Status of the LHC machine: Run2 performance, LS2 and Run 3 outlook

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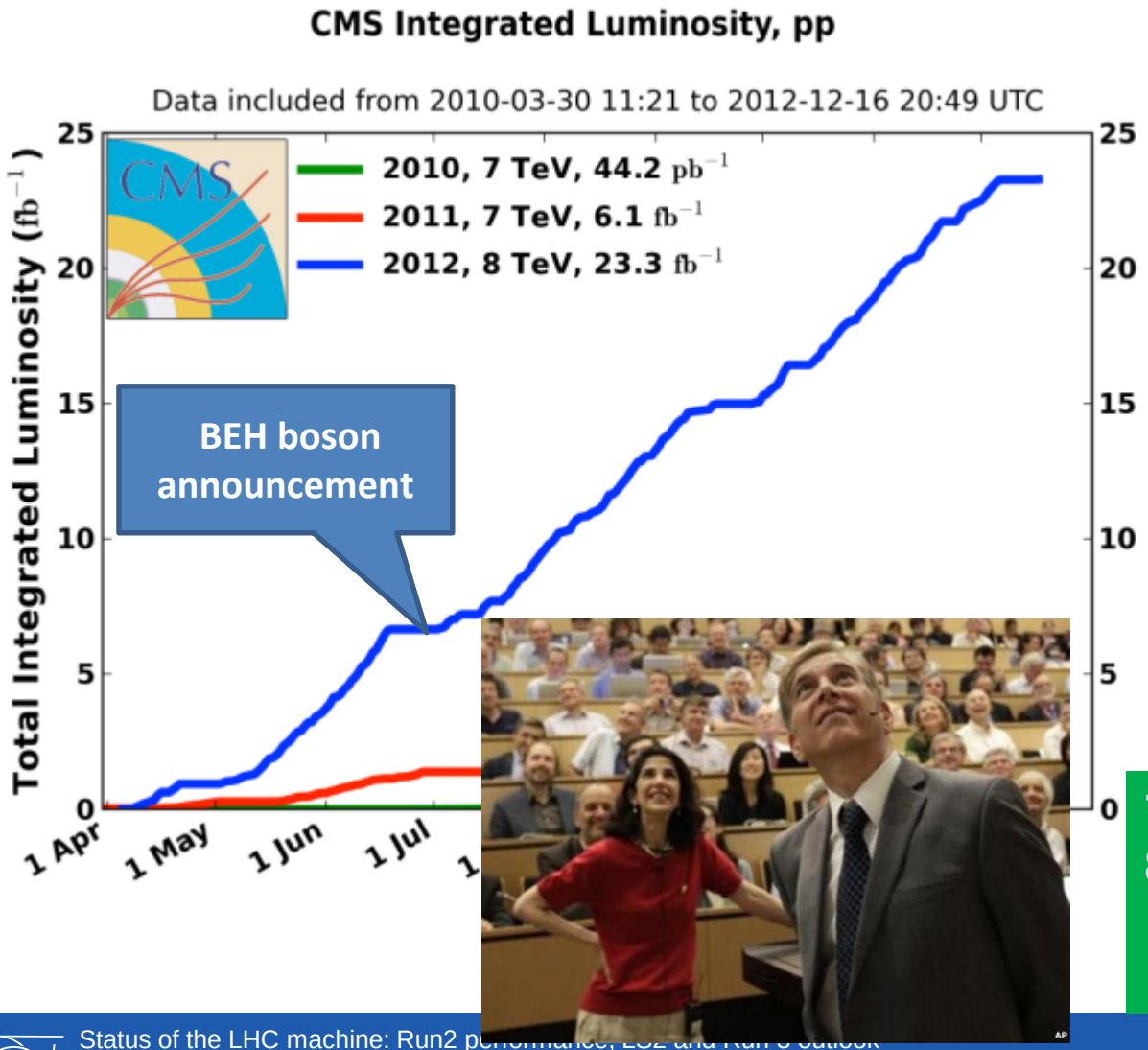
8th HL-LHC Collaboration Meeting
CERN
15th October 2018

2010-2037…LHC Physics exploitation

2010 - 2012	**Run 1 ; 7 and 8 TeV**
2013 - 2014	***LS1***
2015 - 2018	**Run 2 ; 13 TeV**
2019 - 2020	*LS2: Maintenance, upgrade and* ***LIU***
2021 - 2023	**Run 3 ;14 TeV**
2024 - 2025	*LS3: maintenance and HL-LHC installation*
2026 – 2037…	**HL-LHC operation**

LHC 2010-2012: Run 1



Σ ~30 fb^{-1}

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

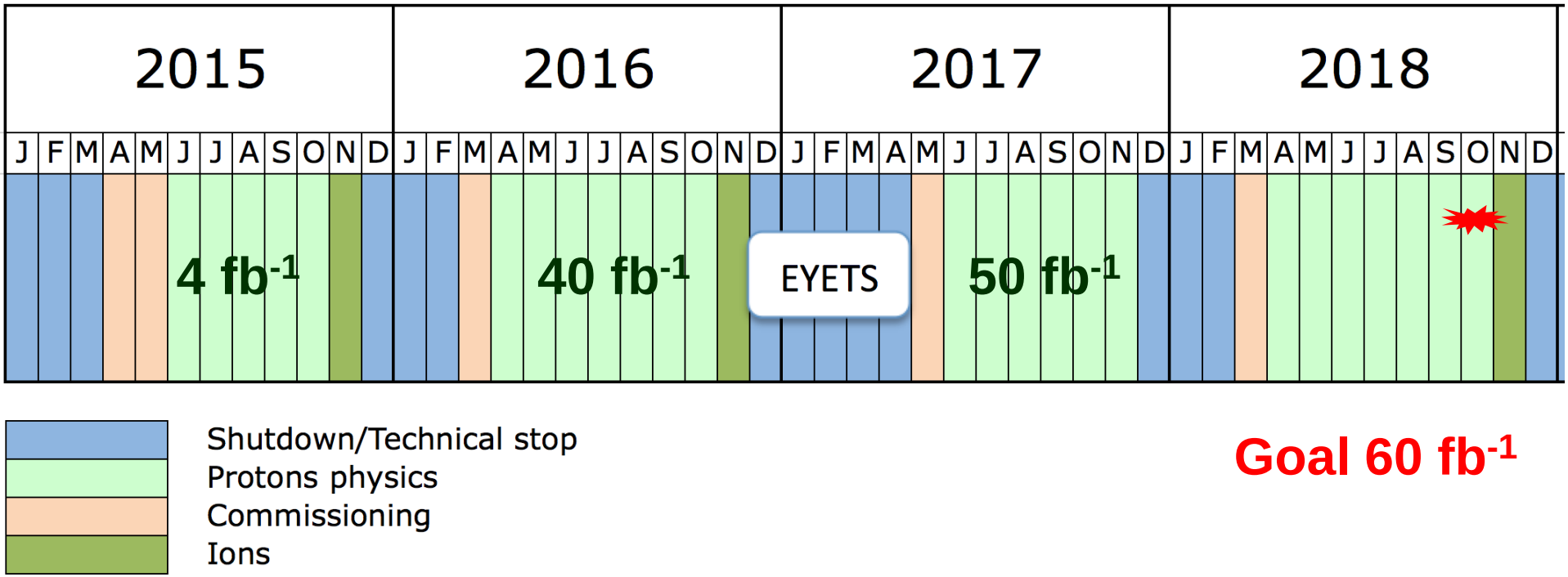
2011: **6.1 fb^{-1}**
7 TeV CoM
… exploring limits

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

7 TeV cm in 2010 and 2011
8 TeV cm in 2012
Up to 1380 bunches
with1.5 10^{11} protons

Run 2 : 2015 – 2018

13 TeV, 25ns



Goal 60 fb^{-1}

Goal Run1+ Run2 = 150 fb^{-1}

LHC 2017 operation

2017 goal:

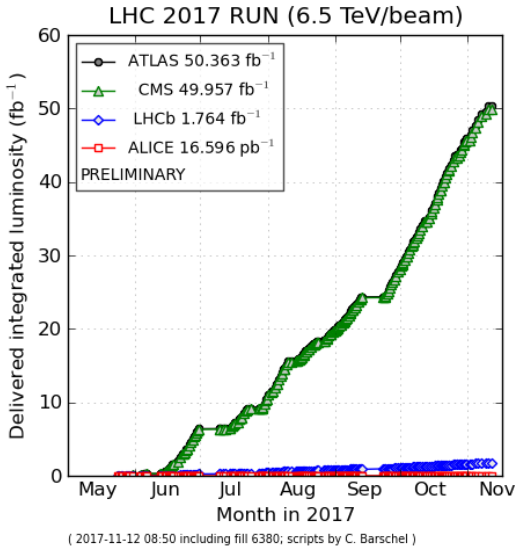
45 fb^{-1}

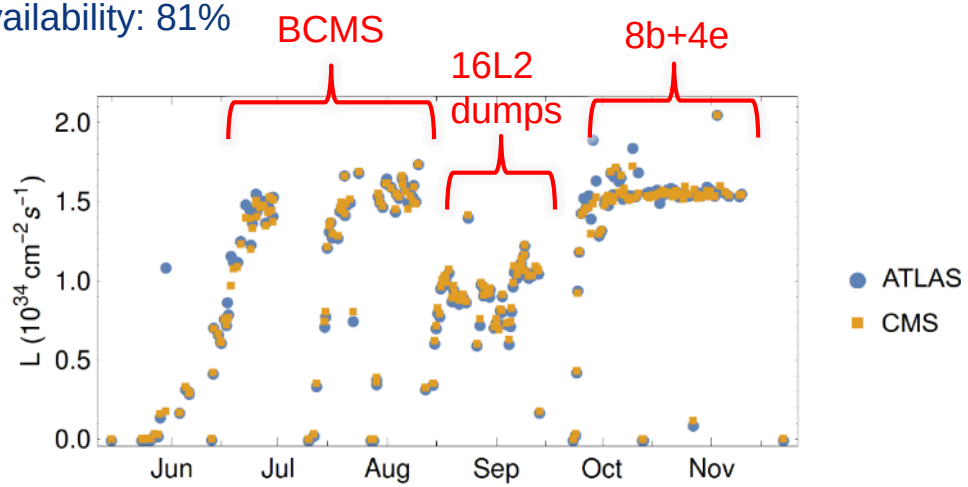
Peak luminosity
2.2 10^{34} cm^{-2} s^{-1}

With luminosity levelling at
1.5 10^{34} cm^{-2} s^{-1}

Lower β* 30 cm
(new ATS optics)

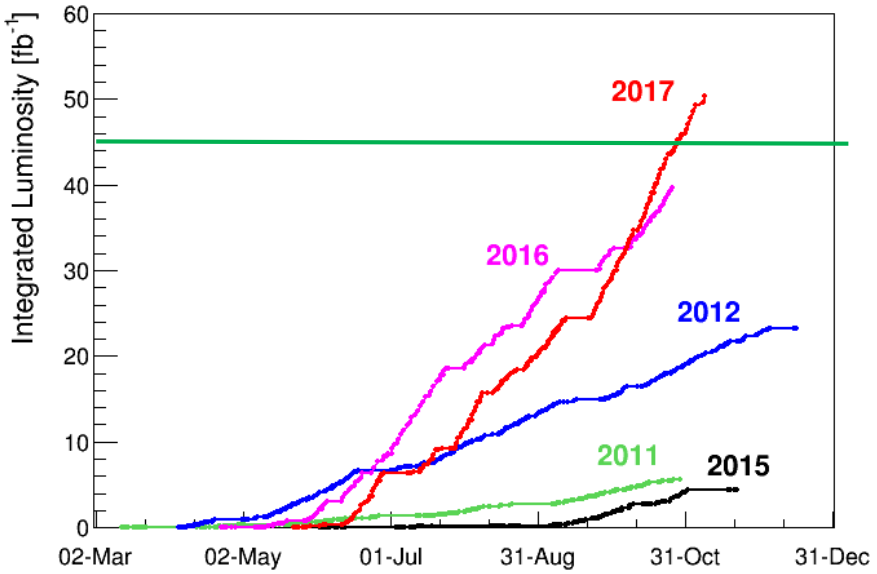
Availability: 81%

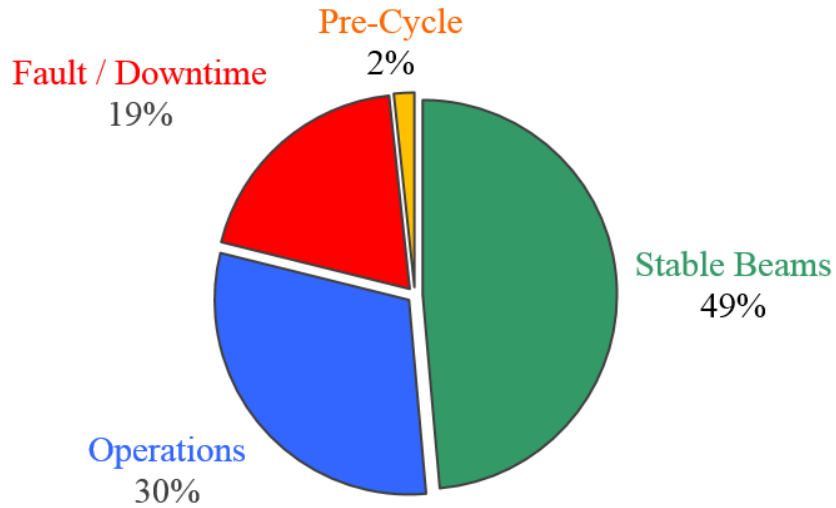




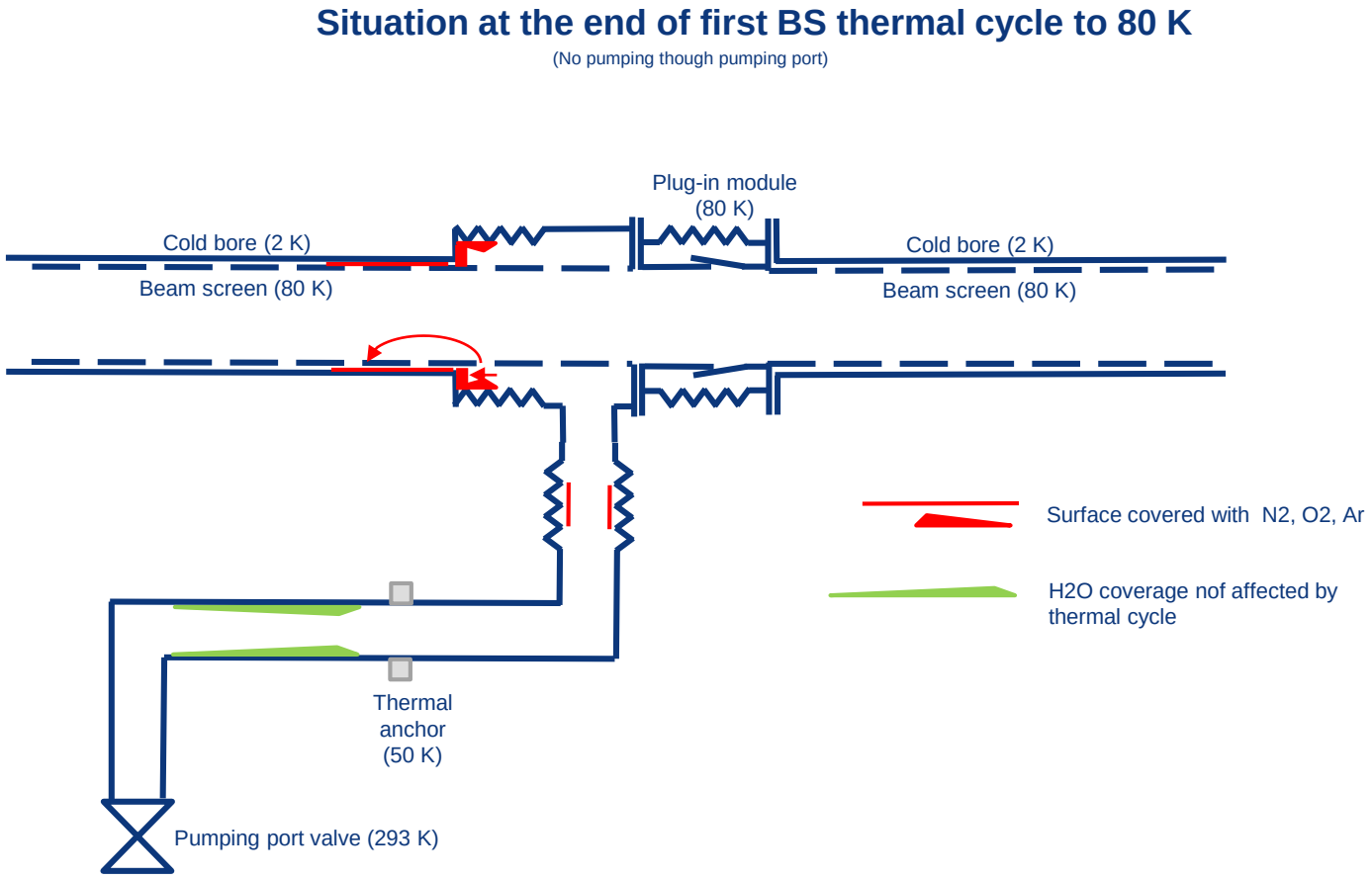
LHC takes <0.03 % of the CERN protons

Achieved : 50 fb^{-1}

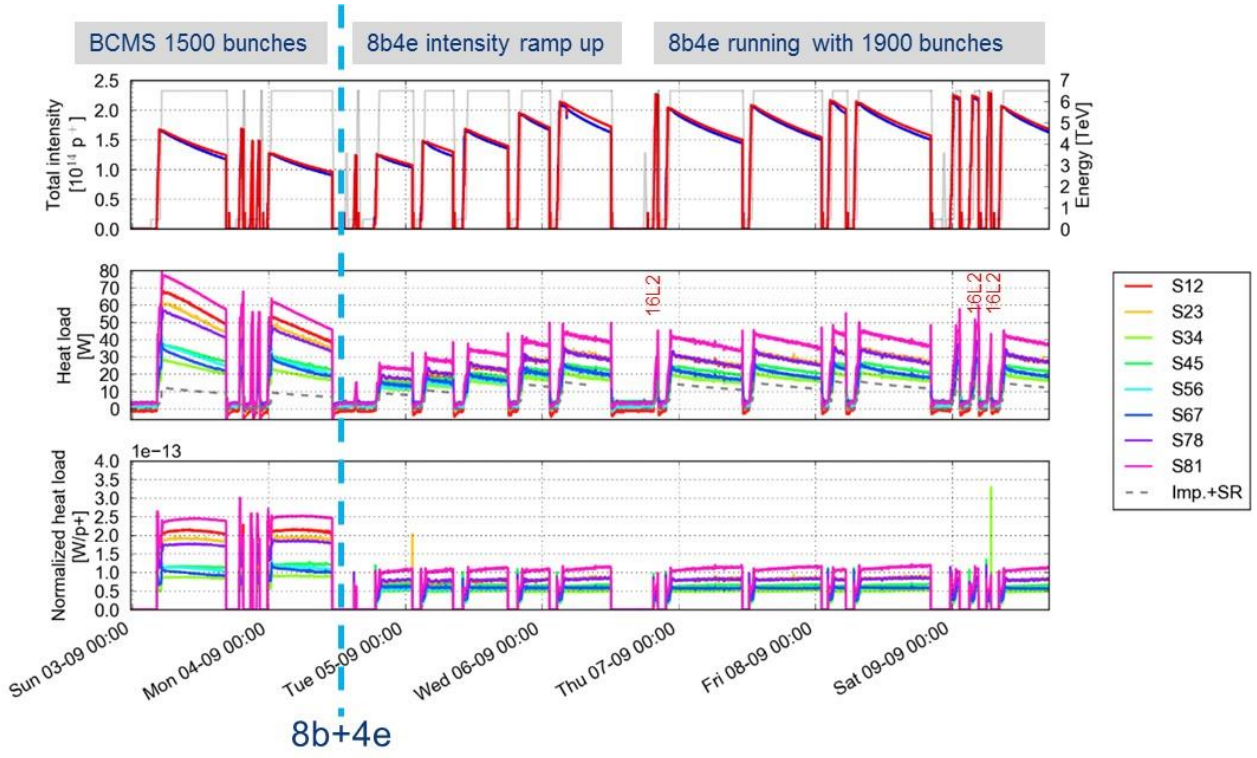


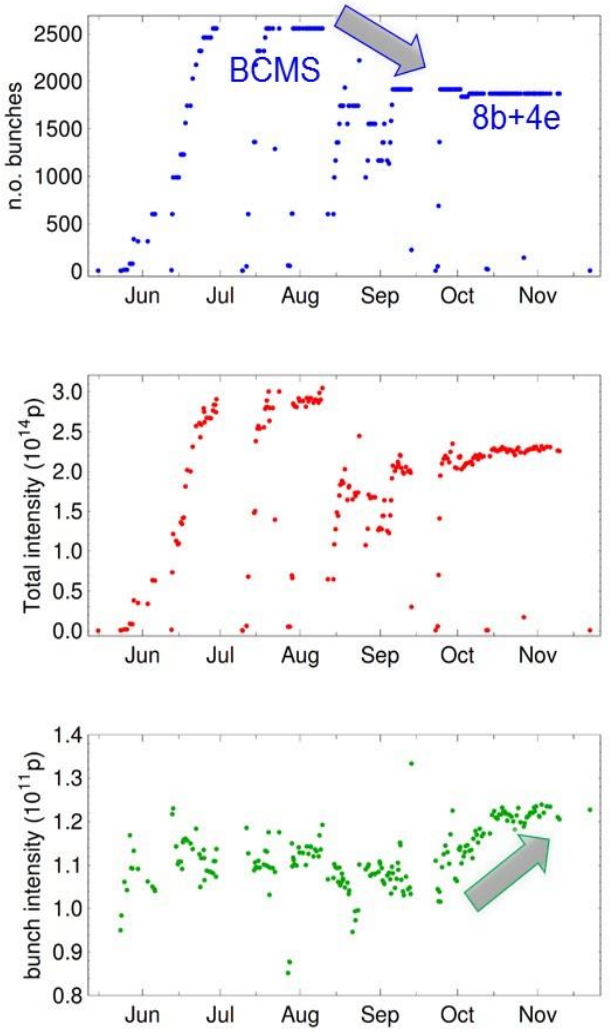


LHC “16L2”: Air inlet as “most probable” cause



LHC: Cryogenics Heat Load BCMS versus 8b4e





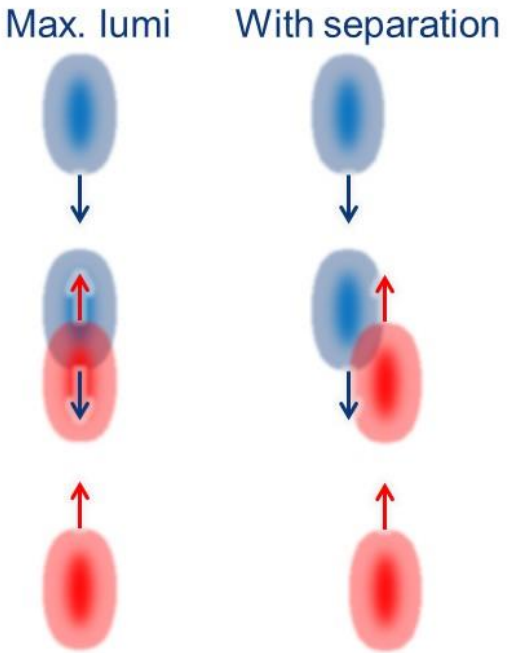
8b4e = **8 b**unches + **4 e**mpty buckets

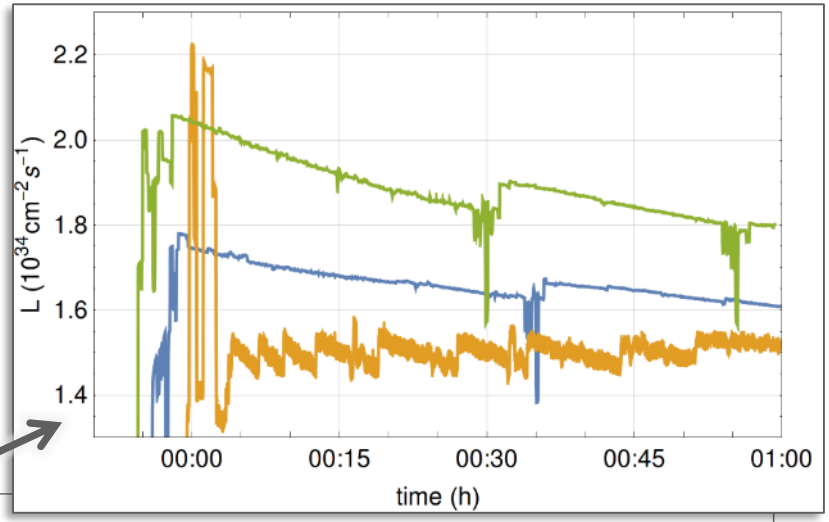
For same LHC bunch intensity PSB bunch intensity and transverse emittance is ~50% of standard scheme

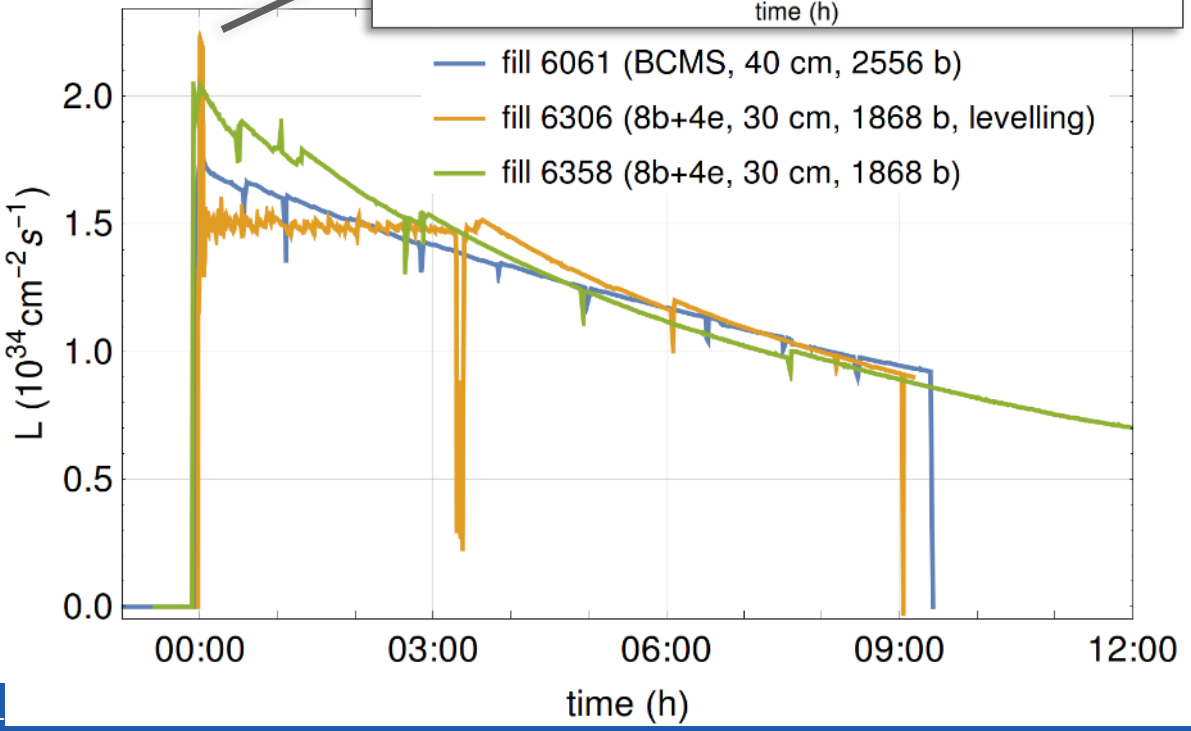
but limitation on the bunch numbers and pile-up

LHC 2017 : separation levelling

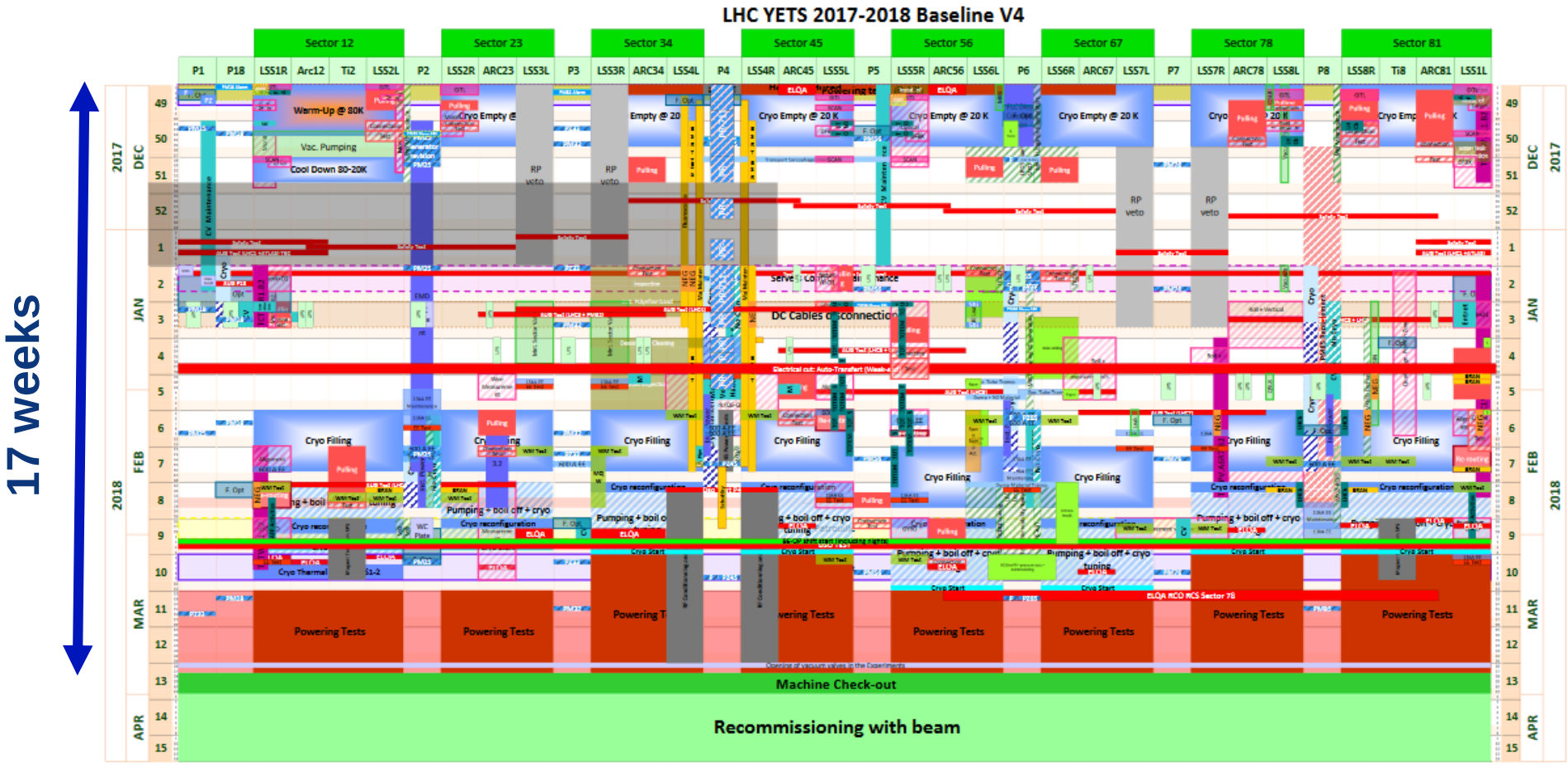
- Introduced separation levelling for all experiments (Separation levelling is used since many years for ALICE and LHCb)
- Dynamic orbit bump changes overlap of colliding bunches
- Initial spike before leveling reaching 2.2×10^{34} $cm^{-2}s^{-1}$



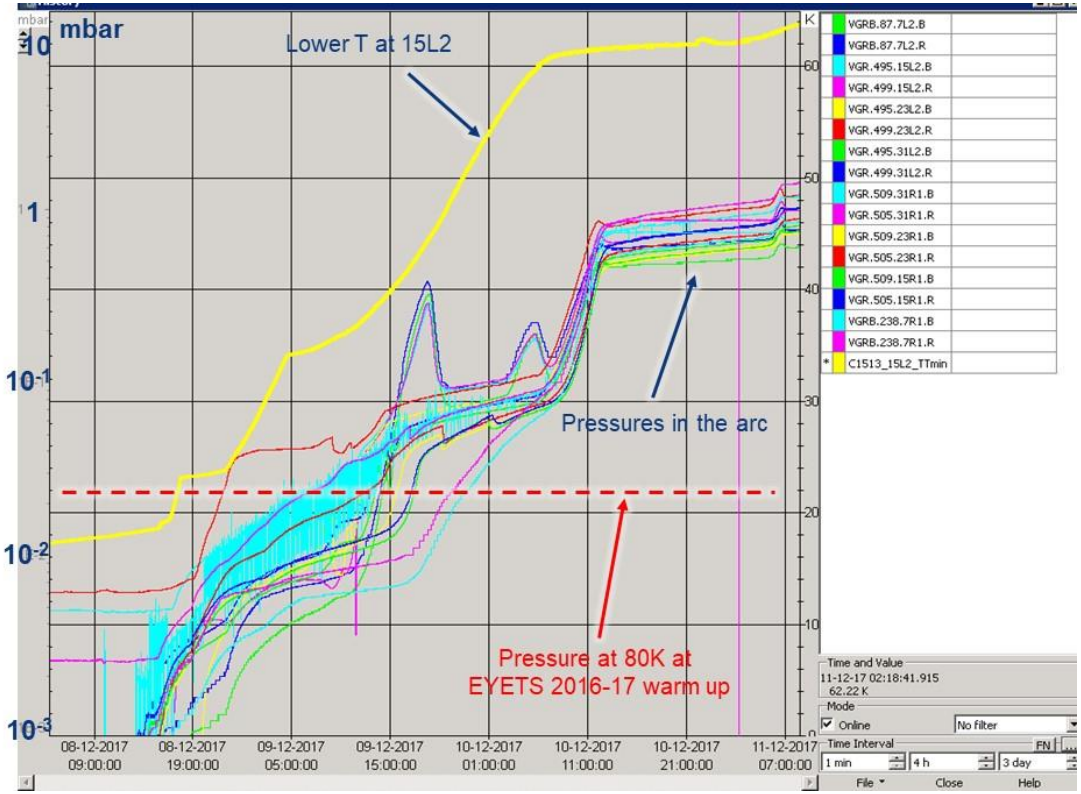




Summary of main activities in the LHC during YETS 2017-2018



LHC: sector 1-2 warming-up at the start of the YETS 2017-2018



Estimated quantity of extracted air

$$M_{N_2} = 8.4\,\mathrm{g}$$

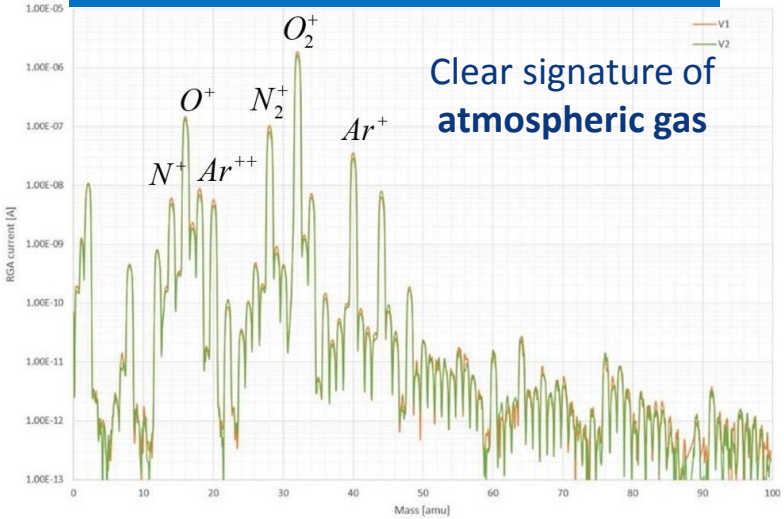
$$V_c = 10.5\,cm^3 \text{ per beamline}$$

$$V_{STP} = 7\,\lambda(\text{air at 1 bar, room temperature, per beamline})$$

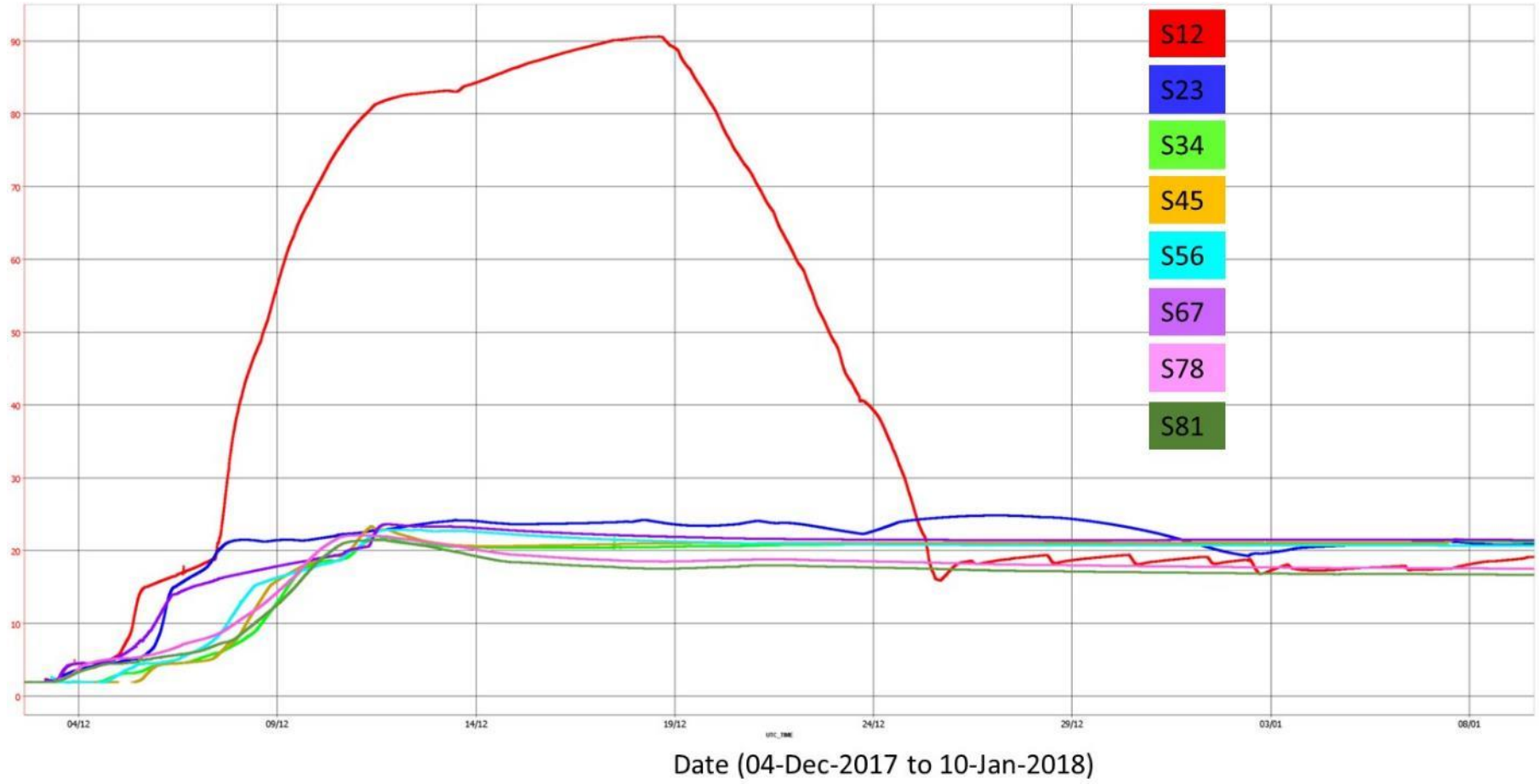
Estimated quantity of extracted water vapour

$$M_{H_2O} = 0.1\,\mathrm{g}\,(\text{per beamline})$$

Results from gas analysis in 16L2



LHC: sector 1-2 warmed up up to 90 K and cooled down



LHC 2018: Smooth & Fast Intensity Ramp-up

Intensity ramp up plan: 3 - 12 - 72 - 300 - 600 - 900 - 1200 - 1800 - 2400 – 2550

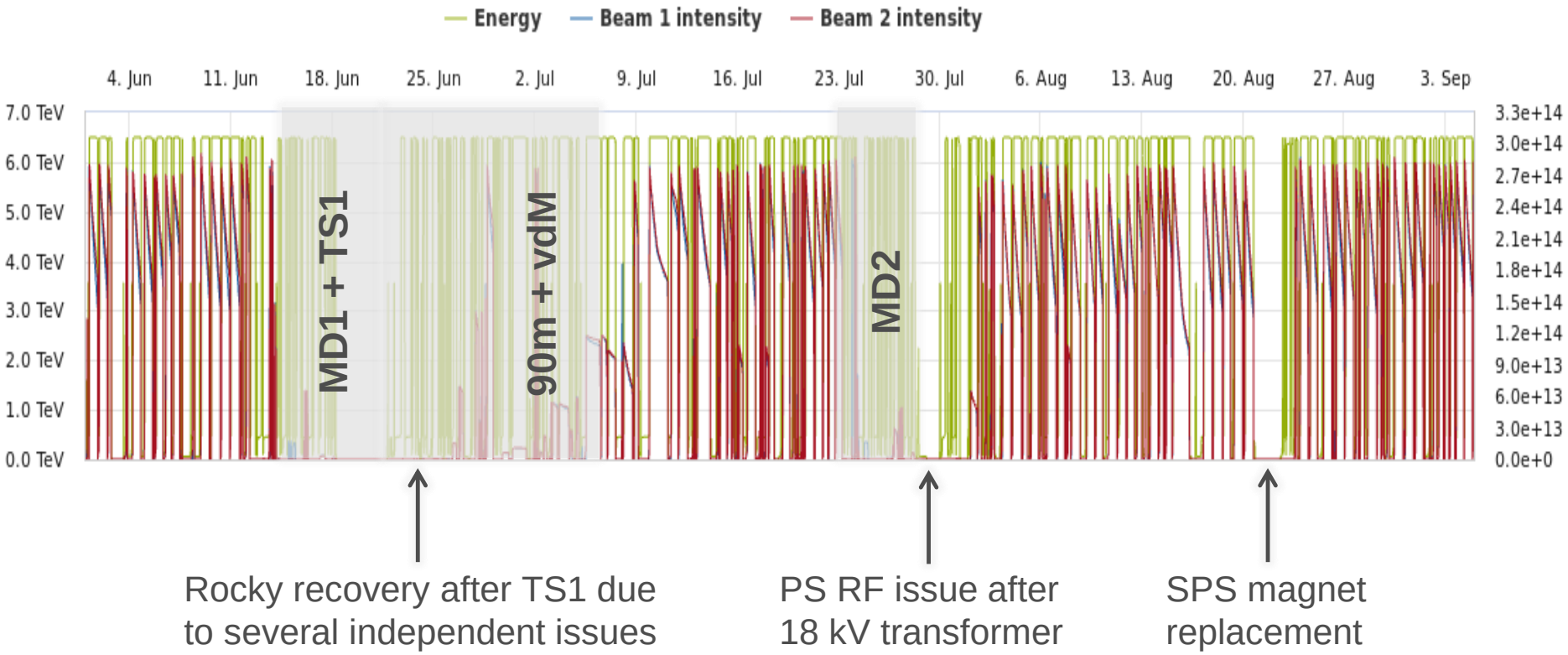
Establish cycle
Machine Protection dominated
Intensity dominated

- With interleaved beam commissioning and intensity ramp up **1227 bunches in only 10 days** (excl. scrubbing)
  - In 2017 it took 15 days
- **2556 bunches** reached after **17 days**
  - In 2017 it took 24 days.

- **This is thanks to excellent machine availability and dedicated teams, signing off checklists for every step at any moment**

LHC : Overview of pp run since May

- Most of the time, high-intensity fills stacked next to each other
- Few longer faults



Rocky recovery after TS1 due to several independent issues

PS RF issue after 18 kV transformer

SPS magnet replacement

Faults with longest duration

PS RF issue following 18 kV transformer failure

(end of July)

- Several knock-on effects of transformer failure: Trip of transmission lines and injectors, PSB main power supply failed, RF problem in the PS (longest recovery)
- No beam for 1.5 days, then only single bunches and later 12b trains possible

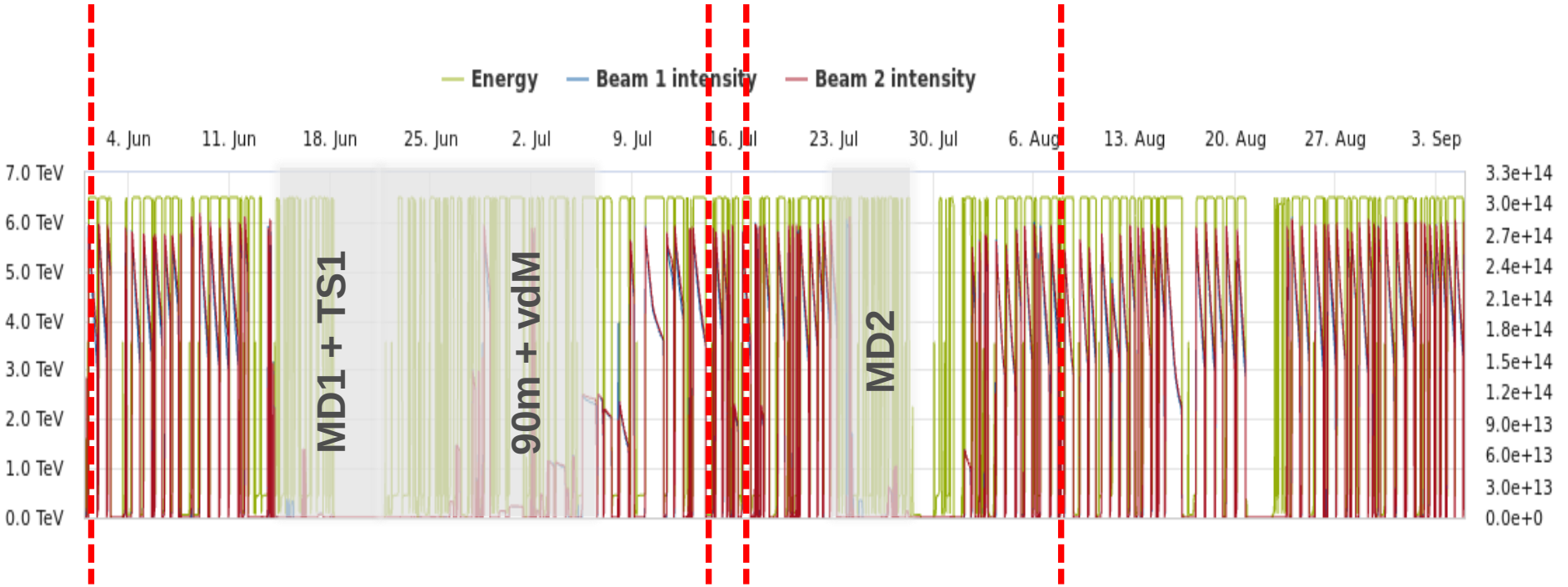
SPS dipole replacement

(~ 20 August)

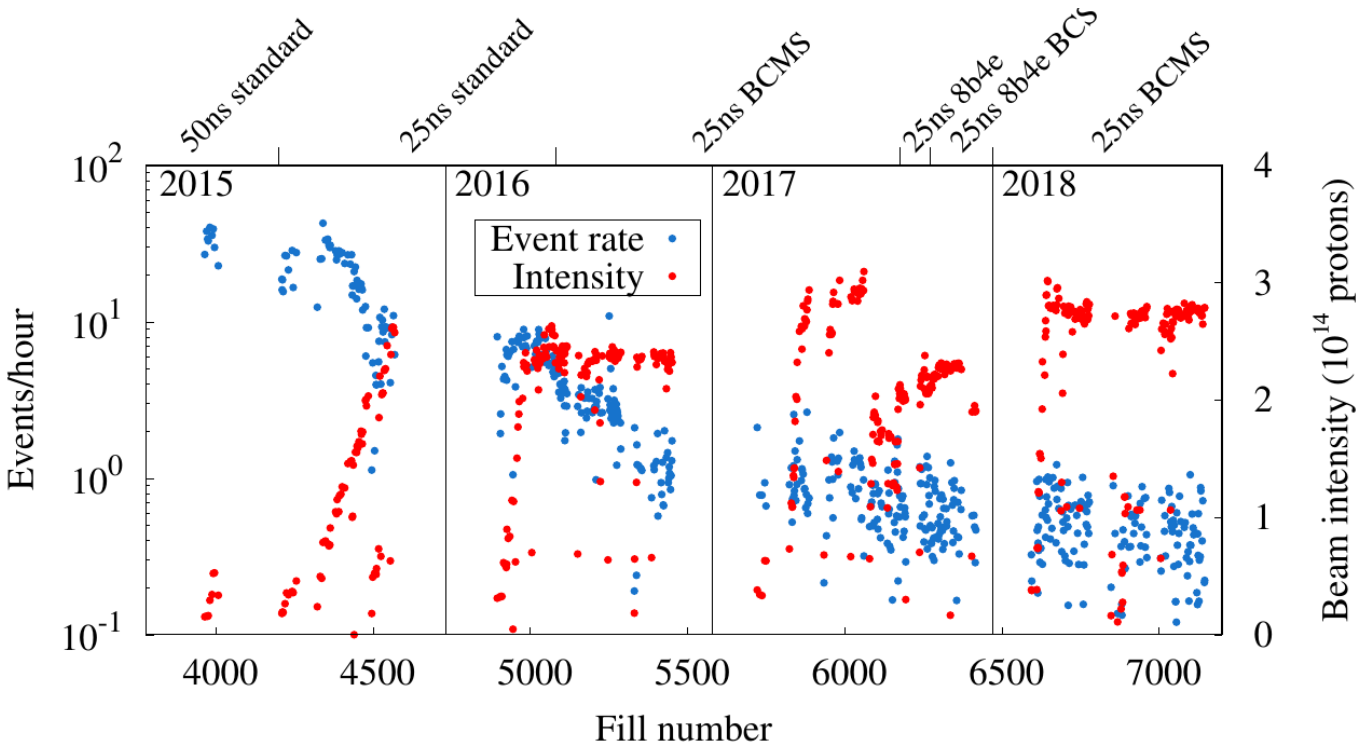
- Magnet damaged by beam, causing vacuum leak
- Replacement only possible after radiation cooldown

LHC : Status of 16L2

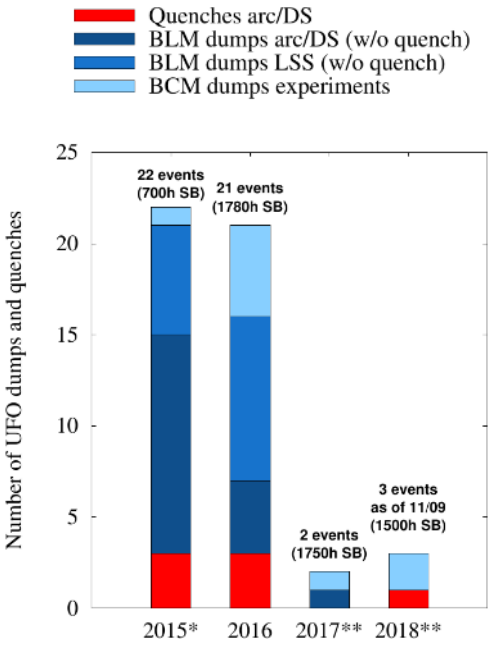
- Very fast losses starting in cell 16L2 believed to be caused by beam interacting with macro-particles of frozen air
- 4 dumps due to 16L2 since end of May, 3 in stable beams
  - Long time now since last event 🤫



LHC : Evolution of arc UFO rates in 2015–2018



Fill-by-fill arc UFO rates (cells ≥12) in stable beams (only fills with ≥1 h in STABLE and with >100b per beam)

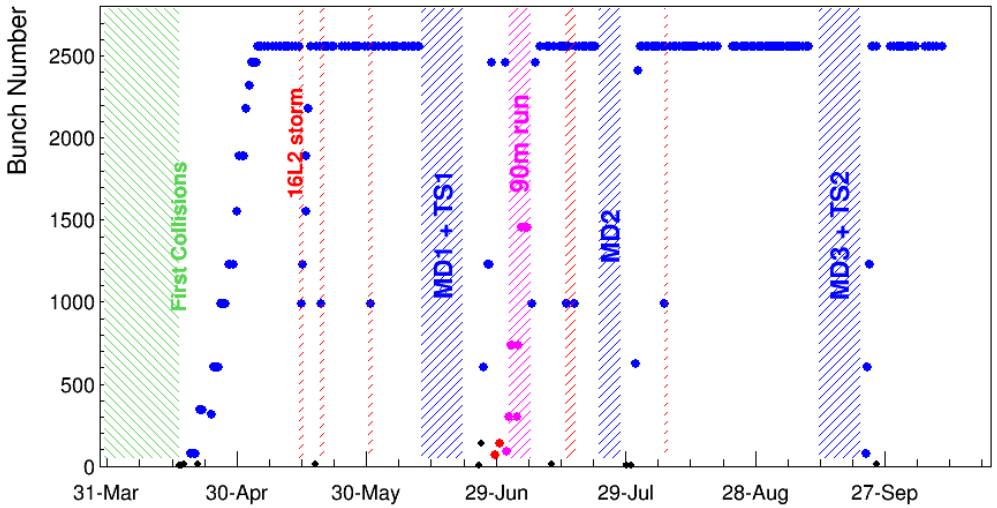


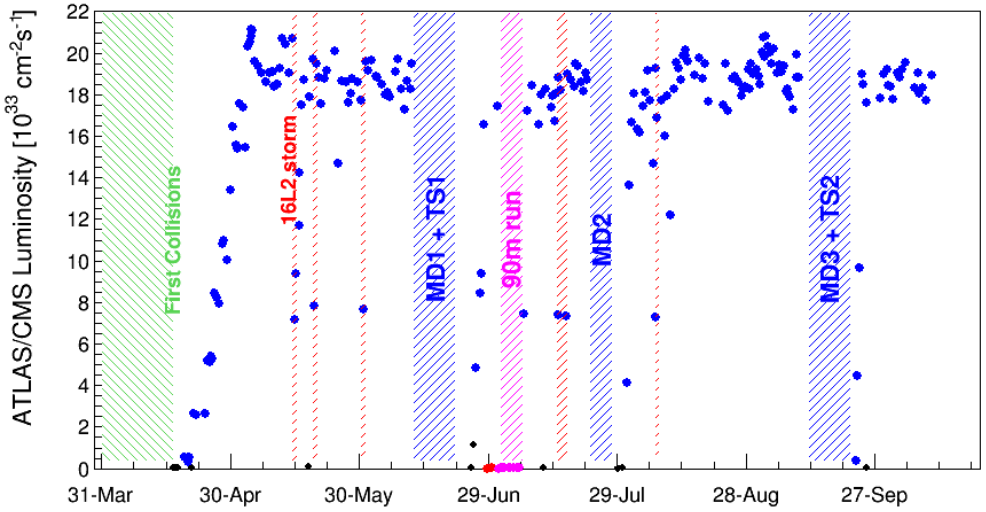
* 2015 events do not include dumps and quenches in cell 15R8 (ULO location)

** 2017/18 events do not include dumps and quenches in cell 16L2

SB = Stable Beams

LHC 2018: Performance up to now



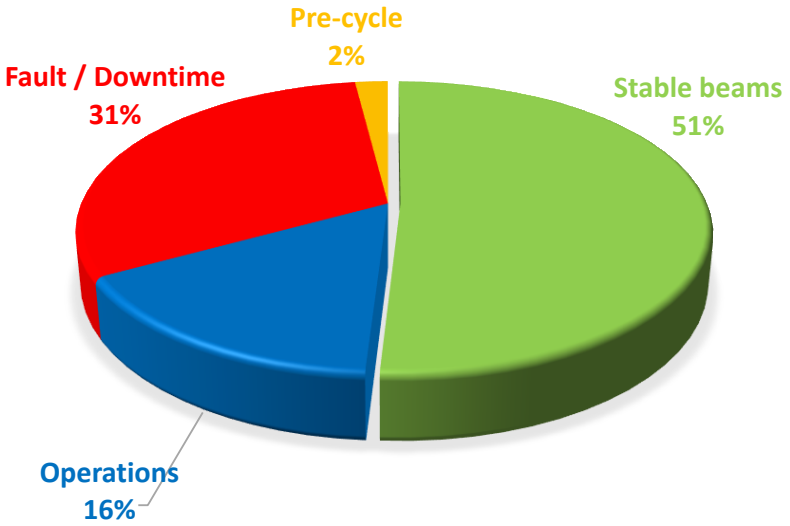


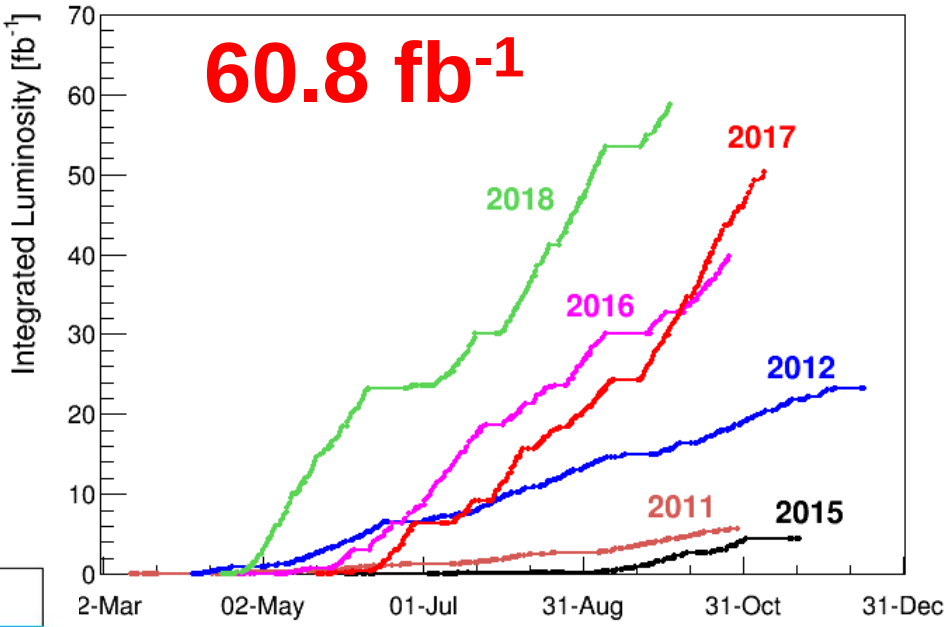
- Full machine (2556 bunches) reached on May 5th
- Four “16L2 storms” encountered with successful recovery
- Bunch intensity is not really pushed to avoid issues with 16L2
- Steadily close to 2×10^{34} $cm^{-2}s^{-1}$ (twice the LHC design value)

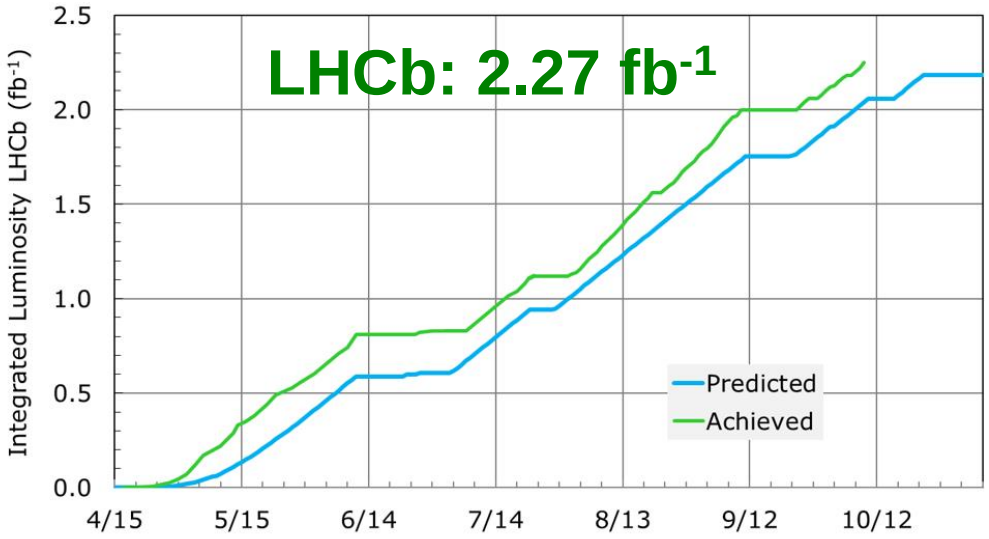
LHC Beam parameters achieved

Parameter	2018	Design
Energy [TeV]	**6.5**	7.0
No. of bunches	**2556**	2808
Max. stored energy per beam (MJ)	**312**	362
β* [cm]	**30→25**	55
p/bunch (typical value) [10^{11}]	**1.1**	1.15
Typical normalized **emittance** [µm]	**~1.8**	3.75
Peak **luminosity** [10^{34} $cm^{-2}s^{-1}$]	**2.1**	1.0

LHC 2018: Beam Availability and Performance

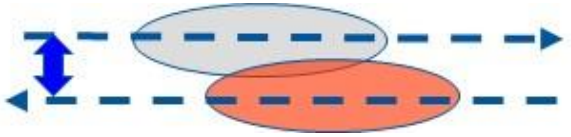






ATLAS : 59.9 fb^{-1}
CMS : 61.8 fb^{-1}

LHCb and ALICE: luminosity levelling



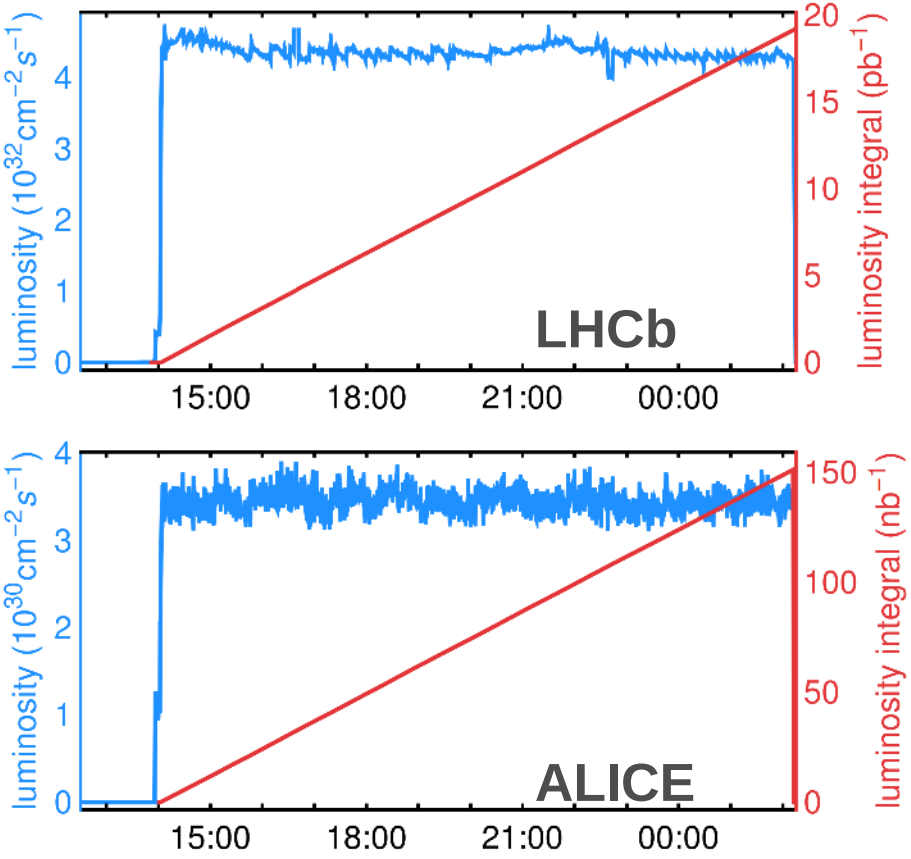
Levelling by beam offset

LHCb:

- separation leveling around 4.4×10^{32} $cm^{-2}s^{-1}$
- typical production around 20 pb^{-1} in a fill not dumped prematurely

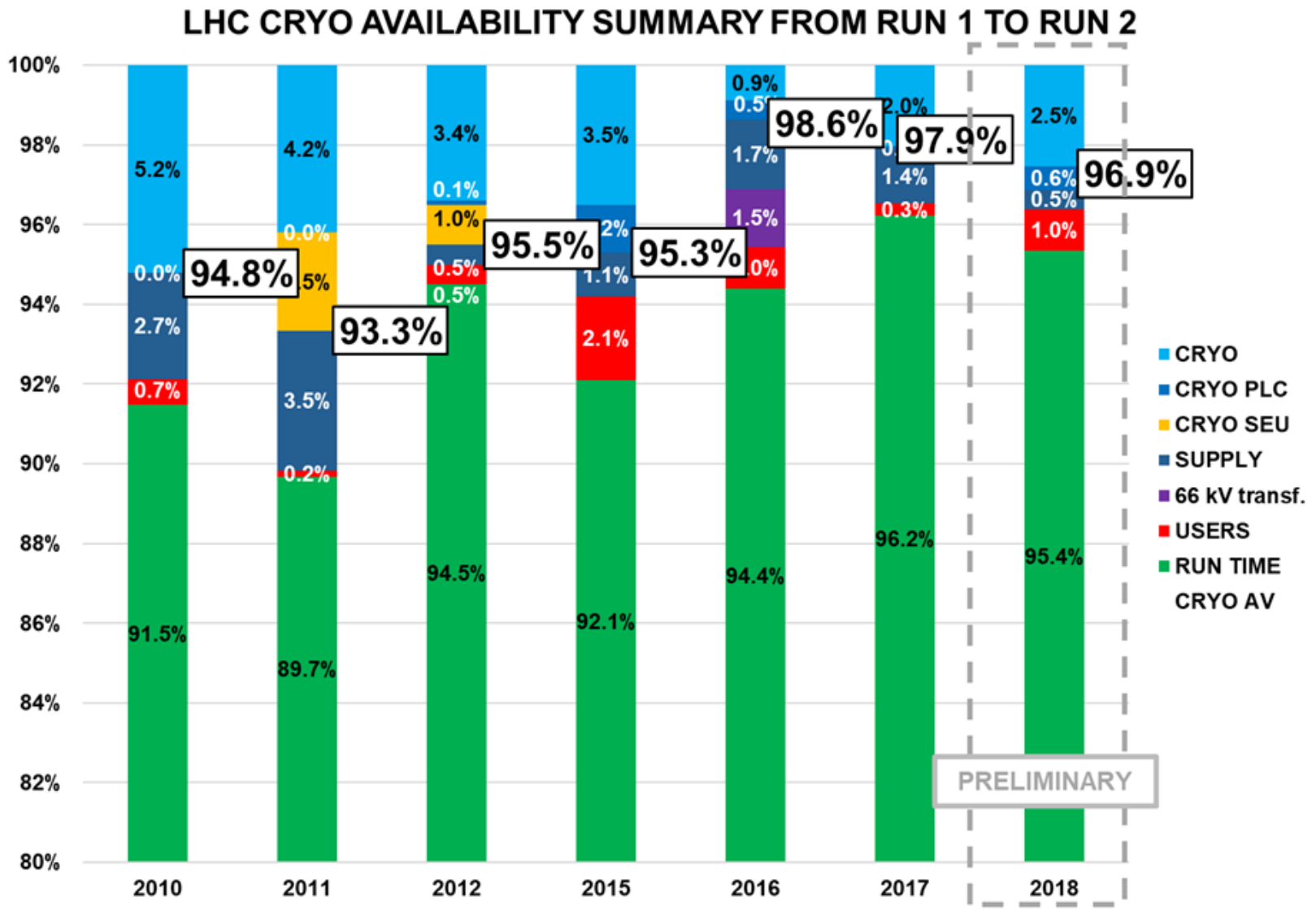
ALICE

- separation leveling around 3.5×10^{30} $cm^{-2}s^{-1}$
- typical production around 150 nb^{-1} in a fill not dumped prematurely

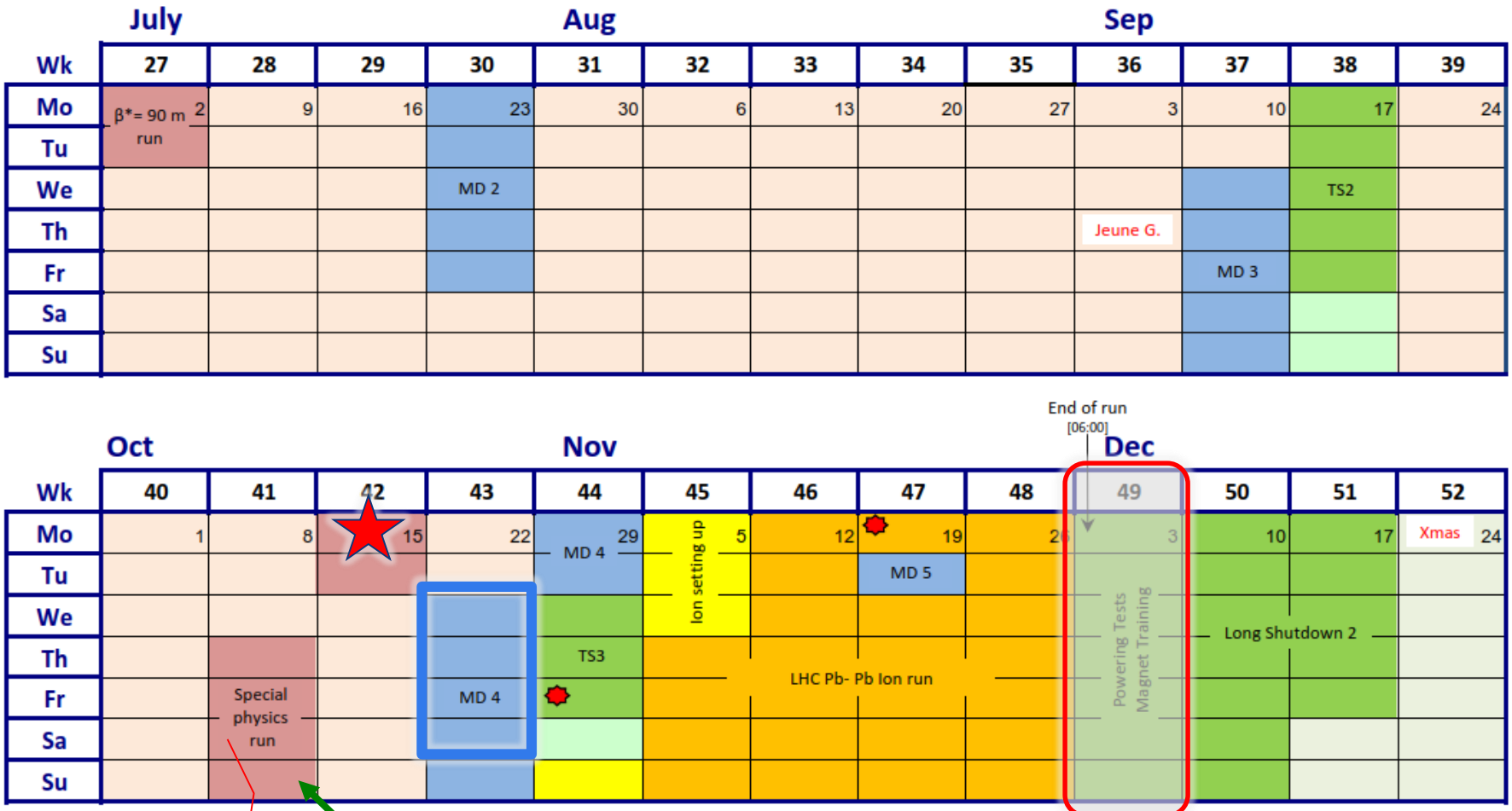


Fill 7127, 5th September 2018

LHC cryogenics availability summary from Run 1 to Run2



LHC: outlook on rest of 2018

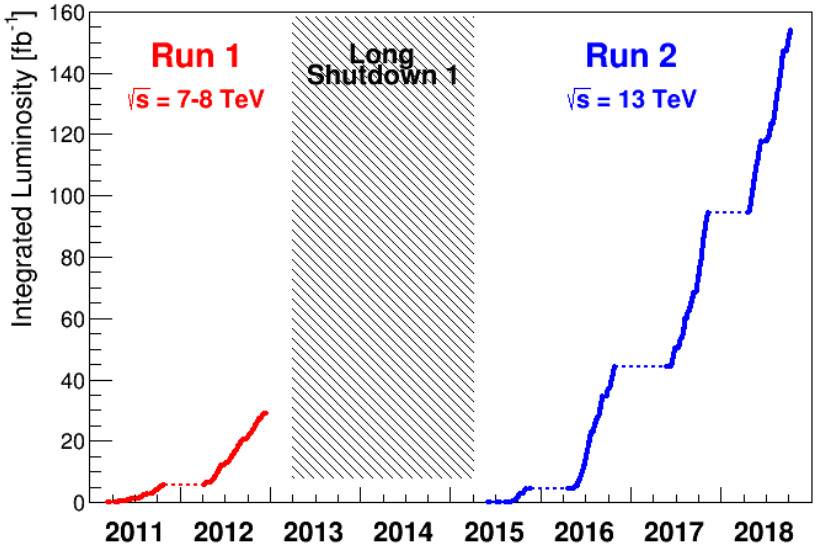


Low energy high beta run 900 GeV

Whole program was completed!
Both experiment achieved that target goal of one million events in respectively good background conditions.

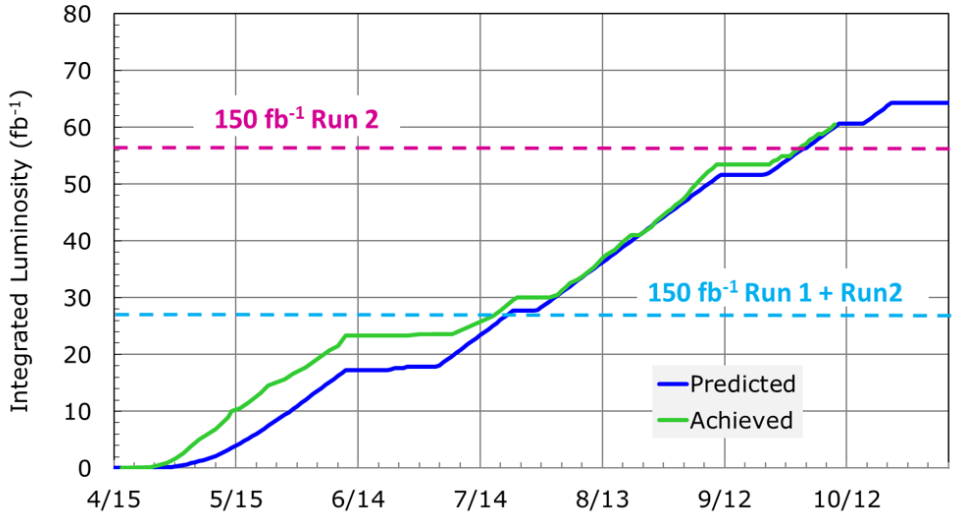
Magnet training tests to aiming for 7 TeV after LS2

Run1 + Run 2: Luminosity Production



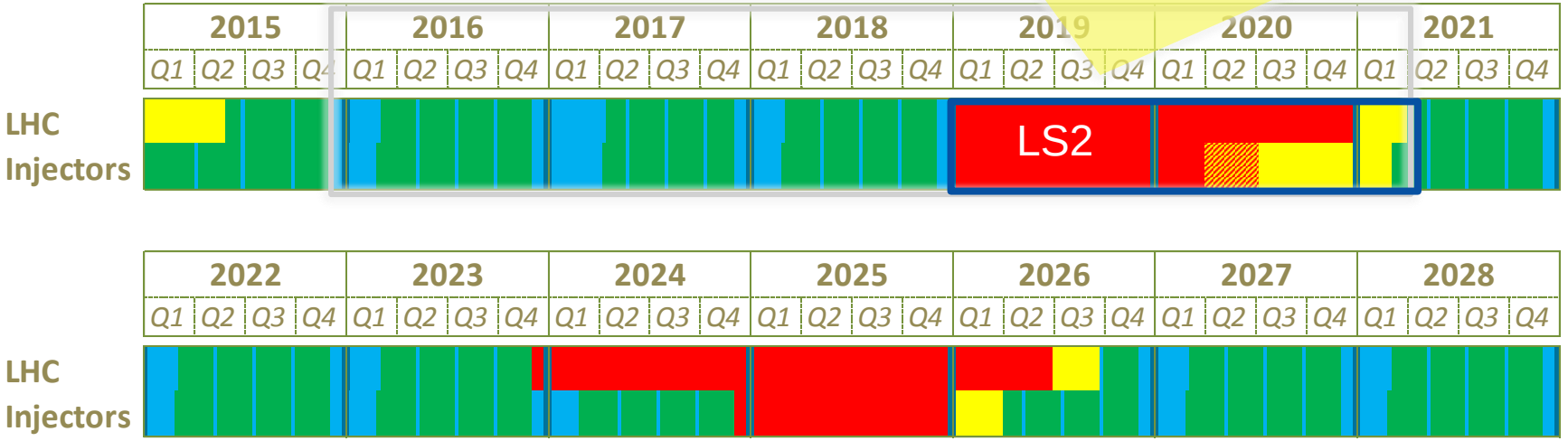
Period	Int. Luminosity [fb^{-1}]
Run 1	29.2
Run 2: 2015	4.2
Run 2: 2016	39.7
Run 2: 2017	50.2
Run 2: 2018	60.8
Total Run1 + Run 2	184.1

Sunday 14.10.2018



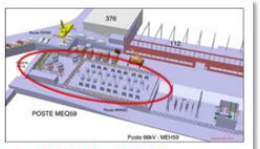
The Long Shutdown 2 (LS2)

- **Perform major Maintenance and Consolidations**
- **Increase intensity/brightness in the injectors to match HL-LHC requirements (LIU Project)**
- **Increase injector reliability and lifetime to cover HL-LHC run (until ~2035) closely related to consolidation programs (in synergy with LIU Project)**
- **Anticipate HL-LHC work**



LS2 (2019-2020 period): coordination of multi projects

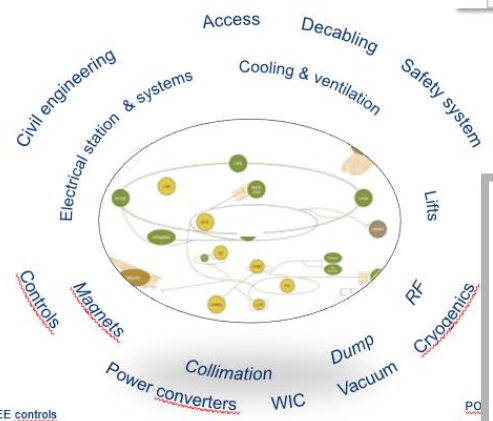
Consolidation & upgrades

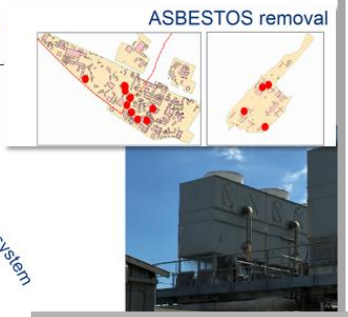

New MEQ59 Static Var Compensator


New MST SPS extraction septum

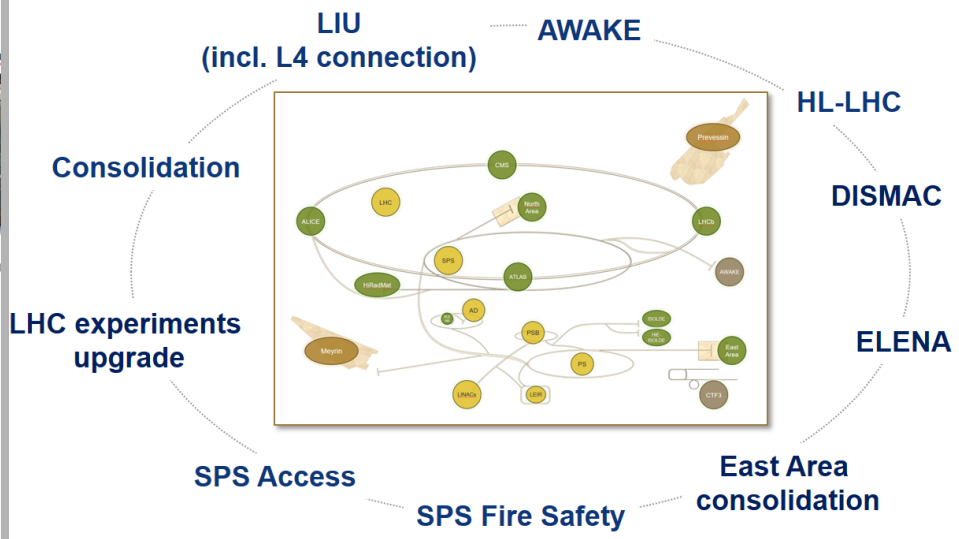

LHC EE controls


LHC EE controls

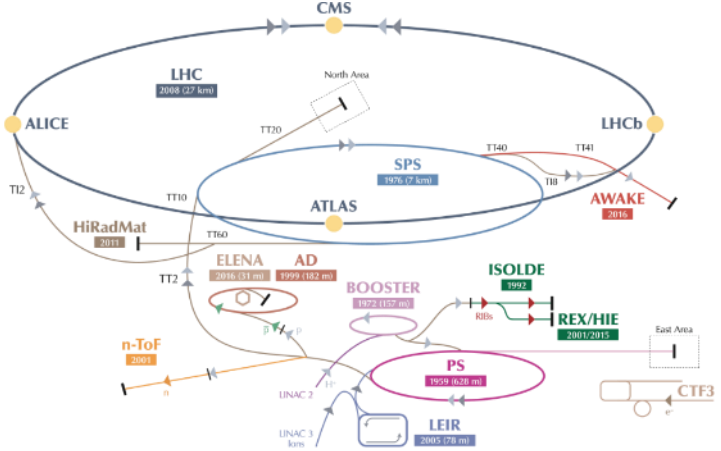




The main projects during LS2



Goals and means of the LHC Injectors Upgrade: LIU project



Increase injector reliability and lifetime to cover HL-LHC run (until ~2040) closely related to consolidation program

⇒ Upgrade/replace ageing equipment (power supplies, magnets, RF…)

⇒ Improve radioprotection measures (shielding, ventilation…)

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

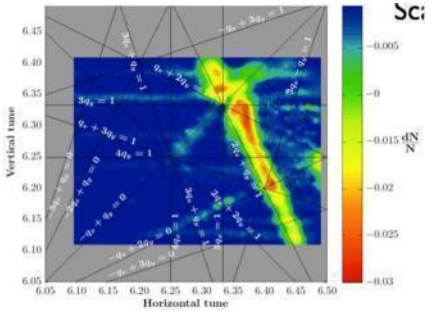
LS2 : (2019-2020), LHC Injector Upgrades (LIU)

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:

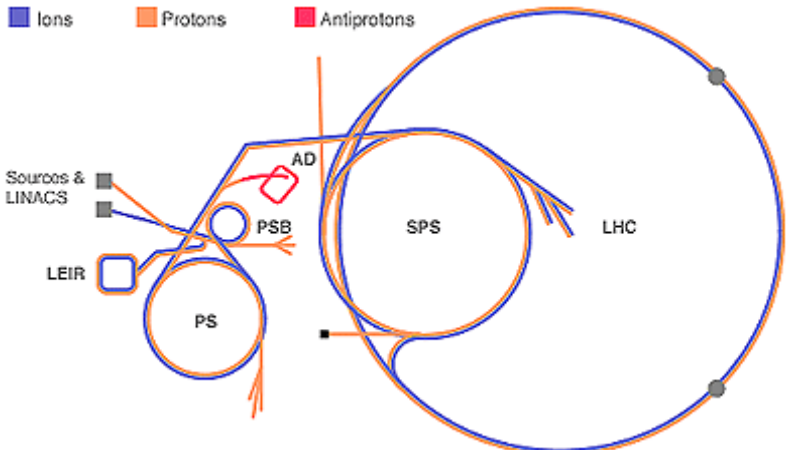
- Increase of injection energy from 1.4 GeV to 2 GeV to increase PS space charge threshold
- Transverse resonance compensation
- New RF Longitudinal feedback system
- New RF beam manipulation scheme to increase beam brightness



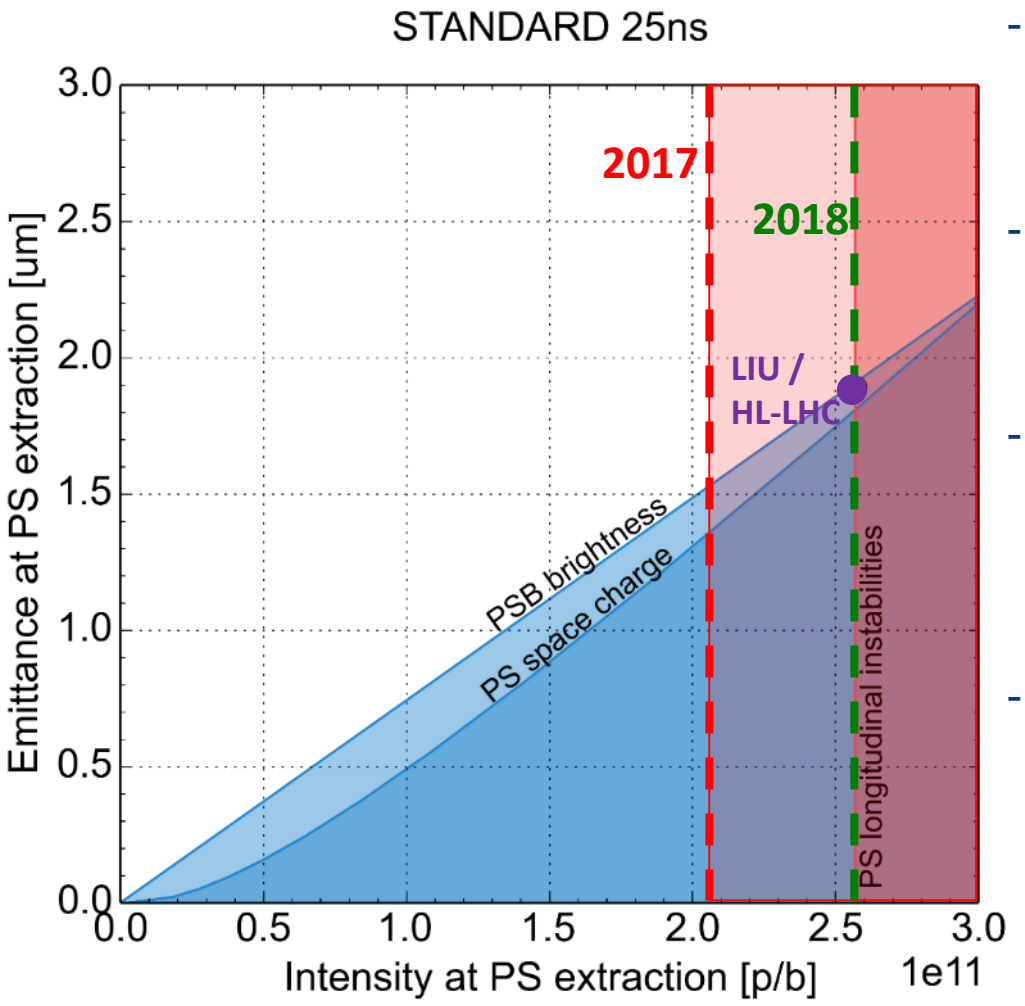
SPS

- 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

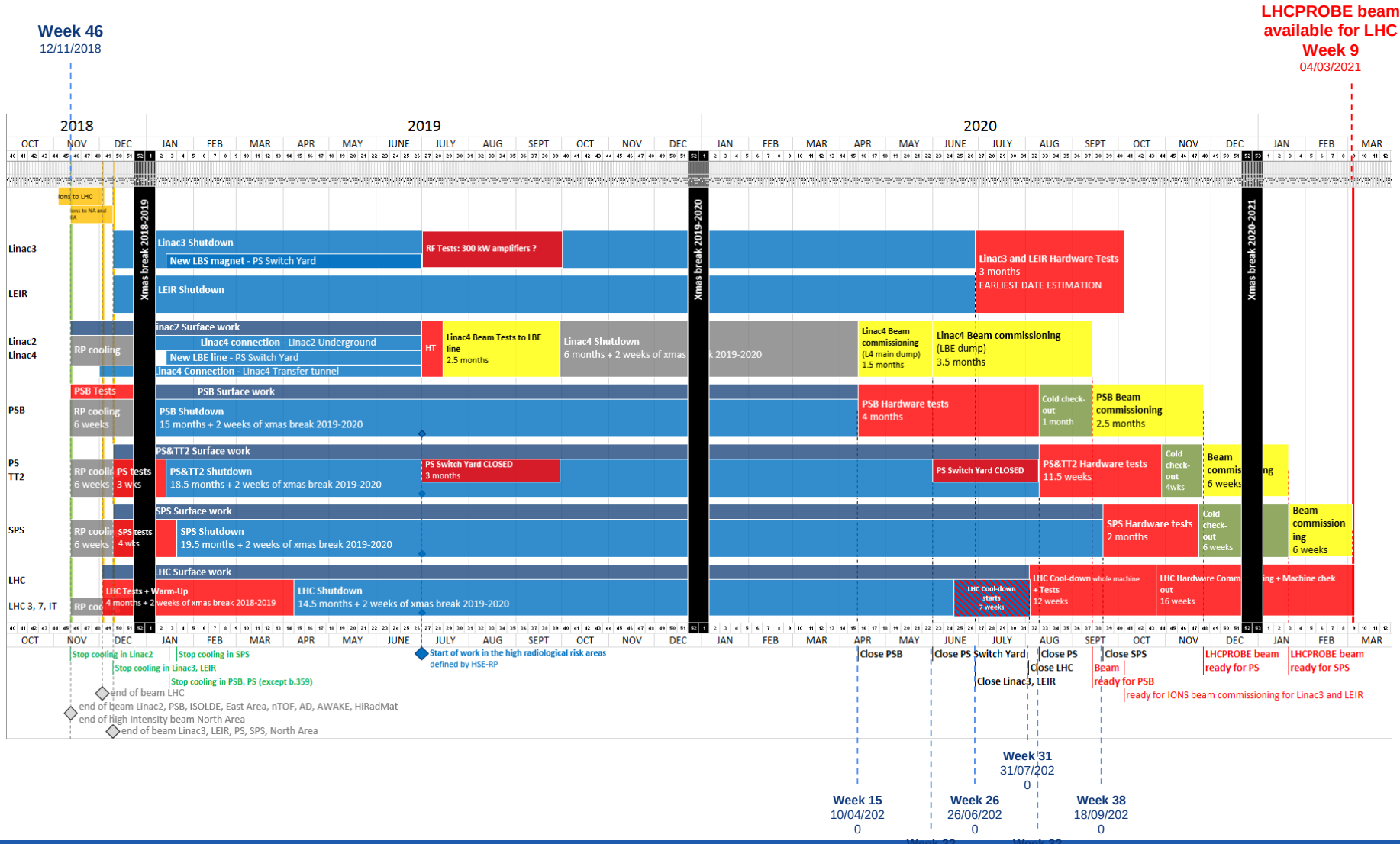


PS intensity reach

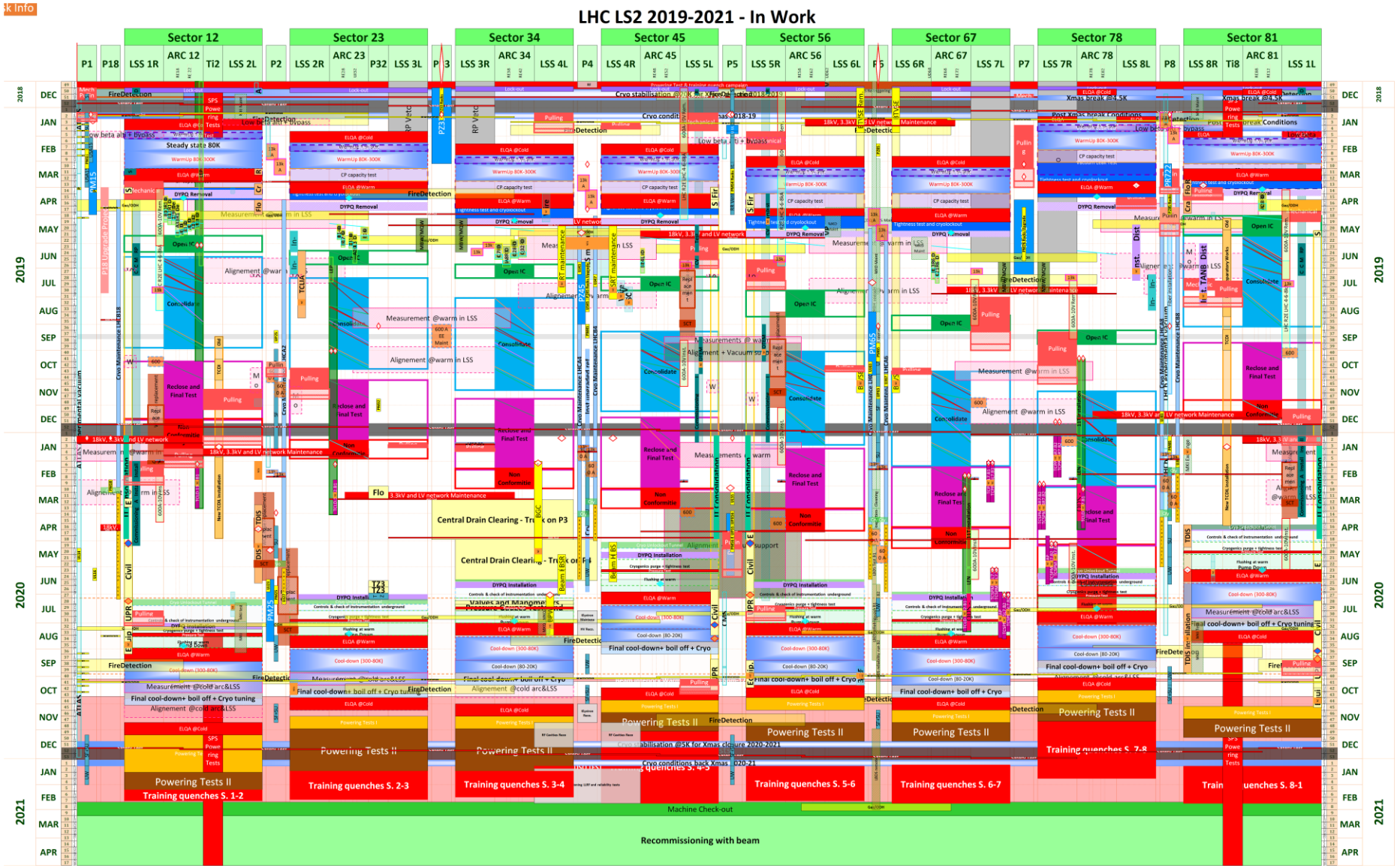


- LIU / HL-LHC beam parameter target at the PS to SPS extraction : **2.6 10^{11} p/b** in 1.9 μm
- **2017**: Despite new RF longitudinal damper system, beam intensity limited to **2.1 10^{11} p/b**
- **2018**: Additional RF upgrades implemented together with extensive beam optimisation allowed reaching the target intensity **2.6 10^{11} p/b**
- Intensity reach and reproducibility being studied until end of Run 2. Beam performance review scheduled in January 2019 to define the final operational strategy – incl. decision on Landau cavity mitigation

Master Schedule of the Long Shutdown 2 (2019-2020)



LHC: LS2 planning (version October 2018)

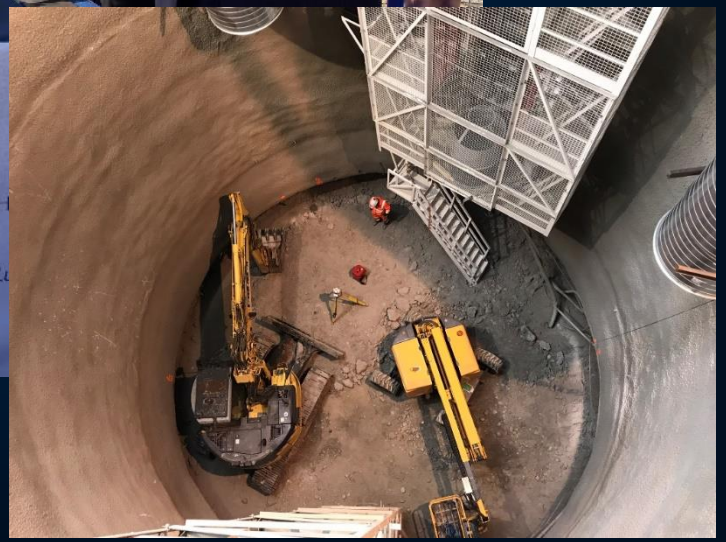


HL-LHC: Civil Engineering Pt 1 and Pt5 has started

HL-LHC first stone ceremony, 15th June 2018

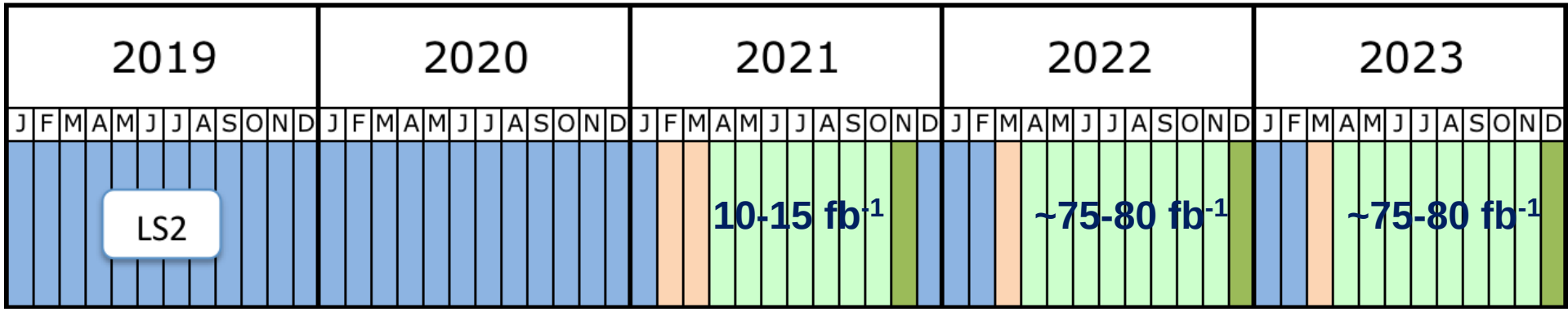
Point 1

Point 5



Run 3 outlook

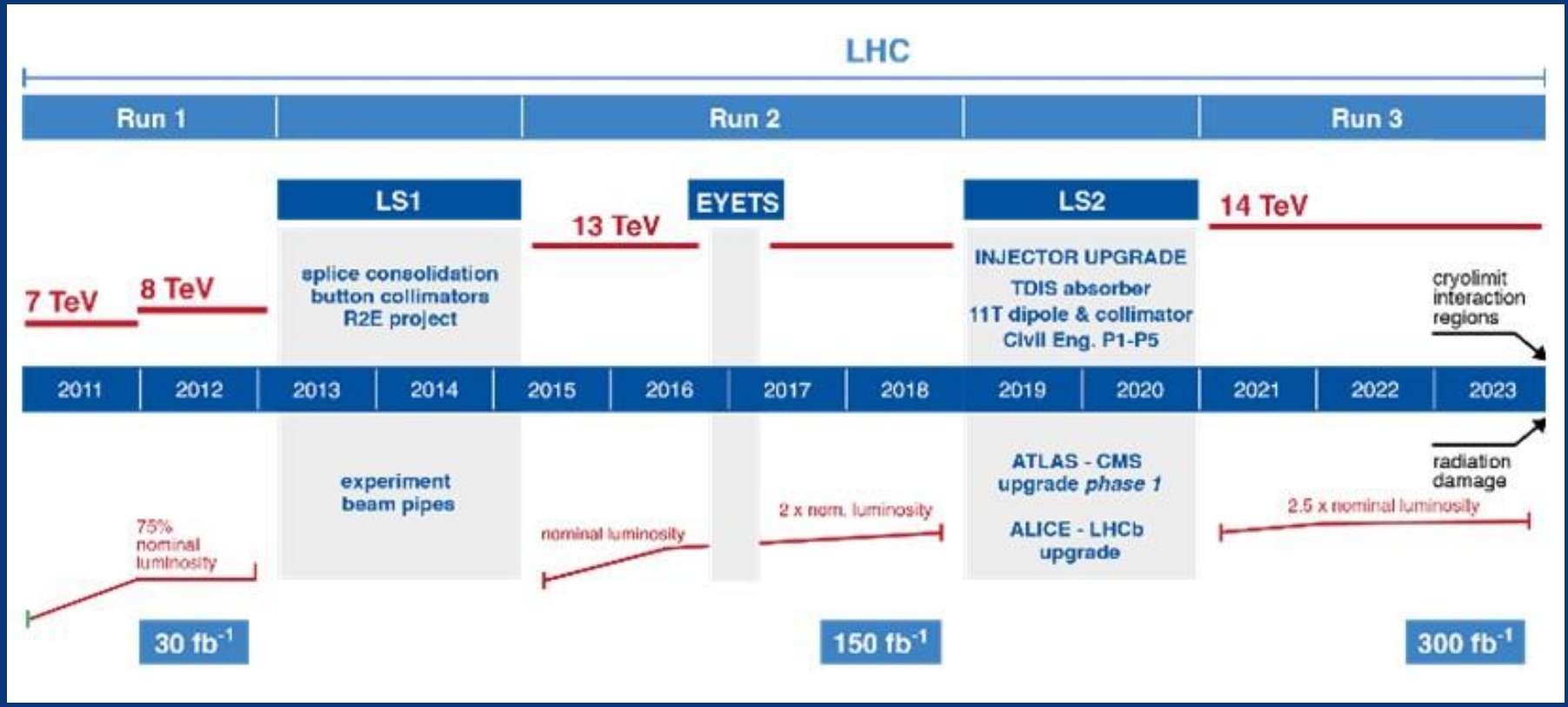
∑(Run1 + Run2 + Run 3) > 300 fb^{-1}



2021: beam commissioning in the injectors after LIU upgrade
LHC 14 TeV commissioning and operation

2022-2023: production years at 14 TeV ;
Lpeak ~ 2.0-2.2 10^{34} $cm^{-2}s^{-1}$; luminosity levelling

~350 fb^{-1}



Successful Run 1 and Run 2 : > 185 fb^{-1}
Solid preparation for LS2 activities. In full swing to start less of 2 months
LIU ready for installation and successful MD in 2018
HL-LHC Civil Engineering: a good start

Run 3 at 14 TeV
End of 2023 : ~350 fb^{-1} => HL-LHC installation during LS3 (2024-2025)

Thanks for your attention