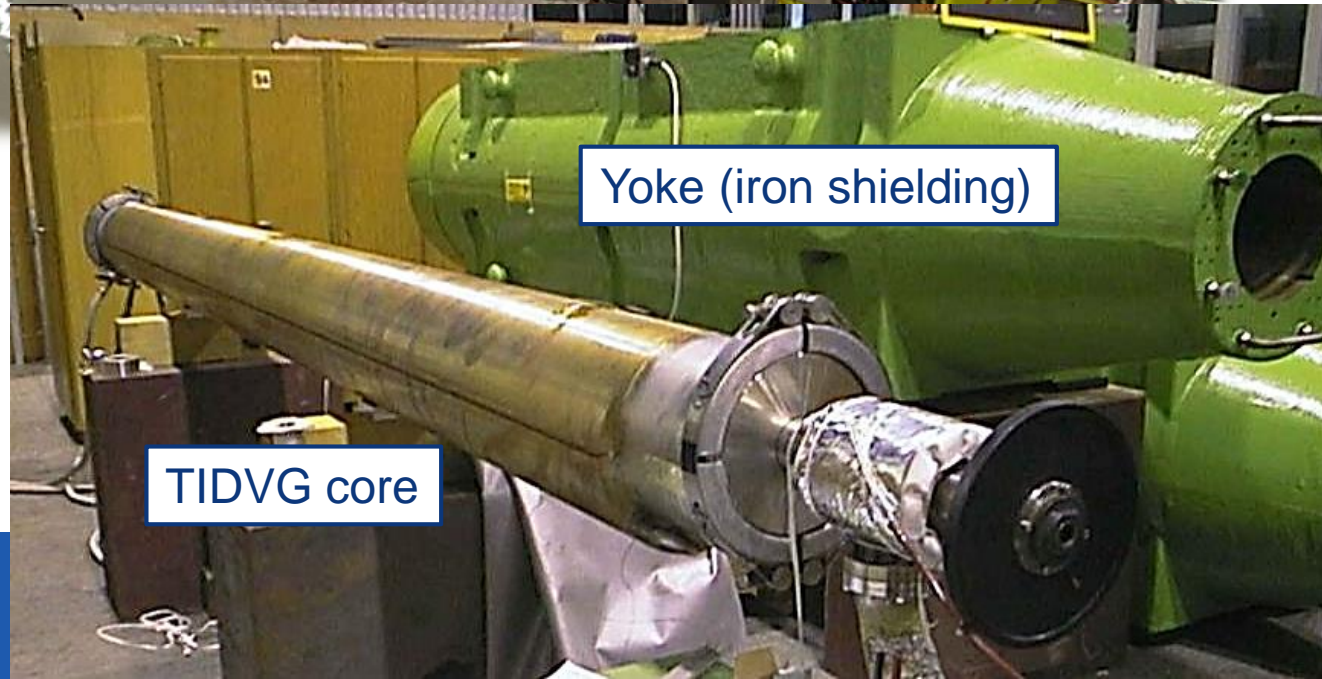
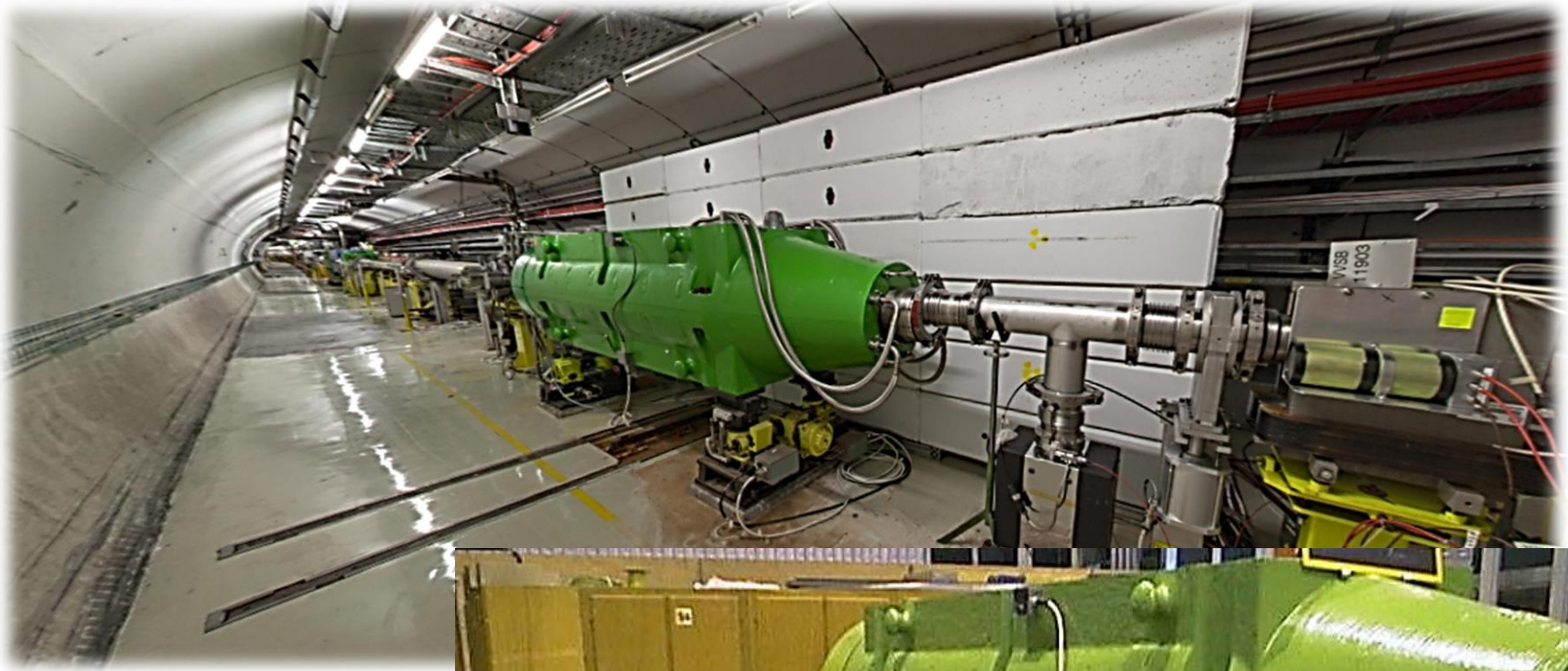
LHC EYETS Overview

LHC EYETS 2016-2017 - Baseline



today

SPS tunnel: internal beam dump (TIDVG#3)



Yoke (iron shielding)

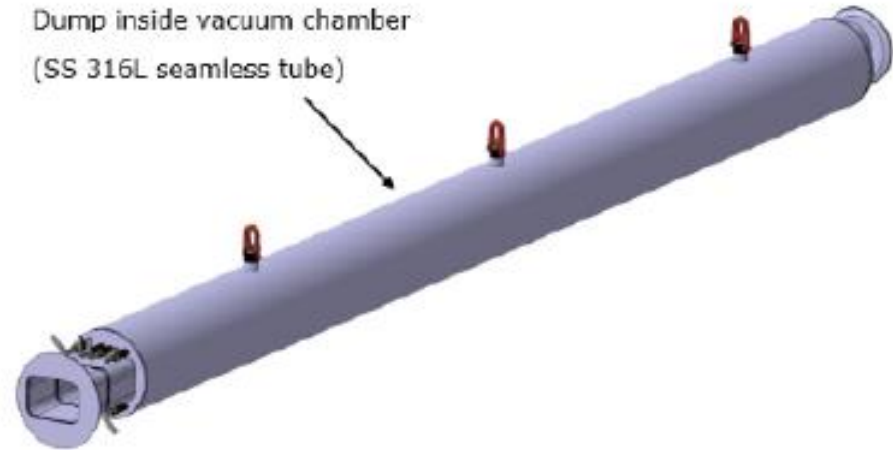
TIDVG core

SPS beam dump: new design (TIDVG#4) ; **crash program**

Vacuum tightness is ensured by a seamless 316L tube – no welds inside the shielding



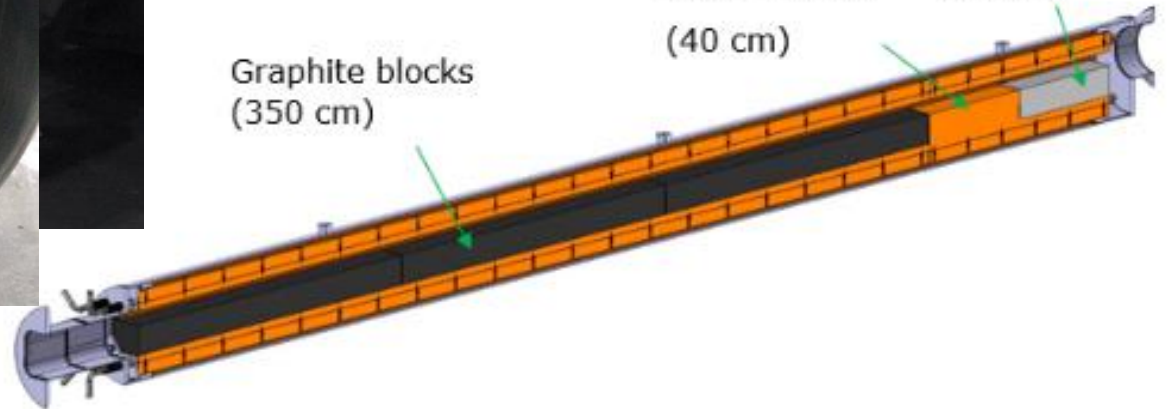
Dump inside vacuum chamber
(SS 316L seamless tube)



Graphite blocks
(350 cm)

CuCrZr block
(40 cm)

Tungsten block
(40 cm)



SPS new beam dump: assembly (TIDVG#4)

- The dump core has been successfully assembled at CERN in January 2017
- 3.5 m graphite, 40 cm CuCrZr and 40 cm Inermet

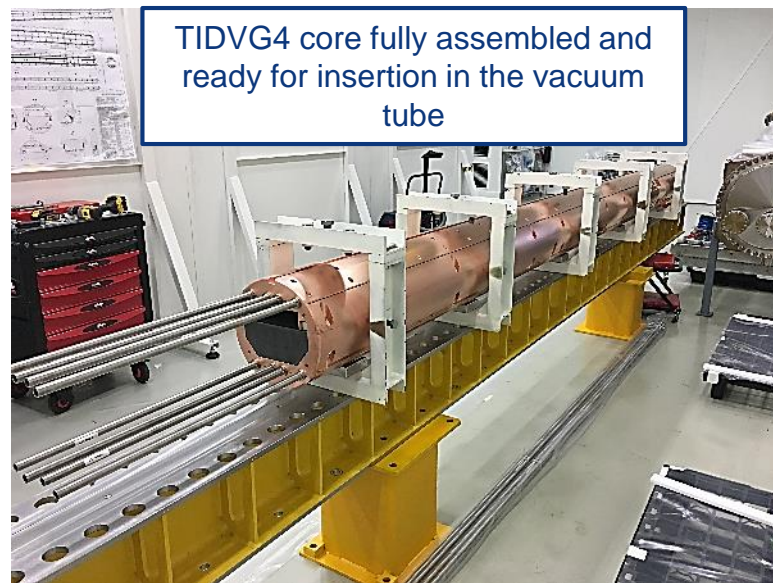
Graphite inside the CuCrZr core



Medium/high-Z absorber

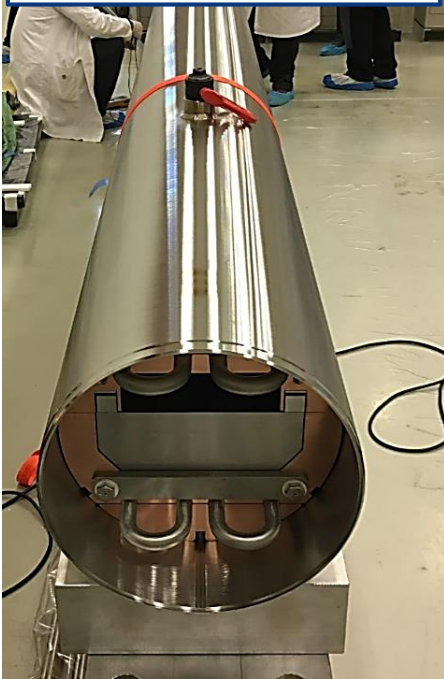


TIDVG4 core fully assembled and ready for insertion in the vacuum tube



SPS new beam dump: insertion, final assembly and bake-out

TIDVG4 core fully inserted
(downstream)



Final leak detection (downstream)



Beginning of the bake-out

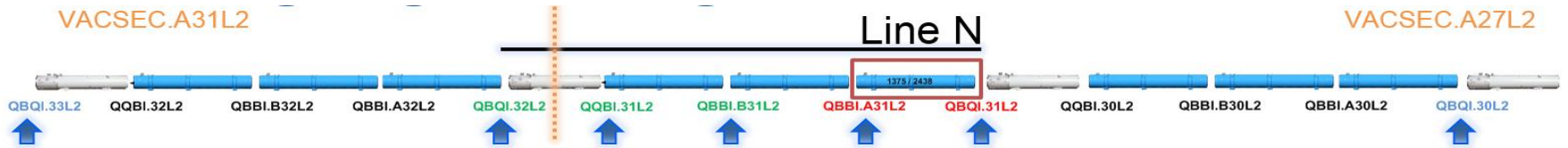


So far so good ... 😊

TIDVG#4 installation (and TIDVG#3 removal) decision to be taken today at LMC

Bake-out in tunnel foreseen to be finished by early April 2017 (ready for beam operation)

LHC : Magnet Exchange during eYETS

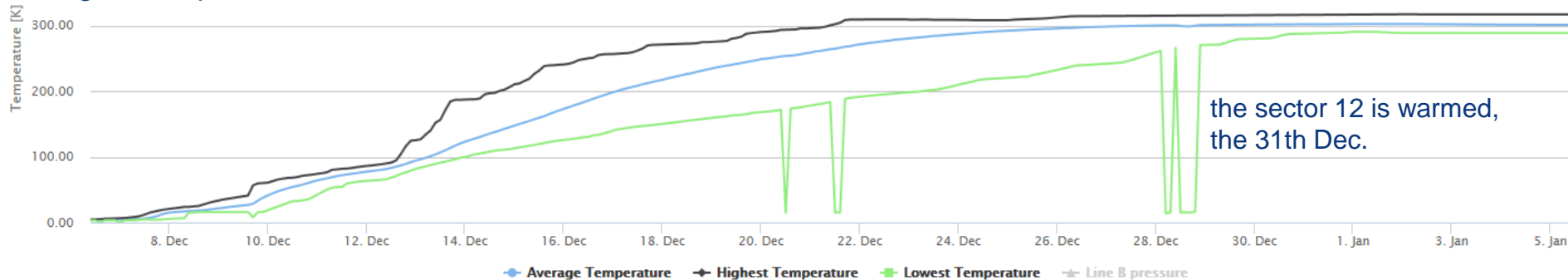


7 interconnections must be opened for the re-connection and the validation of the auxiliary circuits (correctors)

21 weeks required for the warm-up, exchange of the magnet, cool-down and the re-commissioning of the sector
4 ½ weeks (7days/7) will be necessary to disconnect and re-connect the dipole



Magnet temperature of sector 1-2



LHC : Magnet Exchange during eYETS

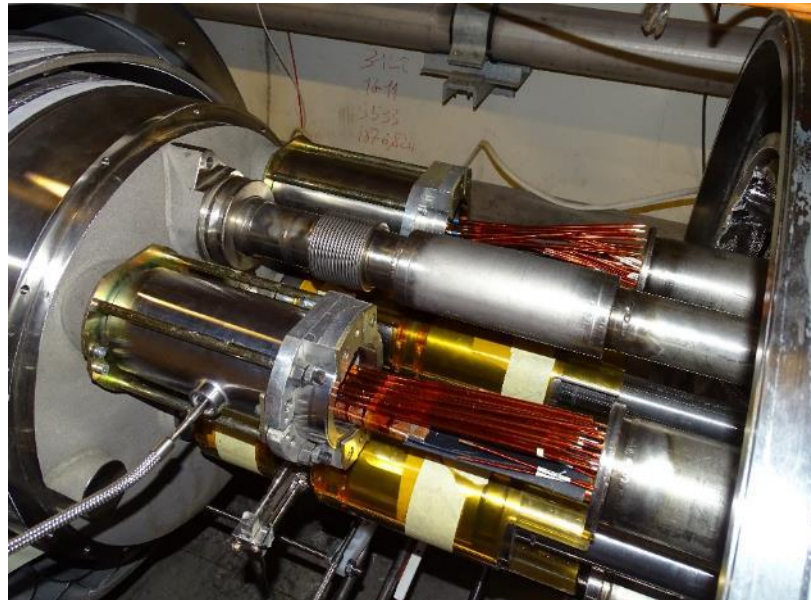
Magnet exchange on January 16th

New A31L2 magnet installation



3 weeks for magnet re-connection and local qualification

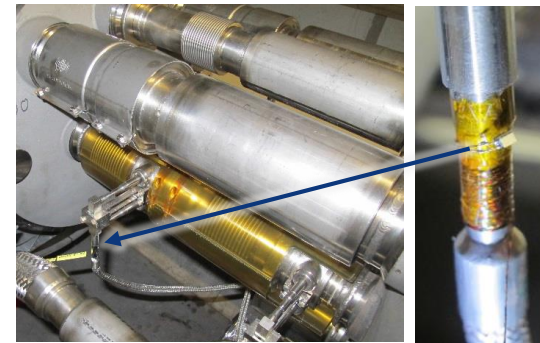
- Constant quality control validation by TE/MSC
- Electrical continuity by EIQA (for correctors)
- Welding visual inspection by EN/MME
- Leak test by TE/VSC
- Additional instrumentation installed by TE/CRG



Re-connection in progress (All but M lines)



13kA splices and shunts soldered



Additional temperature sensors

LHC : Magnet Exchange during eYETS

Ready for closure (February 6th).



Successful global test :

- EIQA test
- Validation of the re-welding by a controlled pressurisation
- Leak test and vacuum insulation pumping

Cool down started February 15th



LHC Performance Workshop 2017 - 23-26 January 2017

A great workshop after
a great year 2016
to prepare 2017,
Run 2, LS2, Run3,...
LIU and HL-LHC





LHC Performance Workshop (Chamonix'17)
23rd -16th January 2017

Summary session:

Wednesday, 1st March 2017

14:00-15:00, Main Auditorium

LHC schedule 2017

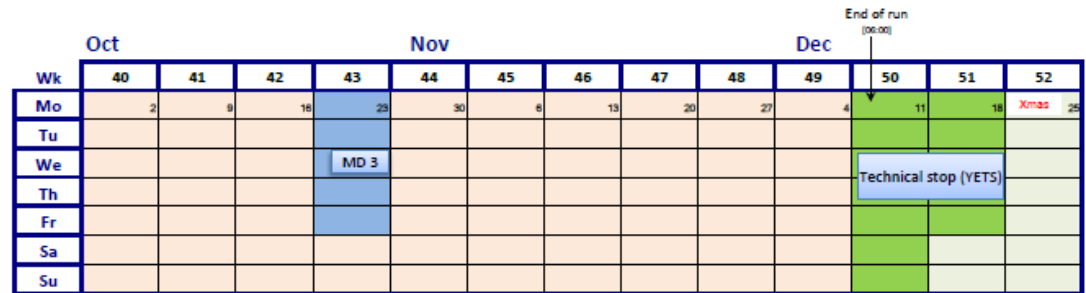
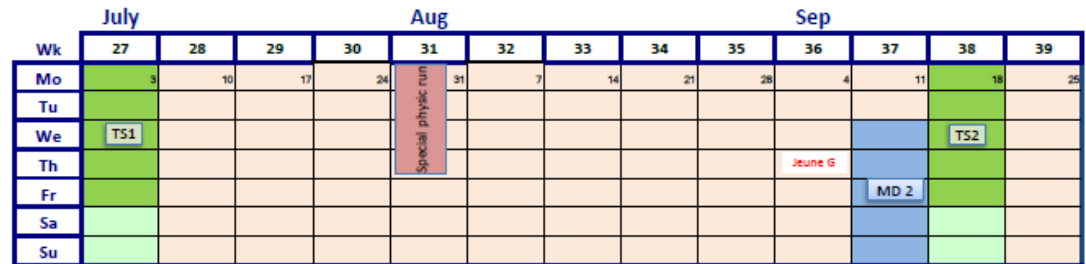
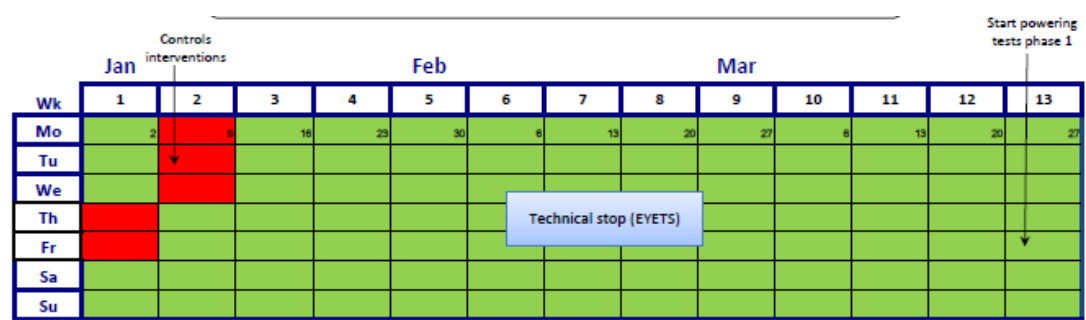
a new production year

$\sim 45 \text{ fb}^{-1}$ (final goal on March 1st)

keeping the LHC availability close to 50% (stable beams)

Initially 15 days of MD; later during 2017 according integrated luminosity : + 3 days ?

Special runs: VdM scans, ... and see slide 24



LHC schedule 2017 (version 0.6) : summary table

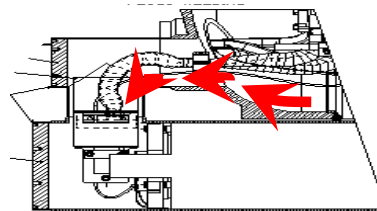
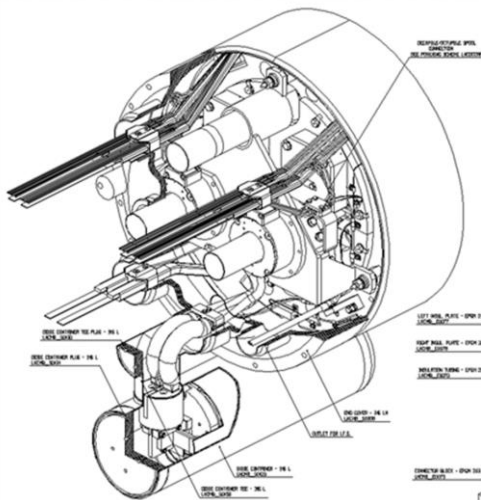
Phase	Days	Ratio to total beam time
Commissioning & Intensity ramp up	35	15%
Scrubbing	7	3%
Proton Physics at 13 TeV	145	65%
<i>Special Physics Runs</i>	8	4%
Machine Developments (MD)	15 (+3 ?)	7%
Technical Stops (TS1 & TS2)	10	4%
Technical Stop Recovery	4	2%
Total	224	100%

2016 Proton Physics : 164 days

Beam energy : Run 2 @ 13 TeV c.m.

NO change of beam energy in 2017 and 2018

Goal is to prepare the LHC to run at 14 TeV during Run 3.



Study how to reinforce the insulation (and to clean) during LS2 the electrical part connecting the dipole bypass diode.

Powering tests before and during LS2 should be defined

Working group was set up after Chamonix workshop:
How ?, How long ?, How much ?

2017 scenarios

Parameter	Standard 25 ns	BCMS 25 ns	BCMS 25 ns Pushed	Comments
Energy [TeV]	6.5	6.5	6.5	
β^* (1/2/5/8) [m]	0.4 / 10 / 0.4 / 3	0.4 / 10 / 0.4 / 3	0.33/ 10 / 0.33 / 3	Either 40 cm as 2016 or further squeeze to 33cm
Long-range separation [sigma] - assumed emittance	10 sigma - 3.5 um	10 sigma - 2.5 um	10 sigma - 2.5 um	
Half X-angle (1/2/5/8) [μ rad]	-185 / 120 / 185 / -150	-155 / 120 / 155 / -150	-170 / 120 / 170 / -150	Went to 140 with lower intensities in 2016
Number of colliding bunches (1/5)	2736	2448	2448	BCMS - 144 bunches/injection from SPS
Bunch population	1.25e11	1.25e11	1.25e11	around 1.3e11 injected for both Standard and BCMS
Emittance into Stable Beams [μ m]	3.2	2.3	2.3	Nominal 2.6 for Standard, 1.4 for BCMS at injection
Bunch length [ns] - 4 sigma	1.05	1.05	1.05	As 2016
Peak Luminosity (L0)	1.4e34	1.7e34	1.9e34	
Peak mean pile-up (<i>inel xsection 80 mb</i>)	37	51	56	Fast decay at start of fill
Average mean pile-up	27	33	36	NB Have to assume average fill length and lumi lifetime. Assume average fill length of 13 hours (June-July 2016 - optimistic)
Average luminosity lifetime (tau)	21 hours	15 hours	14 hours	Approx. - assuming burn only

2017 plans

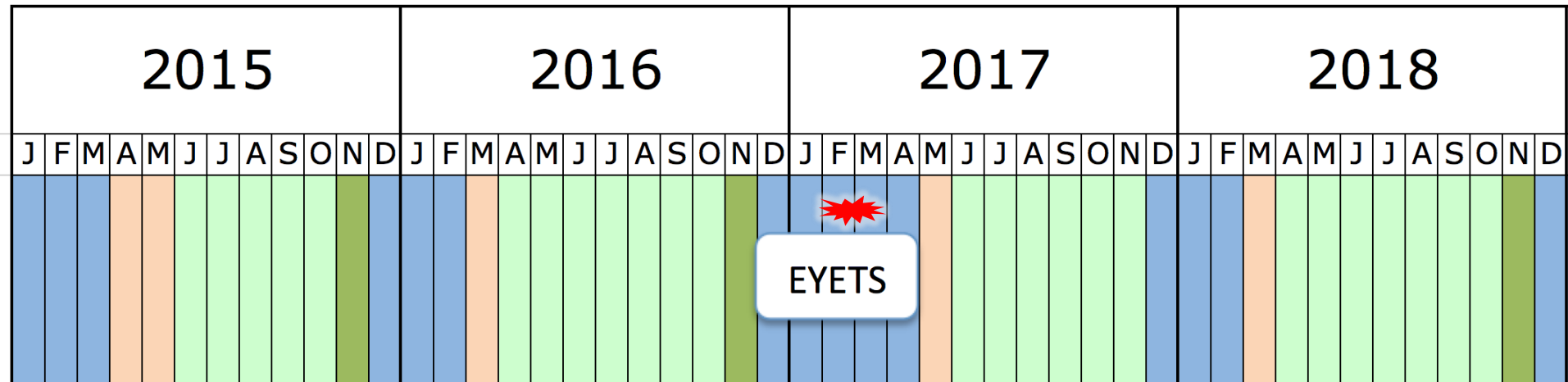
- Keep pushing performance and availability (~50%)
- BCMS beams (Smaller emittance though cycle; lower electron cloud heat load; faster intensity ramp-up; lower total beam current; lower losses; better for R2E... pile-up ?) => **maximize integrated luminosity**
- Starting with ATS optics; β^* 40 cm and later towards 33 cm
(would deploy HL-LHC optics and open up the exploration of its possibilities)
=> expect to reach 1.7 to $1.9 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ (inner triplet cooling limit ?)
- Look forward to HL-LHC without compromising present performance: ATS, beta* levelling, RF full de-tuning, electron cloud,...
- Look forward to the post-LS2 LIU era and how to exploit the potential

2017 special runs ?

- 5 TeV pp reference run (for Pb-PB and p-Pb physics analysis)
 - LHCC should take a decision if to do at end of 2017 or end of 2018 just before the ion run
 - LHCC should define the duration: 7-10 days or 4-5 days of stable days
- High β^* run at low energy (900 GeV/2 TeV ?)
(TOTEM and ATLAS(ALFA))
 - 2018 or Run 3 ?
 - To schedule 1 day of machine time in 2017 to investigate possibilities ?
- 90 m-like β^* run with maximum luminosity
(TOTEM and ATLAS(ALFA))
 - LHCC: 2018 ? Duration : ~1-2 weeks including setup

Run 2 and Run 3

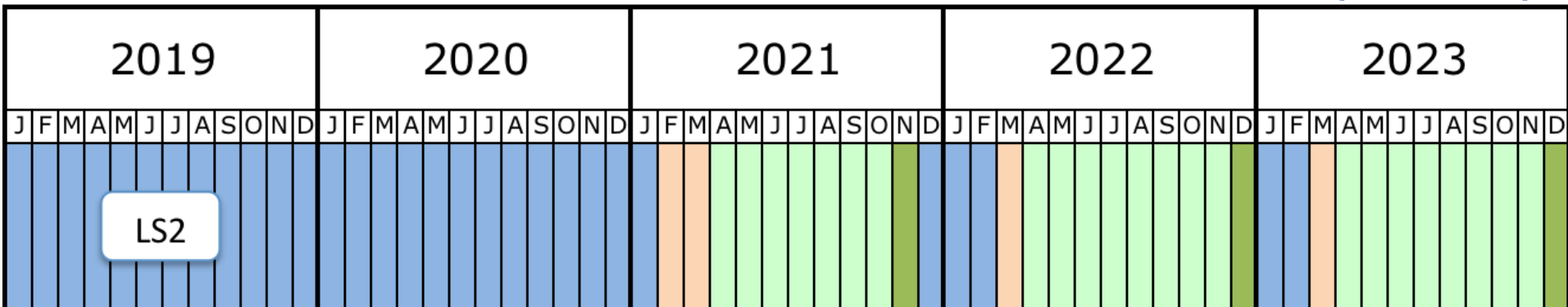
Ion runs end of 2018 (Pb-Pb)



EYETS

>120 fb⁻¹ (13 TeV)

Σ 300 fb⁻¹ (14 TeV ?)

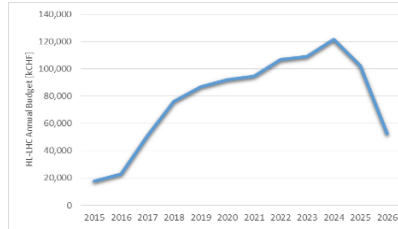
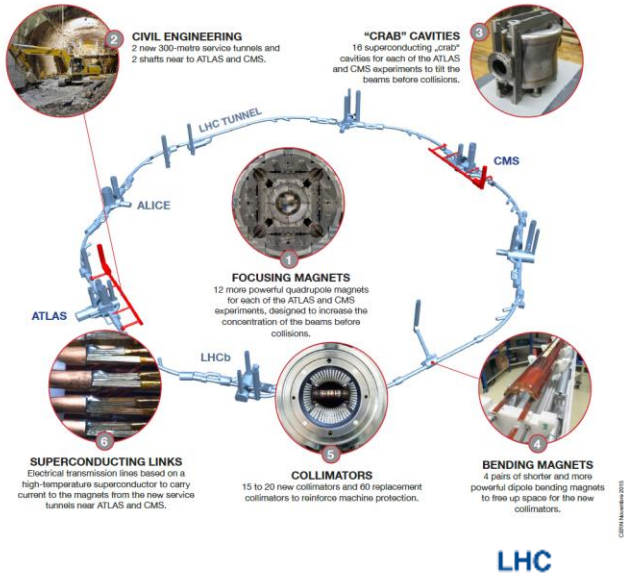


LS2



HL-LHC project

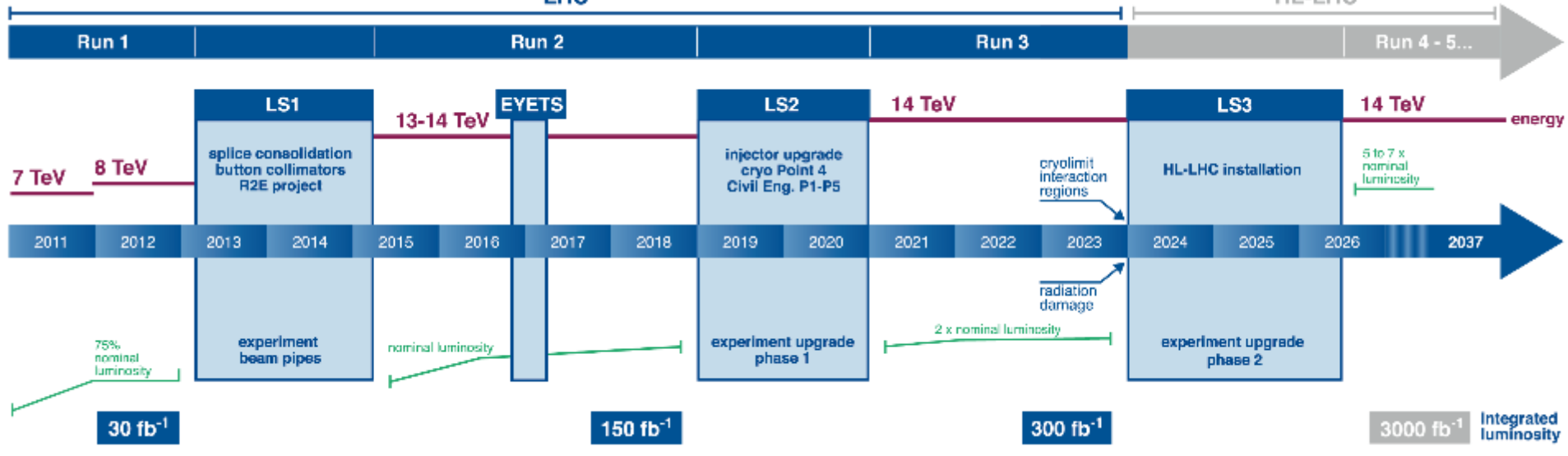
formal approval by CERN Council (June 2016)



Cost to Completion

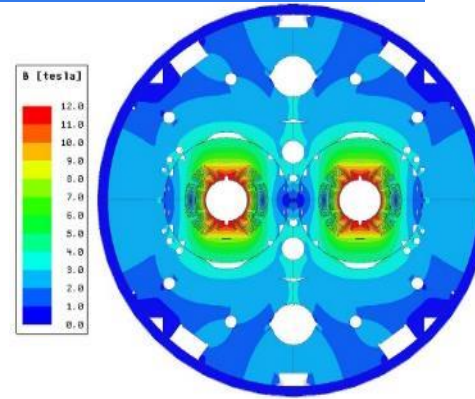
Material : 950 MCHF
Personnel: 1600 FTE-years

Major intervention on more than 1.2 km of the LHC with new technologies: Nb₃Sn magnets, Crab cavities,...



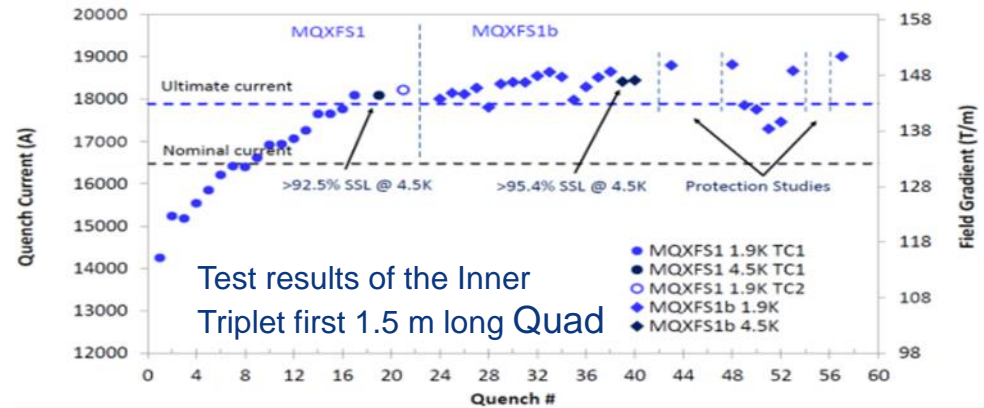
HL-LHC Main achievement 2016

The 11 T dipole 2 m long model reached a B_{\max} of 12.5 T

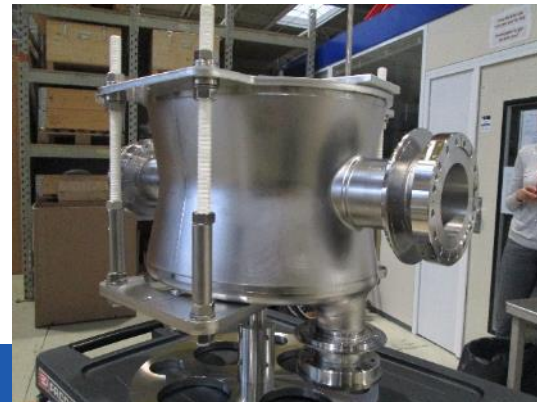


Cross section of the 11 T dipole

Test of the first full cross-section (150 mm aperture) Triplet Quadrupole, 1.5 m long, half CERN, half USA: it went beyond ultimate ($B_{\max \text{ eq.}}$ of 12.5 T)



Completion of the first Crab Cavity, type Double Quarter Wave at CERN just before Christmas!



First Crab Cavity produced at CERN

2017 Main Objectives of HL-LHC

Construction and test of first prototypes (full length) of both 11 T dipole and Inner Triplet Quadrupole; mass production of Nb₃Sn cables

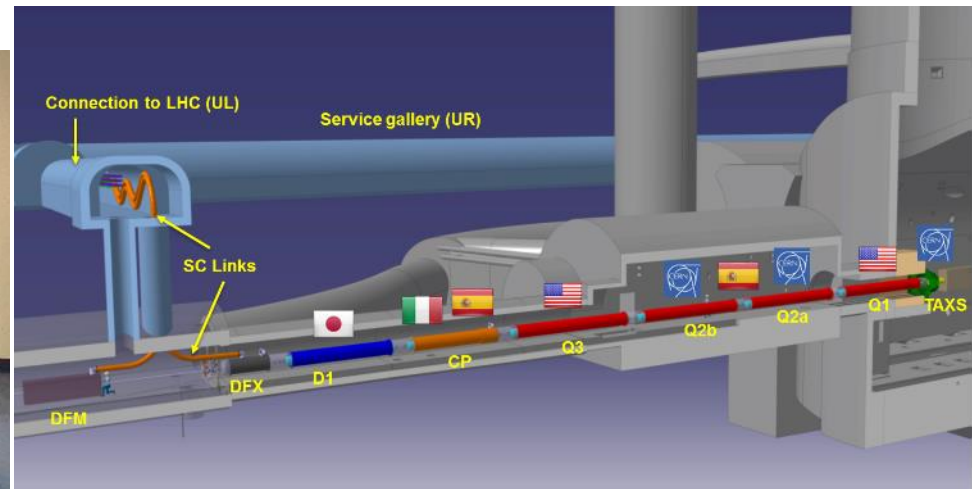
Construction of first complete cryo-module of the Crab Cavity, test in SM18. Cryogenics and infrastructure for testing in SPS.

Finalize Technical Specifications and launch of the tender of the large C.E. construction for HL-LHC in P1 and P5 to meet adjudication in March 2018.

2nd Cost & Schedule review of LIU and HL-LHC (17-19th October 2016)



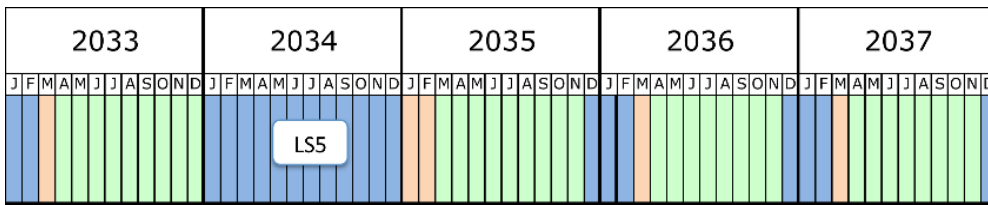
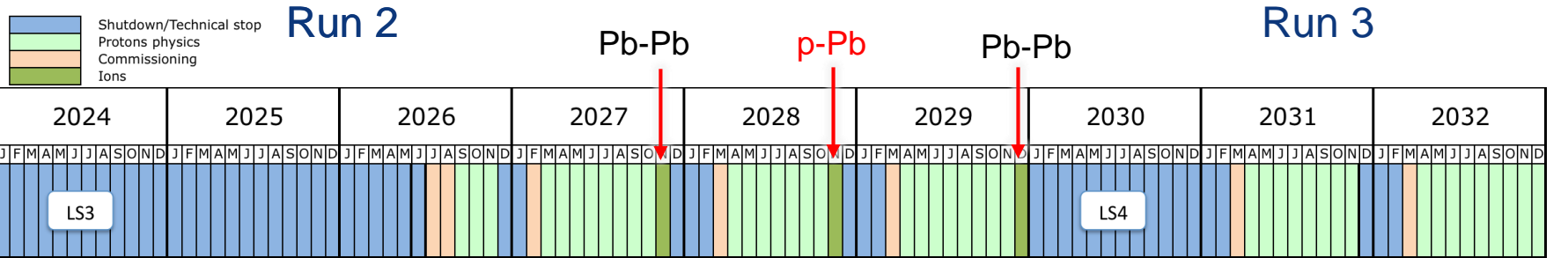
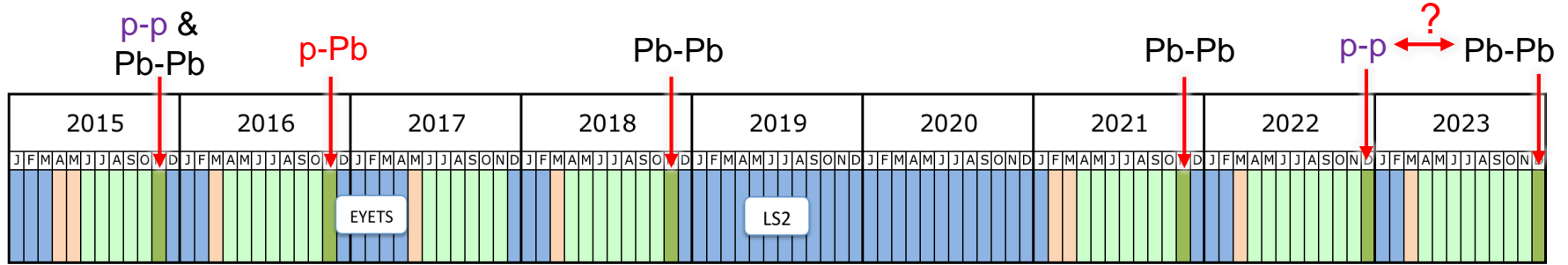
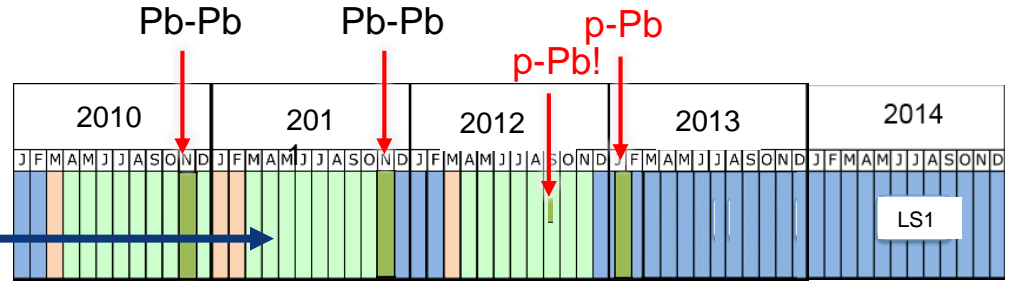
Inner Triplet Region



LHC heavy-ion runs, past & future

LHC will have done 12 ~one month heavy ion runs between 2010 and 2030 (LS4). Five done already.

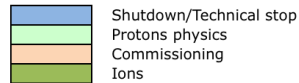
Run 1



Run 6

Run 4

Run 5



Run 2

Run 3



Thanks for your attention



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