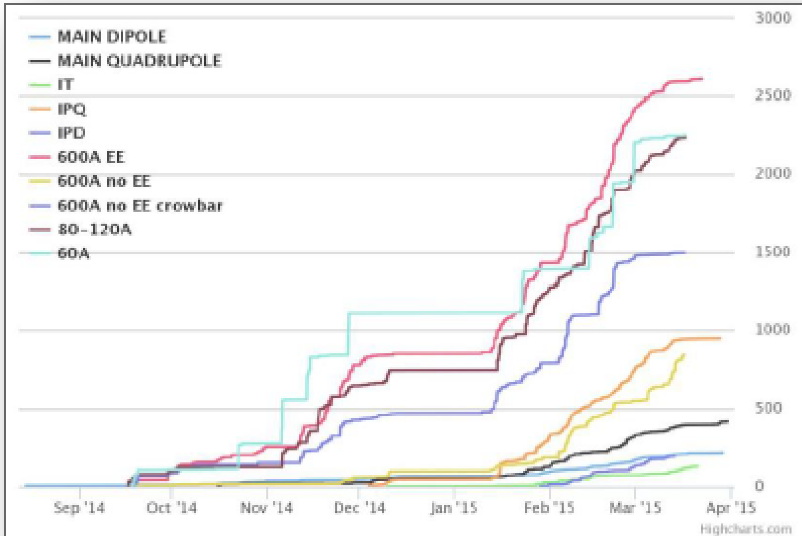
LHC machine status

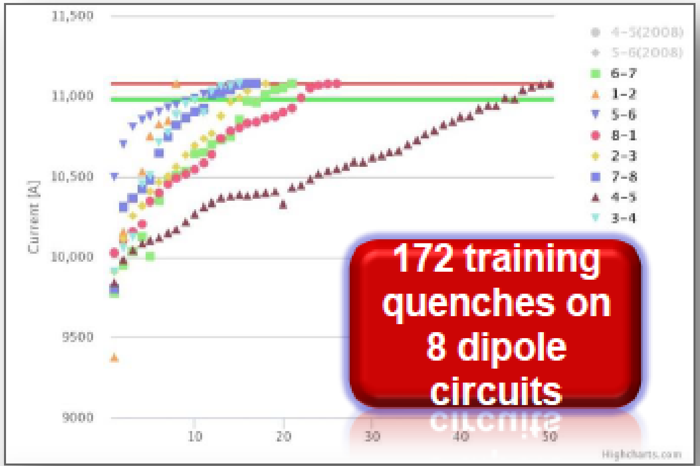
LHCC 3rd June 2015

Mike Lamont for the LHC team

The LHC powering tests overview



Powering tests were completed at 8 am on Friday April 03rd



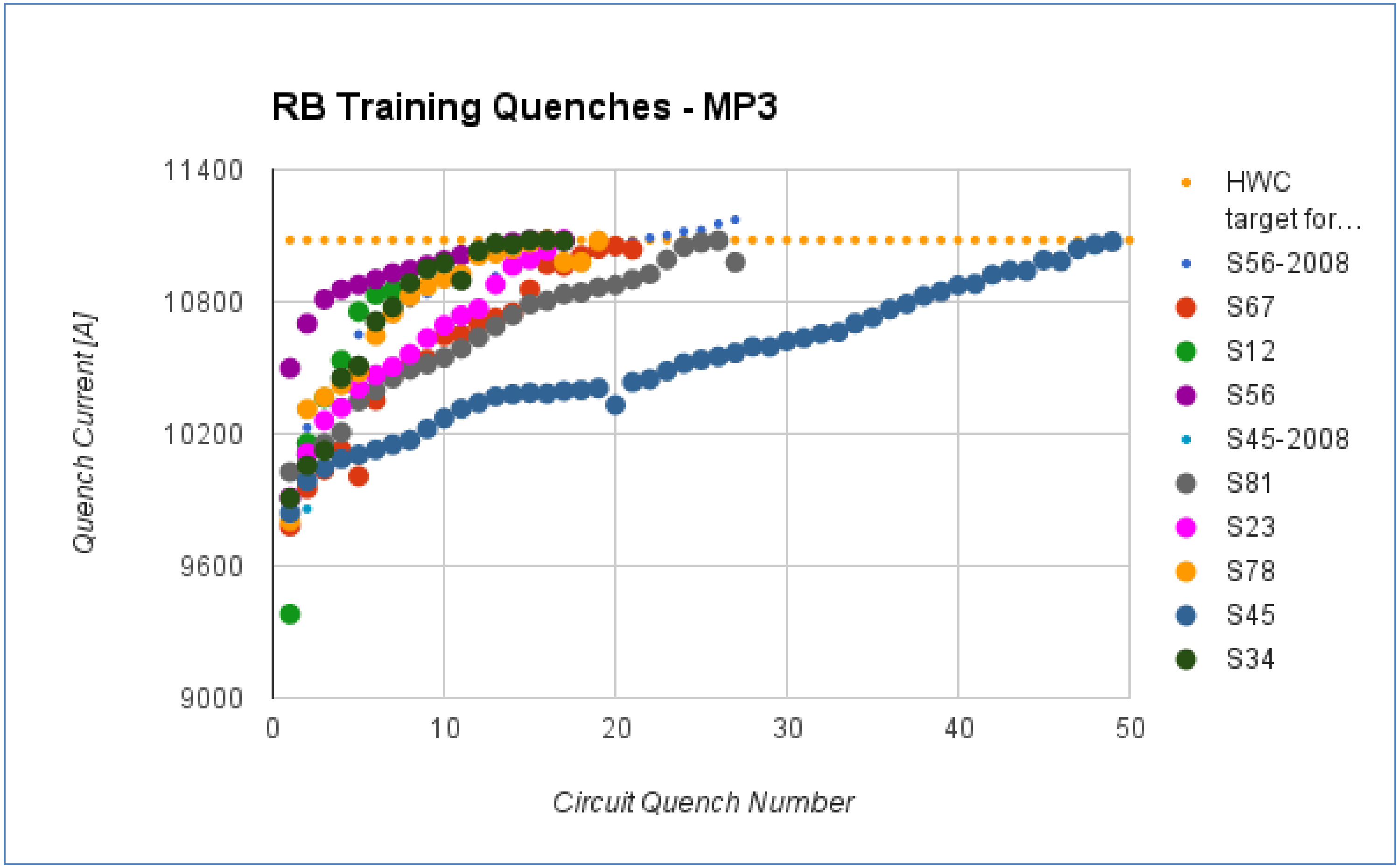
Circuit	Status	#M Firm 1	#M Firm 2	#M Firm 3	#MQ Firm 1	#MQ Firm 2	#MQ Firm 3	#MQ total	#CQ total
RB.A12	11080 A reached	50	95	9	2	1	4	7	7
RB.A23	11080 A reached	56	58	40	0	2	15	17	17
RB.A34	11080 A reached	44	81	29	1	7	8	16	16
RB.A45	11080 A reached	48	44	62	-	3	48	51	49
RB.A56	11080 A reached	28	42	84	0	0	18	18	17
RB.A67	11080 A reached	57	36	61	0	1	21	22	21
RB.A78	11080 A reached	53	40	61	2	10	7	19	19
RB.A81	11080 A reached	64	24	66	0	3	26	29	26

Since September 15th 2014:

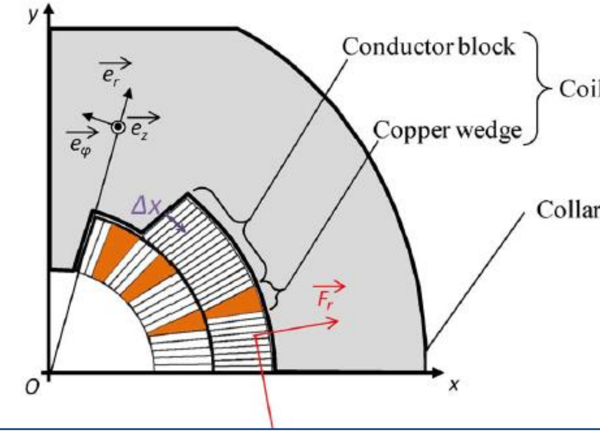
1566 superconducting circuits commissioned through execution and analysis of **more than 10.000 test steps** (~13.800 test steps including re-execution)

Dipole training 1/2

- 154 dipoles per sector, powered in series
- Ramp the current until single magnet quenches - “training quench”
- Usually quench 3 – 4 other dipoles at the same time
- Cryogenics recovery time: 6 – 8 hours



Dipole training 2/2



Training: frictional energy released during conductor motion

Campaign summary

Training quenches during HWC 2014-2015 occurring until I_PNO+100 A has been reached for the first time									
Circuit	Status	#M Firm 1	#M Firm 2	#M Firm 3	#MQ Firm 1	#MQ Firm 2	#MQ Firm 3	#MQ total	#CQ total
RB.A12	11080 A reached	50	95	9	2	1	4	7	7
RB.A23	11080 A reached	56	58	40	0	1	15	16	16
RB.A34	11080 A reached	44	81	29	1	5	8	14	14
RB.A45	11080 A reached	48	44	62	0	3	48	51	49
RB.A56	11080 A reached	28	42	84	0	0	15	15	14
RB.A67	11080 A reached	57	36	61	0	1	20	21	20
RB.A78	11080 A reached	53	40	61	2	8	6	16	16
RB.A81	11080 A reached	64	24	66	0	3	26	29	26
	Total:	400	420	412	5	22	142	169	162

#M: Number of magnets in a sector.

#MQ: Number of magnet training quenches in a sector.

#CQ: Number of circuit quenches in a sector.

- All magnets have been trained to well over 7 TeV in SM18 before installation
- Extensive re-training in situ was not expected

LHC - 2015

- Target energy: 6.5 TeV
  - looking good
- Bunch spacing: 25 ns
  - strongly favored by experiments (pile-up limit around 50)
- Beta* in ATLAS and CMS: 80 to 40 cm

Energy

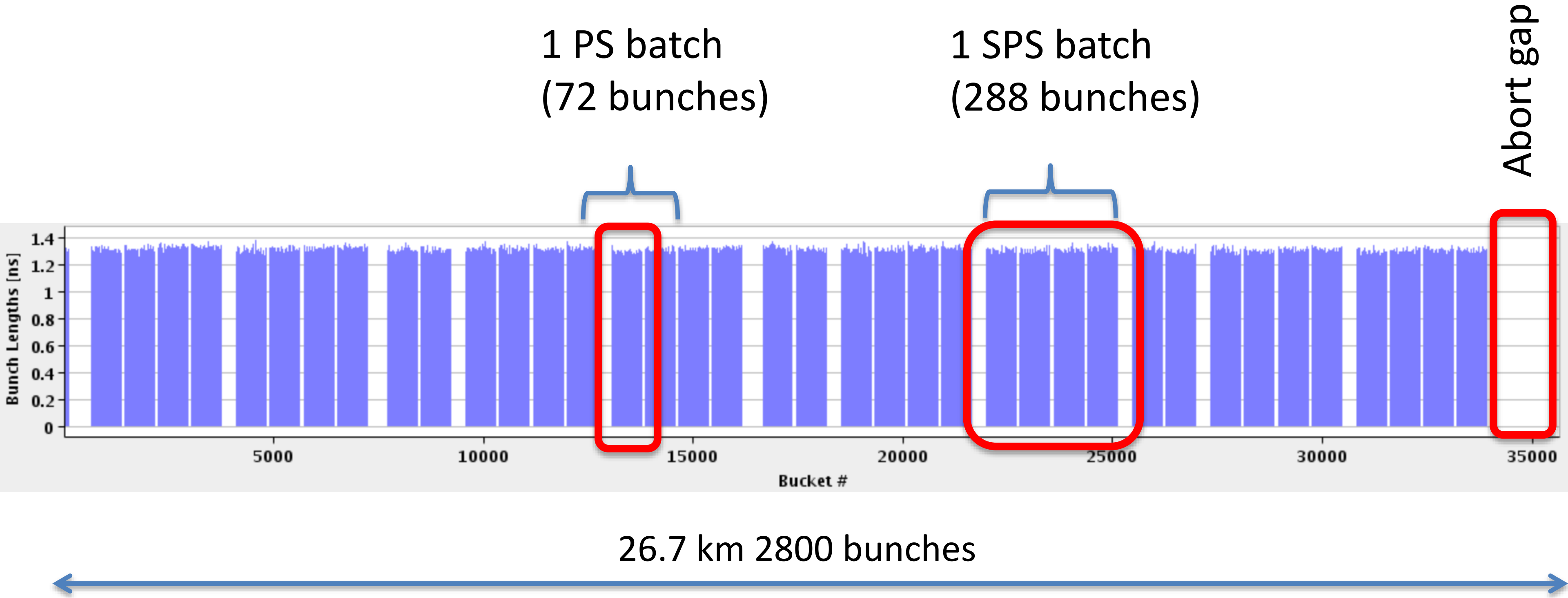
- Lower quench margins
- Lower tolerance to beam loss
- Hardware closer to maximum (beam dumps, power converters etc.)

25 ns

- Electron-cloud
- UFOs
- More long range collisions
- Larger crossing angle, higher beta*
- Higher total beam current
- Higher intensity per injection

LHC bunch structure - 2015

- 25 ns bunch spacing
- ~2800 bunches
- Nominal bunch intensity 1.15 x 10^{11} protons per bunch



New limits of ~2 PS batches per injection from the injection protection absorbers – will reduce the maximum number of bunches to around 2500

2015: beta* in IPs 1 and 5

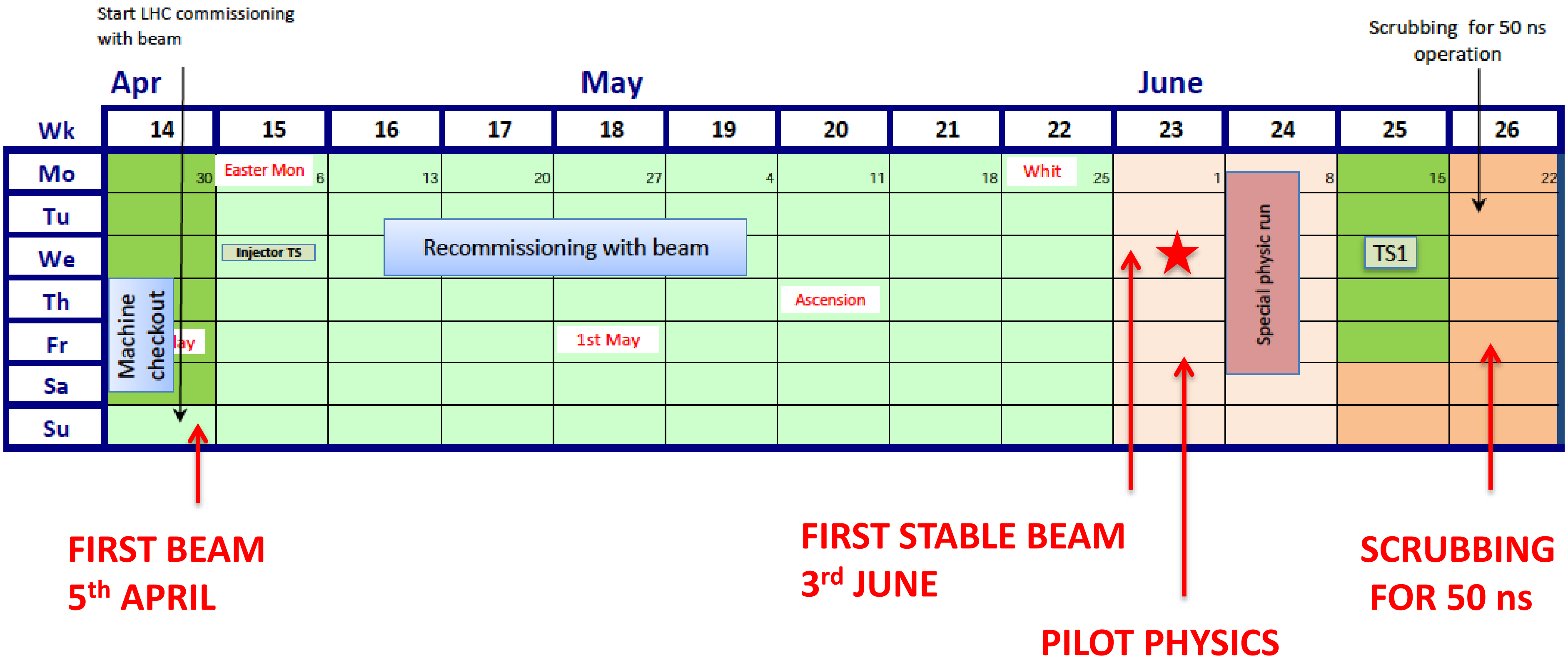
- Many things have changed. Start carefully and push performance later.
- Start-up: **β*= 80 cm – (very) relaxed**
  - 2012 collimator settings
  - 11 sigma long range separation
  - Aperture, orbit stability… checks ongoing
- Ultimate in 2015: **β*= 40 cm**
  - **Possible reduction later in the year**

$$\boxed{\mathcal{L} \propto \frac{1}{\beta^*}}$$

2015 commissioning strategy

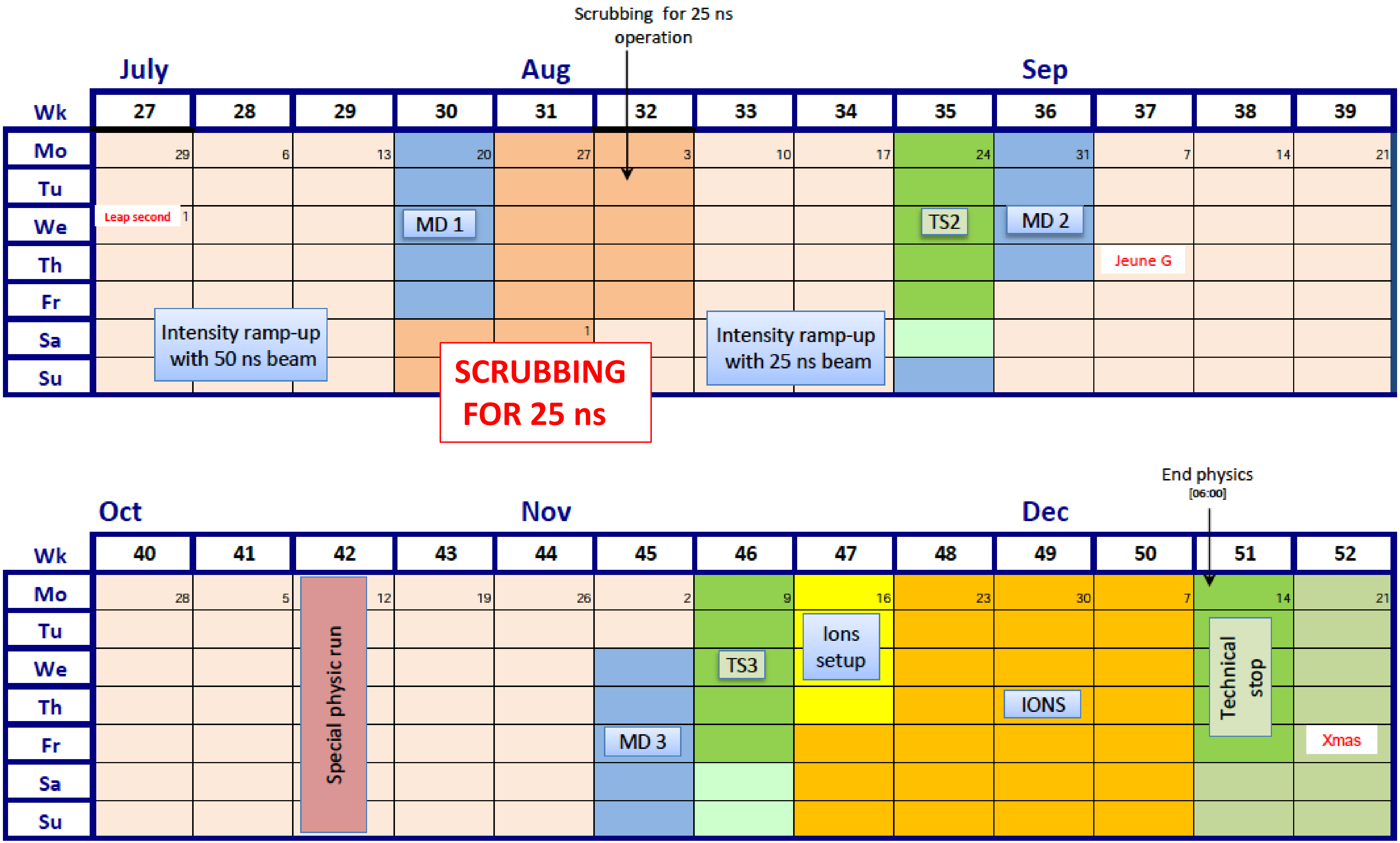
- **Low intensity commissioning of full cycle – 8 weeks**
- Pilot physics – low number of bunches
- Special physics run: LHCf and luminosity calibration
- Scrubbing for 50 ns
- Intensity ramp-up with 50 ns
  - Characterize vacuum, heat load, electron cloud, losses, instabilities, UFOs, impedance
- Scrubbing for 25 ns
- Ramp-up 25 ns operation with relaxed beta*
- Possibly commission lower beta*
- 25 ns operation

2015 Q2



- 8 weeks beam commissioning
- Pilot physics – up to at least 40 bunches per beam
- 5 days special physics at beta* = 19 m (VdM, LHCf, TOTEM & ALFA)
- Start technical stop – 15th June

Q3/Q4 2015


Scrubbing for 25 ns operation
July
Aug
Sep
Wk
27
28
29
30
31
32
33
34
35
36
37
38
39
Mo
Tu
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6
13
20
27
3
10
17
24
31
7
14
21
Leap second
1
MD 1
TS2
MD 2
Jeune G
1
Intensity ramp-up with 50 ns beam
SCRUBBING FOR 25 ns
Intensity ramp-up with 25 ns beam
End physics
[06:00]
Oct
Nov
Dec
Wk
40
41
42
43
44
45
46
47
48
49
50
51
52
Mo
Tu
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Su
28
5
12
19
26
2
9
16
23
30
7
14
21
Special physic run
Ions setup
TS3
IONS
MD 3
Technical stop
Xmas

2015 – latest schedule

Phase	Days
Initial Commissioning	57
Scrubbing	23
Special physics run 1 (LHCf/VdM)	5
Proton physics 50 ns	**9 + 21**
Proton physics 25 ns	**70**
Special physics run 2 (TOTEM/VdM)	7
Machine development (MD)	15
Technical stops	15
Technical stop recovery	3
Ion setup/Ion run	4 + 24
Total	**253 (36 weeks)**

Schedule - comments

- Picked up some 4 weeks delay from:
  - Powering tests/quench training overrun
  - Earth fault resolution
- Proton-proton physics down to 70 days
  - Decrease in beta* to be reviewed after gaining some experience (although considerable progress made during commissioning)
- Ion program unaffected
  - Proton-proton reference data will be difficult to squeeze in

Commissioning

- **System commissioning with beam**
  - Collimation
  - Beam dump
  - Feedbacks
  - Beam instrumentation
  - Machine protection
  - RF
  - Transverse damper
  - Injection
- **Machine characterization**
  - Optics measurement and correction
  - Magnetic machine
- **Operations**
  - High intensity injection
  - Ramp to 6.5 TeV
  - Squeeze

Injection - probe

Ramp - probe

Flat-top - probe

Squeeze - probe

Injection - nominal

Ramp - nominal

Flat-top - nominal

Squeeze - nominal

Collide & validation

Complete
Ongoing

Milestones

Circulating beam	Sunday 5th April
Ramp to 6.5 TeV	Friday 10th April
First 13 TeV collisions	Wednesday 20th May
First Stable beams	Wednesday 3rd June

Working throughout with:

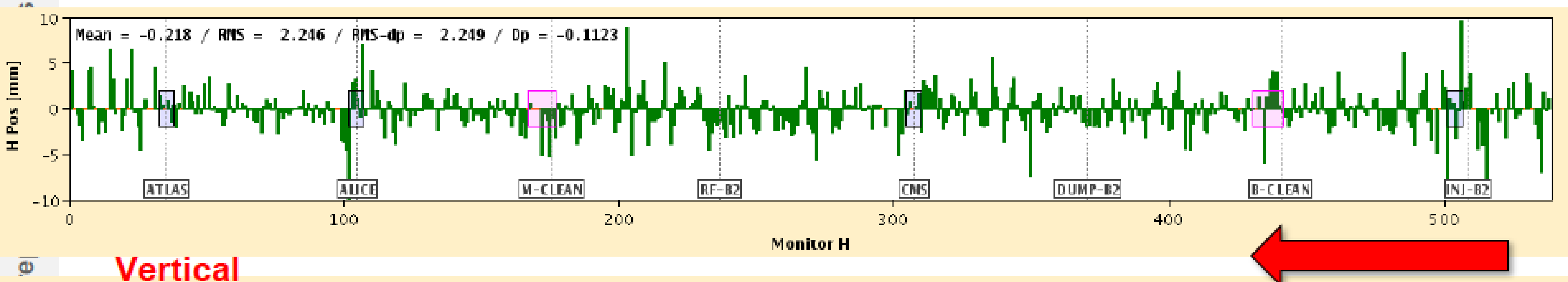
- **probes (5e9 protons per bunch) or**
- **1 or 2 nominals (1.2e11 protons per bunch)**

THIS IS NOT BAD!

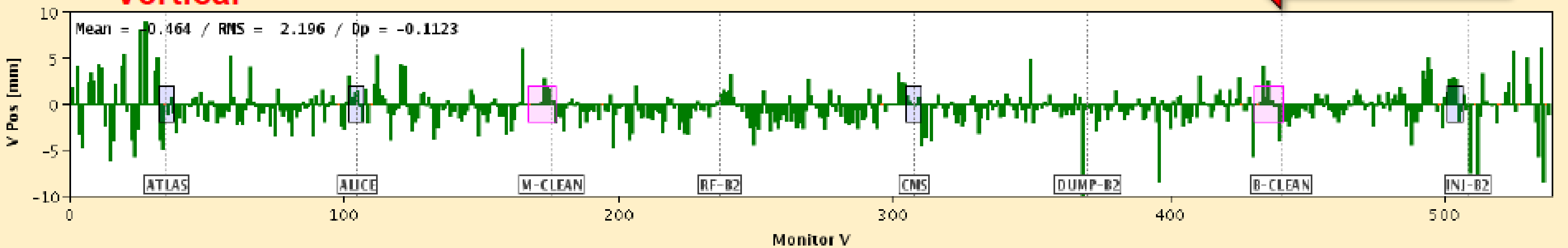
Threading – Easter Sunday

- Threading of B2 started at 10:12, ended 10:41.
  - *Followed by 1 hour of work to establish a closed orbit and circulate more than 25 turns.*
- Threading of B1 started at 11:54, ended 12:26.
  - *Almost immediately obtained a closed orbit and more than 25 turns.*

Horizontal



Vertical



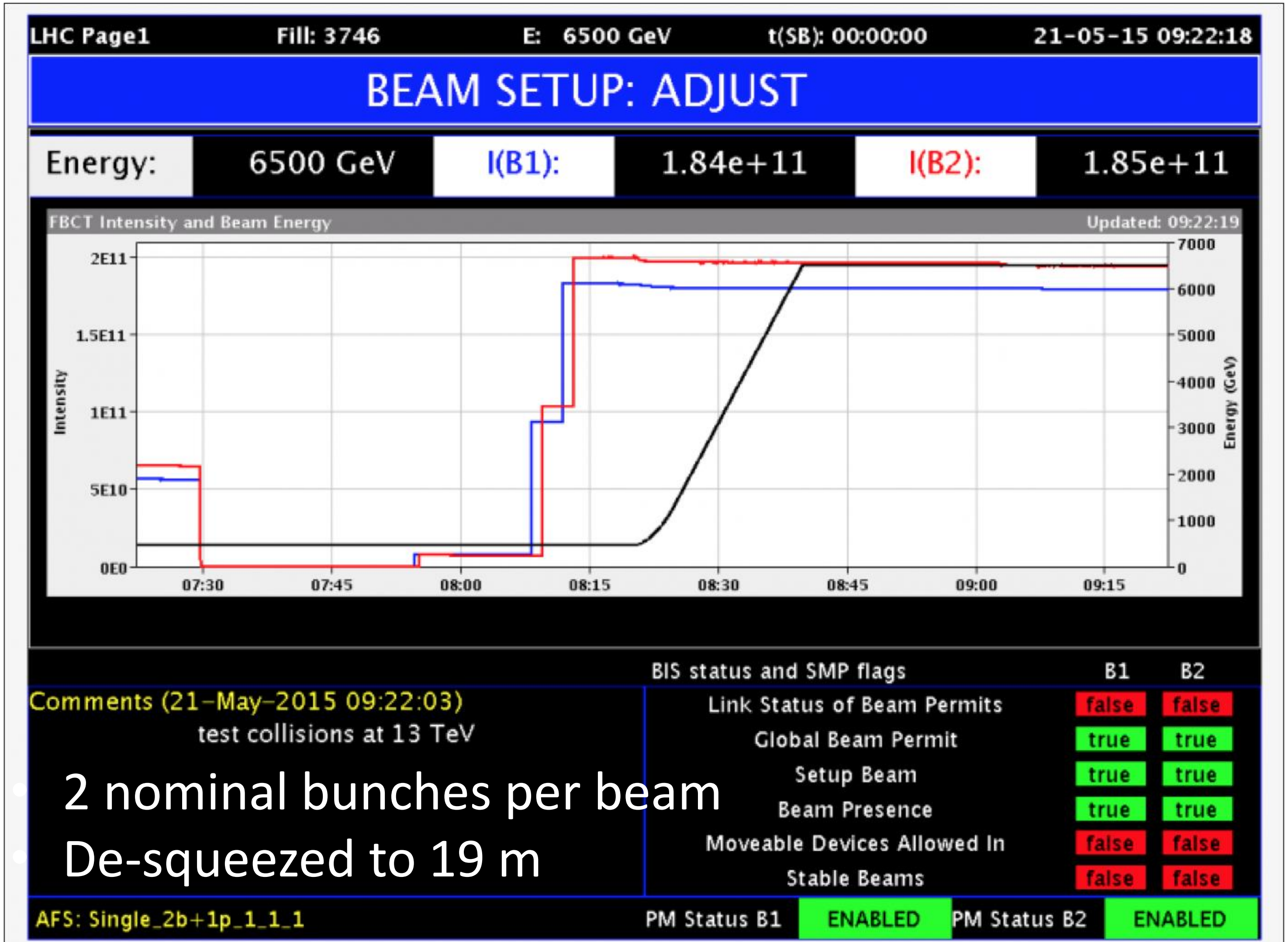
6.5 TeV for the first time

01:03 10th April

First images of collisions at 13 TeV

by Cian O'Luanaigh

21st May



- 2 nominal bunches per beam
- De-squeezed to 19 m

Test collisions continue today at 13 TeV in the Large Hadron Collider (LHC) to prepare the detectors ALICE, ATLAS, CMS, LHCb, LHCf, MOEDAL and TOTEM for data-taking, planned for early June (Image: LHC page 1)

First Stable Beams

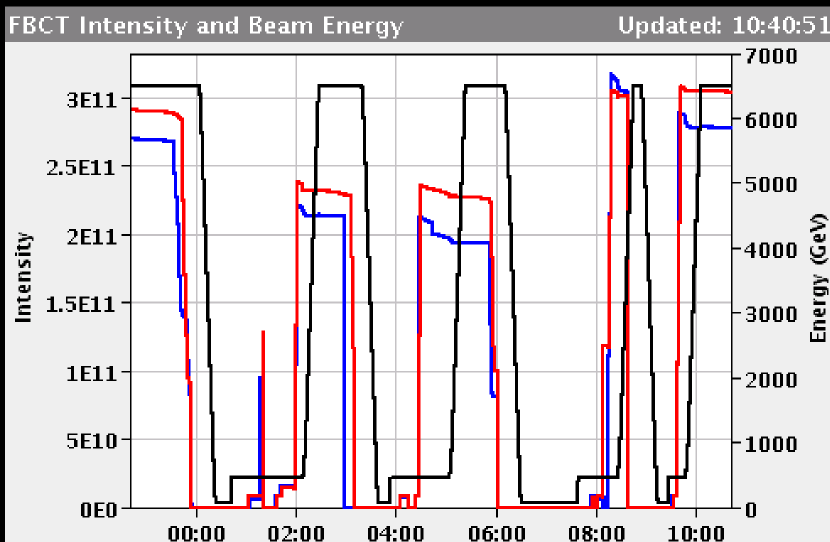
This morning

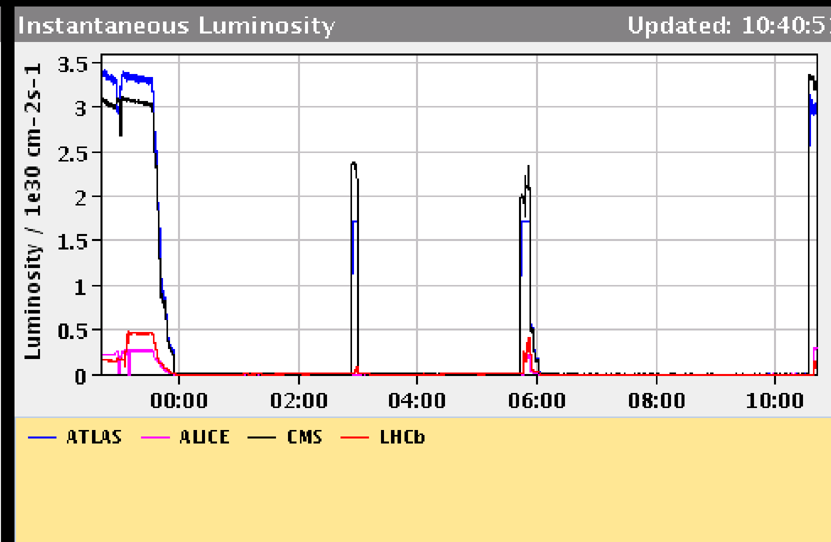
- 07:00 Injection delayed
  - Issue with interlocked BPM
  - SPS beam dump kicker fault
- 08:25 Start ramp
- 08:38 Beams dump at 4.1 TeV
  - Software interlock related to interlock BPM fix!
- 09:46 Start ramp
- 10:15 Start squeeze
- 10:40 Stable beams

LHC Page1 | Fill: 3819 | E: 6500 GeV | t(SB): 00:00:19 | 03-06-15 10:40:51

PROTON PHYSICS: STABLE BEAMS

Energy:	6500 GeV	I(B1):	2.93e+11	I(B2):	2.96e+11





Comments (03-Jun-2015 10:40:01)

collapsed separation bumps in IP1 and 5
collapsed separation bumps in I IP2 and 8
preparing for stable beams

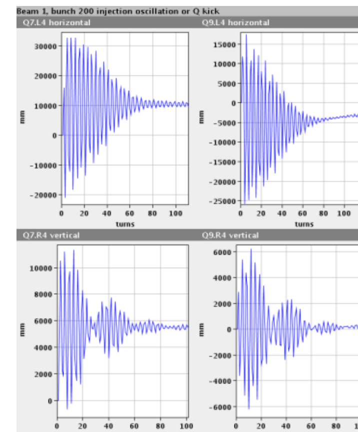
BIS status and SMP flags	B1	B2
Link Status of Beam Permits	false	false
Global Beam Permit	true	true
Setup Beam	false	false
Beam Presence	true	true
Moveable Devices Allowed In	true	true
Stable Beams	true	true

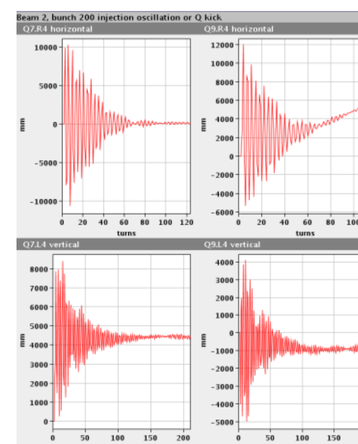
AFS: Single_3b_2_2_2_with_nc_probes

PM Status B1 ENABLED | PM Status B2 ENABLED

Of note 1/2

- A lot of lessons learnt from Run 1
- Excellent and improved system performance:
  - Beam Instrumentation
  - Transverse feedback
  - RF
  - Collimation
  - Injection and beam dump systems
  - Vacuum
  - Machine protection
- Improved software & analysis tools
- Experience!





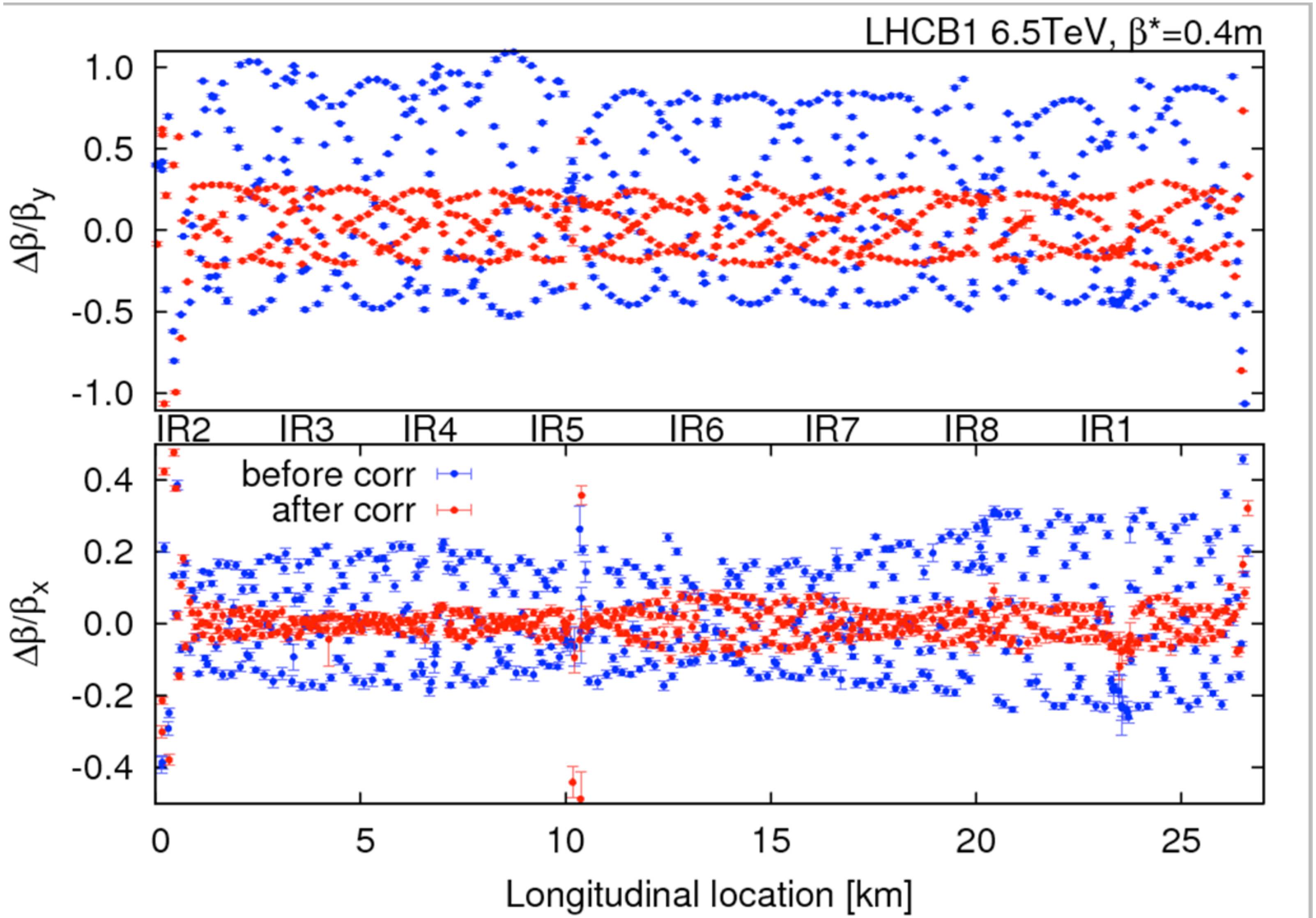
Of note 2/2

- Magnetically reproducible as ever
- Optically good, corrected to excellent
- Aperture
  - measurements at top energy, 80cm, before and after collision indicate that the aperture is ok and compatible with the present collimation hierarchy. This is a very good result.
- Behaving well at 6.5 TeV
  - One additional training quench so far
- Operationally well under control
  - Injection, ramp, squeeze, de-squeeze

Still have to face the intensity ramp-up

- **UFOs, e-cloud, vacuum, beam induced heating, instabilities**

Optics - 40 cm



OMC team

Flat top collimator gaps

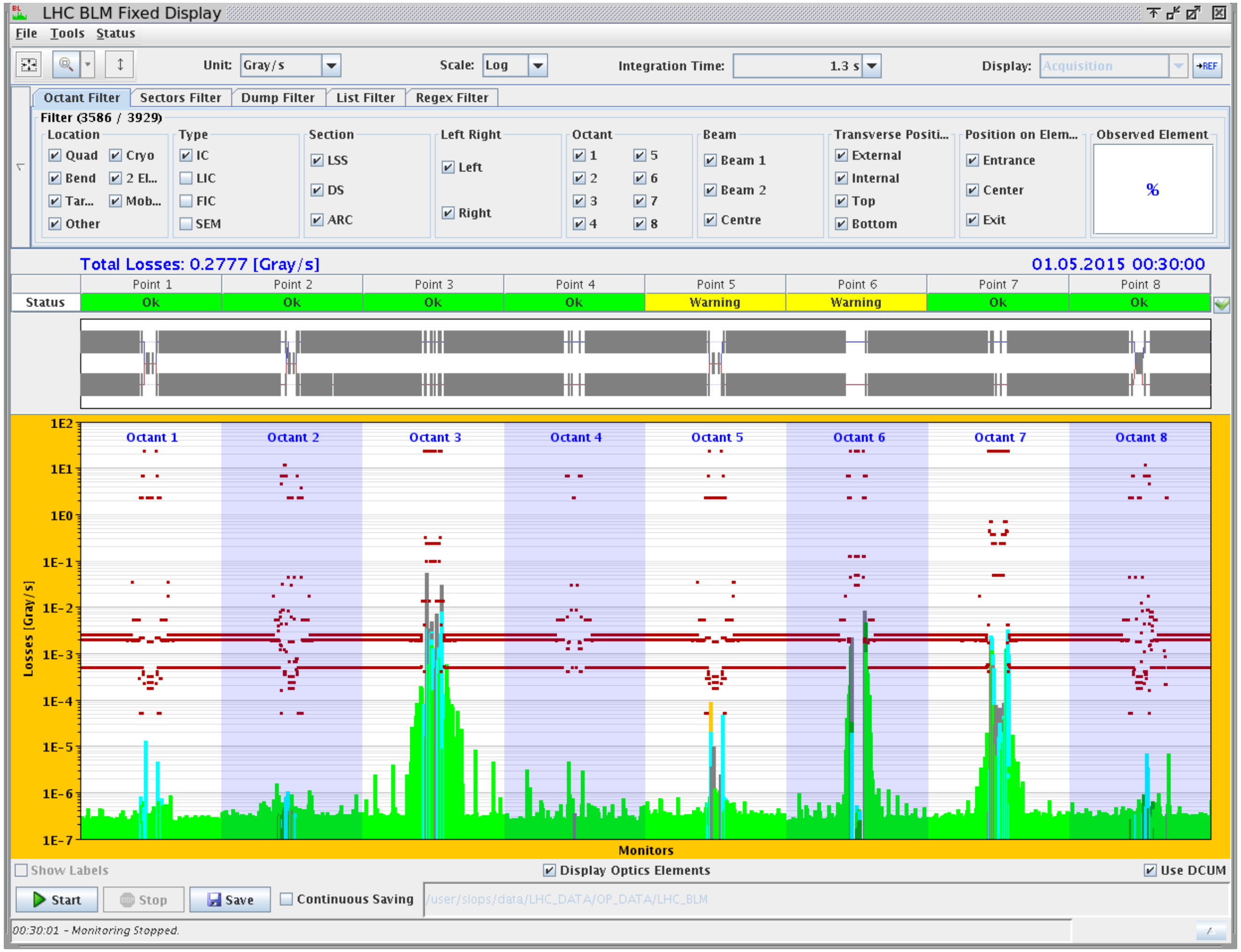
LHC Collimators | Beam: B2 | Set: HW Group:LHC COLLIMATORS 18-05-2015 23:13:13

L(mm) MDC		PRS R(mm)
	IP1	
8.7	TCTPV.4R1.B2	-6.11
9.46	TCTPH.4R1.B2	-11.38
24.95	TCL.6L1.B2	-25.01
25.02	TCL.5L1.B2	-25.04
25.02	TCL.4L1.B2	-25.02
	IP2	
7.38	TCTPV.4R2.B2	-3.94
5.69	TCTPH.4R2.B2	-5.67
	IP3	
3.56	TCLA.7L3.B2	-3.63
4.44	TCLA.6L3.B2	-5.81
4.97	TCLA.B5L3.B2	-6.05
5.99	TCLA.A5L3.B2	-5.91
2.5	TCSG.B5L3.B2	-3.49
2.52	TCSG.A5L3.B2	-2.79
1.71	TCSG.4L3.B2	-2.41
3.24	TCSG.5R3.B2	-2.79
4.22	TCP.6R3.B2	-3.48
	IP5	
24.97	TCL.6L5.B2	-25.01
25	TCL.5L5.B2	-24.99
25	TCL.4L5.B2	-25.01
7.76	TCTPV.4R5.B2	-7.01
12.71	TCTPH.4R5.B2	-8.16
	IP6	
4.53	TCSP.A4L6.B2	-4.95
4.07	TCDQA.A4L6.B2	
	IP7	
3.15	TCLA.A7L7.B2	-1.98
2.57	TCLA.D6L7.B2	-2.48
5.01	TCLA.C6L7.B2	-2.7
3.93	TCLA.B6L7.B2	-4.08
2.73	TCLA.A6L7.B2	-1.67
3.42	TCSG.6L7.B2	-3.14
2.19	TCSG.E5L7.B2	-2.64
2.25	TCSG.D5L7.B2	-2.56
2.29	TCSG.B5L7.B2	-2.55
1.81	TCSG.A4L7.B2	-2.42
2.38	TCSG.A4R7.B2	-1.79
2.23	TCSG.B4R7.B2	-2.22
1.44	TCSG.D4R7.B2	-1.53
2.64	TCSG.A5R7.B2	-2.05
2.21	TCSG.B5R7.B2	-2.4
1.9	TCSG.A6R7.B2	-1.92
0.55	TCP.B6R7.B2	-2.04
1.43	TCP.C6R7.B2	-1.58
2.04	TCP.D6R7.B2	-0.13
	IP8	
24.94	TCLIB.6L8.B2	-25
24.94	TCLIA.4L8	-25.01
54.95	TDI.4R8	-55.01
6.03	TCTPV.4R8.B2	-5.26
2.59	TCTPH.4R8.B2	-8.77
	TI8	
2.54	TCDIH.87441	-0.84
4.03	TCDIV.87645	-3.54
3.19	TCDIV.87804	-1.1
0.78	TCDIH.87904	-2.79
3.04	TCDIH.88121	-4.04
7.33	TCDIV.88123	-5.01

BETATRON_HOR | BETATRON_VER | OFFMOMENTUM_POS_DP | OFFMOMENTUM_NEG_DP

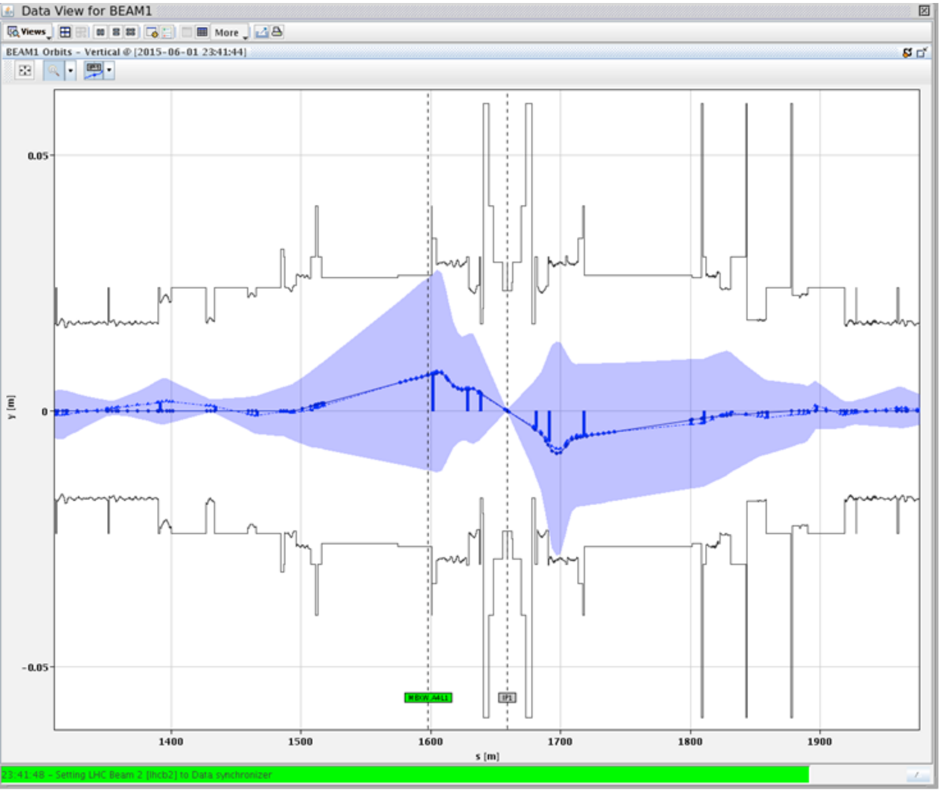
Coll team

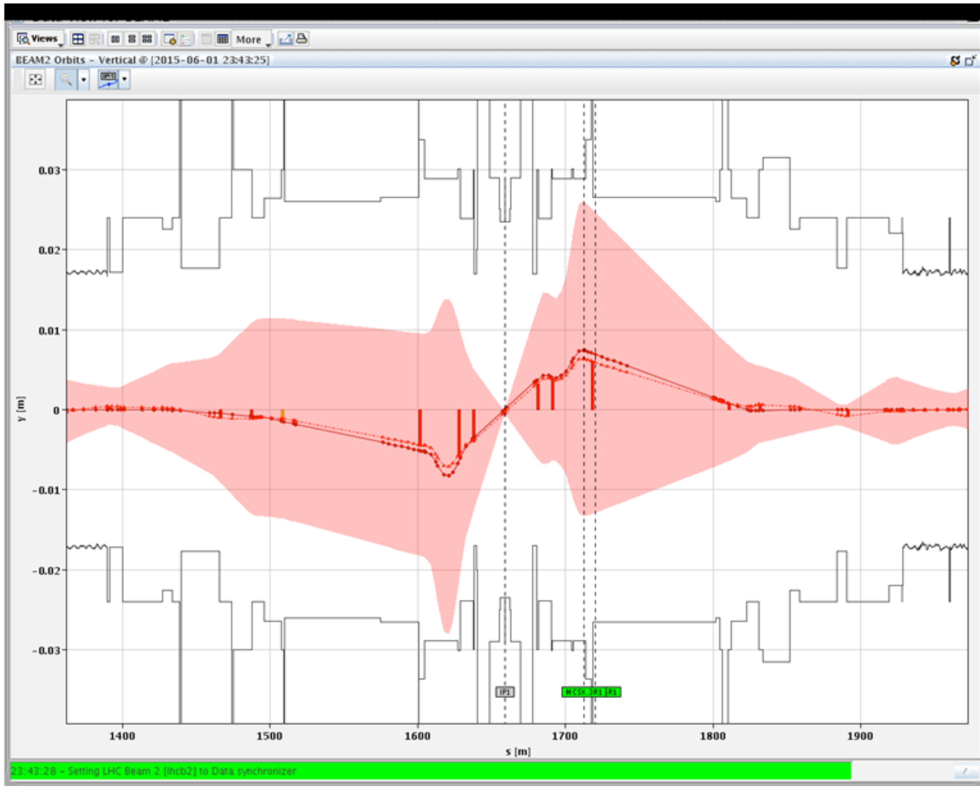
Off momentum loss map 6.5 TeV



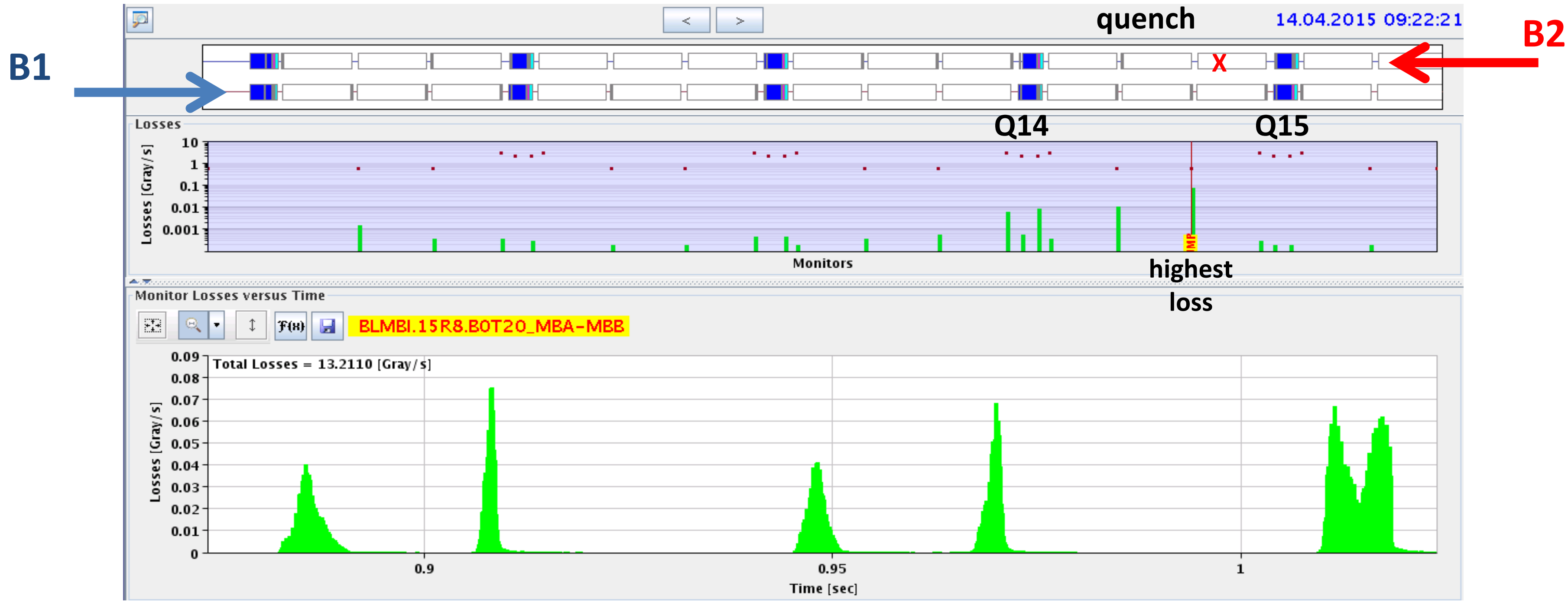
Novel features of collimation system – BPM equipped tertiary collimators, automatic beam based set-up

Aperture


Data View for BEAM1
BEAM1 Orbits - Vertical @ [2015-06-01 23:41:44]
0.05
0
-0.05
y [m]
1400
1500
1600
1700
1800
1900
s [m]
IP1
23:41:48 - Setting LHC Beam 2 [lhcb2] to Data synchronizer


BEAM2 Orbits - Vertical @ [2015-06-01 23:43:25]
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
y [m]
1400
1500
1600
1700
1800
1900
s [m]
IP1
23:43:28 - Setting LHC Beam 2 [lhcb2] to Data synchronizer

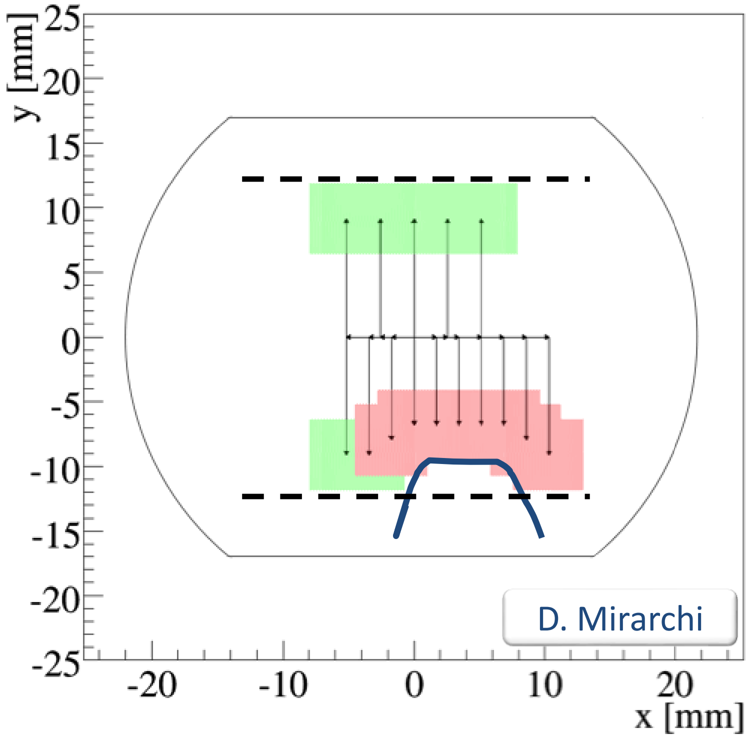
MUFOs in 15R8



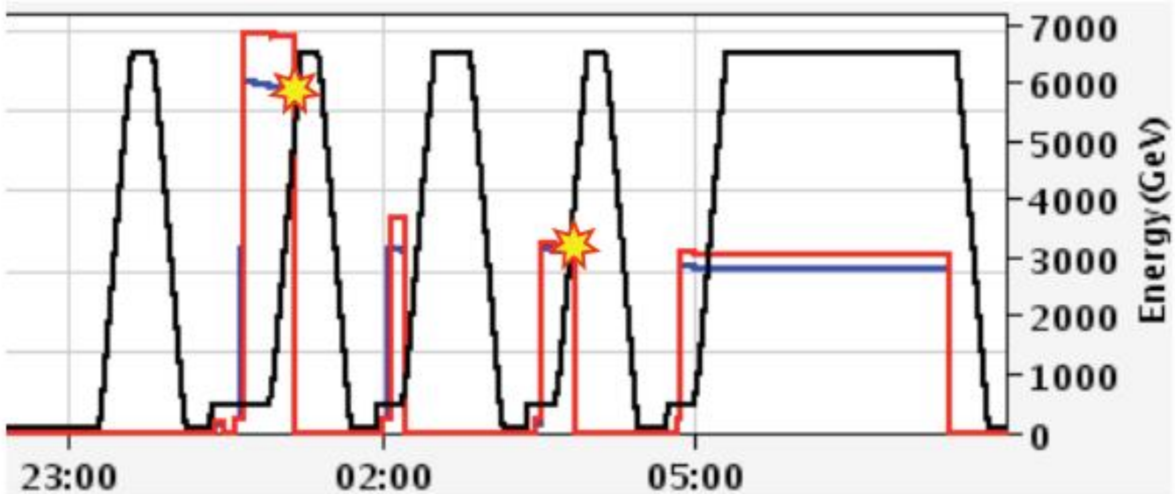
- Multiple loss events after a short time at 6.5 TeV compatible with particles falling into the beam
  - loss patterns point to a specific position in the middle of a dipole magnet
  - Quenched twice, numerous BLM triggered dumps…

Aperture restriction in 15R8
ULO (Unidentified Lying Object)

- Aperture restriction measured at injection and 6.5 TeV
- Presently running with orbit bumps
  - -3 mm in H, +1 in V, to optimize available aperture
  - aperture probably not limiting for operation
- Behaviour with higher intensities and bunch trains still unknown
- MUFOs went away but last week



UFO in 15R8 are back



Dump 1: 5.1 TeV with 2 bunches
Dump 2: 4.3 TeV with 1 bunch

This following a 15R8 aperture scan. **A worry.**

2015: ATLAS and CMS performance

- Conservative beta* to start
- Nominal bunch population
- Reasonable emittance into collisions
- Assume same machine availability as 2012

	Nc	Beta *	ppb	EmitN	Lumi [$cm^{-2}s^{-1}$]	Days (approx)	Int lumi	Pileup
50 ns	1300	80	1.2e11	2.5	4.8e33	21	~1 fb^{-1}	25
2015.1	2448	80	1.2e11	3.1	7.1e33	35	~4 fb^{-1}	21
2015.2	2448	40	1.2e11	3.1	1.2e34	30	~5 fb^{-1}	35

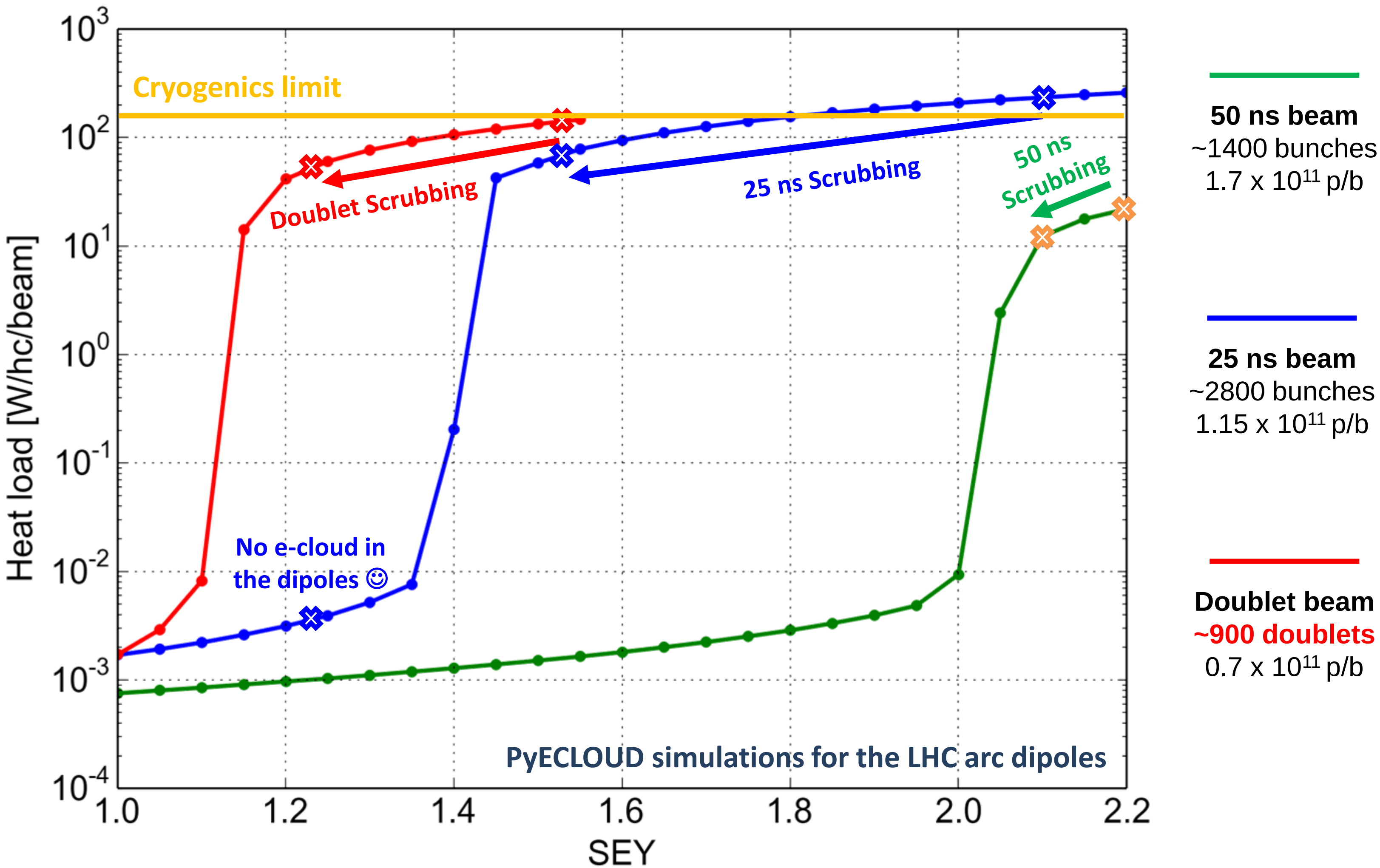
Official GPD luminosity target for the year was 10 fb^{-1}
Now on the challenging side – let's say 5 to 10 fb^{-1}

Special physics runs

- First run 5 day run scheduled for next week
  - LHCf and luminosity calibration with VdM scans. TOTEM and ALFA to piggy-back.
  - De-squeeze to 19-19-19-24 m commissioned (and test collision delivered)
  - Roman Pot set-up and validation still to do
  - Pilot physics and ~10 pb^{-1} to be delivered before but in good shape
- Second 7 day run for later in year
  - VdM and 90 m run for TOTEM and ALFA
  - Procedures and tools for set-up in good shape – should allow effective exploitation of scheduled time

"Doublet" scrubbing beam: PyECLOUD simulation results

Buildup simulations show **a substantial enhancement of the e-cloud** with the "doublet" bunch pattern



Giovanni Iadarola and Giovanni Rumolo

Conclusions

- Looking good at 6.5 TeV
  - Great job done in LS1 and during powering tests
  - Impressive progress so far, lot of lessons learnt in Run 1 and fed-forward
- Fundamentals look sound, no show stoppers for the moment
  - Some irritants – resolution cost time
- Next challenge - higher intensity and e-cloud
- 2015 will be a short year for proton physics but lay foundations for production for the rest of Run 2