LHC status and plans towards HL-LHC

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4th June 2018

2018 Machine/Beam Parameters

LHC 2017 operation

2017 goal:

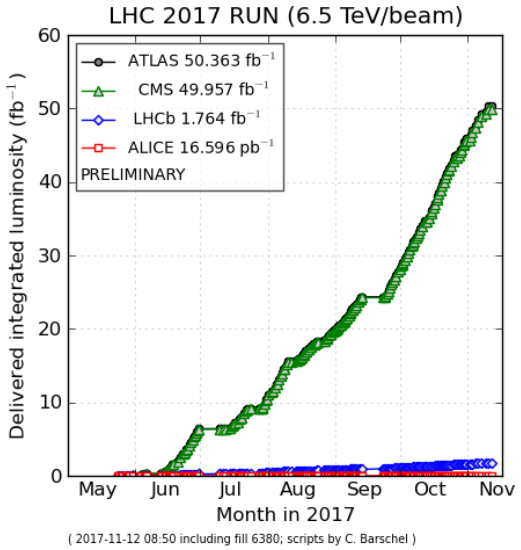
45 fb^{-1}

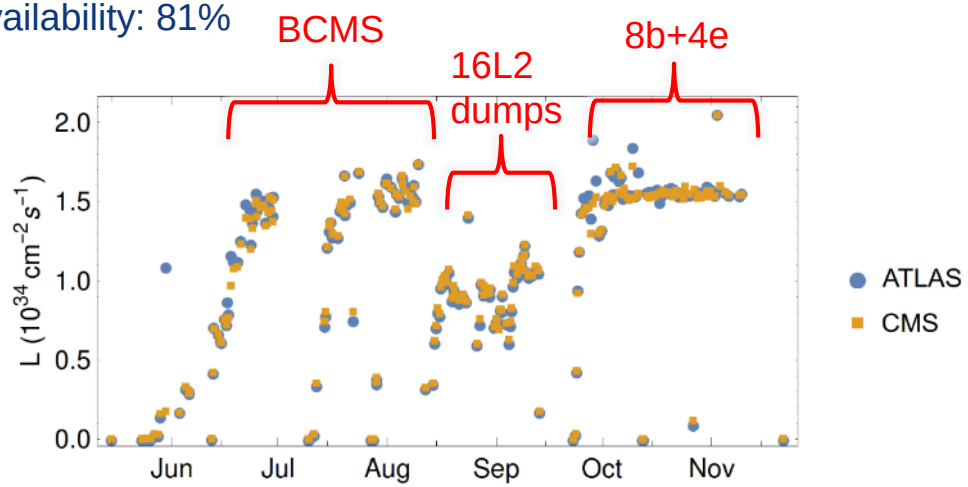
Peak luminosity
2.2 10^{34} cm^{-2} s^{-1}

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

Lower β* 30 cm
(new ATS optics)

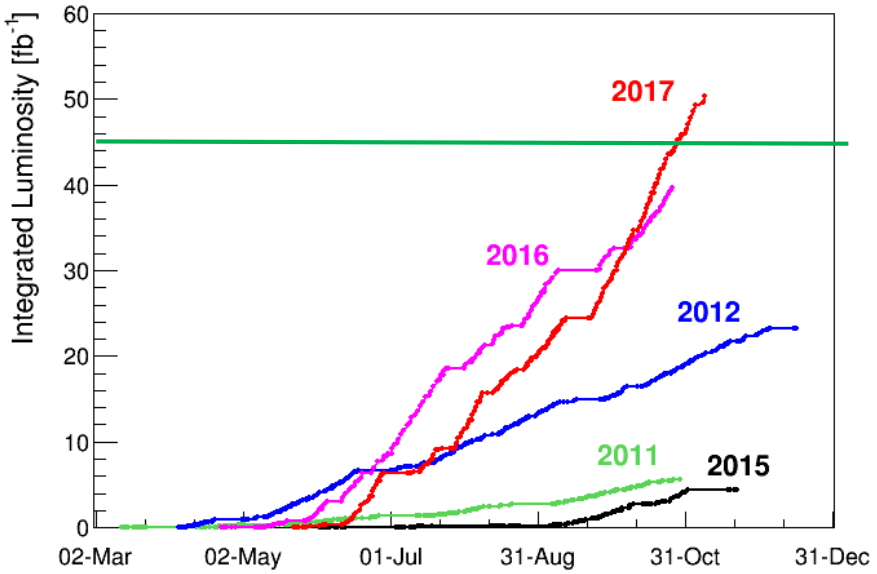
Availability: 81%

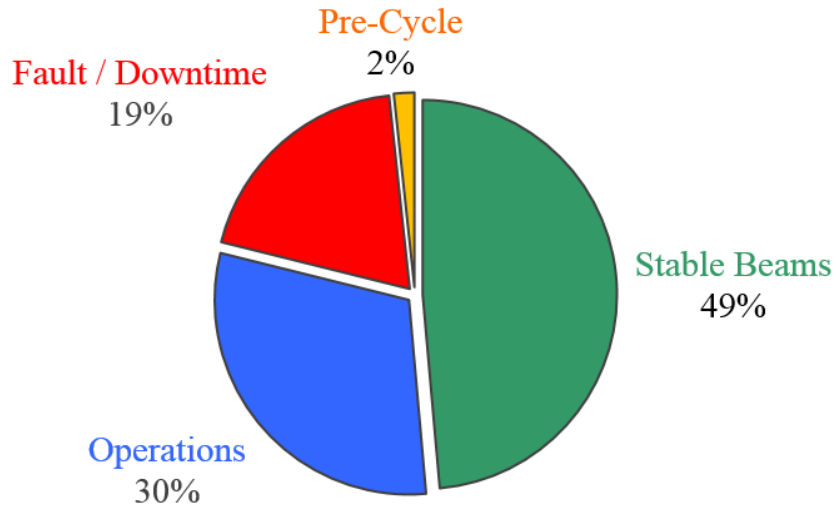




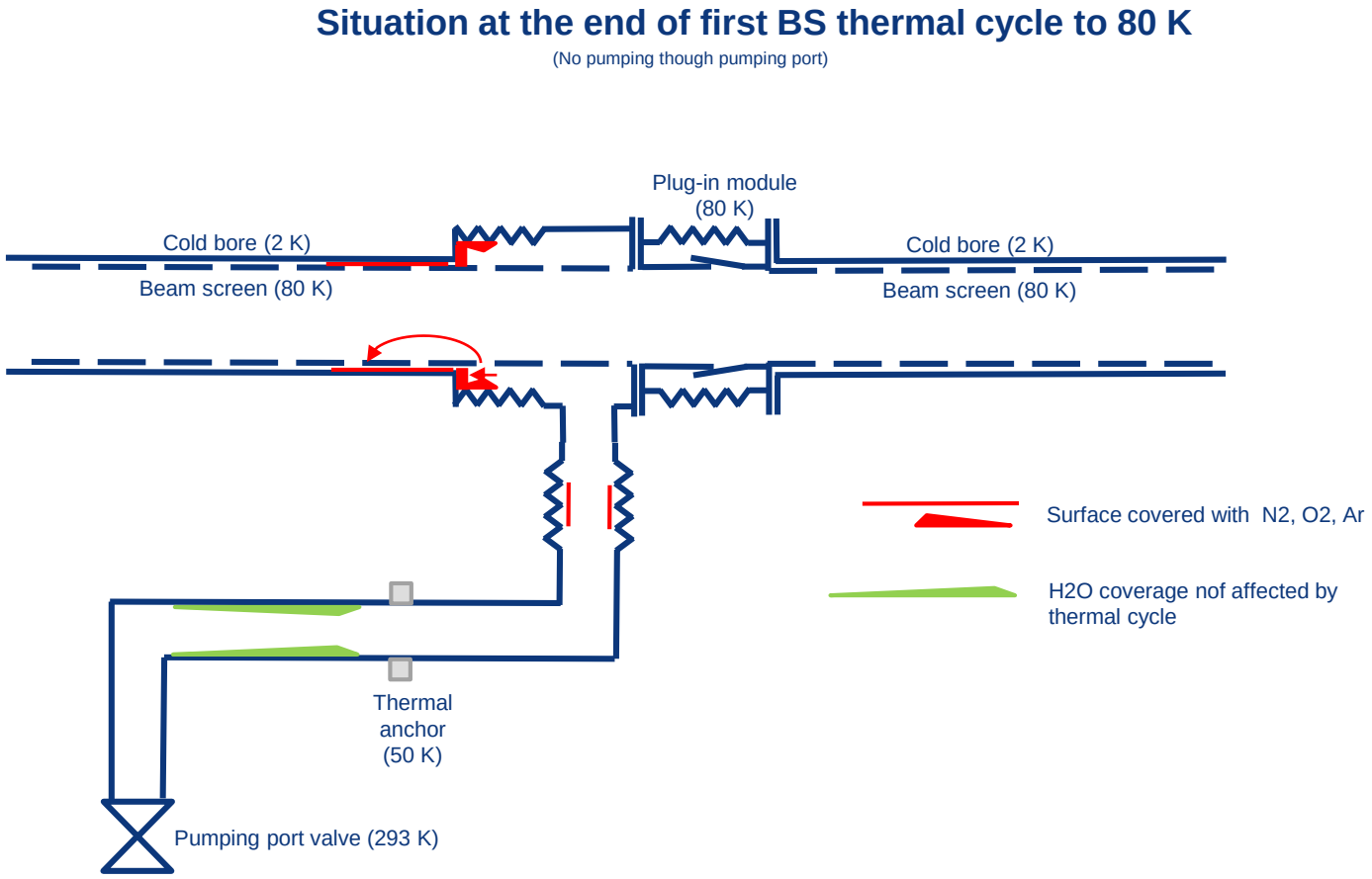
LHC takes <0.03 % of the CERN protons

Achieved : 50 fb^{-1}

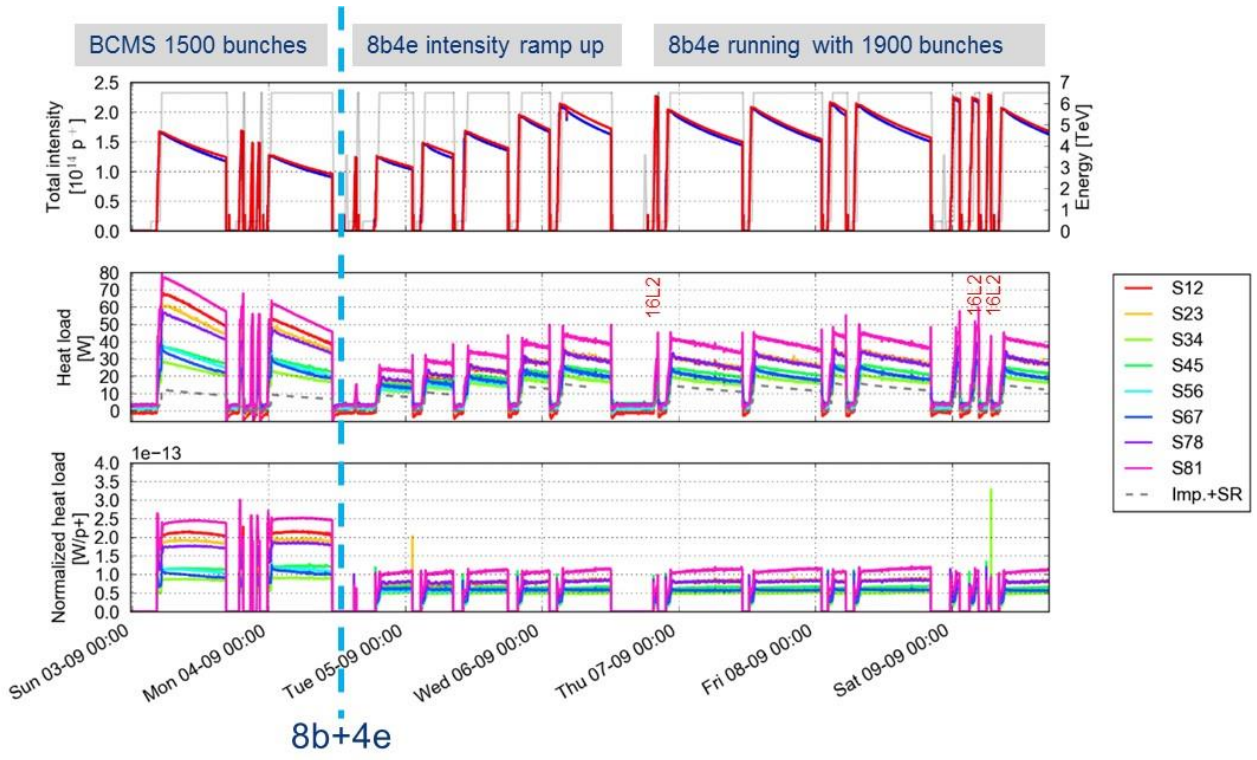


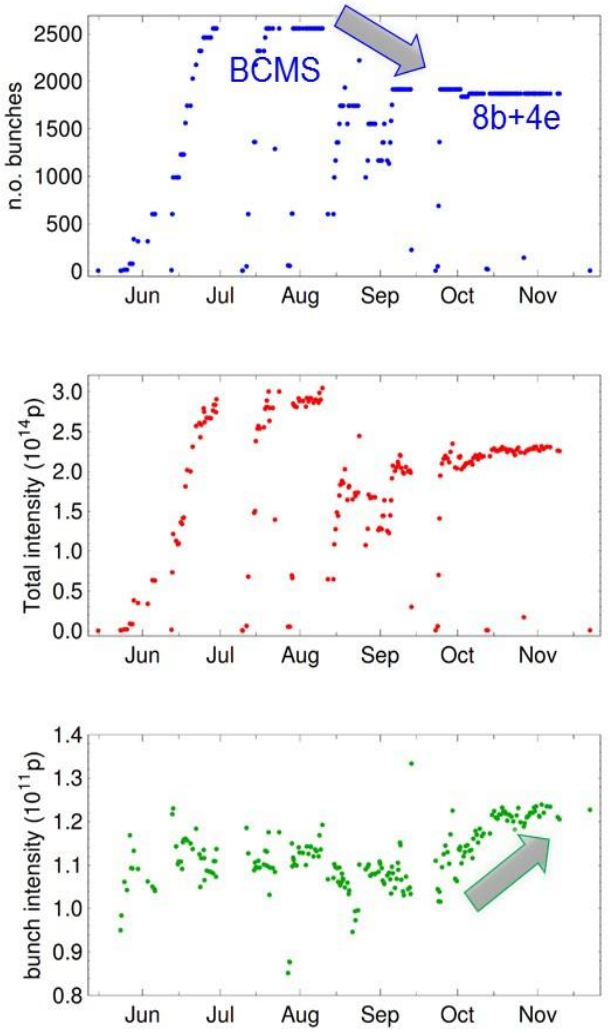


LHC “16L2”: Air inlet as “most probable” cause



LHC: Cryogenics Heat Load BCMS versus 8b4e



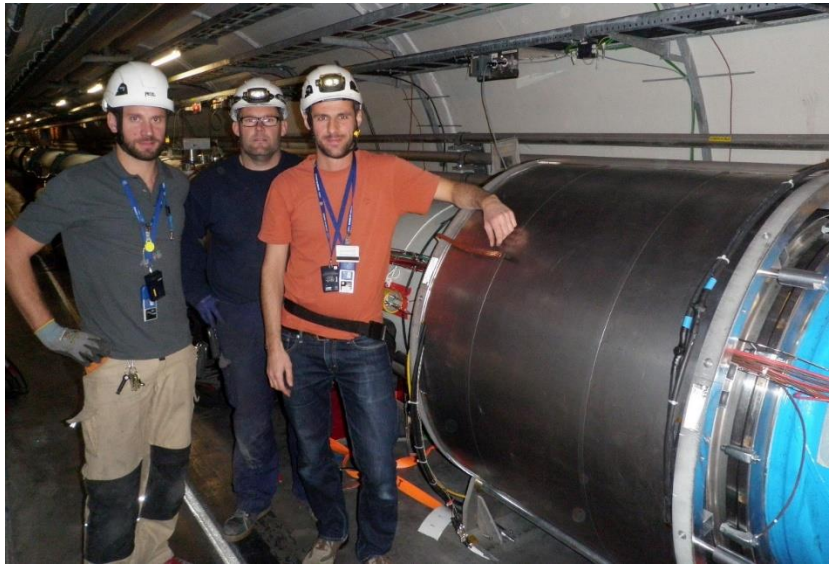


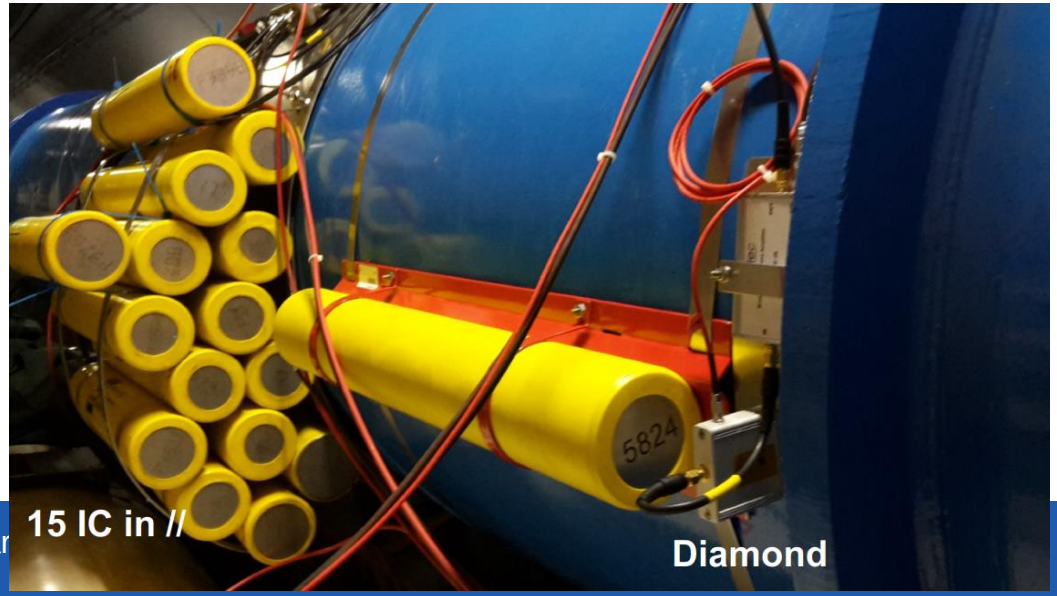
8b4e = **8 b**unches + **4 e**mpty buckets

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

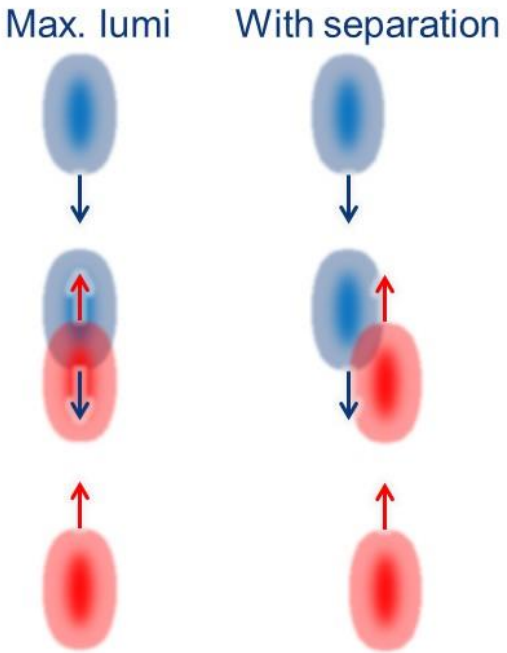
16L2 interconnect : solenoid and more diagnostics

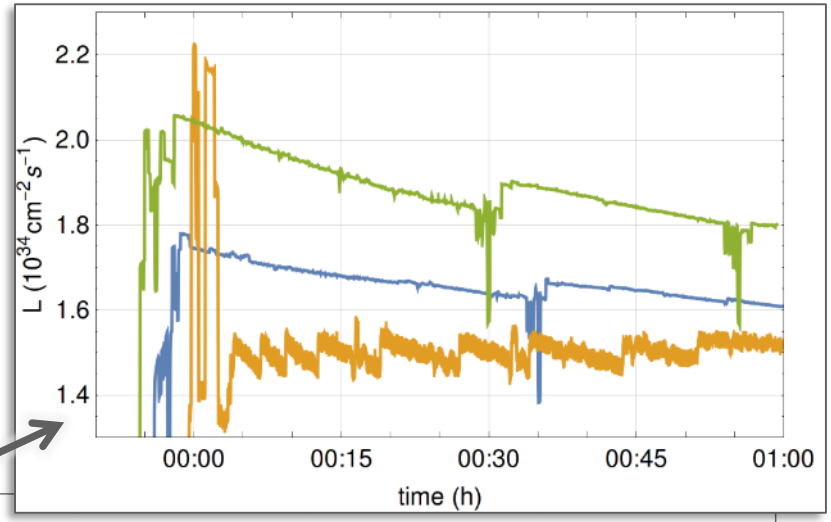


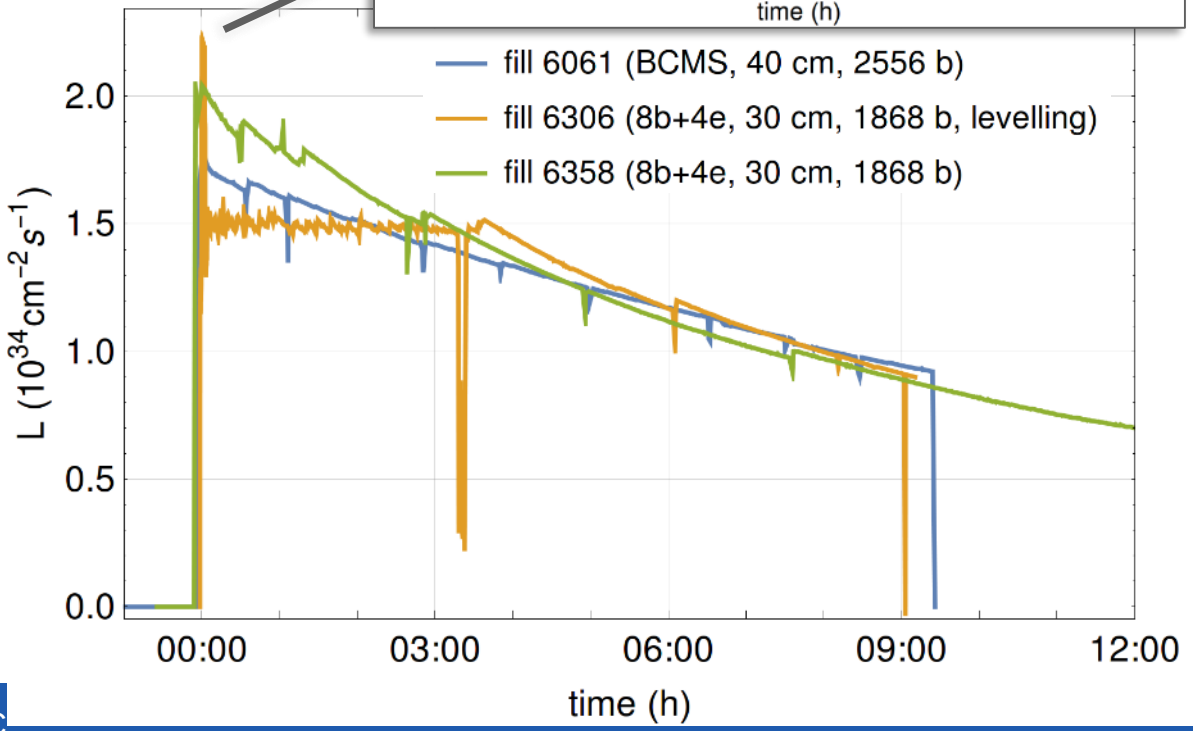


LHC 2017 : separation levelling

- 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} $cm^{-2}s^{-1}$

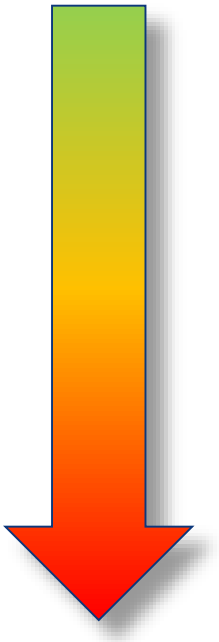






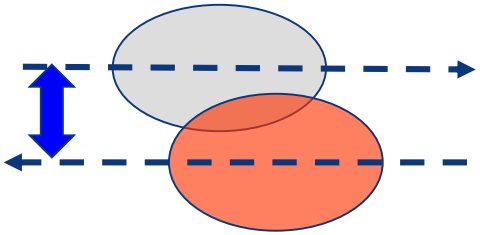
Luminosity levelling

- In certain conditions and depending on the experiments request, it is desirable to adapt the luminosity dynamically with beams in collision – **levelling**
- Each levelling technique has its advantages and drawbacks

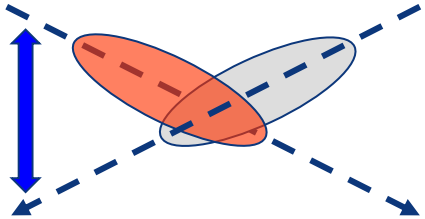


Complexity

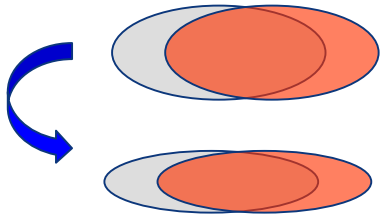
Levelling by beam offset / separation



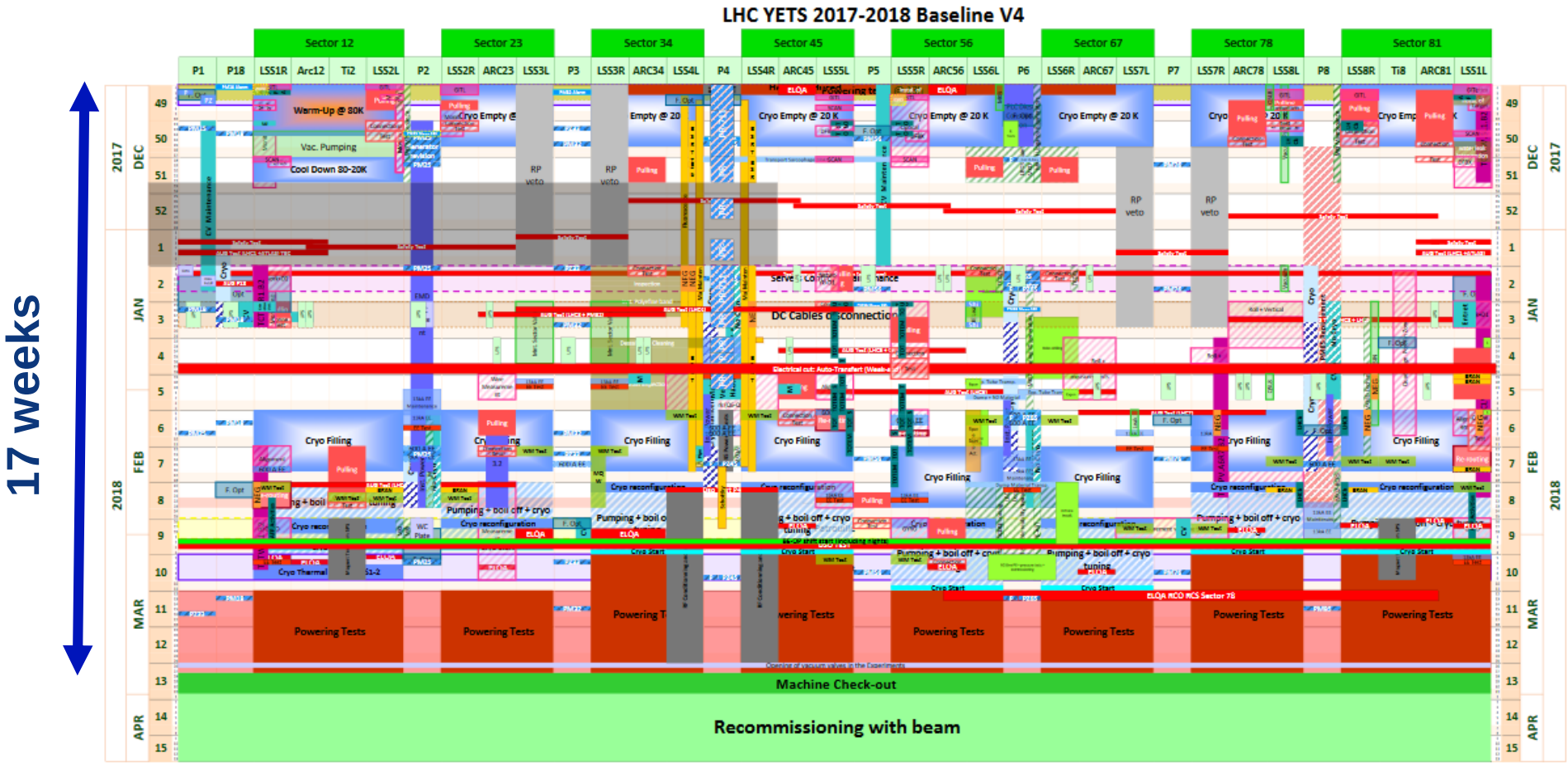
Levelling by crossing angle



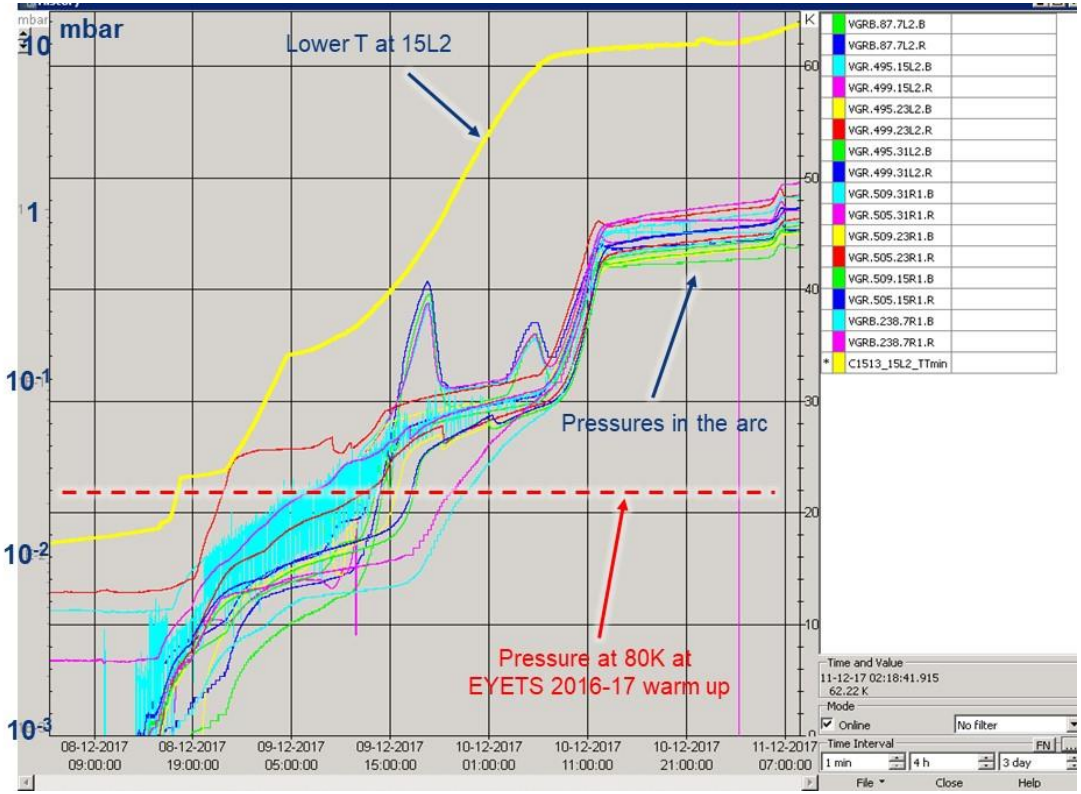
Levelling by β^* (= beam size at IP)



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

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

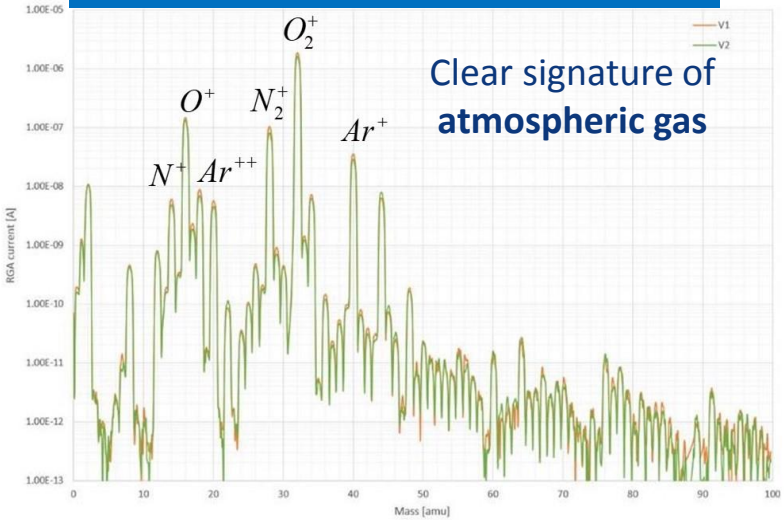
$$V_c = 10.5\,cm^3 \text{ per beamline}$$

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

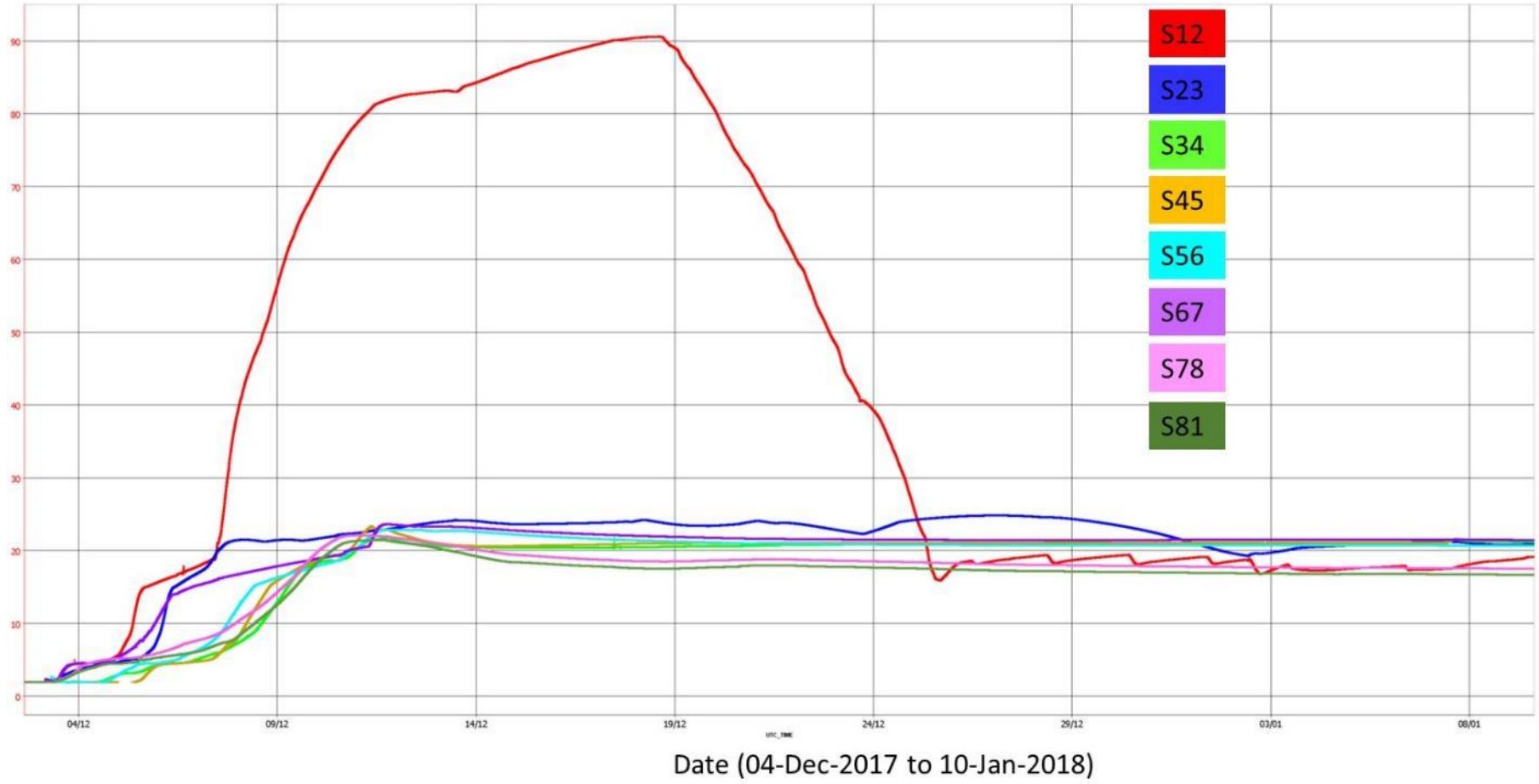
Estimated quantity of extracted water vapour

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

Results from gas analysis in 16L2



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



LHC schedule 2018

A production year to complete Run 2 (13 TeV)

Goal 60 fb^{-1} ATLAS/CMS

2 fb^{-1} for LHCb

with 131 days of p-p physics

55 fb^{-1} and 1.8 fb^{-1} if 119 days

keeping the LHC high availability and >50% stable beams

Pb-Pb run : 24 days + 4 days setting-up

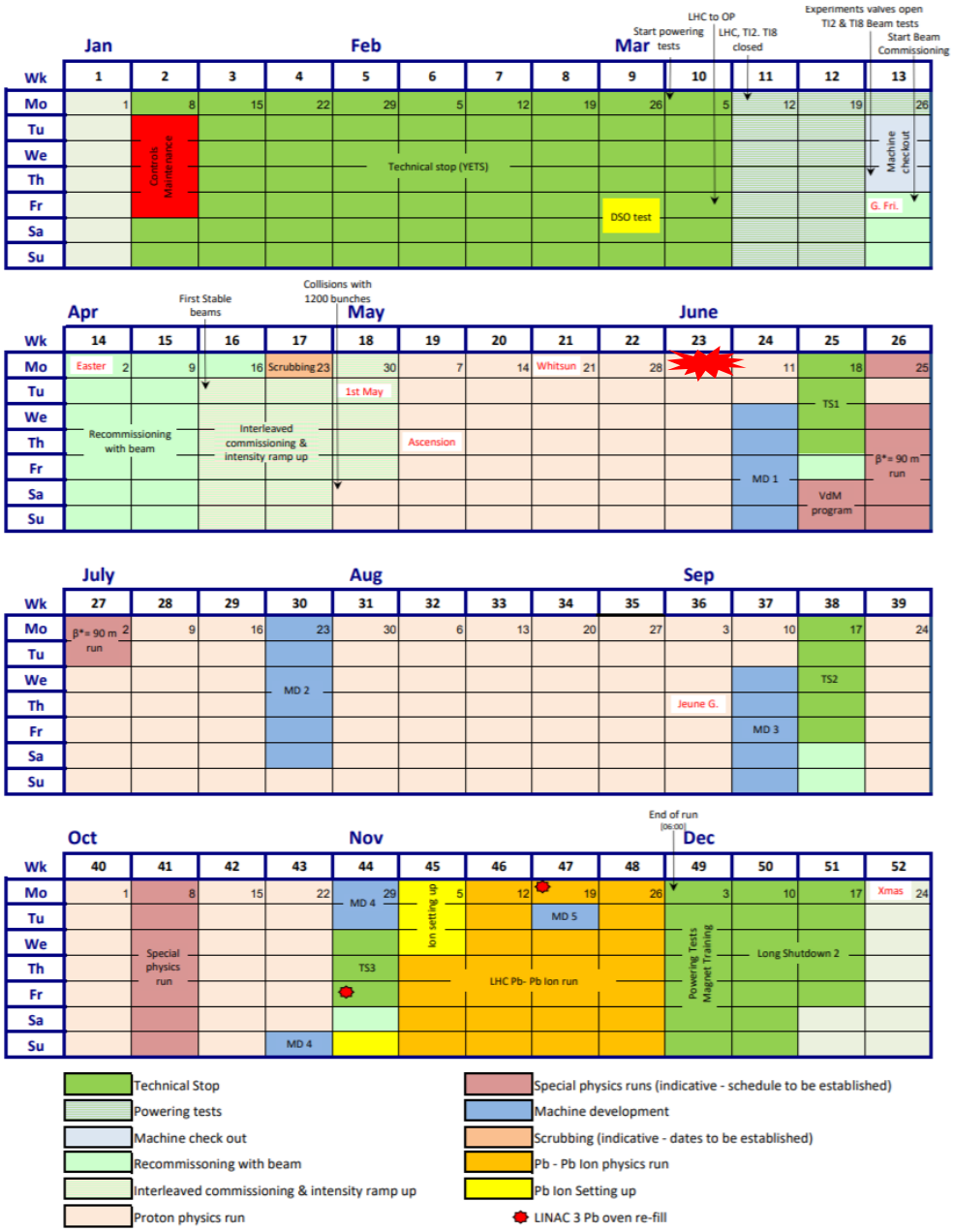
Goal: > 600 µb^{-1} ALICE (Run 2 > 1nb^{-1})

Special runs: 9 days (16 days ?)

20 days of MD

+ 3-5 days, later during 2018 according integrated luminosity

Week 49: **powering tests to 14 TeV**
(Main dipole circuit ONE sector training to 14 TeV)



2018 Machine/Beam Parameters

Parameter	Design	2018
Bunch population N_b [10^{11} p]	1.15	**~1.2 (→ 1.4)**
No. bunches per train	288	**144**
No. bunches	2780	**2556**
Emittance ε [mm mrad]	3.5	**~2.2**
Full crossing angle [μrad]	**285**	**300 → 260**
β^* [cm]	55	**30 → 27.5 → 25**
Peak luminosity [10^{34} $cm^{-2}s^{-1}$]	1.0	**~2**
Integrated luminosity [fb^{-1}]		**~60**

The “CMS bump” to compensate ground movement was increased from **-1.5 mm** to **-1.8 mm**

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 2018: LHC Statistics Since First Collissions

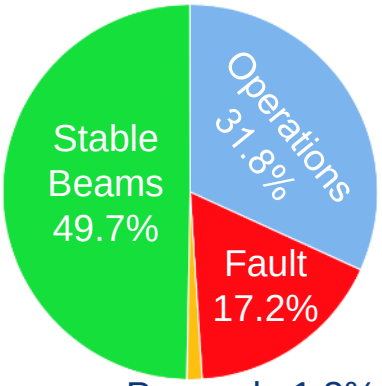
Availability

82.8%

Stable beams

49.7%

Fault vs Operation Time Distribution



Pre-cycle 1.3%

Fault labels

60A BPM Interaction | TIOC

Min Turnaround

0.9h

Avg Turnaround

7.6h

Fault count

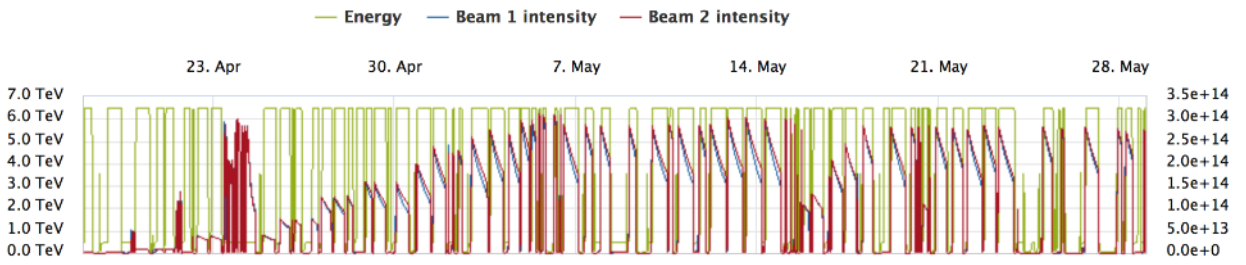
154

Max Turnaround

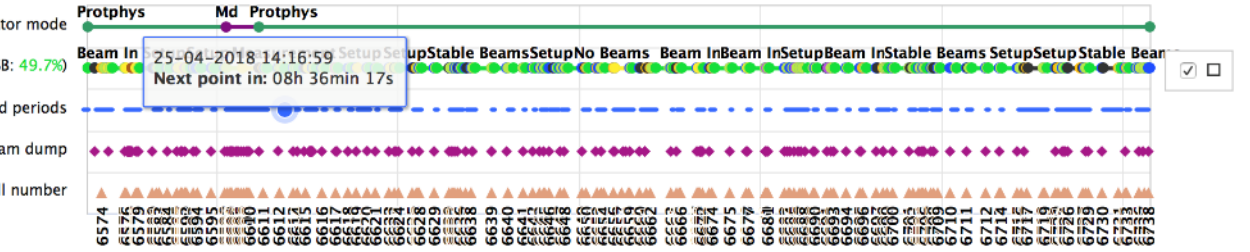
39.3h

LHC Activity

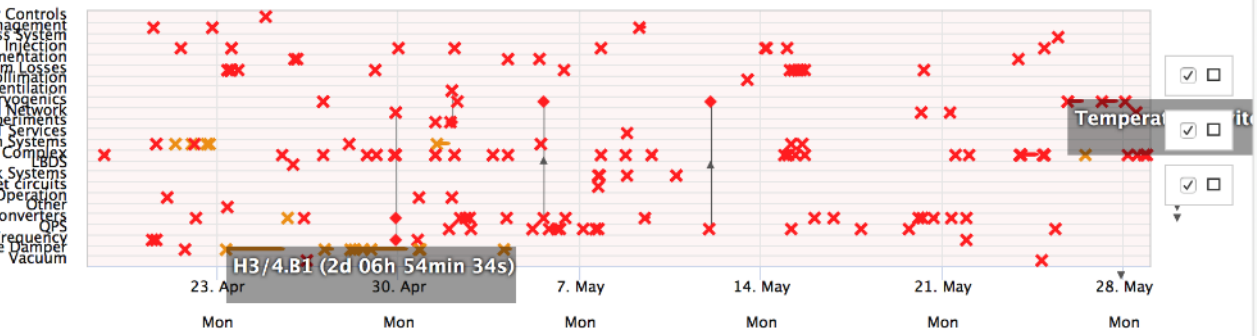
17.04.2018 – 28.05.2018



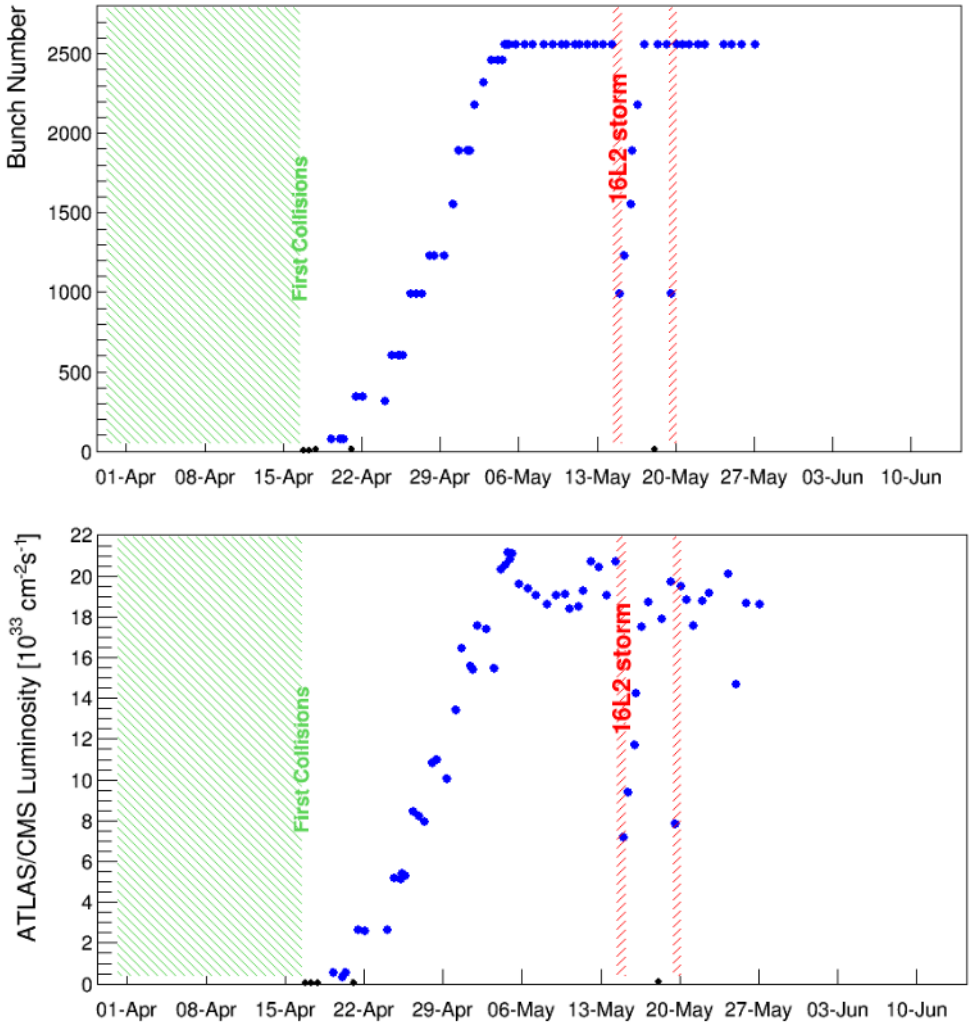
Accelerator Mode Activity



Faults in Selected Window

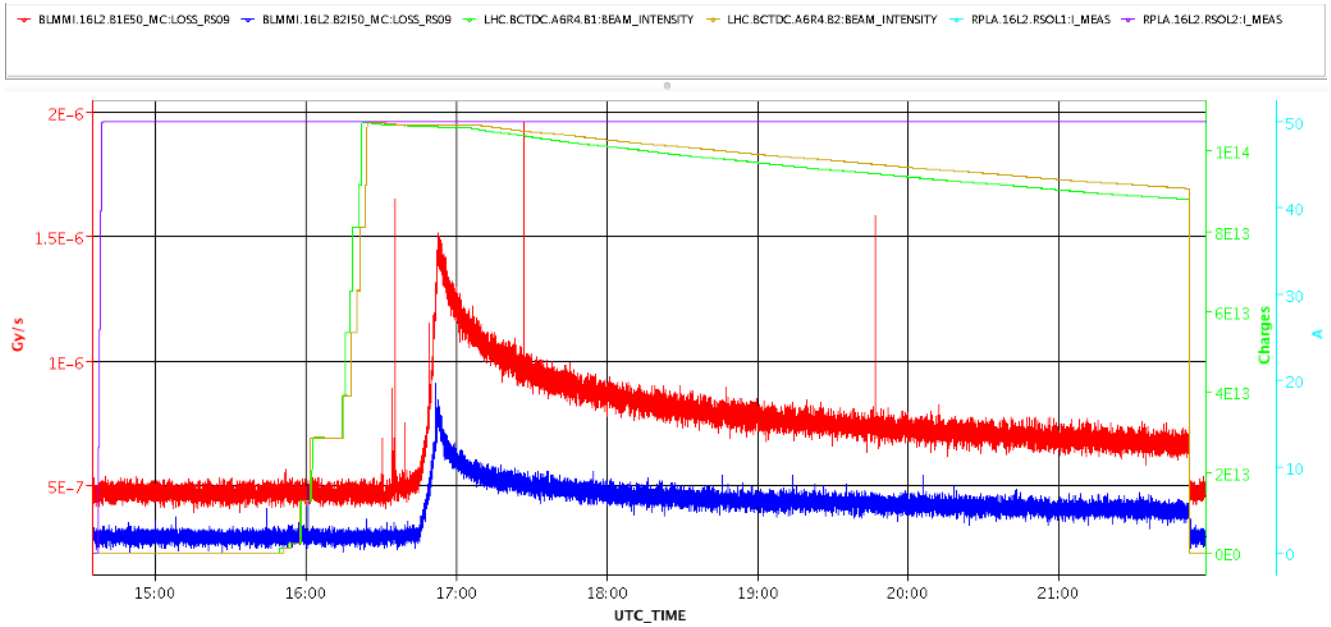


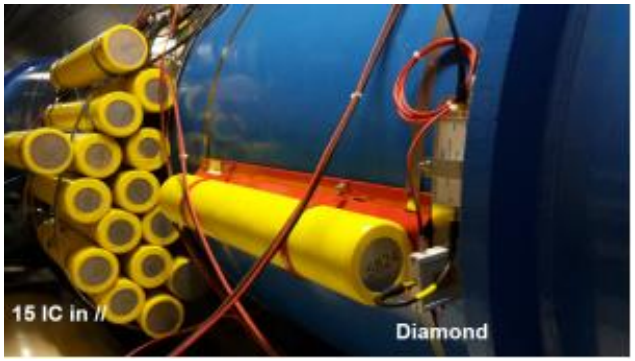
LHC 2018: Performance up to now



- Full machine (2556 bunches) reached on May 5th
- Peak lumi in stable beams of 2.1×10^{34} $cm^{-2}s^{-1}$ reached during intensity ramp up
  - Might be a new record, pending luminosity measurement calibration
- After that small step back in bunch intensity
- Two “16L2 storms” encountered with successful recovery

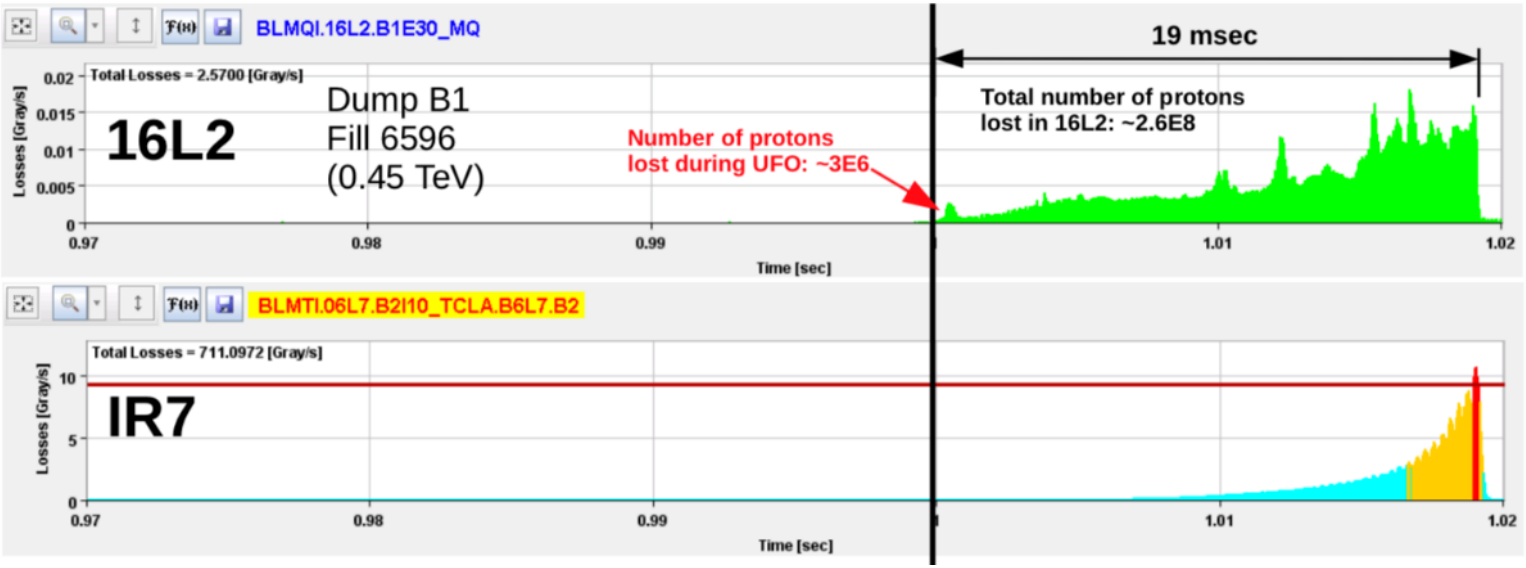
LHC 2018: “16L2 Storms”





- Steady state losses partly suppressed by solenoid
- Loss peaks can trigger beam dump

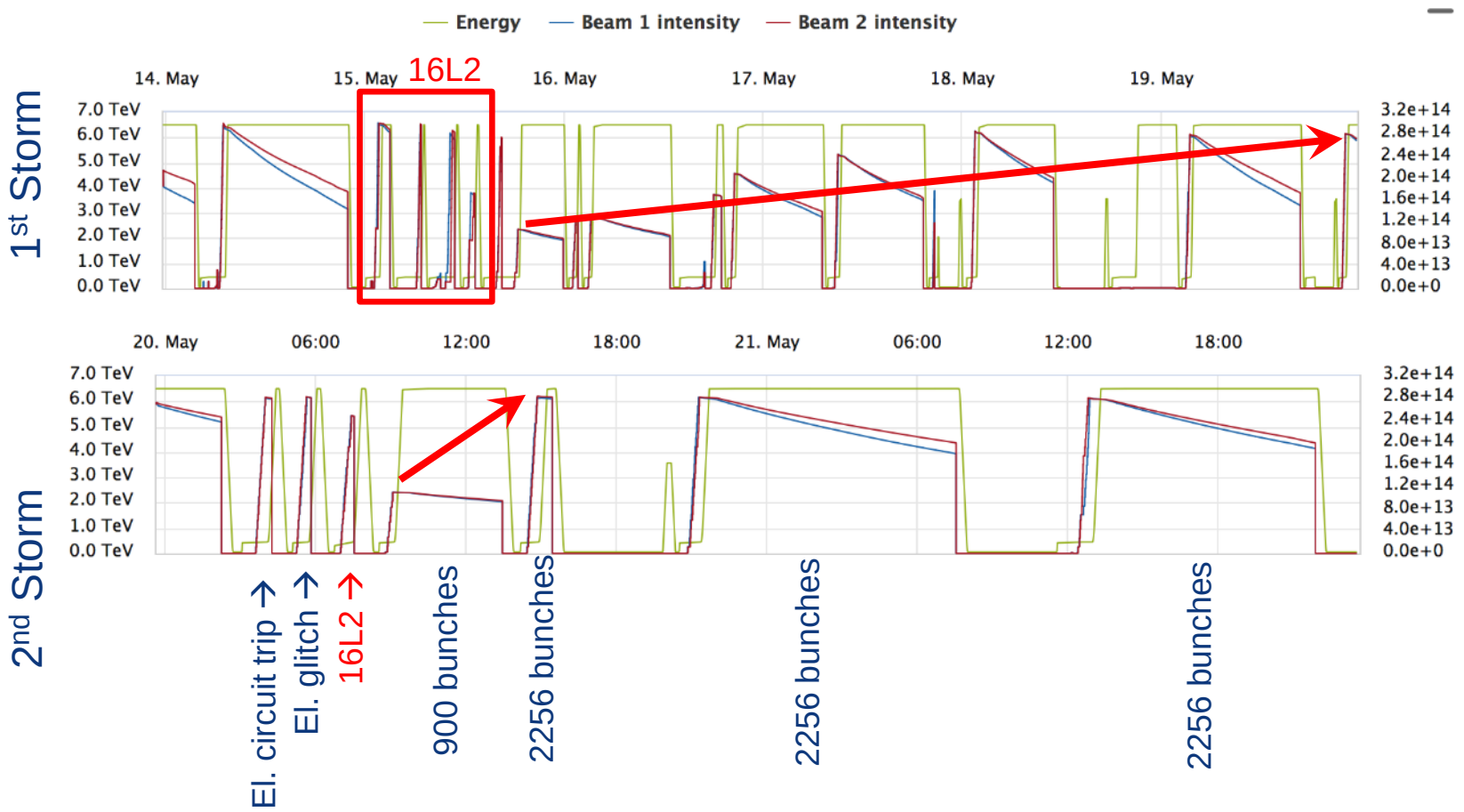
LHC 2018: Time Structure of Losses



Looks very similar to 2017:

- Events starts with a spike at 16L2
- This is followed by a “loss runaway” at 16L2
- After about 10 ms a transverse instability is triggered, which causes fast losses at the collimators dumping the beams

LHC 2018: “16L2 Storm” Recovery

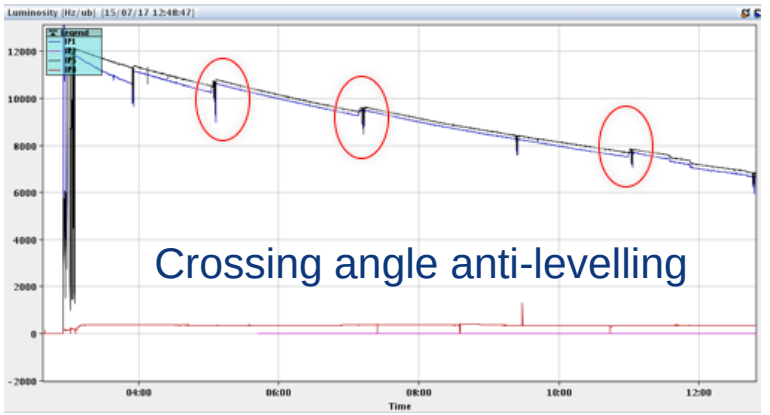


- 1st storm a recovery à la 2017 was used
- 2nd storm was recovered with a single fill with 900 bunches, losing little time…

LHC 2018: Luminosity (Anti-)Levelling

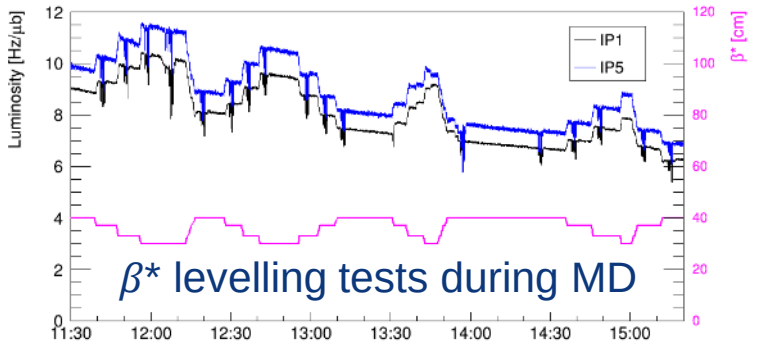
In 2017 the step-wise crossing angle anti-levelling was introduced

- 3 steps depending on the luminosity burn-off



In 2018:

- **The crossing angle anti-levelling is done continuously, down to 130 μrad**
- **A step-wise β* anti-levelling has been added**
- **β*=30 cm → 27.5 cm → 25 cm**



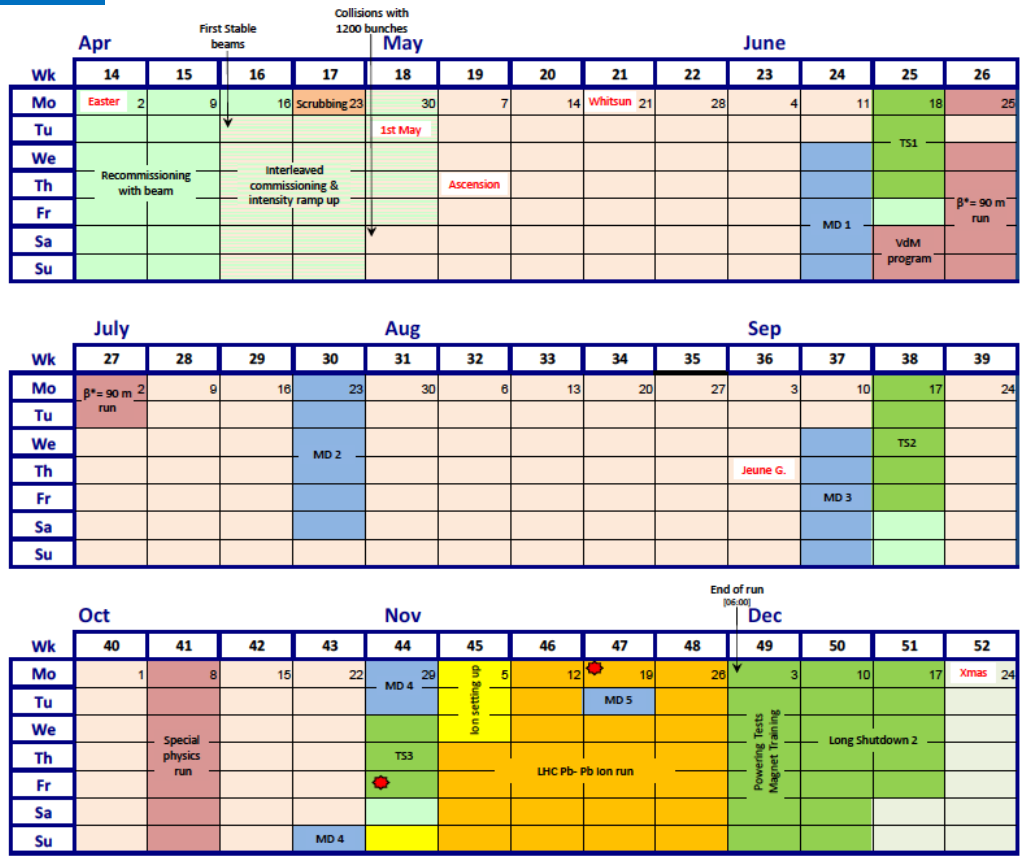
This allows minor gain in integrated luminosity, but is a vital exercise for future (HL-LHC) levelling

LHC 2018: Special Runs

Van de Meer run scheduled for week 26 and under preparation

Seven day long β*=90 cm run scheduled for week 26 & 27

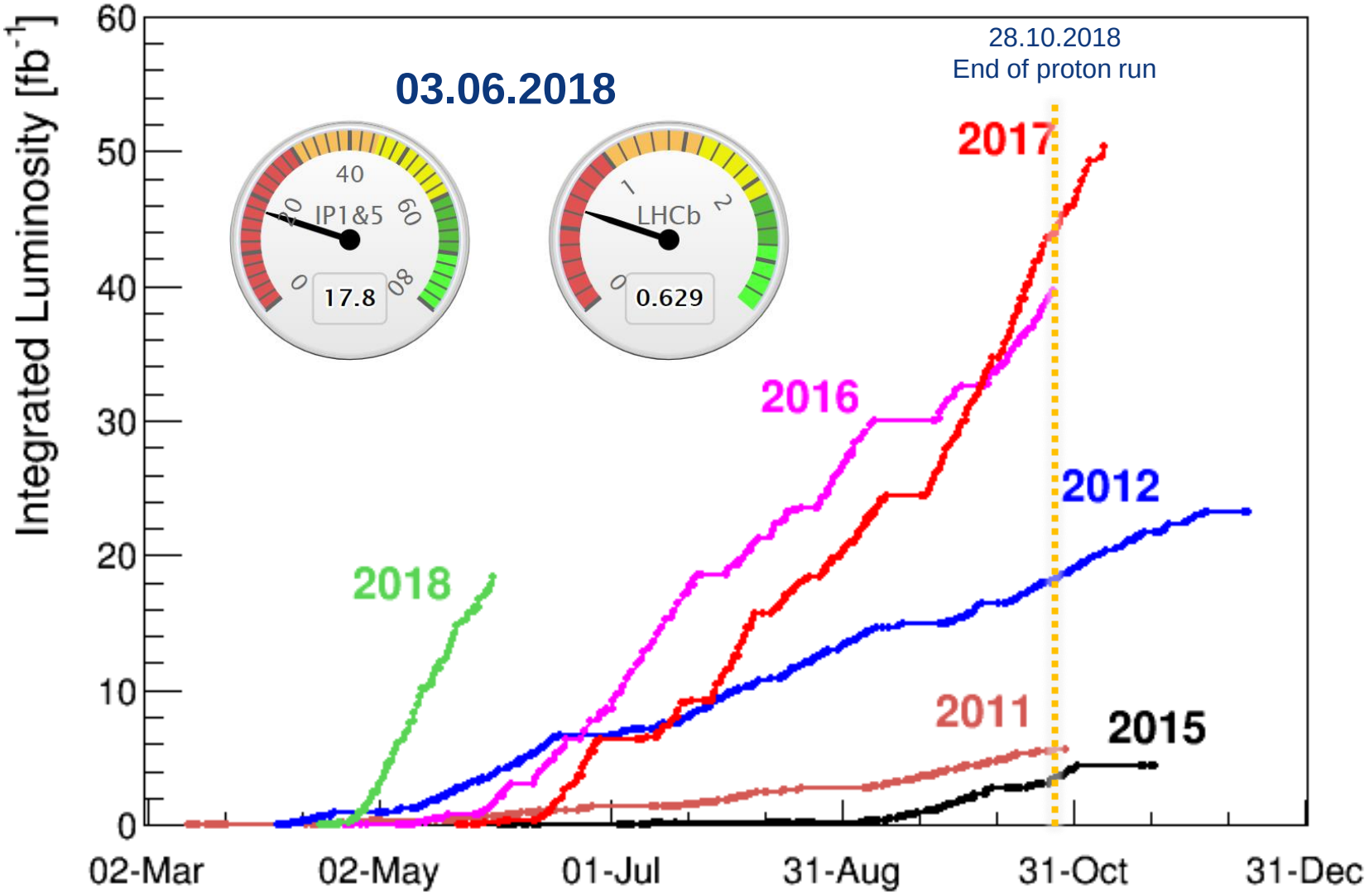
Setting up well advanced



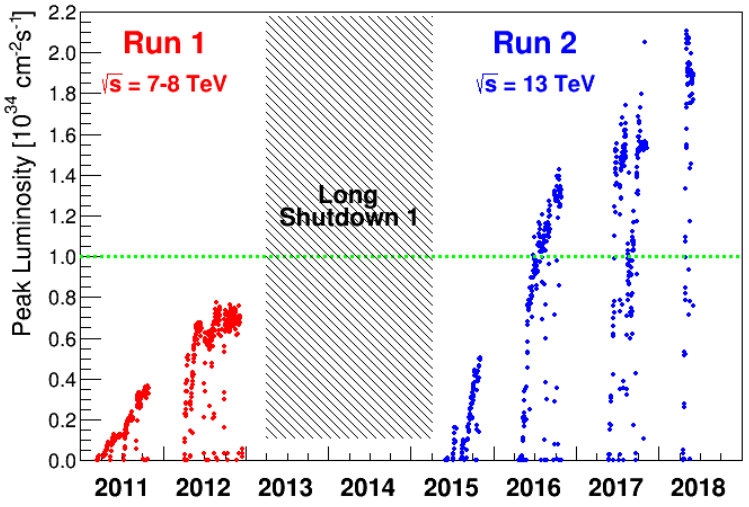
Special runs week 41 are a place holder for Low energy high β run

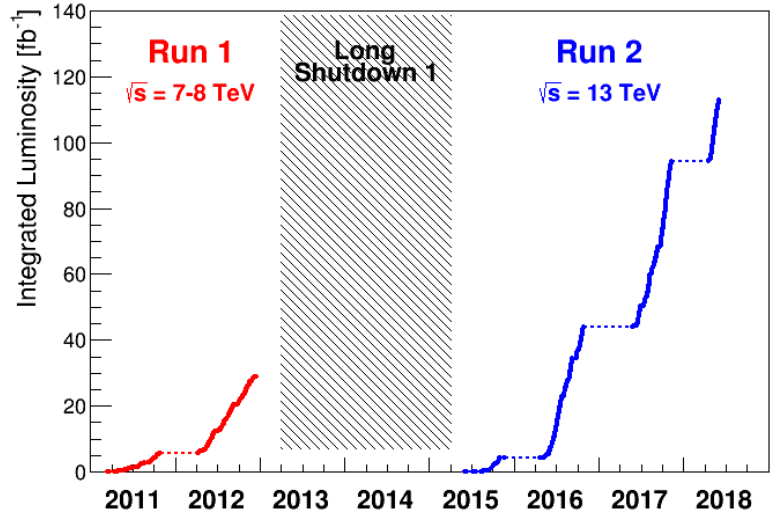
- Tests in 2017 and recently at 900 GeV were unsuccessful due to background noise growth, which is not (yet) fully understood
- Not sure if doubling the energy would solve the background issue

Multi-annual Integrated Performance



Run1 + Run 2: Luminosity Production





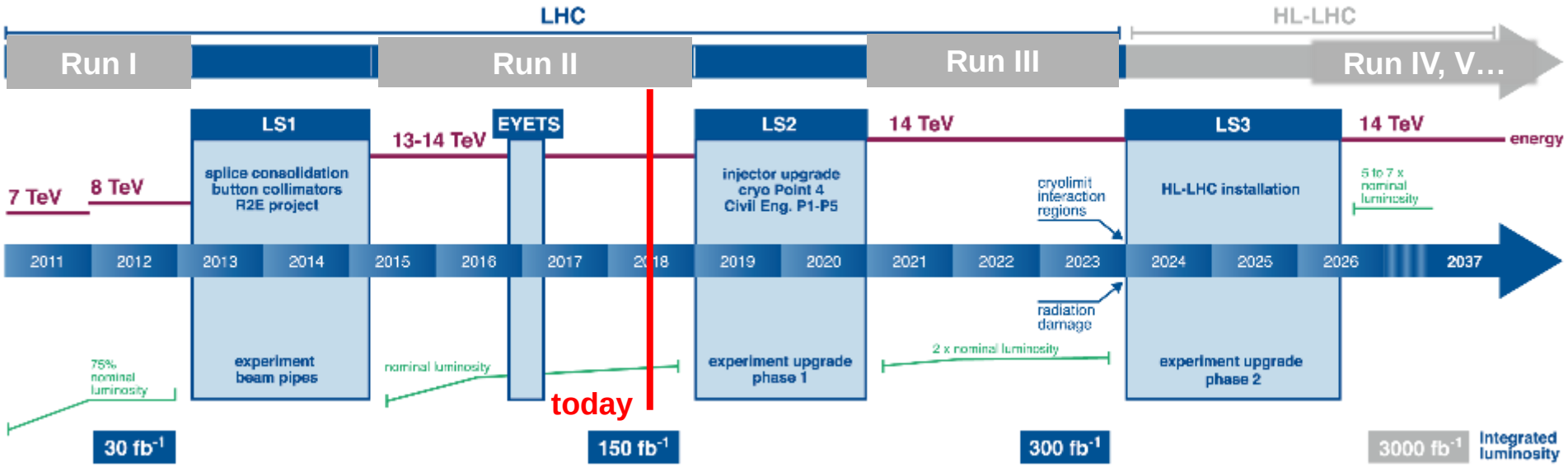
Peak Luminosity

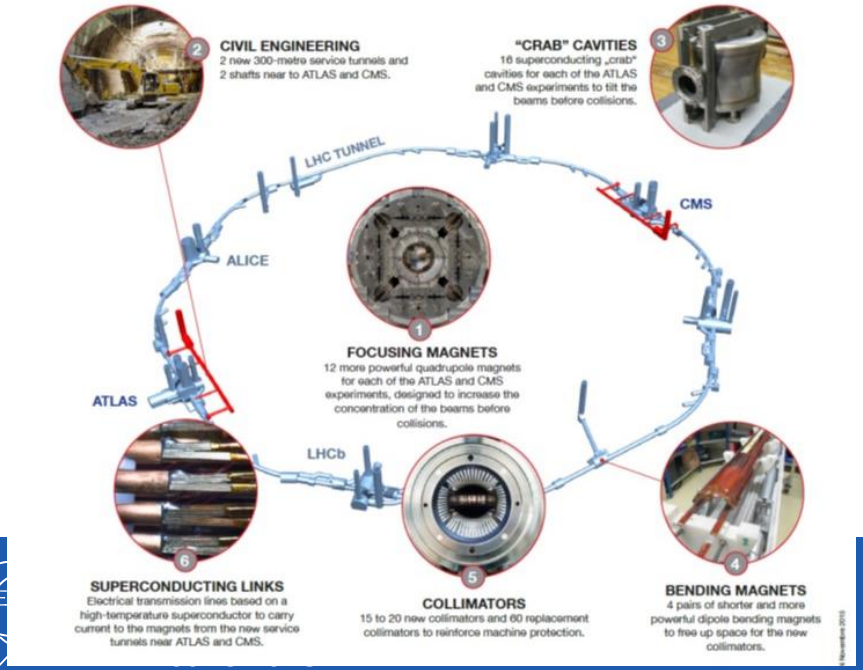
2018 shows steepest increase in peak luminosity of all years

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	17.8
Total Run 1+ 2	141.1

03.06.2018

LHC plan and HL-LHC (High Luminosity LHC)





The HL-LHC Project: *300 fb^{-1} → 3000 fb^{-1}*

Major intervention on more than 1.2 km of the LHC

CERN aims at fostering R&D collaborations and knowledge exchange also with SMEs, a perfect opportunity to match their capacity with the requirements of HL-LHC

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 **$\mu \sim 140$ (~ 200)** (➔ peak luminosity of **5 (7.5) 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 :

$$L = \frac{n_b \times N_1 \times N_2 \times g \times f_{rev}}{4p \times b^* \times e_n} \times F(f, b^*, e, s_s)$$

➔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

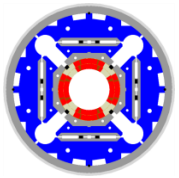
➔6) Improve machine ‘Efficiency’ ➔ minimize number of unscheduled beam aborts

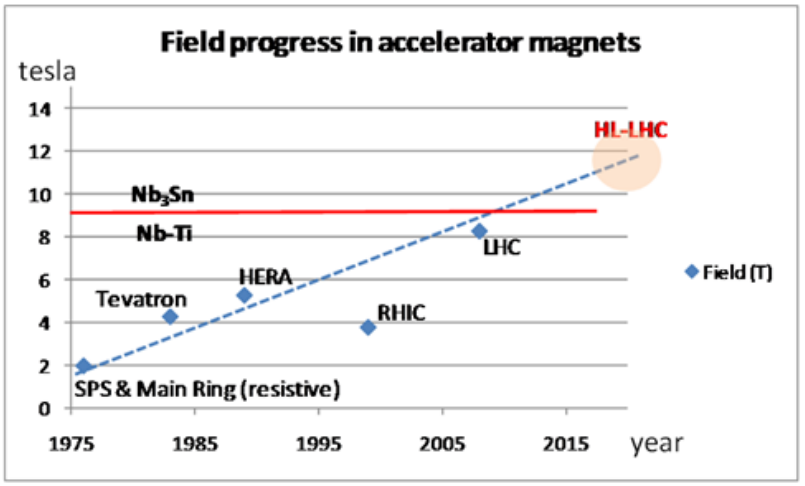
Squeezing the beams: High Field SC Magnets

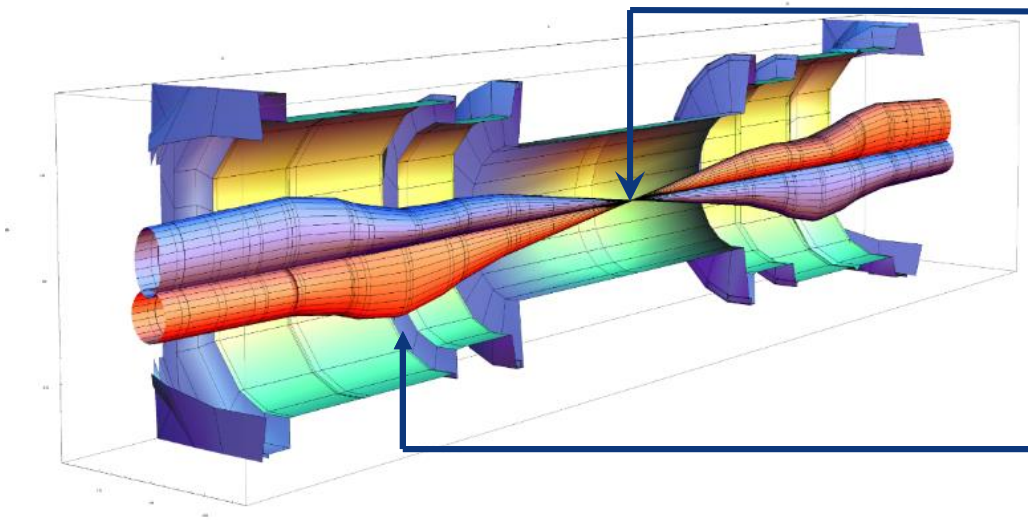
Quads for the inner triplet
Decision 2012 for low-β quads
Aperture ∅ 150 mm – 140 T/m
(B_{peak} ≈12.3 T)
operational field, designed for 13.5 T

=> Nb_3Sn technology

(LHC: 8 T, 70 mm)

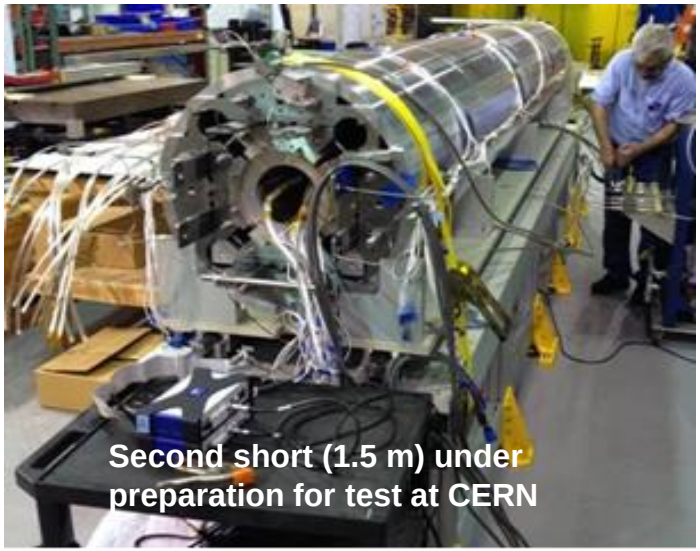




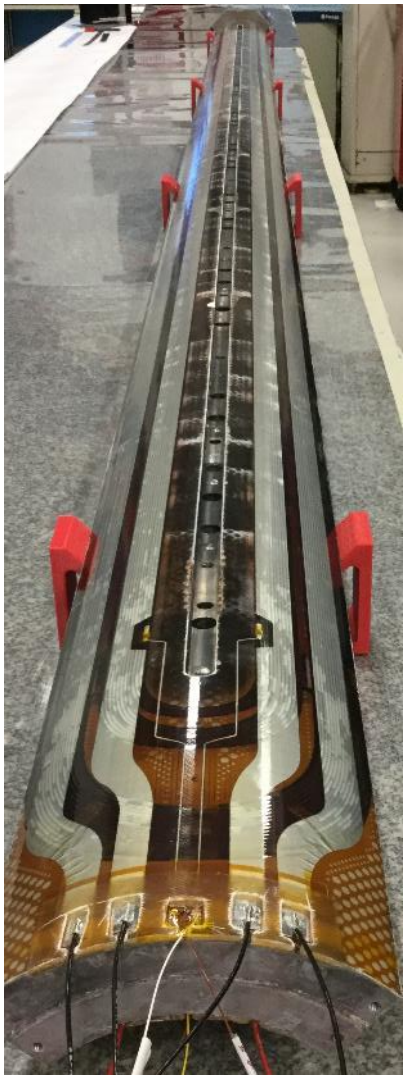


	$\beta_{triplet}$	Sigma triplet	β*	Sigma*
Nominal	~4.5 km	1.5 mm	55 cm	17 um
HL-LHC	~20 km	2.6 mm	15 cm	7 um

Nb_3Sn quadrupole: 1st long prototype under construction



Second short (1.5 m) under preparation for test at CERN



LARP

Insertion of coil package inside mechanical structure of the first IT quad prototypes (4.2 m long) in LBNL-USA

Nb_3Sn quadrupole: 1st long prototype under construction

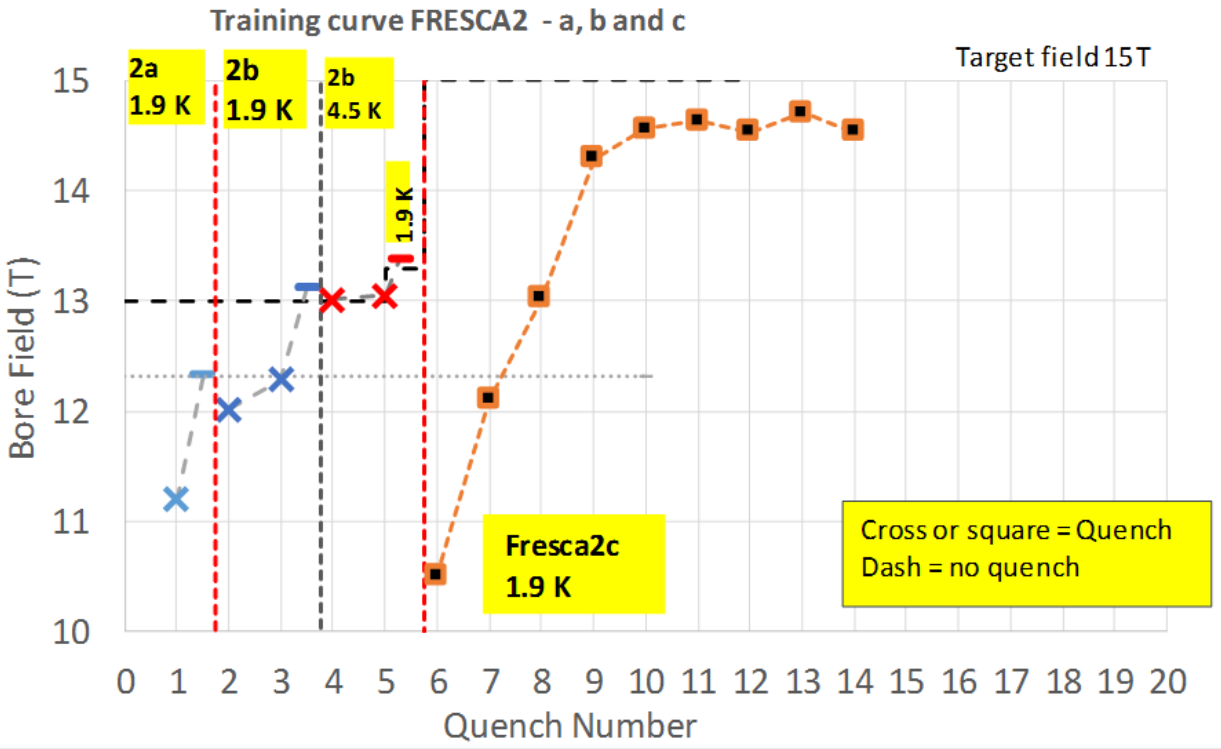
11T dipole (Nb_3Sn): long prototype under assembly at CERN

11T dipole (Nb_3Sn): long prototype ready to be tested (June 2018)

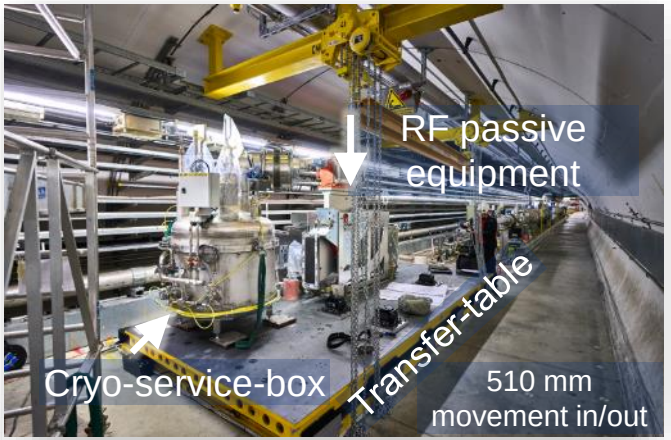
FRESCA2 dipole: the first project as R&D for HL-LHC

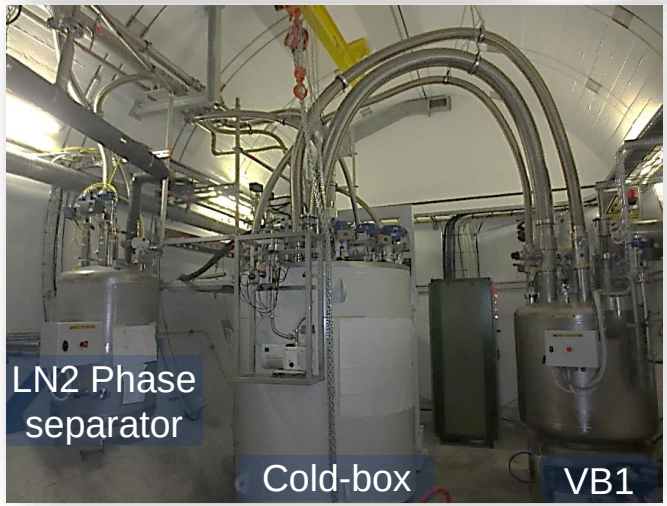
Nb3Sn dipole for cable test facility.

Nominal design field 13 T (ultimate 15 T): reached **14.6 T**, few quenches!

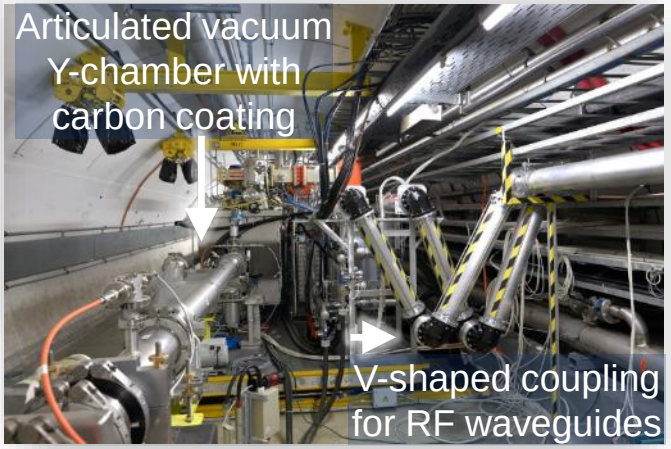


HL-LHC SPS CryoTest stand for Crab-Cavities



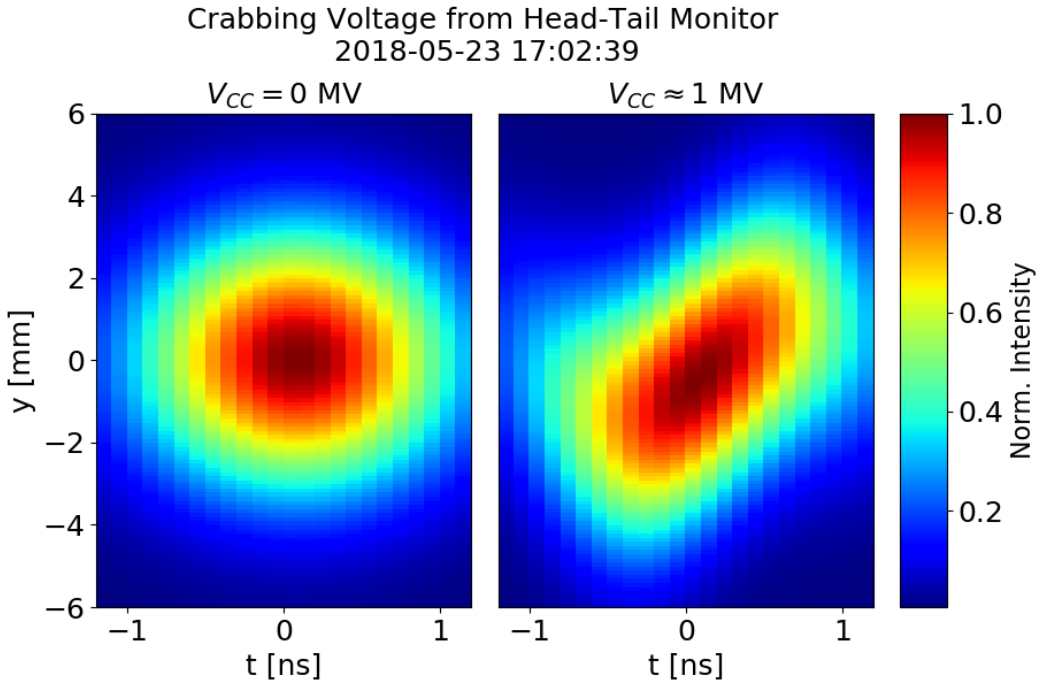


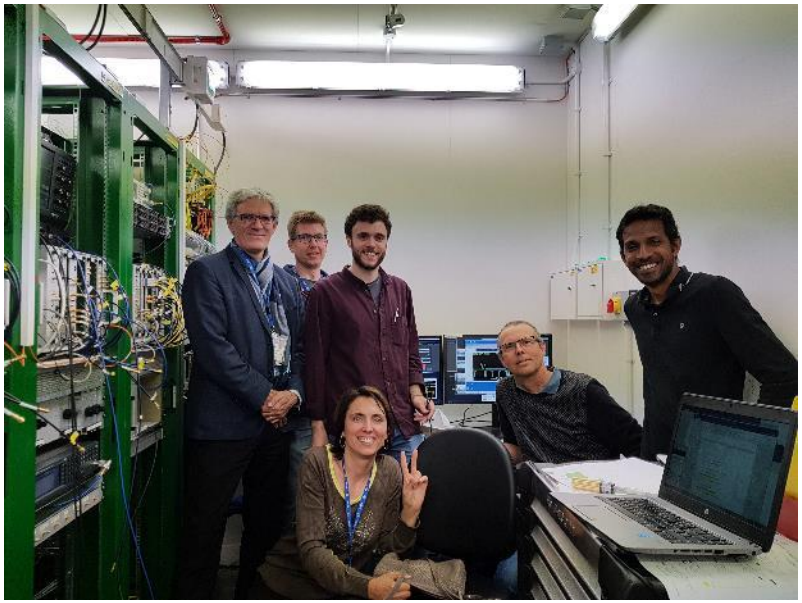
DQW crab-cavity cryomodule



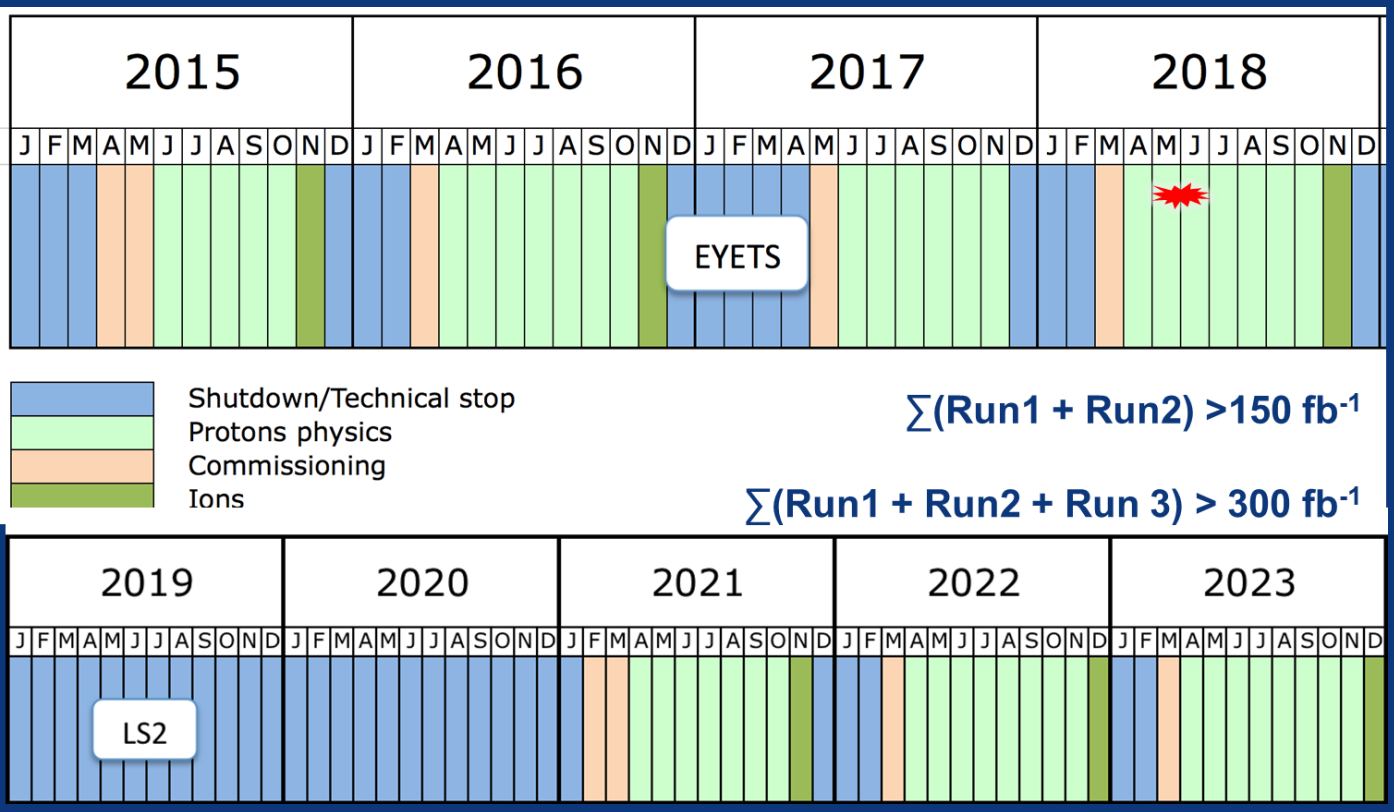
HL-LHC SPS CryoTest stand for Crab-Cavities

First tilting of the proton beam by a Crab Cavity
SPS: 23rd May 2018 at 1 MV (3.4 MV nominal)





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



2018: a production year to complete Run 2
(today 112 fb^{-1})

- LIU installation during LS2
- HL-LHC : construction phase

Thanks for your attention