LHC Status

Mike Lamont
for the LHC team

LHC - 2015

- Target energy: 6.5 TeV
  - looking good after a major effort
- Bunch spacing: 25 ns
  - strongly favored by experiments – pile-up
- Beta* in ATLAS and CMS: 80 to 40 cm

Energy

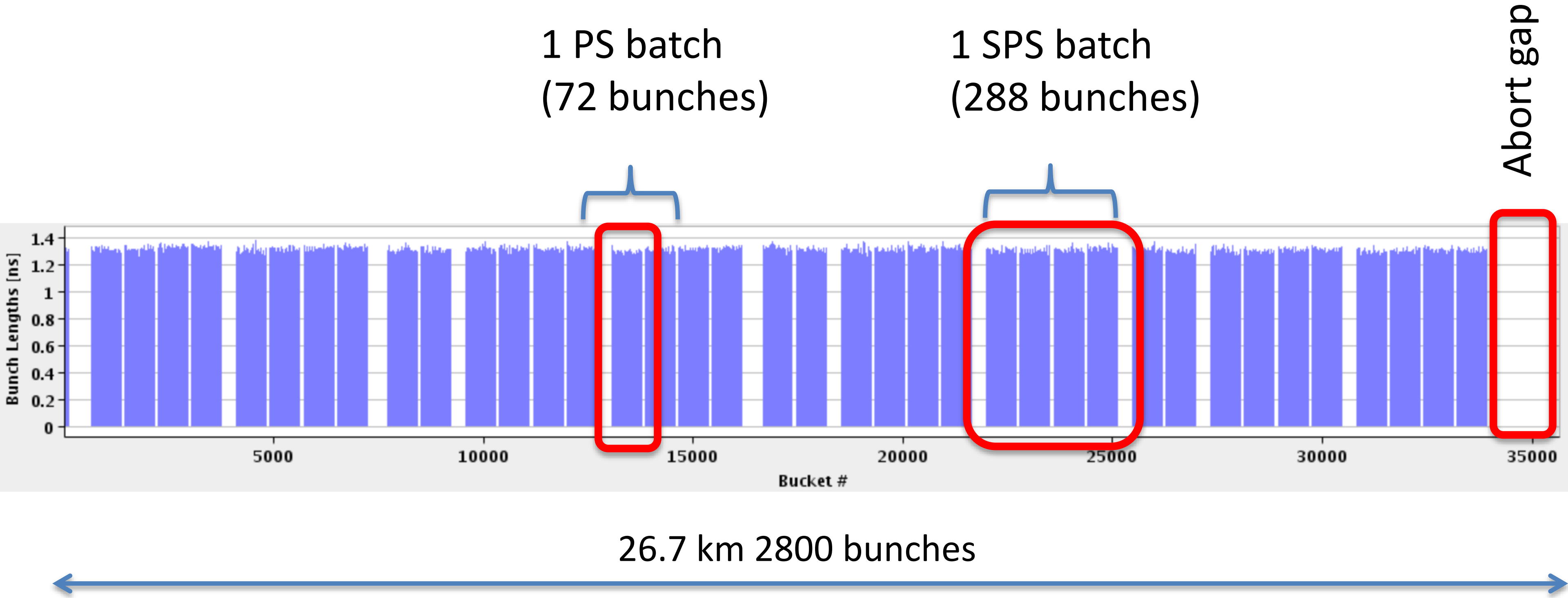
- Lower quench margins
- Lower tolerance to beam loss
- Hardware closer to maximum (beam dumps, power converters etc.)

25 ns

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

Nominal LHC bunch structure

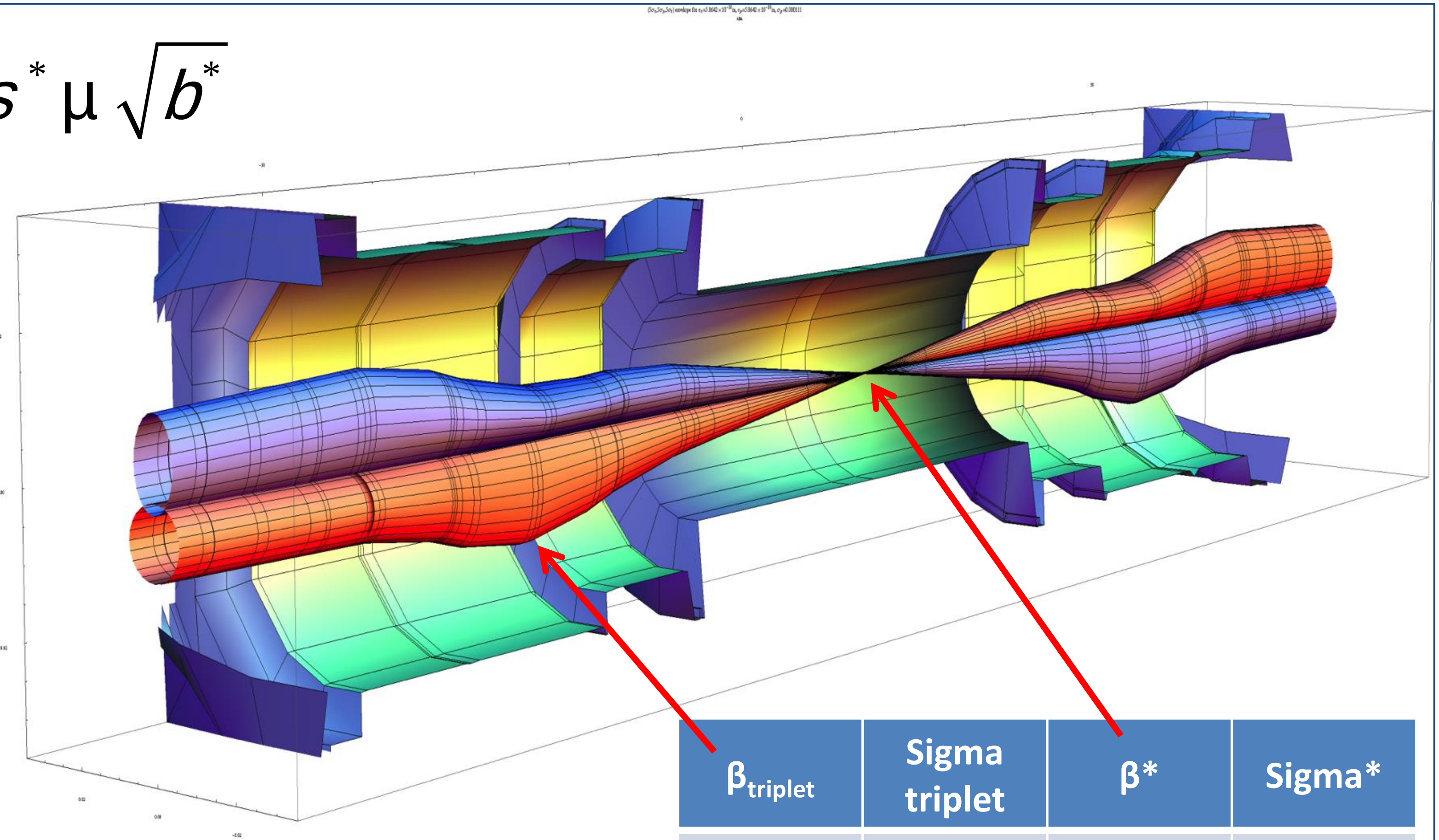
- 25 ns bunch spacing
- ~2800 bunches
- Nominal bunch intensity: 1.2×10^{11} protons per bunch



Beta*

- Lower beta* implies larger beams in the triplet magnets
- Aperture concerns dictate caution

$s^{*}\ \mu \sqrt{b^{*}}$



$\beta_{triplet}$	Sigma triplet	β*	Sigma*
~4.5 km	1.5 mm	55 cm	17 um

Image courtesy John Jowett

2015: beta* in IPs 1 and 5

- Start-up: **β*= 80 cm – (very) relaxed**
  - 2012 collimator settings
  - 11 sigma long range separation-> crossing angle
  - Aperture, orbit stability… looking good

- Ultimate in 2015 and Run 2: **β*= 40 cm**
  - Validated during last machine development
  - Reduction later in the year not completely ruled out…

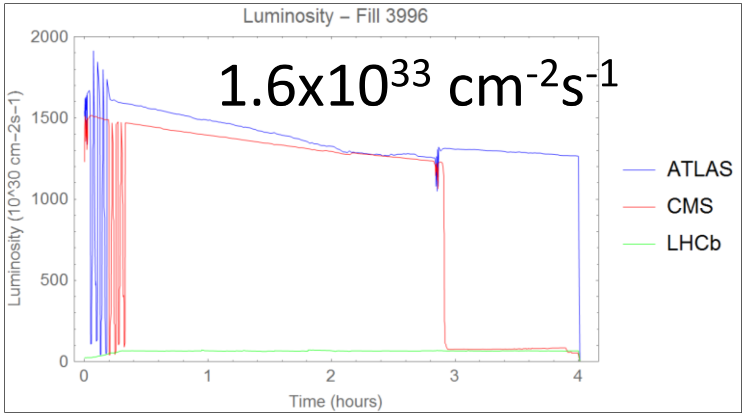
$$\mathcal{L} \propto \frac{1}{\beta^*}$$

2015 commissioning strategy

1. Initial Beam commissioning
   ~2 months
2. **First stable beams** at 6.5 TeV
   low intensity
3. Scrubbing for 50 ns
   (50 & 25 ns) ~10 days
4. Phased intensity increase with 50 ns
   ~3 weeks
5. Scrubbing for 25 ns
   ~14 days
6. **25 ns physics**
   (including intensity ramp up) ← Ongoing

5th April
first beam

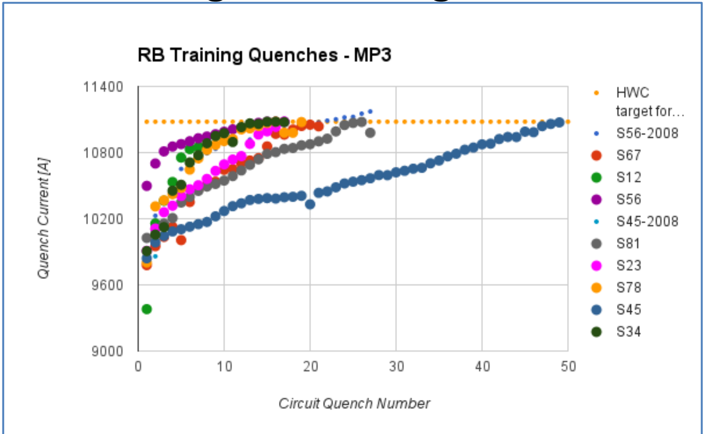
10th April: 6.5 TeV for the first time



July 14th: 476b (50 ns)

APRIL | MAY | JUNE | JULY | AUGUST

Finish magnet training



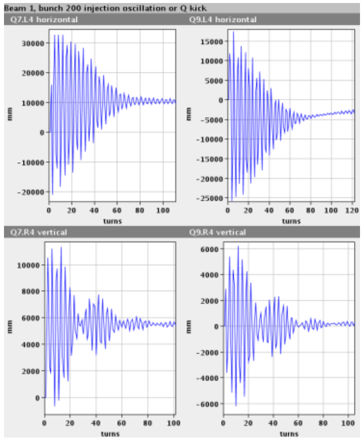
3rd June: First Stable Beams

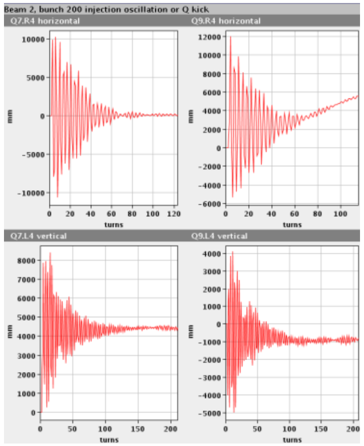
August 23rd
25 ns, 459 bunches
1×10^{33} cm^{-2}s^{-1}

2015

Initial commissioning 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!





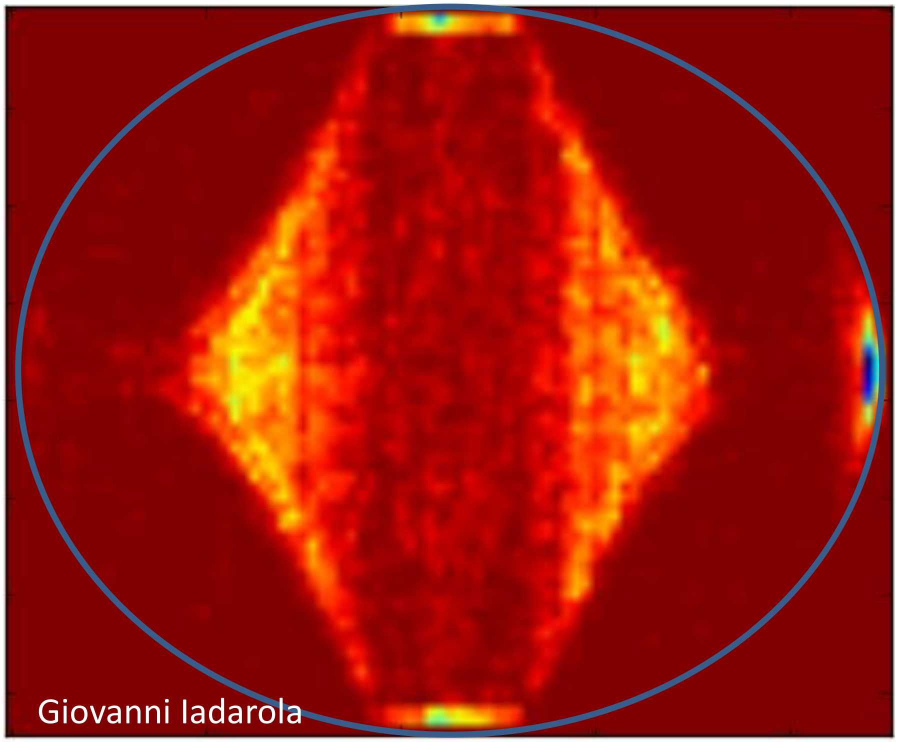
Initial commissioning 2/2

- Magnetically reproducible as ever
- Optically good, corrected to excellent
- Aperture is fine and compatible with the collimation hierarchy.
- Magnets behaving well at 6.5 TeV
  - 11 additional training quenches
- Operationally things well under control
  - Injection, ramp, squeeze etc.

Electron cloud

When an accelerator is operated with small bunch spacing an **Electron Cloud (EC)** can develop in the beam chamber due to the Secondary Emission from the chamber's wall.

Dipole chamber @ 7TeV

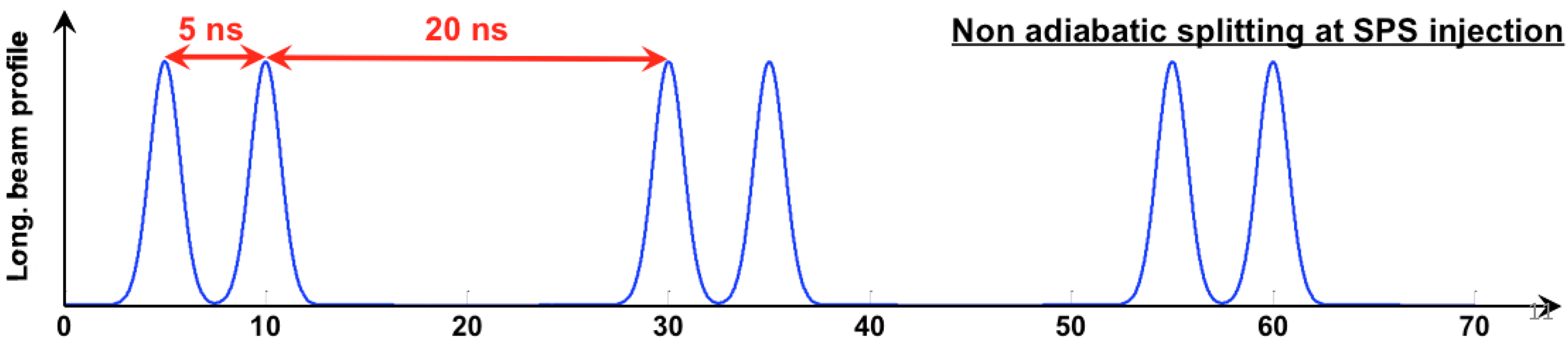


- **Strong impact on beam quality** (EC induced instabilities, particle losses, emittance growth)
- **Dynamic pressure rise**
- **Heat load** (on cryogenic sections)

Electron bombardment of a surface has been proven to reduce drastically the **secondary electron yield (SEY)** of a material. This technique, known as **scrubbing**, provides a mean to suppress electron cloud build-up.

Scrubbing 2015

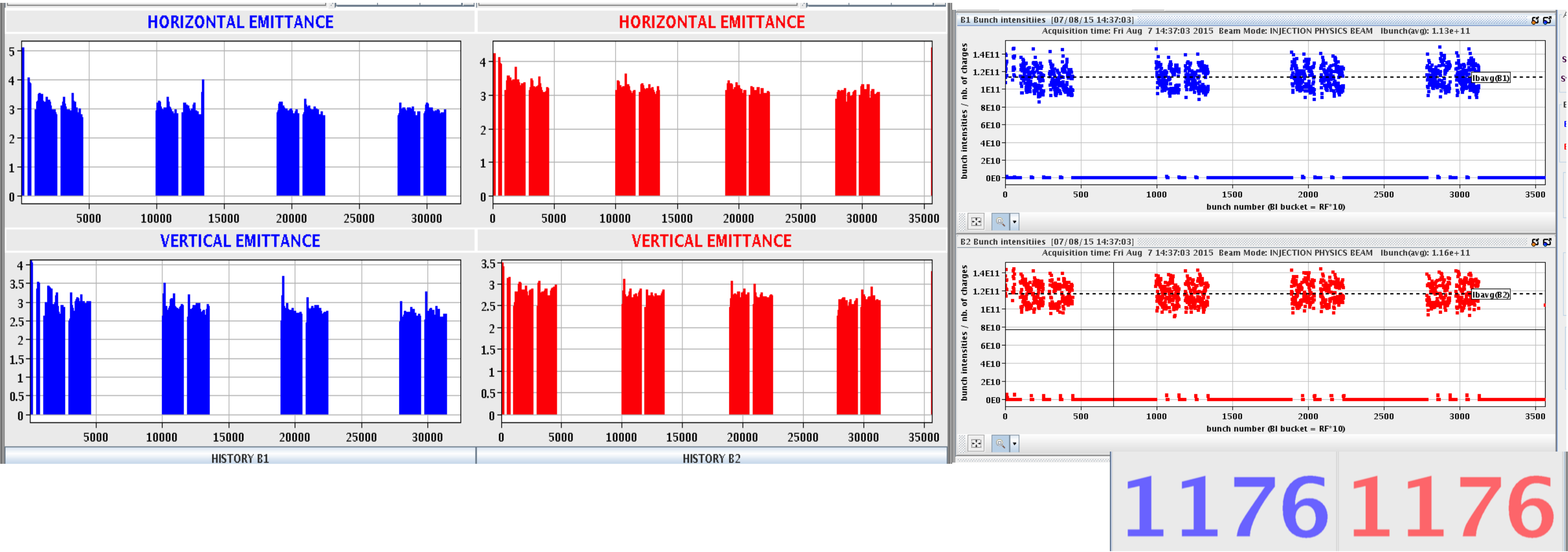
- E-cloud goes with bunch spacing
  - lot worse with 25 ns – more scrubbing required
- Doublet scrubbing beam looked attractive…
- A two stage scrubbing strategy was pursued:
  - Scrubbing 1 (50 ns and 25 ns) to allow for operation with 50 ns beams at 6.5 TeV
  - Scrubbing 2 (25 ns and Doublet) to allow for operation with 25 ns beams at 6.5 TeV



25 ns scrubbing - exit

- Use of doublet beam difficult – more 25 ns scrubbing required
- Present beam quality at 450 GeV OK for up to ~1500 bunches

- Possible limitations from injection protection devices and injection kickers ~1200 bunches…



50 ns: 476 bunches – mid July

Fill	Stable beams /Lost	bunches	Peak Lumi 10^{33} $cm^{-2}s^{-1}$	Int Lumi pb^{-1}	dumped by
3992	5h18m	476	1.4	22.16	QPS RB.A81
3994	Top of ramp	476			UFO 10L3
3995	Flat top	476			UFO with quench, 34L8
3996	4h4m	476	1.6	20.23	QPS board in B29R2
4000	Ramp 2.0 TeV	476			UFO with quench at ULO
4001	69s	476	1.4	<0.1	QPS board in B11.L1
4003	Ramp 2.2 TeV	476			UFO at ULO
4006	10m	476	1.6	0.79	QPS board in B16R1
4008	2h34m	298	0.9	7.86	QPS board in B29R2
4013	Ramp 6.1 TeV	476			RCS.A78B2 earth fault
4015	Ramp 6.2 TeV	476			RCS.A78B2 earth fault
4018	Flat-top	476			UFO 12L6
4019	31m	476	1.5	2.3	UFO 15L2

Initial 25 ns ramp-up – end August

Fill	Stable beams /Lost	bunches	Peak Lumi $cm^{-2}s^{-1}$	Int Lumi pb^{-1}	dumped by
41xx	Collisions	8	-	-	Earth fault S78
41yy	Squeeze	8	-	-	Earth fault S78
4201	**2h40m**	26	5.9e31	0.5	Water leak
4204	Flat top	86	-	-	Instability
4205	**9h57m**	86	1.732	5.2	Programmed dump
4207	**4h24m**	86	1.6e32	2.6	Electrical glitch
4208	**5h12m**	86	1.9e32	3.0	UFO (plus quench)
4210	**1h17m**	158	3.6e32	1.5	BPM interlock
4211	**1h55m**	158	3.8e32	1.8	BPM interlock
4212	1h4m	158	4.5e32	1.7	Cryogenics glitch
4214	5h16m	158	4.5e32	7.4	Power converter trip
4219	6m	219	6.0e32	0.1	RF trip
4220	10h16m	219	6.22e32	19.3	OP dump

Initial 25 ns ramp-up – end August

Fill	Stable beams /Lost	bunches	Peak Lumi $cm^{-2}s^{-1}$	Int Lumi pb^{-1}	dumped by
4224	10m	315	8.3e32		Cryo MSR8
4225	2h23m	315	7.7e32		Cryo MSR8
4228	Squeeze	315			QPS SEU
4230	Adjust	315			RF trip
4231	**5h26m**	315	6.9e32	11.1	**QPS SEU S34**
4237	Flattop	315			**QPS SEU L1**
4243	**4h23m**	315	8.3e32	12.1	BPMS low intensity
4246	**10h25m**	**296 (50 ns)**	1.05e33	27.0	**OP dump**
4249	**19m**	459	8.9e32	1.0	**QPS SEU S81**
4252	Ramp	459			**QPS SEU**
4254	**37m**	458	9/9e32	2.1	Cryo comms
4256	2h18m	458	1.0e33	7.7	UFO 19R2
4257	19m	458	9.6e32	1.1	**QPS SEU**

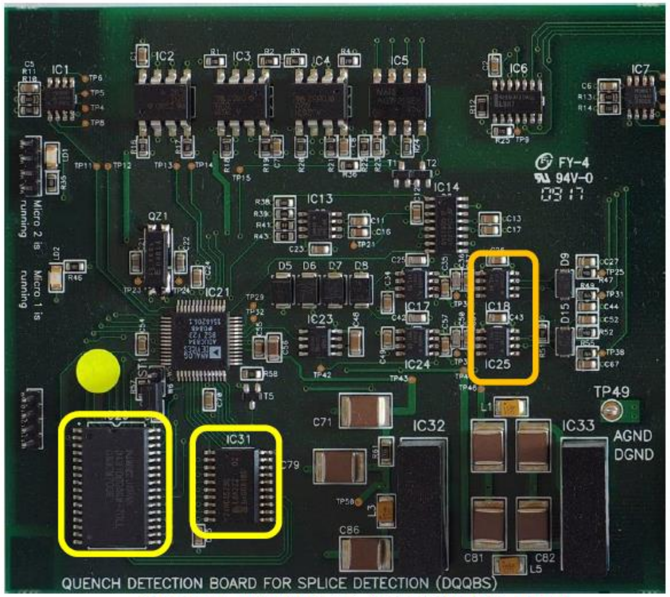
Main issues

Intensity ramp-up designed to flush out **intensity related issues** – successful in that regard

- Quench Protection System (QPS)
  - Non radiation hard components
- Unidentified Falling Objects (UFOs)
  - Distributed around the ring
- UFOs at the ULO
  - Appear to be suppressed by local warm-up of beam screen
- Earth faults (not intensity related)
  - RCS.A78B2 - 154 sextupole correctors on main dipoles
  - Main dipoles A78 – intermittent fault

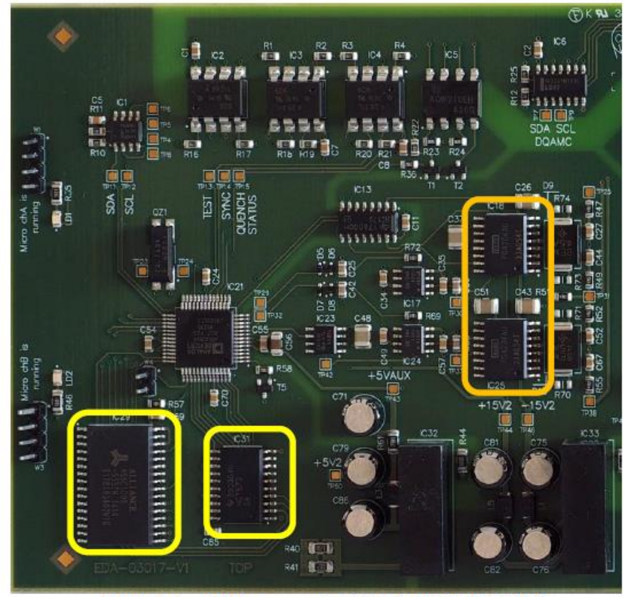
Origin of the SEU problem – recall
Relevant differences between mDQQBS and DQQBS

DQQBS



SRAM: NEC D431000AGW-70LL
D-Latch: NXP 74HCT573
Amplifier: INA141

mDQQBSv2/v3

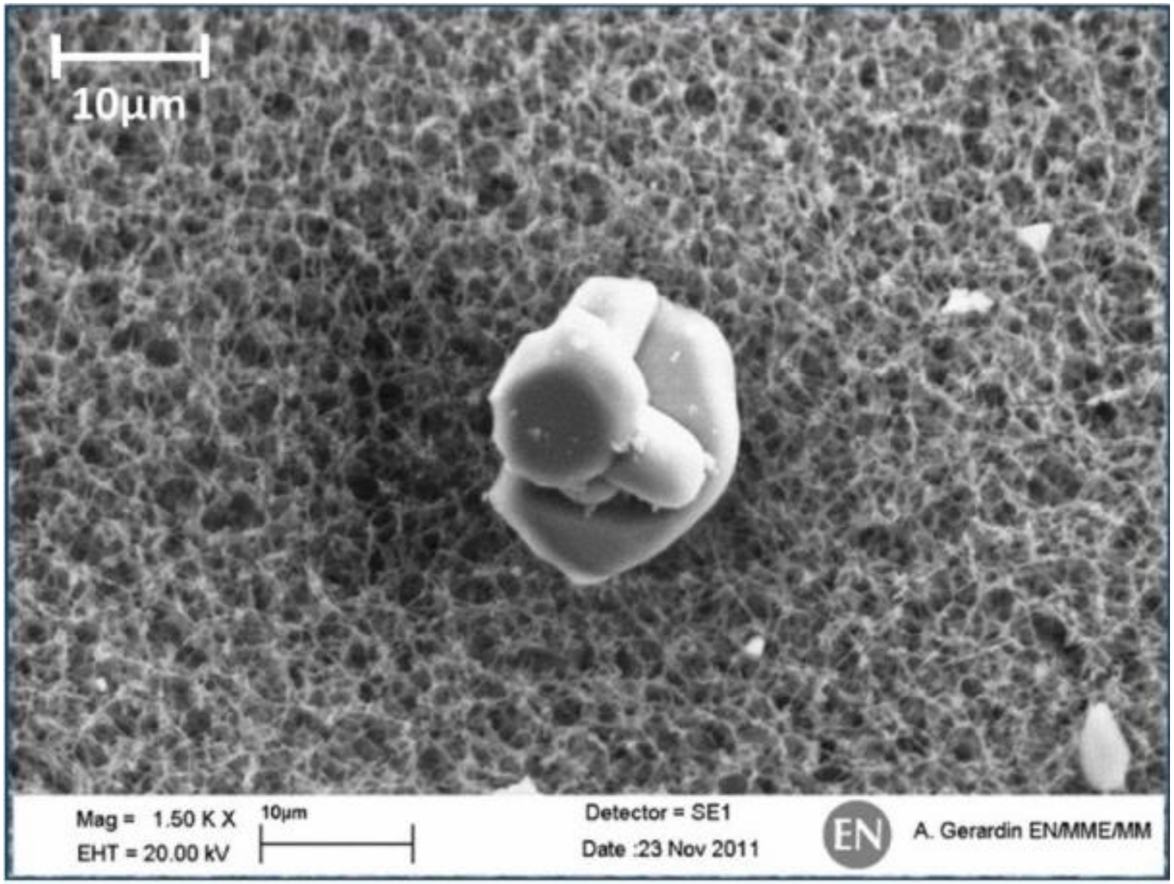


SRAM: Alliance AS6C1008-55SIN
D-Latch: TI 74HCT573
Amplifier: PGA204
Different batch of ADuC834

- 1268 modified boards used for special tests (CSCM) during circuit re-commissioning.
- Replaced during last technical stop – things looking a lot better

UFOs

A nice picture of some dust



T. Baer CERN-THESIS-2013-233

Accepted interpretation of a UFO event:

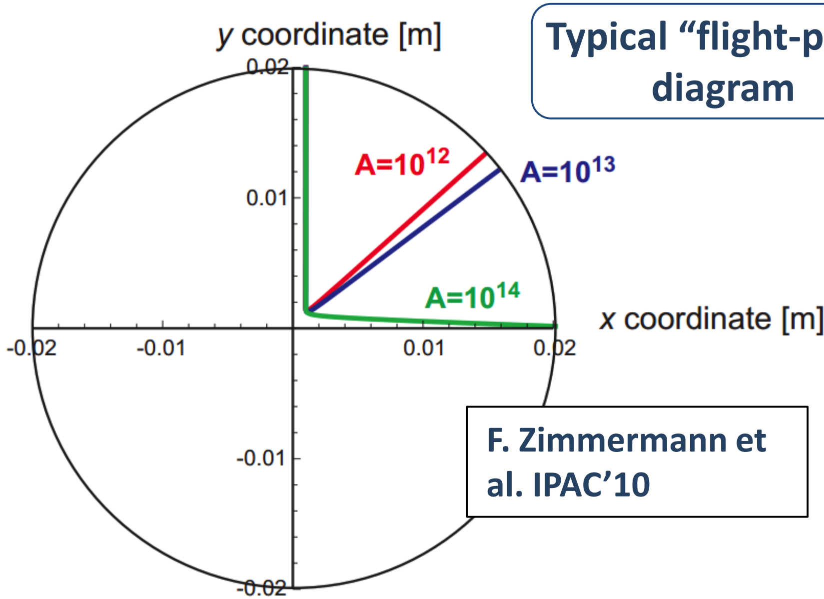
1. A **macroparticle (dust) falls** from the top of the beam screen

2. The **macroparticle is subsequently ionized** due to elastic collisions with the beam

3. The now positively charged **macroparticle is subsequently repelled away** from the beam

4. For the duration of the UFO-to-beam interactions, there may be **significant losses due to inelastic collisions, resulting in a beam dump and or magnet quench!**

Typical "flight-path" diagram

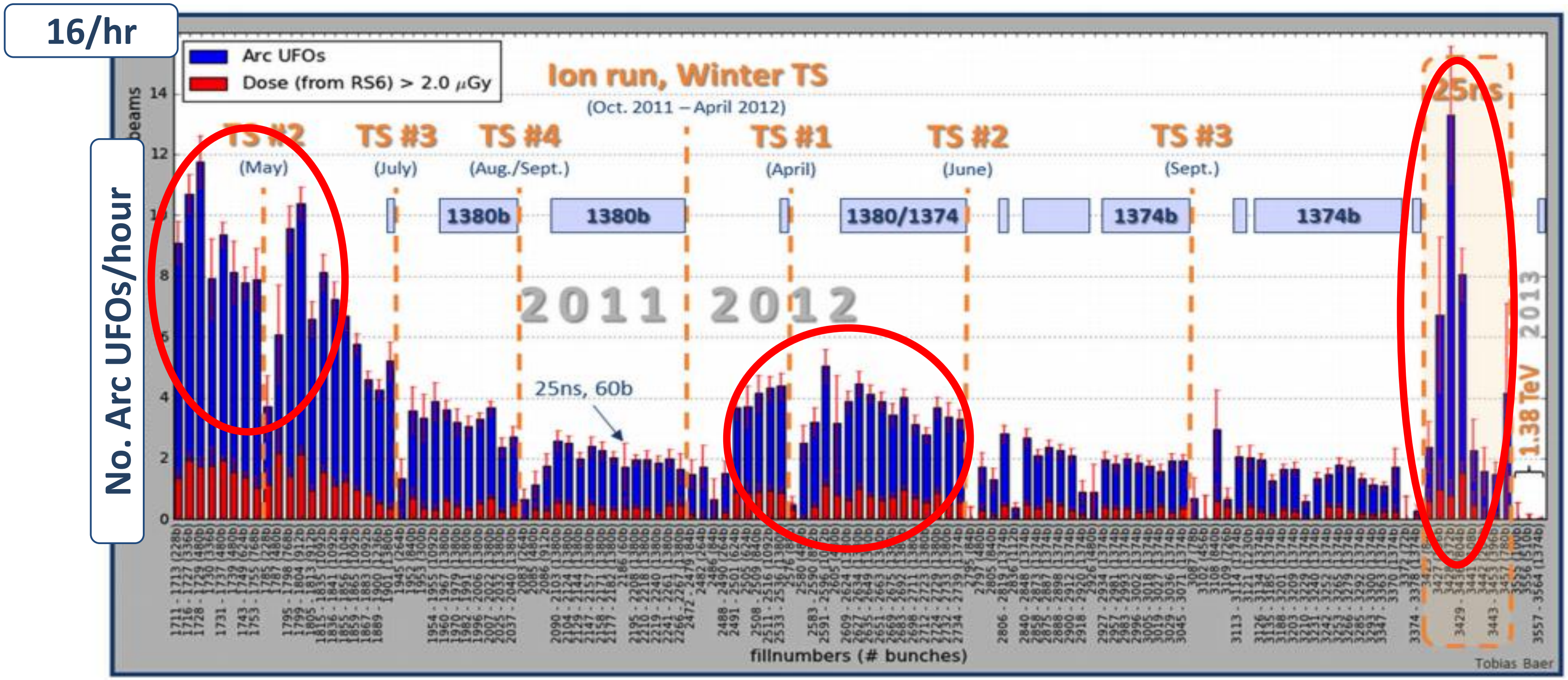


F. Zimmermann et al. IPAC'10

UFO simulation for a given mass, A.

UFOs - strategy

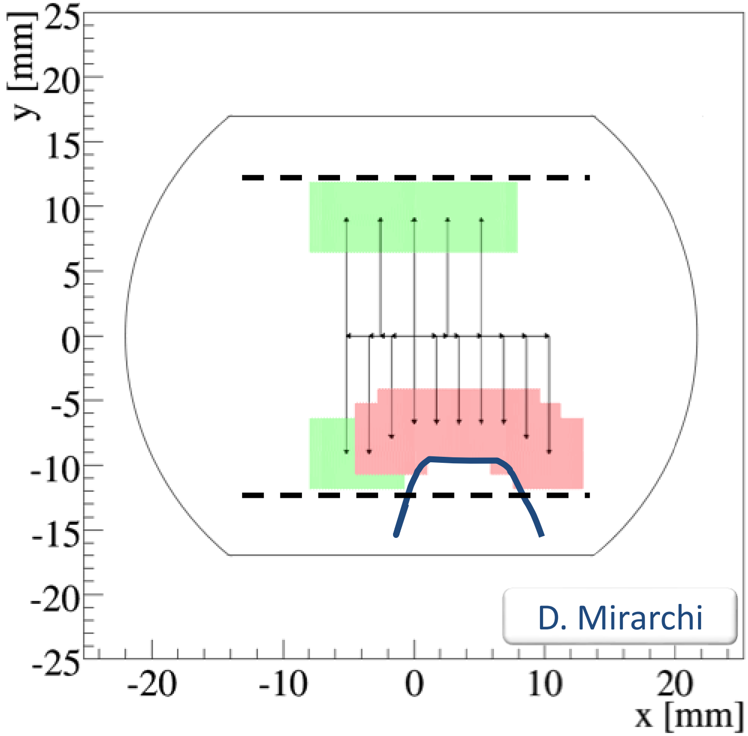
- **No. of UFO events** have been seen to **exceed 10+/hour** with notable increases after long shutdowns and or with a decrease in bunch spacing



- Beam loss monitor thresholds have been set judiciously
- Essentially relying on conditioning (as observed above)

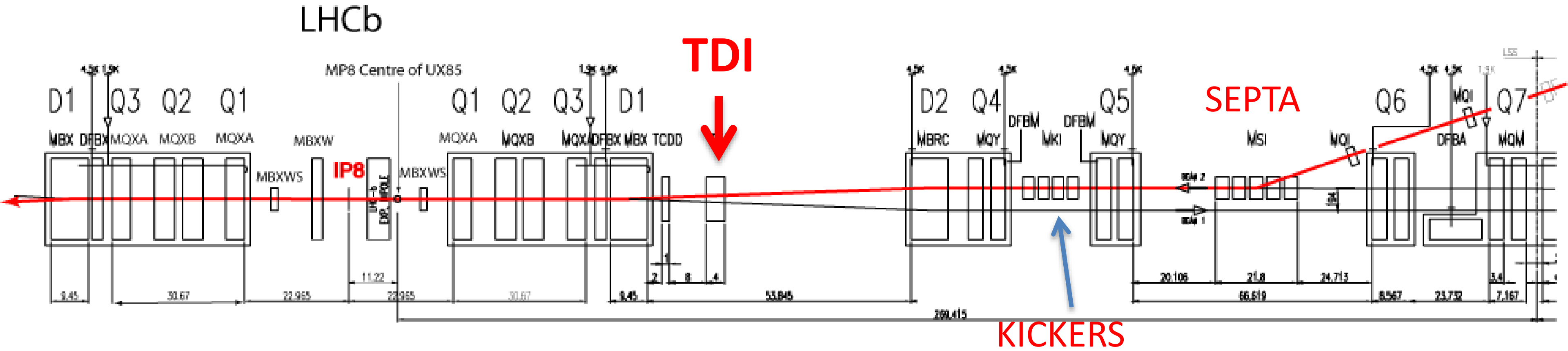
Aperture restriction in 15R8
ULO (Unidentified Lying Object)

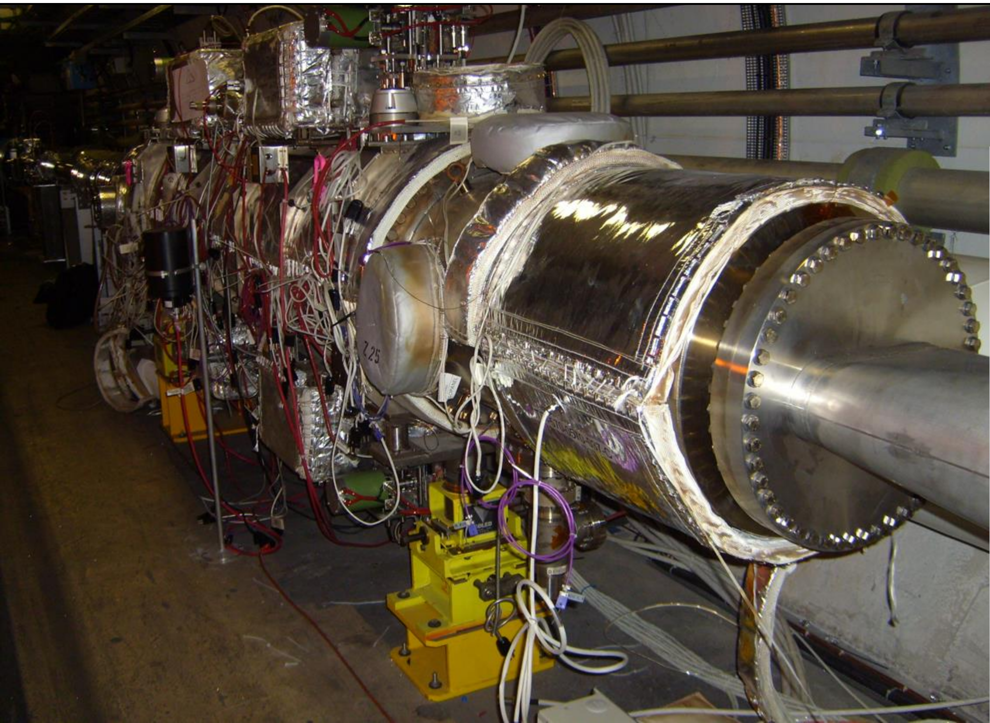
- Aperture restriction measured at injection and 6.5 TeV
- Presently running with orbit bumps
  - -3 mm in H, +1 mm in V, to optimize available aperture
- Behaviour with higher intensities looks OK
- UFOs, DUFOs, MUFOs!



TDI (Injection protection devices)

TDI: movable vertical absorbers – 4.2 m in length – down stream of injection kickers





- Main blocks: hex-boron-nitride
- However during bake-out tests…

TDI.R8

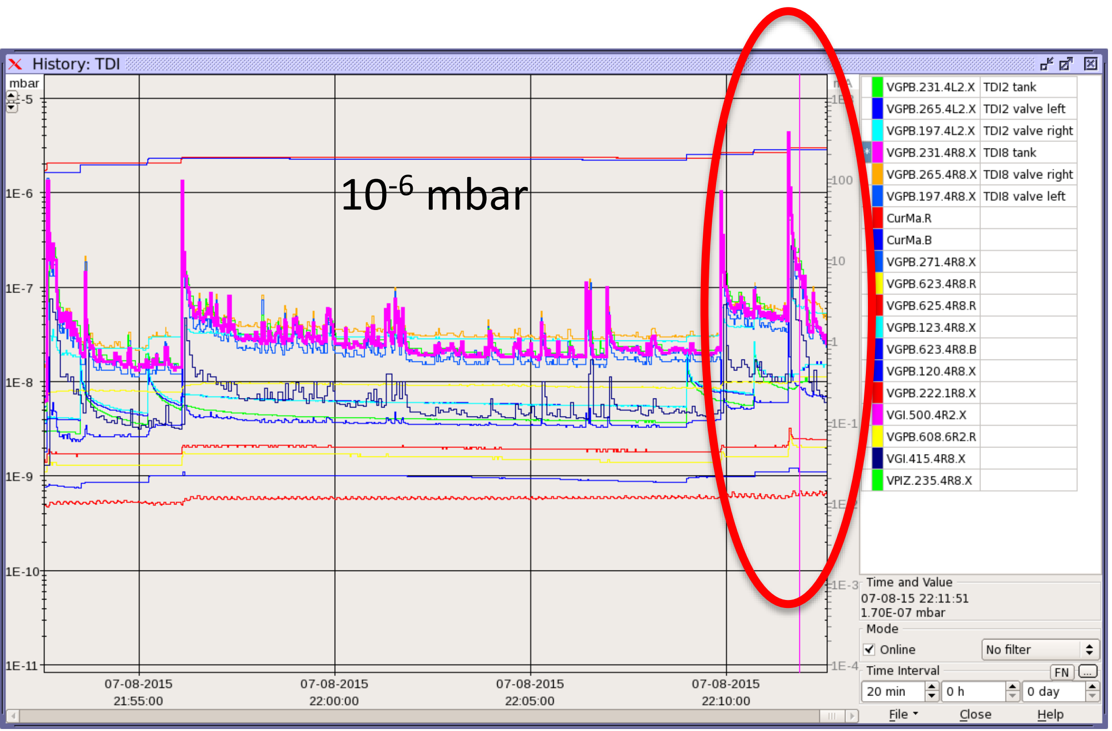
- TDI hBN block cannot withstand temperatures higher than 450 °C (B_2O_3 reactant melting temperature)
- Limitation on number of injection to avoid potential damage (maximum allowed temperature = 400 °C)

Limits of ~2 PS batches per injection (144b) will reduce the maximum number of bunches to around 2400 in 2015

BN blocks to be replaced with graphite in YETS – temporary limitation

TDI beam 2 - vacuum

- In addition during scrubbing, heating and outgassing of TDI right of point 8 has been observed
  - Vacuum spikes up to and above interlock limits



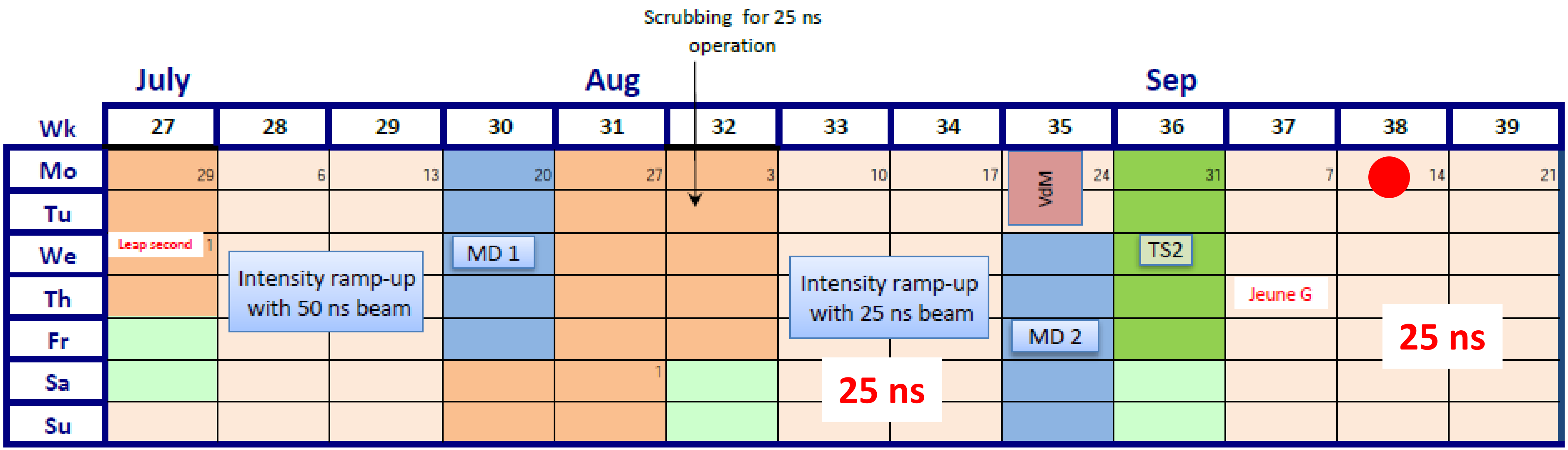
This could slow things down around 1200 bunches

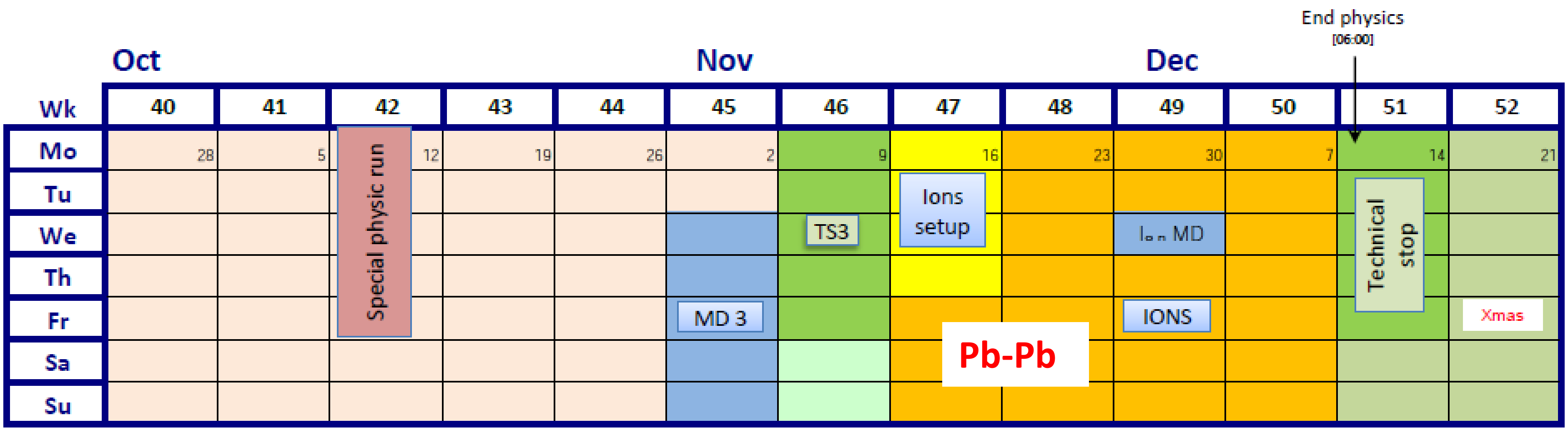
To summarize

- E-cloud – not fully scrubbed (it will get better)
  - Proving challenging for cryogenics at the moment
- QPS – radiation to electronics issue resolved
- UFOs – to work though
- ULO – hope it stays quiet
- Earth faults – background worry
- TDI – to live with until YETS

Painful for 2015 – a commissioning year – but they shouldn't be long term issues for Run 2

Q3/Q4 2015 - latest

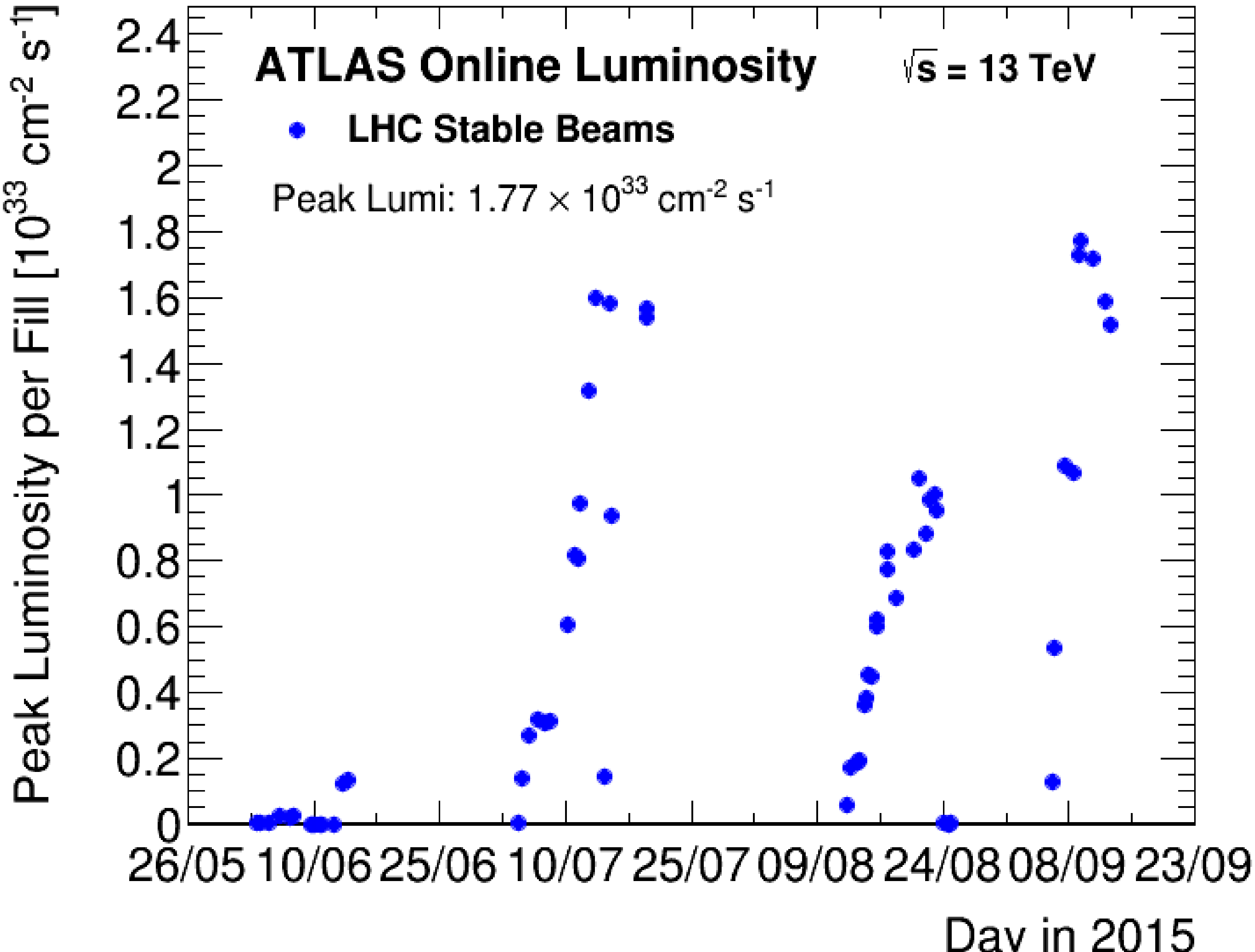




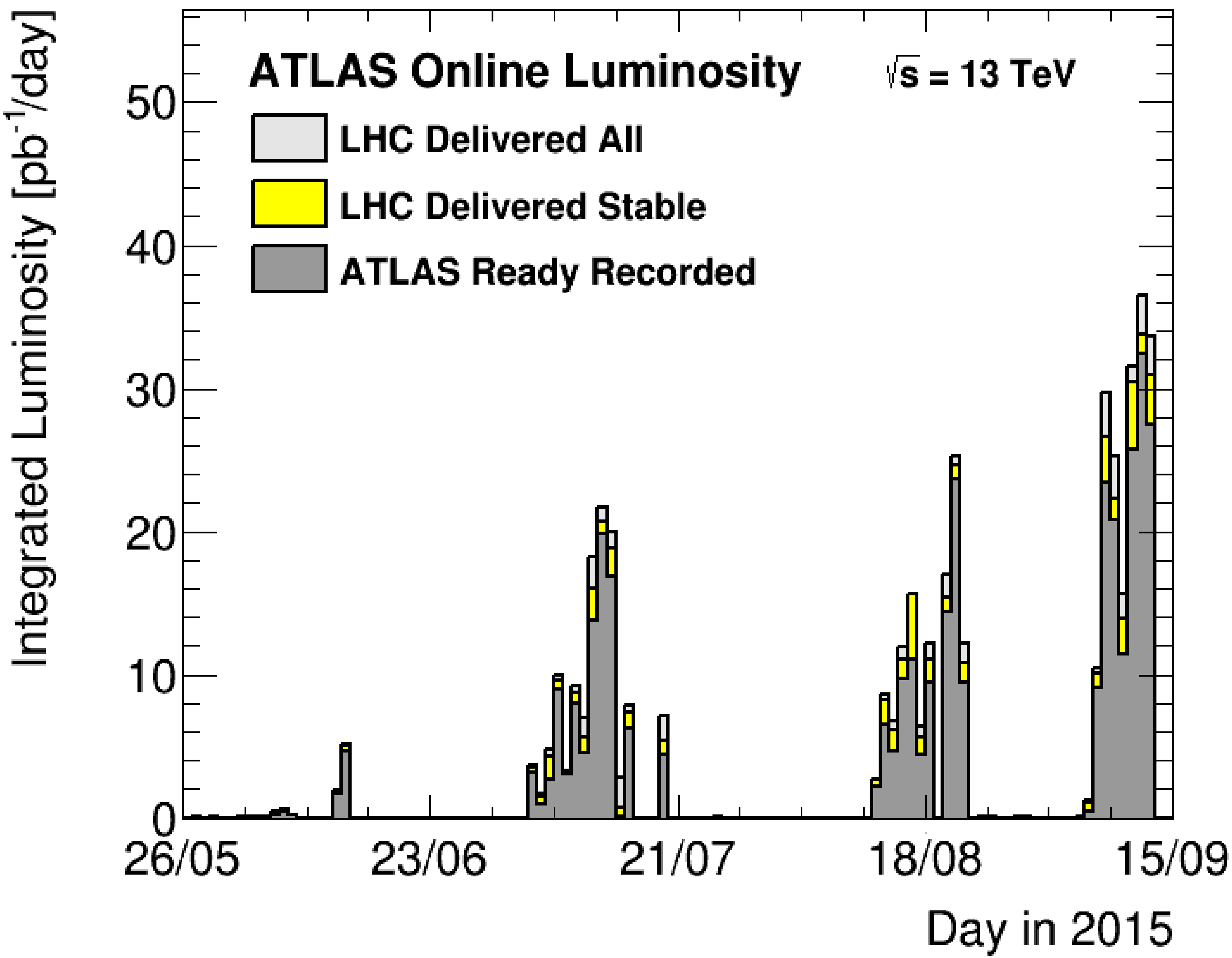
25 ns: after technical stop

Since Sunday 6th September until this morning

Fill	Stable beams /lost	bunches	Peak Lumi $cm^{-2}s^{-1}$	Int Lumi pb^{-1}	dumped by
4322	2h44m	49	1.3e32	1.1	SIS BPM timestamp
4323	6h7m	219	5.4e32	10.1	SIS BPM timestamp
4329	Adjust	459			Cryo:Q6R2 BS temp spike
4332	8h39m	459	1.1e33	26.6	OP dump
4337	7h4m	459	1.1e33	22.0	OP dump
4341	2h4m	745	1.73e33	11.6	RF trip
4342	28m	745	1.77e33	2.7	Cryo point 4 - regulation
4349	13h44m	745	1.72e33	66.9	OP dump
4356	1h41m	745	1.59e33	8.6	RF interlock
4360	4h25m	745	1.52e33	22.3	Electrical glitch



ATLAS Online Luminosity
$\sqrt{s}$ = 13 TeV
LHC Stable Beams
Peak Lumi: 1.77×10^{33} cm^{-2} s^{-1}
Peak Luminosity per Fill [10^{33} cm^{-2} s^{-1}]
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
26/05
10/06
25/06
10/07
25/07
09/08
24/08
08/09
23/09
Day in 2015



ATLAS Online Luminosity
$\sqrt{s}$ = 13 TeV
LHC Delivered All
LHC Delivered Stable
ATLAS Ready Recorded
Integrated Luminosity [pb^{-1}/day]
0
10
20
30
40
50
26/05
23/06
21/07
18/08
15/09
Day in 2015

Status today

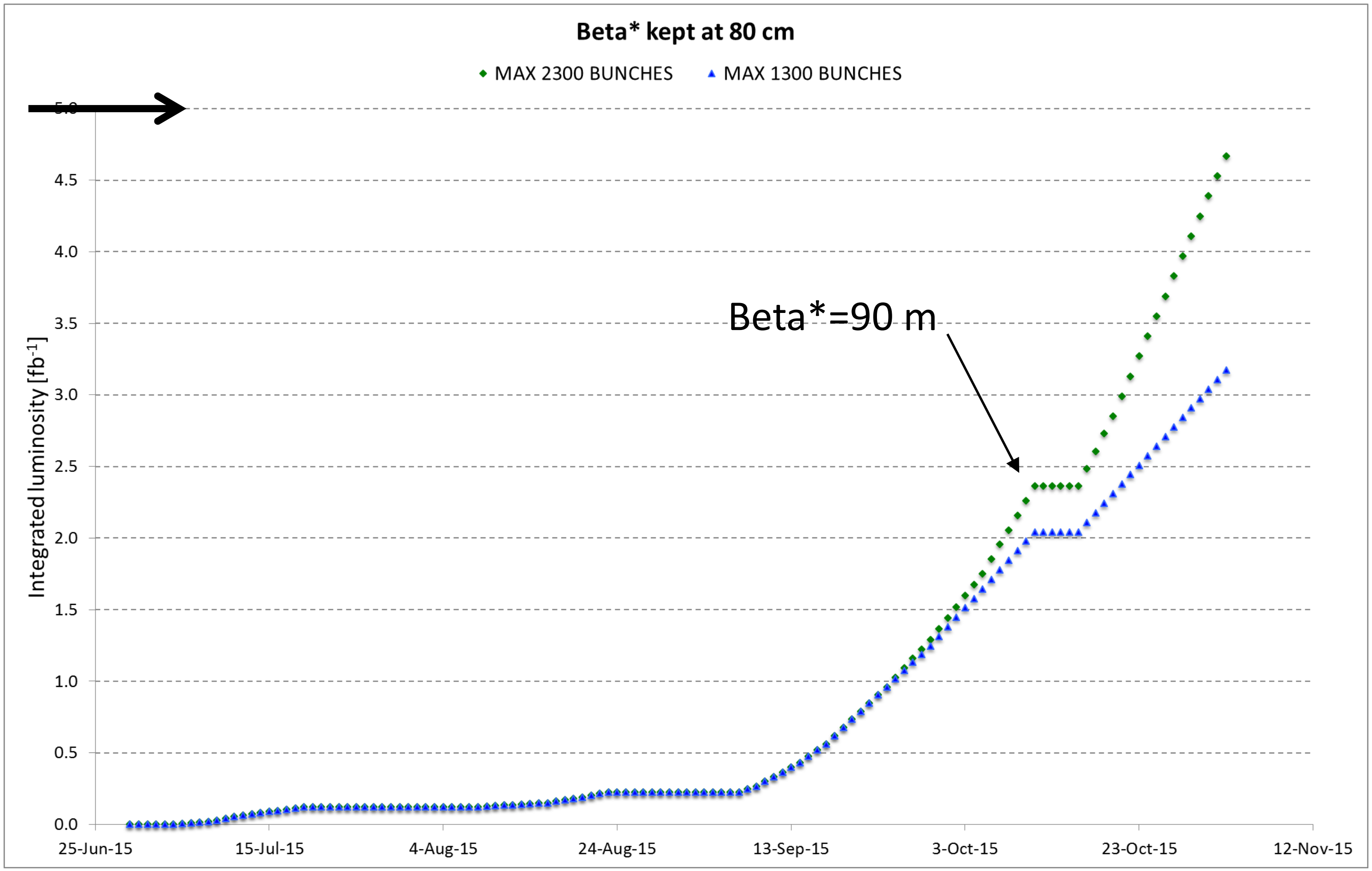
As of Monday 14th September – 46 days proton physics left in 2015

- 745 bunches per beam, 1.7 x 10^{33} $cm^{-2}s^{-1}$
  - Injecting 144 bunches per injection
  - Wrestling with e-cloud induced heat load on beam screens
    - Challenge for cryogenics to regulate with available cooling power
  - Next steps: 1100 – 1700 – 2300 (gently!)
- SEUs, UFOs, ULO – look OK for the moment
- TDI point 8 might start to be an issue around 1200 bunches
  - Beam induced heating and associated out-gassing
  - Looking reasonable at present

Performance…

- Staying at 80 cm: 3 to 4.5 fb^{-1}
- Usual caveats apply – new regime – 25 ns, e-cloud, 6.5TeV!!!

5 fb^{-1}



Conclusions

- 6.5 TeV/fundamentals look good
- Commissioning and scrubbing went well
  - But still have significant electron cloud – will slow progress
- Picked up some hang-over from LS1
  - Quench protection system
  - Earth faults
  - Injection protection devices
  - ULO
- At the end of the day, the LHC is operational at 13 TeV with 25 ns beam - this might regarded as an achievement for all involved.

2015 will be a short year for proton physics but should lay foundations for production for the rest of Run 2 and beyond

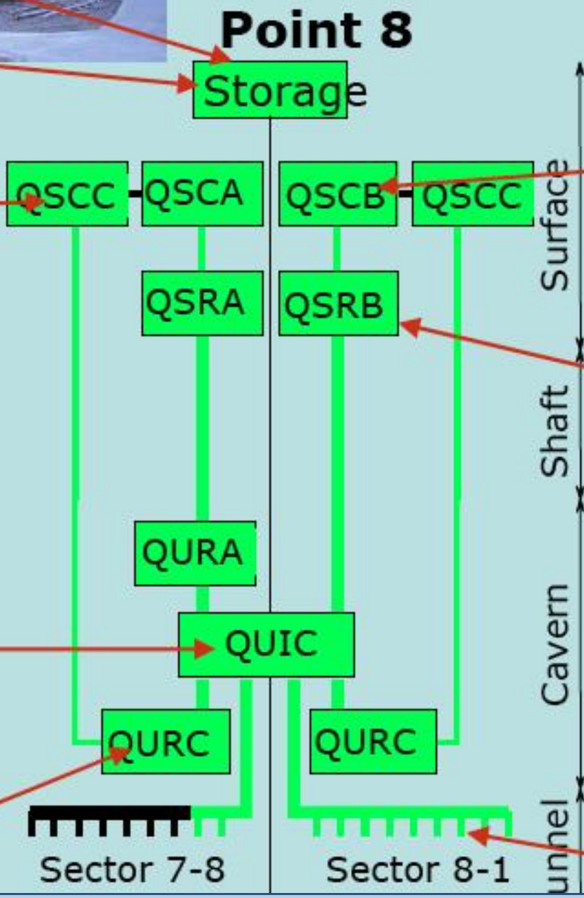
RESERVE

LHC cryogenics is the largest, the longest and the most complex cryogenic system worldwide

Serge Claudet



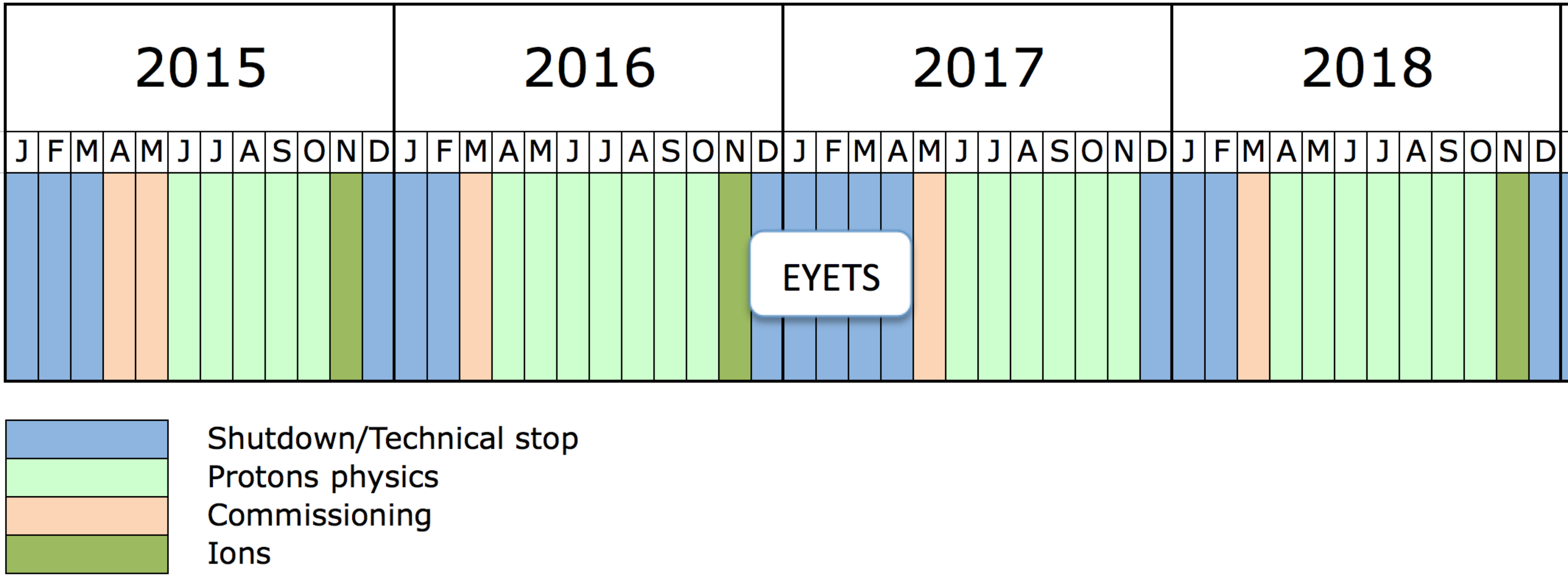




- 24 km of superconducting magnets @1.9 K
- 88 tons of superfluid helium at 1.9 K
- 8 x 18 kW @ 4.5 K

Run 2



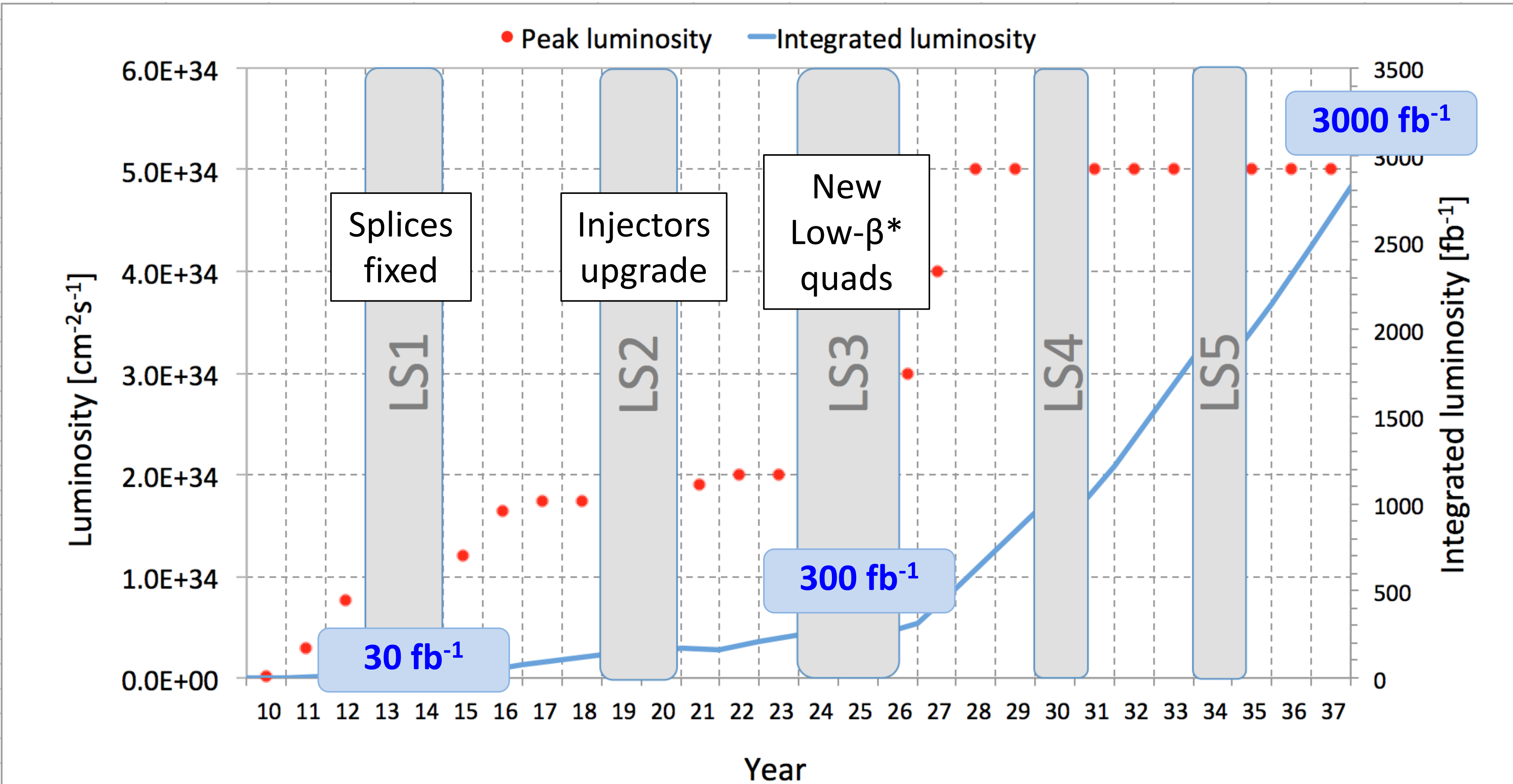
- EYETS – Extended Year End Technical Stop – 19 weeks – CMS pixel upgrade
- Start LS2 at the end of 2018

Run 2 performance

- Start 2016 in production mode
  - 6.5 TeV, machine scrubbed for 25 ns operation
  - Beta* = 40 cm in ATLAS and CMS
  - New injection protection absorbers
  - Peak lumi limited to 1.7e34 by inner triplets
  - Reasonable availability assumed – usual caveats apply – really need to gain experience with 25 ns operation

	Peak lumi E34 $cm^{-2}s^{-1}$	Days proton physics	Approx. int lumi [fb^{-1}]
2015	~0.5	65	3
2016	1.2	160	30
2017	1.5	160	36
2018	1.5	160	36

And beyond



LHC is highest-E, highest-L operational collider → full exploitation ($\sqrt{s}$ ~ 14 TeV, 3000 fb^{-1}) is mandatory:

FG EPS 15