



# LHC Machine Status Report

## 134<sup>th</sup> LHCC Meeting

Rende STEERENBERG

With valuable input from: LHC Machine Coordinators, LHC Operations Team and many specialists

# Topics

- **Hardware and Beam Re-commissioning**
- **LHC Machine Status & Performance**
- **Outlook for the remainder of 2018**

# Hardware and Beam Re-commissioning

# 2018 LHC Schedule – Q1

Version 1.2

	Jan				Feb				Mar				
Wk	1	2	3	4	5	6	7	8	9	10	11	12	13
Mo	1	8	15	22	29	5	12	19	26	5	12	19	26
Tu		Controls Maintenance											
We													
Th					Technical stop (YETS)								
Fr													
Sa													
Su													

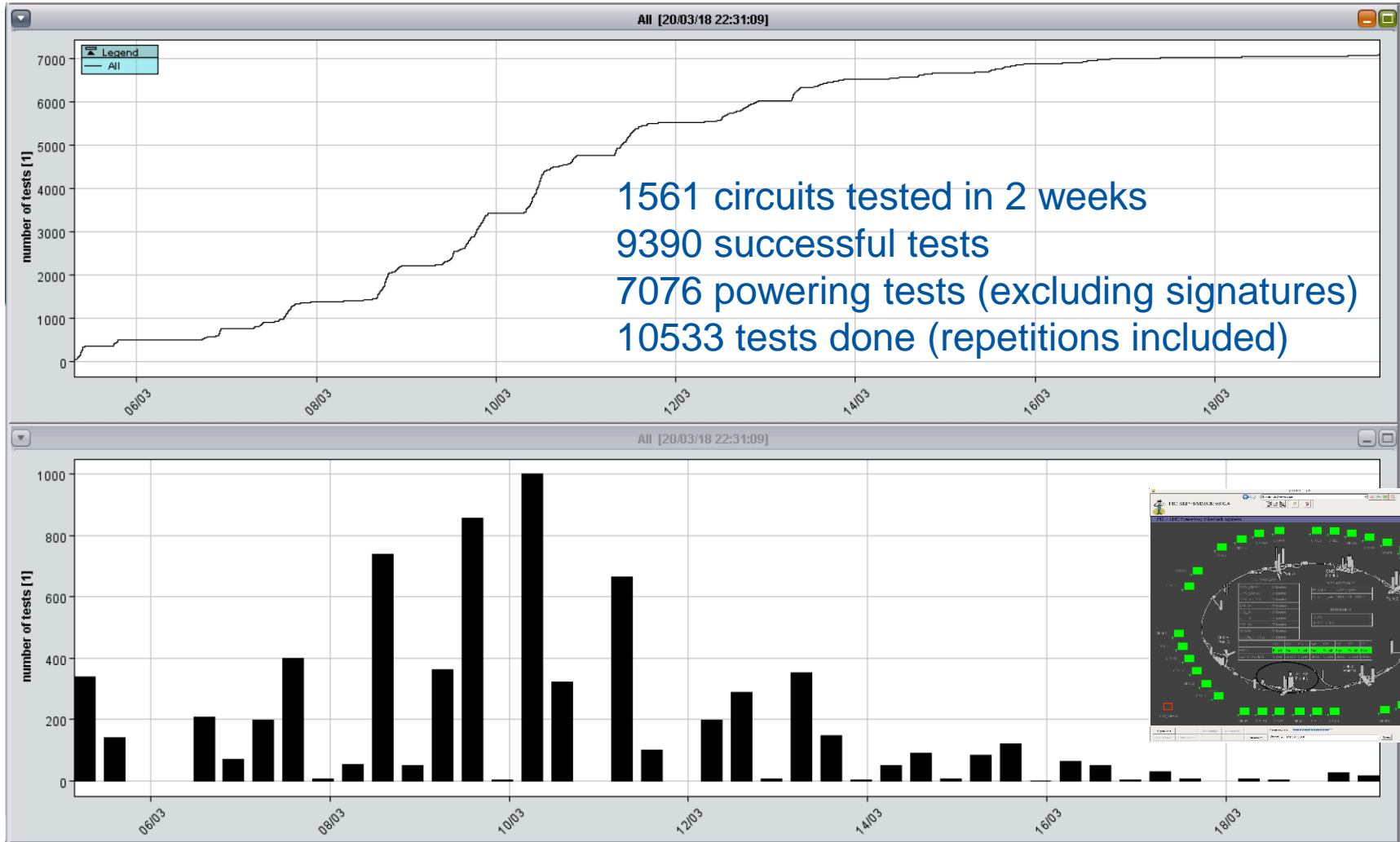
Start powering tests (Mar 9-10), LHC to OP (Mar 10-11), LHC, T12, T18 closed (Mar 11-13), T12 & T18 Beam tests (Mar 13), Experiments valves open (Mar 13).

Version 1.3

	Jan				Feb				Mar				
Wk	1	2	3	4	5	6	7	8	9	10	11	12	13
Mo	1	8	15	22	29	5	12	19	26	5	12	19	26
Tu		Controls Maintenance											
We													
Th					Technical stop (YETS)								
Fr													
Sa													
Su													

Start powering tests (Mar 9-10), LHC to OP (Mar 10-11), LHC, T12, T18 closed (Mar 11-13), Experiments valves open (Mar 13), T12 & T18 Beam tests (Mar 13), Start Beam Commissioning (Mar 13), Machine checkout (Mar 13), G. Fri. (Mar 13).

# Successful & Efficient HW re-commissioning



# 2018 LHC Schedule – Q2

Version 1.2

	Apr			May			June						
Wk	14	15	16	17	18	19	20	21	22	23	24	25	26
Mo	Easter 2 Machine checkout	9	16	23	30	7	14	Whitsun 21	28	4	11	18	VdM program 25
Tu				Scrubbing	1st May								
We		Recommissioning with beam										TS1	
Th				Interleaved commissioning & intensity ramp up		Ascension							
Fr			CMS testbed work								MD 1		$\beta^* = 90$ m run
Sa													
Su													

Start Beam Commissioning (Apr 14-15)  
Collisions with 3 bunches (Apr 16-17)  
Collisions with 1200 bunches (May 19)

Version 1.3

	Apr			May			June						
Wk	14	15	16	17	18	19	20	21	22	23	24	25	26
Mo	Easter 2	9	16	Scrubbing 23	30	7						18	25
Tu					1st May								
We		Recommissioning with beam		Interleaved commissioning & intensity ramp up								TS1	
Th						Ascension			LHCC				
Fr											MD 1		$\beta^* = 90$ m run
Sa												VdM program	
Su													

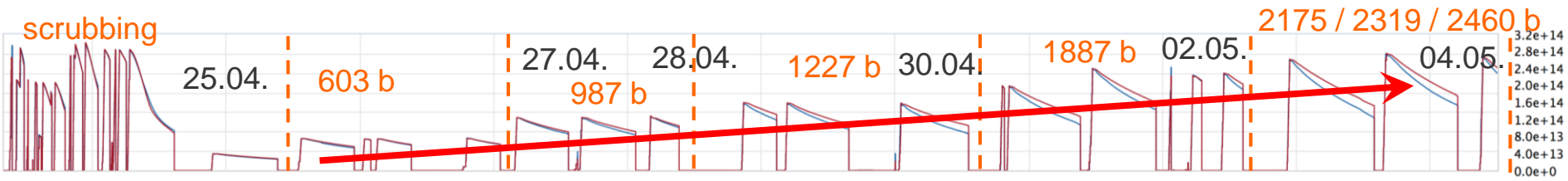
First Stable beams (Apr 16)  
Collisions with 1200 bunches (May 19)

Reached 1200 bunches (May 19)  
Scheduled to be at 1200 but reached 2556 (May 19)

**Full machine 13 days ahead of schedule**



# 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**

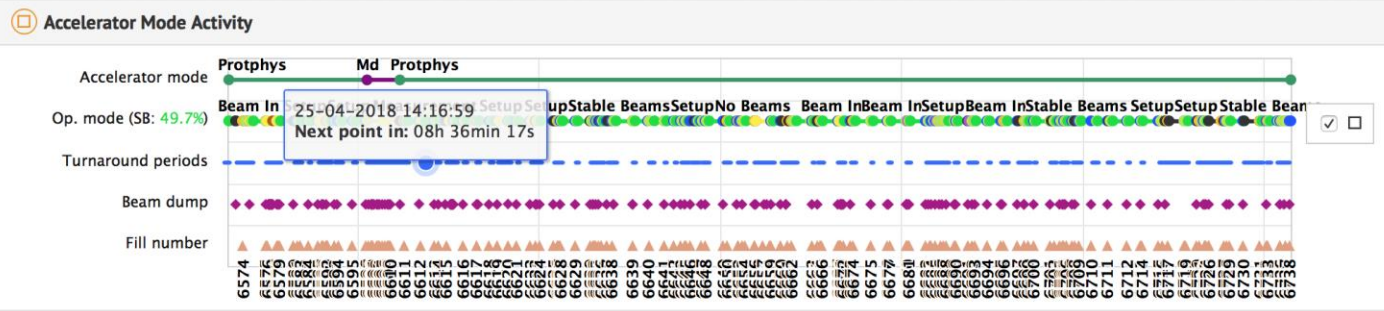
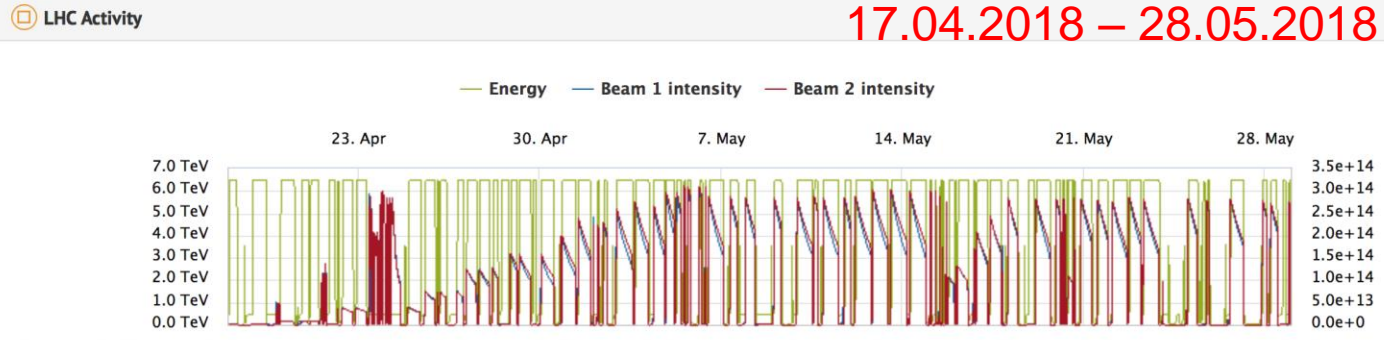
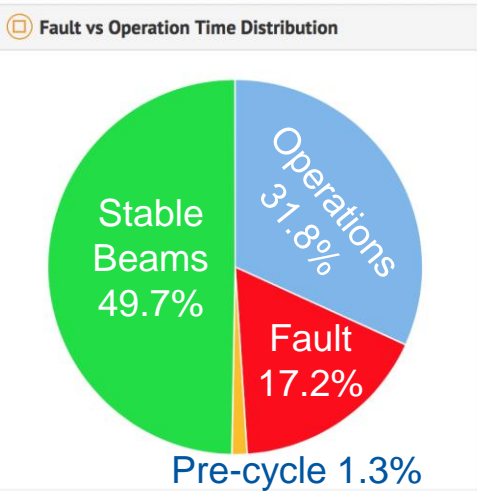


# LHC Machine Status & Performance

# LHC Statistics Since First Collisions

17.04.2018 – 28.05.2018

Availability **82.8%**      Stable beams **49.7%**



Fault labels: 60A BPM Interaction, TIOC

Min Turnaround: **0.9h**

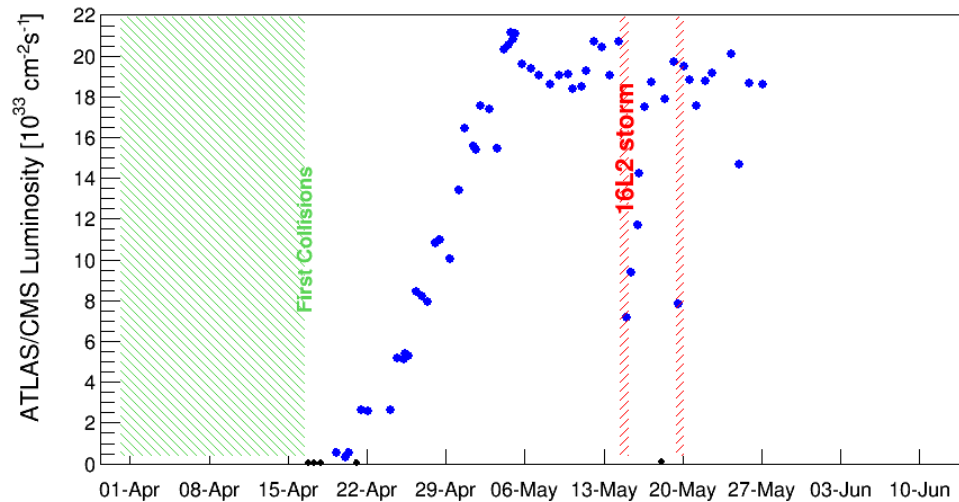
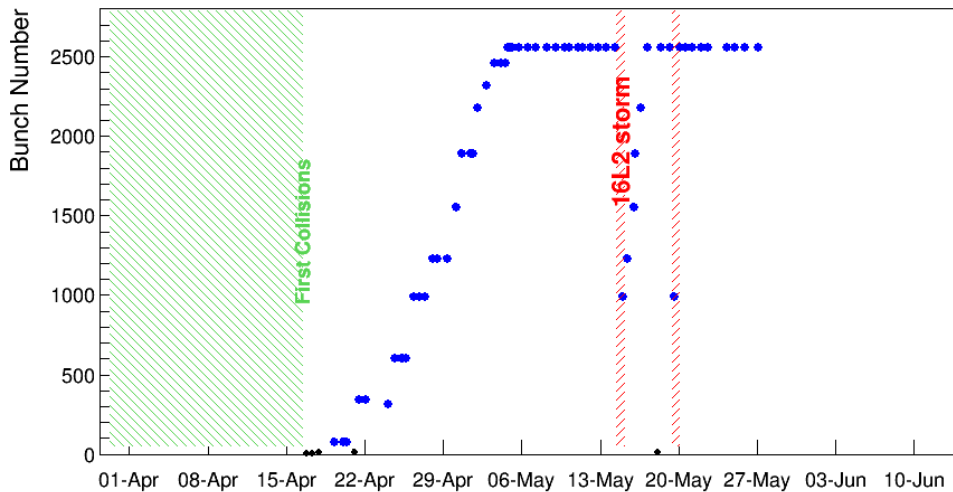
Avg Turnaround: **7.6h**

Fault count: **154**

Max Turnaround: **39.3h**

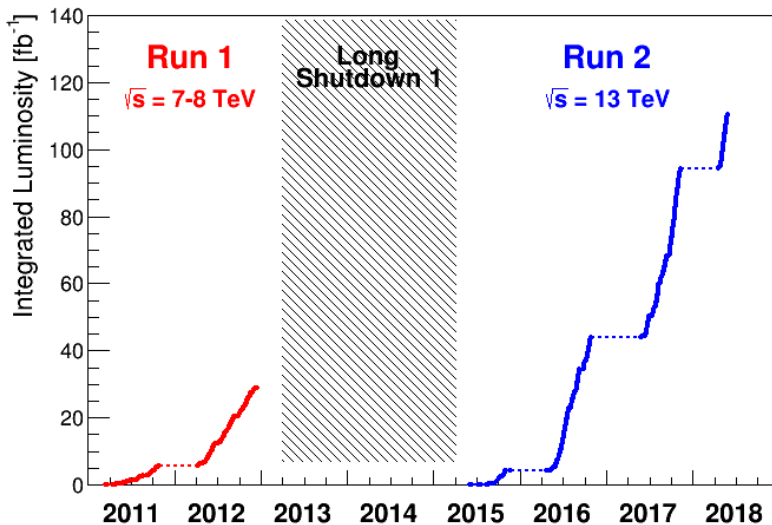
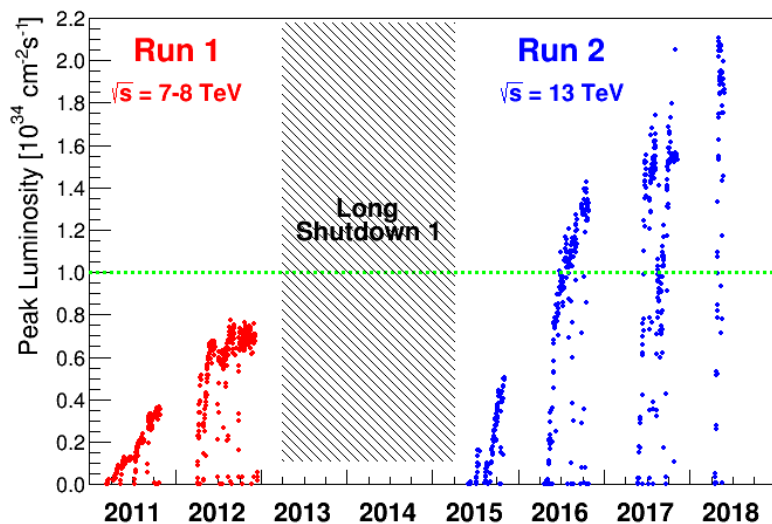


# 2018 LHC Performance up to now



- Full machine (2556 bunches) reached on May 5<sup>th</sup>
- Peak lumi in stable beams of  $2.1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$  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

# Run1 + Run 2 Lumi Production



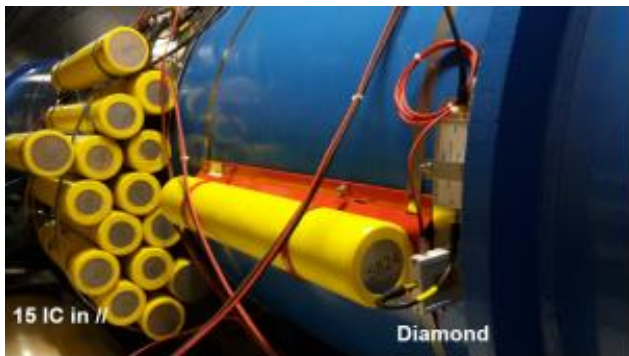
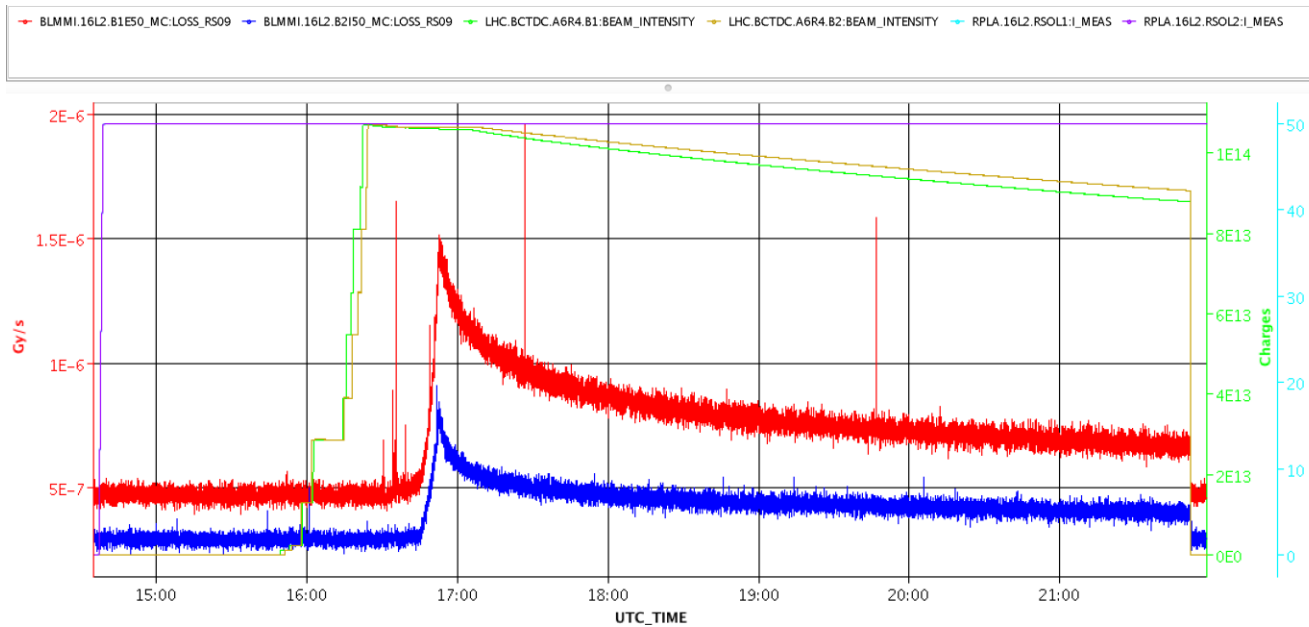
- **Peak Luminosity**

- 2018 shows steepest increase in peak luminosity of all years
- Possibly new record of  $2.1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

Period	Int. Luminosity [fb <sup>-1</sup> ]
Run 1	29.2
Run 2: 2015	4.2
Run 2: 2016	39.7
Run 2: 2017	50.2
Run 2: 2018	16
<b>Total Run 1+ 2</b>	<b>139.3</b>

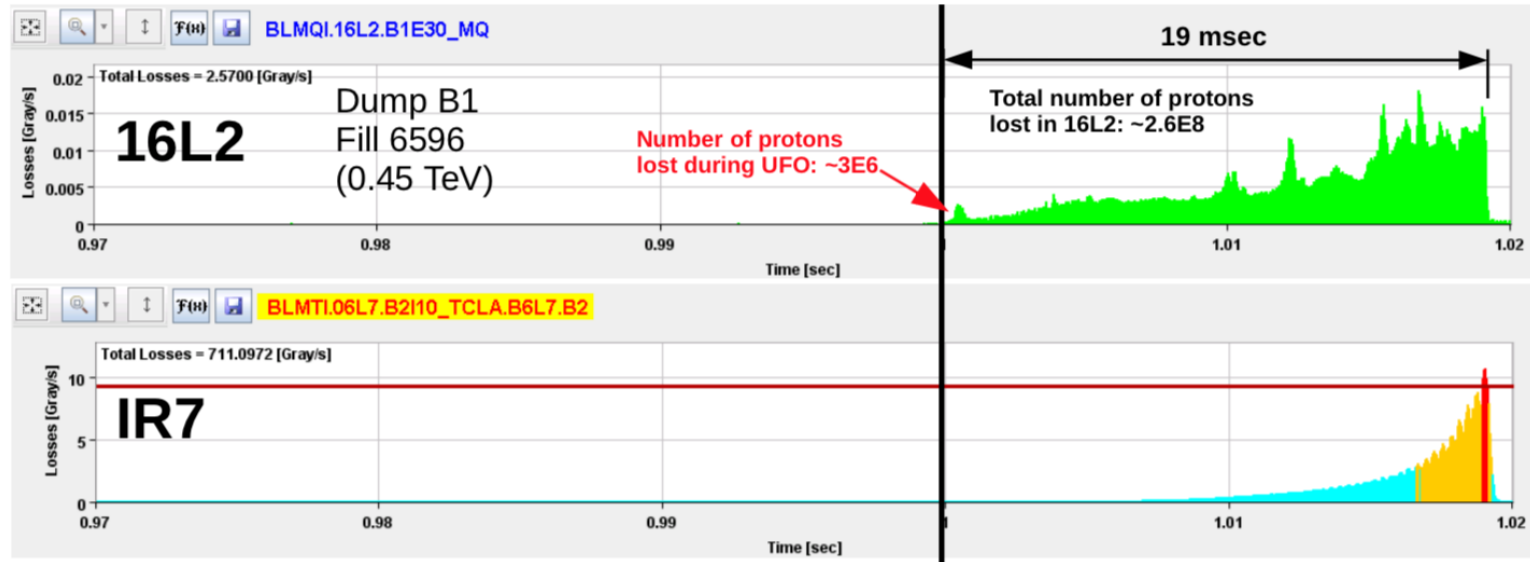
28.05.2018

# The recent “16L2 Storms”



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

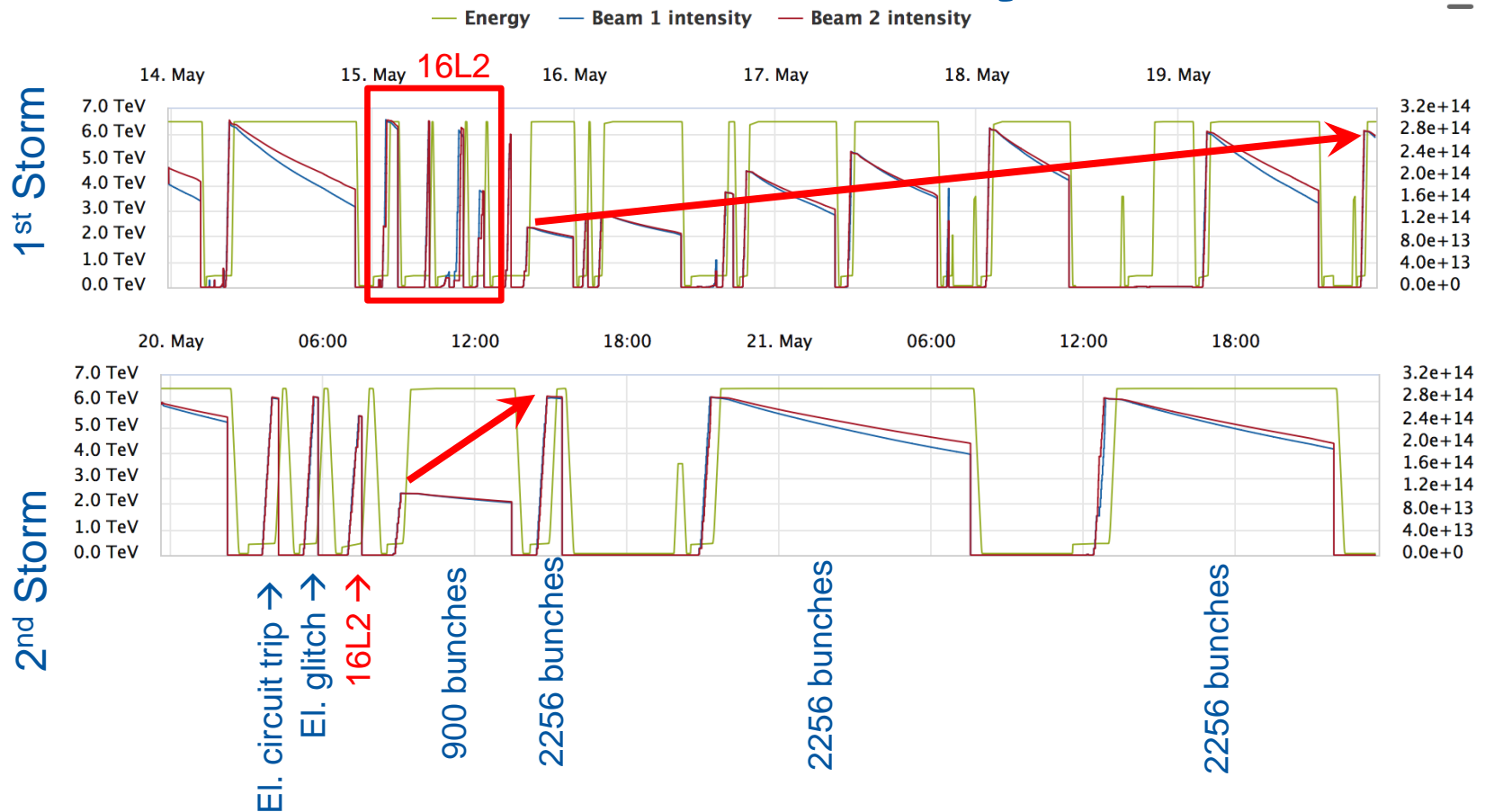
# Time Structure of Losses



- **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

# “16L2 Storm” Recovery

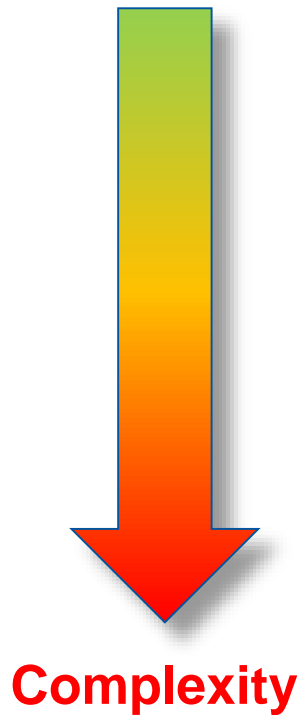


- 1<sup>st</sup> storm a recovery à la 2017 was used
- 2<sup>nd</sup> storm was recovered with a single fill with 900 bunches, losing little time...

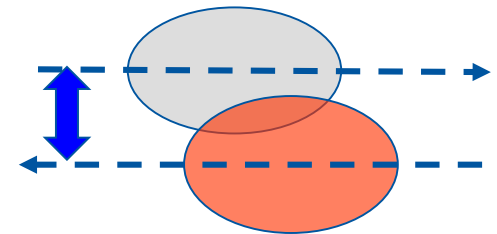


# Luminosity Levelling

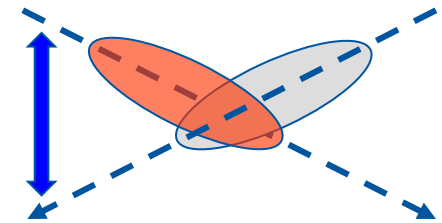
- In certain conditions and depending on the experiments request, it is desirable to adapt the luminosity dynamically with beams in collision – levelling.
  - *Each levelling technique has its advantages and drawbacks.*



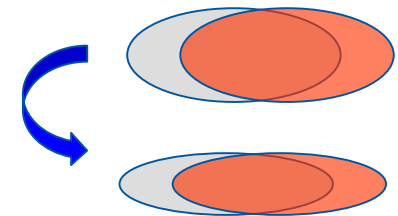
Levelling by beam offset / separation



Levelling by crossing angle



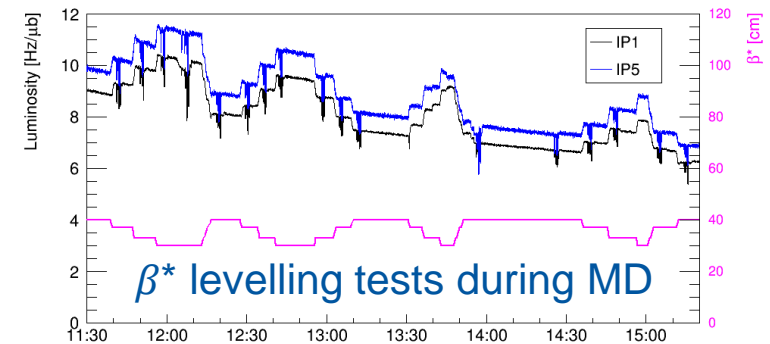
Levelling by  $\beta^*$  (= beam size at IP)





# 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  $130 \mu\text{rad}$
  - A step-wise  $\beta^*$  anti-levelling has been added
  - $\beta^* = 30 \text{ cm} \rightarrow 27.5 \text{ cm} \rightarrow 25 \text{ cm}$



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

# Special Runs

- Van de Meer run scheduled for week 26 and under preparation
- Seven day long  $\beta^*=90$  cm run scheduled for week 26 & 27  
Setting up well advanced

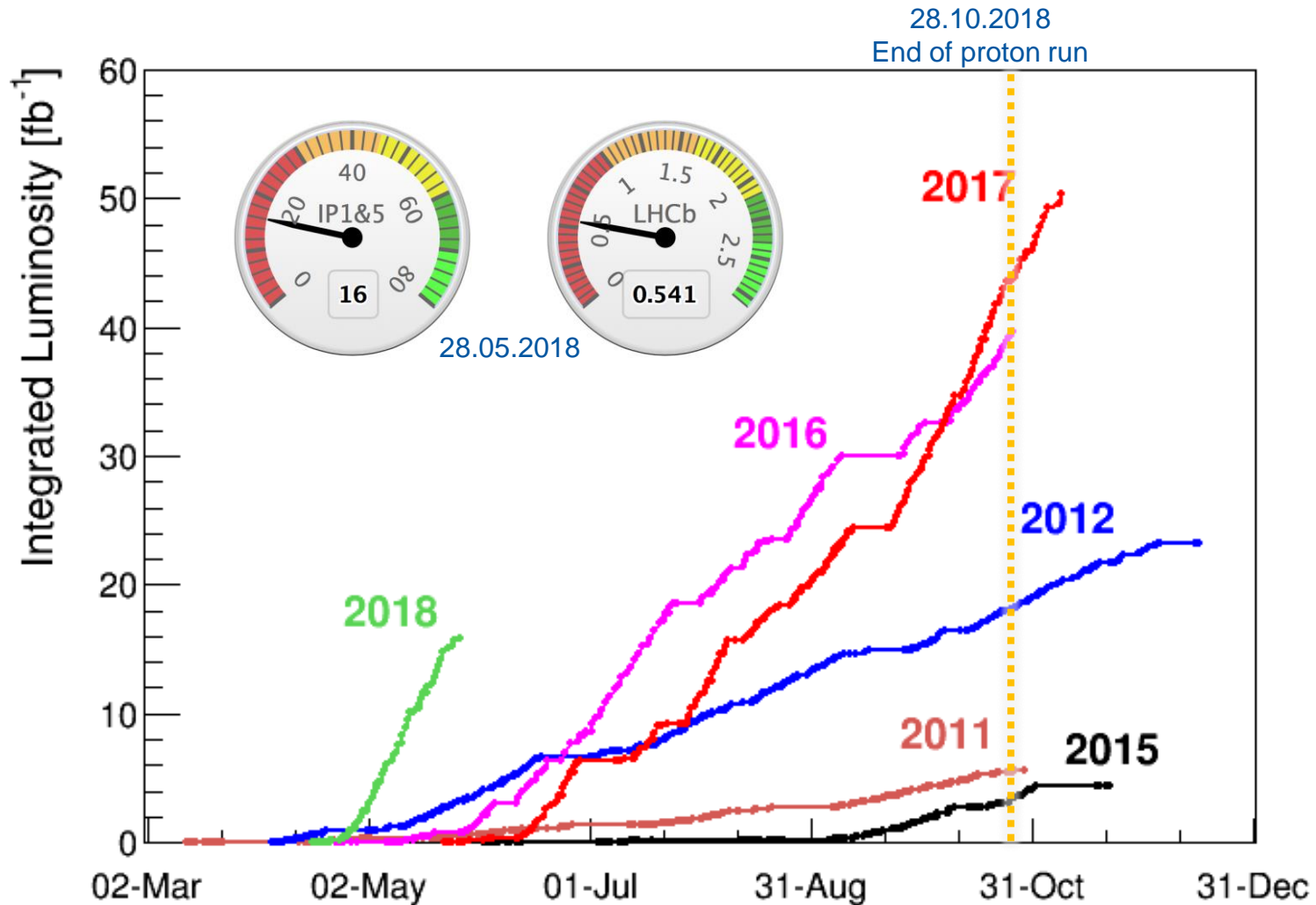
	Apr			May			June						
Wk	14	15	16	17	18	19	20	21	22	23	24	25	26
Mo	Easter 2	9	16	Scrubbing 23	30	7	14	Whitsun 21	28	4	11	18	25
Tu					1st May							TS1	
We													
Th	Recommissioning with beam			Interleaved commissioning & intensity ramp up				Ascension					
Fr											MD 1		$\beta^*=90$ m run
Sa												vdm program	
Su													

	July			Aug			Sep						
Wk	27	28	29	30	31	32	33	34	35	36	37	38	39
Mo	$\beta^*=90$ m run 2	9	16	23	30	6	13	20	27	3	10	17	24
Tu												TS2	
We				MD 2									
Th										Jeune G.			
Fr											MD 3		
Sa													
Su													

	Oct			Nov					Dec				
Wk	40	41	42	43	44	45	46	47	48	49	50	51	52
Mo	1	8	15	22	MD 4 29	5	12	19	26	3	10	17	Xmas 24
Tu						ion setting up		MD 5					
We													
Th		Special physics run			TS3		LHC Pb-Pb ion run				Long Shutdown 2		
Fr										Powering Tests Magnet Training			
Sa													
Su				MD 4									

- Special runs week 41 are a place holder for Low energy high  $\beta$  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



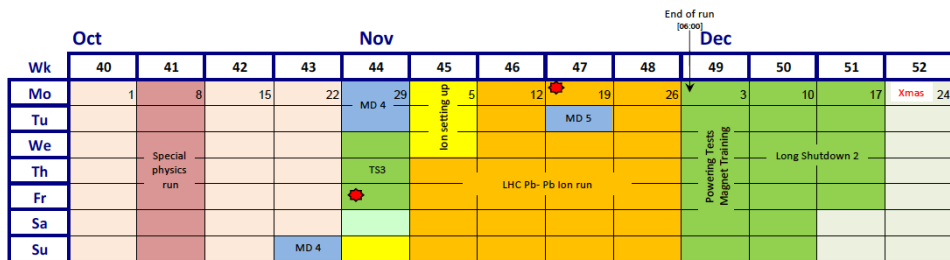
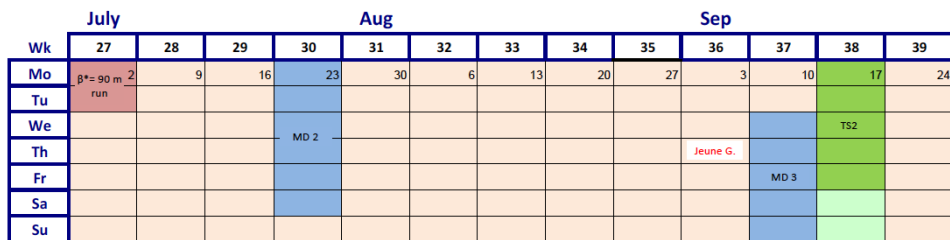
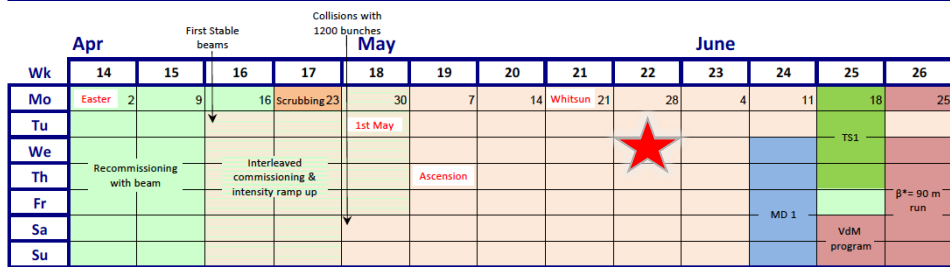
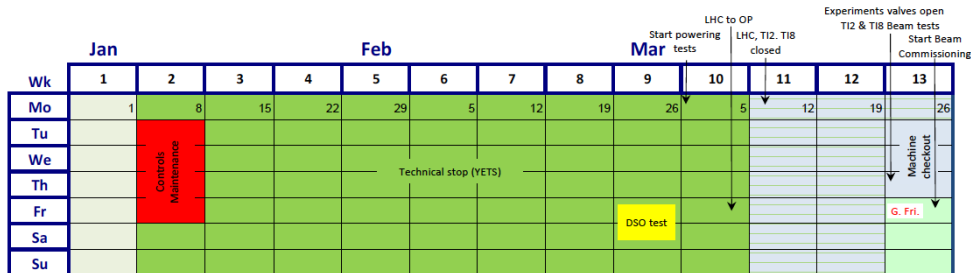
# Outlook for the remainder of 2018

# 2018 Machine/Beam Parameters

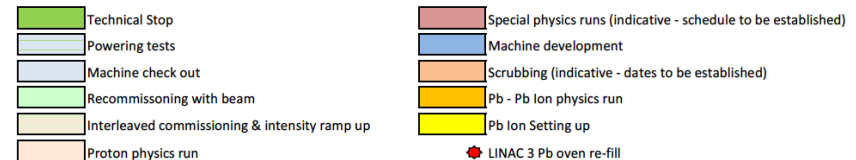
Parameter	Design	2018
Bunch population $N_b$ [ $10^{11}$ p]	1.15	~1.2 ( $\rightarrow$ 1.4)
No. bunches per train	288	144
No. bunches	2780	<b>2556</b>
Emittance $\varepsilon$ [mm mrad]	3.5	~2.2
Full crossing angle [ $\mu$ rad]	<b>285</b>	<b>300 <math>\rightarrow</math> 260</b>
$\beta^*$ [cm]	55	<b>30 <math>\rightarrow</math> 27.5 <math>\rightarrow</math> 25</b>
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**

# 2018 LHC Schedule, version 1.3



- Approved by the Research Board on 6 December 2017
  - Some minor modification after that, mainly adaptation to “as executed”
  - TS1 shortened by 1 day in favor of physics
  - Perhaps still some additional MD time to be allocated
- Specials runs
  - VdM programme is planned
  - $\beta^* = 90$  meter run scheduled
  - Low energy run to be re-discussed following tests
  - 4-week Pb-Pb ions run
- End of 2018 run 3 December 2018
- Magnet tests in view of 7 TeV operation after LS2 during week 49



# Summary Table 2018 - 2017 - 2016

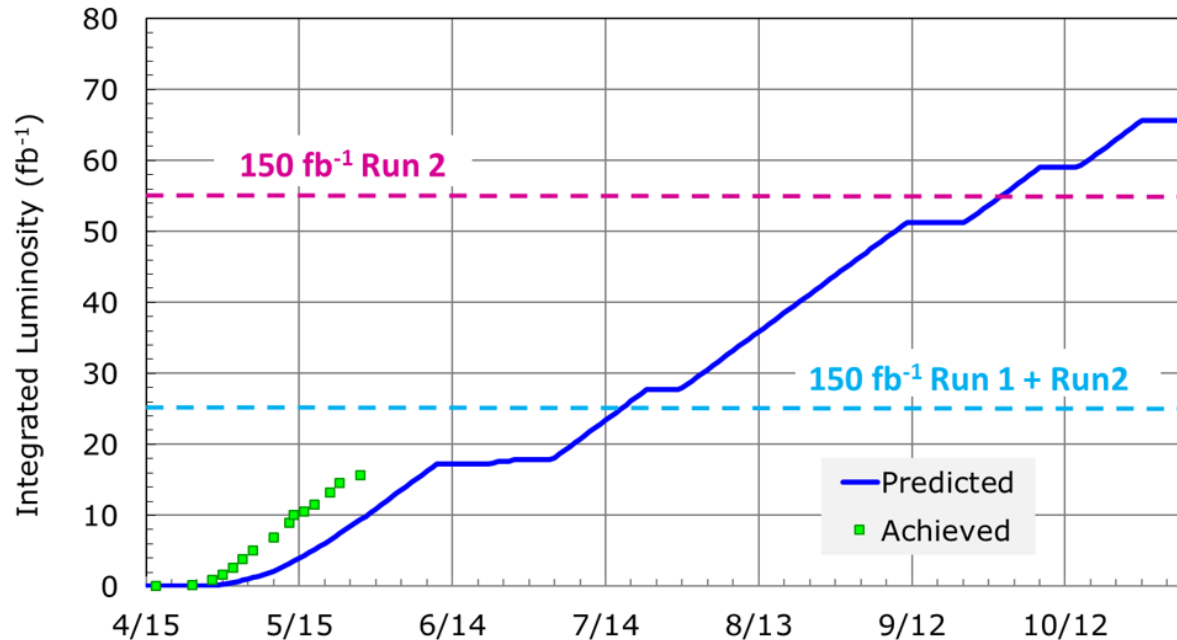
	2018		2017		2016	
Phase	Days	Ratio [%]	Days	Ratio [%]	Days	Ratio [%]
Comm. & Intensity ramp up	33**	13.4	35	16.1	28*	11.3
Scrubbing	1	0.4	7	3.3	2	0.8
<b>25 ns Proton Physics</b>	<b>131</b>	<b>53.3</b>	<b>127</b>	<b>58.5</b>	<b>139</b>	<b>56.3</b>
Special Physics Runs	17	6.9	18	8.3	10	4
Setting up Pb-Pb ion run	4	1.6	-	-	6	2.4
Pb-Pb ion run	24	9.8	-	-	23	9.3
Machine Developments (MD)	20	8.1	18	8.3	21	8.5
Technical Stops (3x)	12	4.9	8	3.7	12	5
Technical Stop Recovery (3x)	4	1.6	4	1.8	6	2.4
<b>Total</b>	<b>246</b>	<b>100</b>	<b>217</b>	<b>100</b>	<b>247</b>	<b>100</b>
<b>Integrated luminosity [fb<sup>-1</sup>]</b>	<b>~ 60</b>		<b>50.2</b>		<b>39.7</b>	

\* Did not fully include intensity ramp up – interleaved commissioning and interleaved intensity ramp up was as of 2017

\*\* With 1200 bunches per beam, previously with 3 bunches

# Integrated Luminosity Forecast

## LHC Performance 2018



2018 is the final production year before Long Shutdown 2  
Important to reach a stable beam time ratio of 50%

**60  $\text{fb}^{-1}$  is the goal for 2018 for ATLAS & CMS**  
**2  $\text{fb}^{-1}$  is the 2018 goal for LHCb**





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