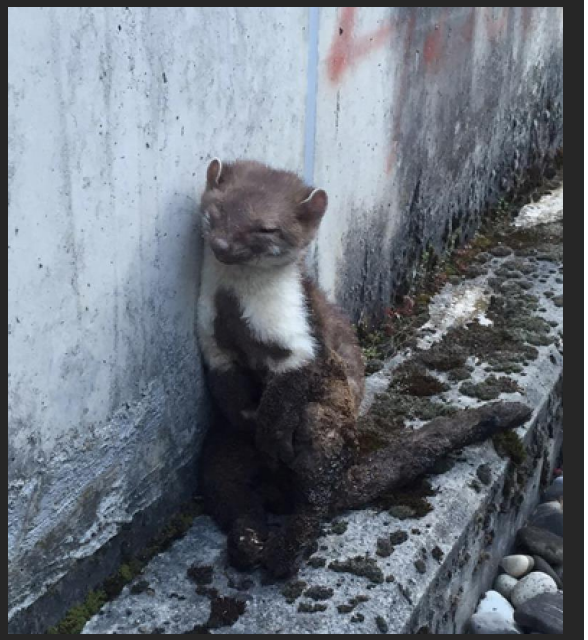
LHC Status and Outlook

Mike Lamont
for the LHC team

2016: Overcome a few problems…

WEASEL



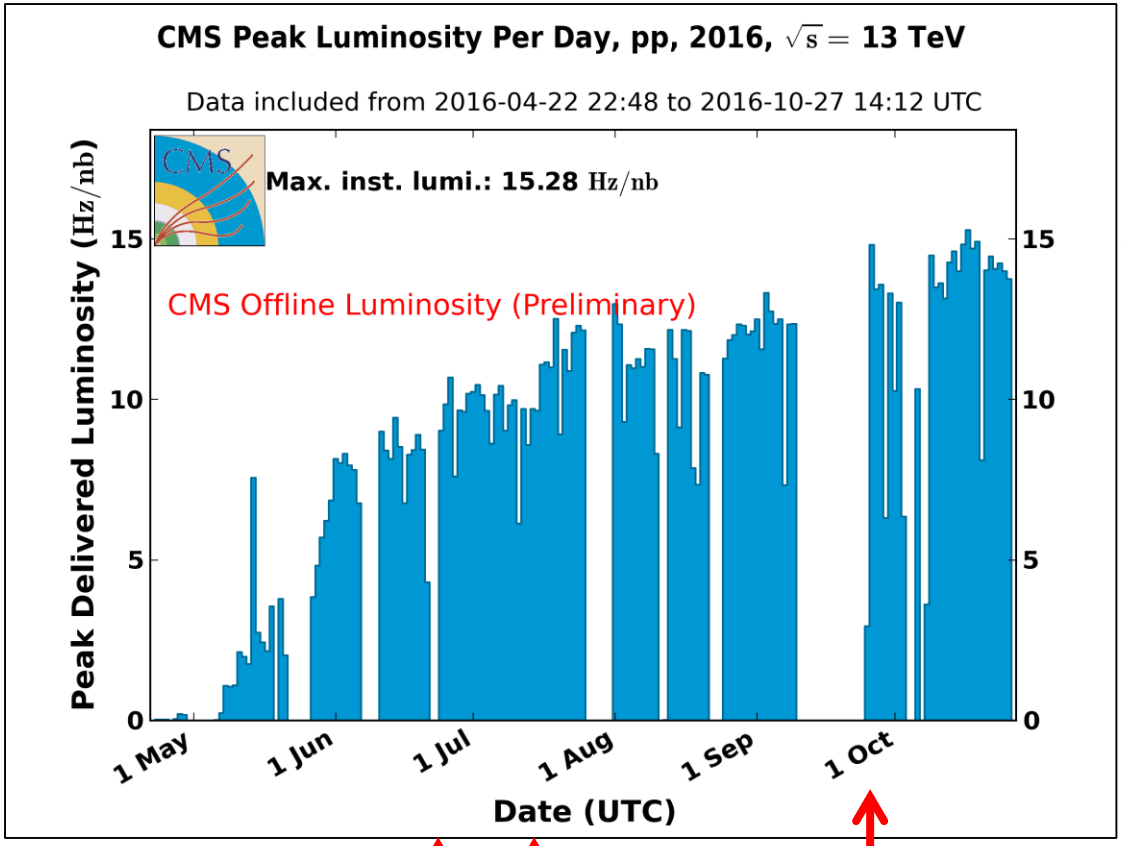
PS MAIN POWER SUPPLY

SPS BEAM DUMP

- **Limited to 96 bunches per injection**
- **2220 bunches per beam cf. 2750**

Thereafter: reasonably quick ramp-up in number of bunches

– Electron cloud still very much with us but effects under control



1.5 x 10^{34} $cm^{-2}s^{-1}$

10^{34}

BCMS

Reduced crossing angle

Design luminosity reached

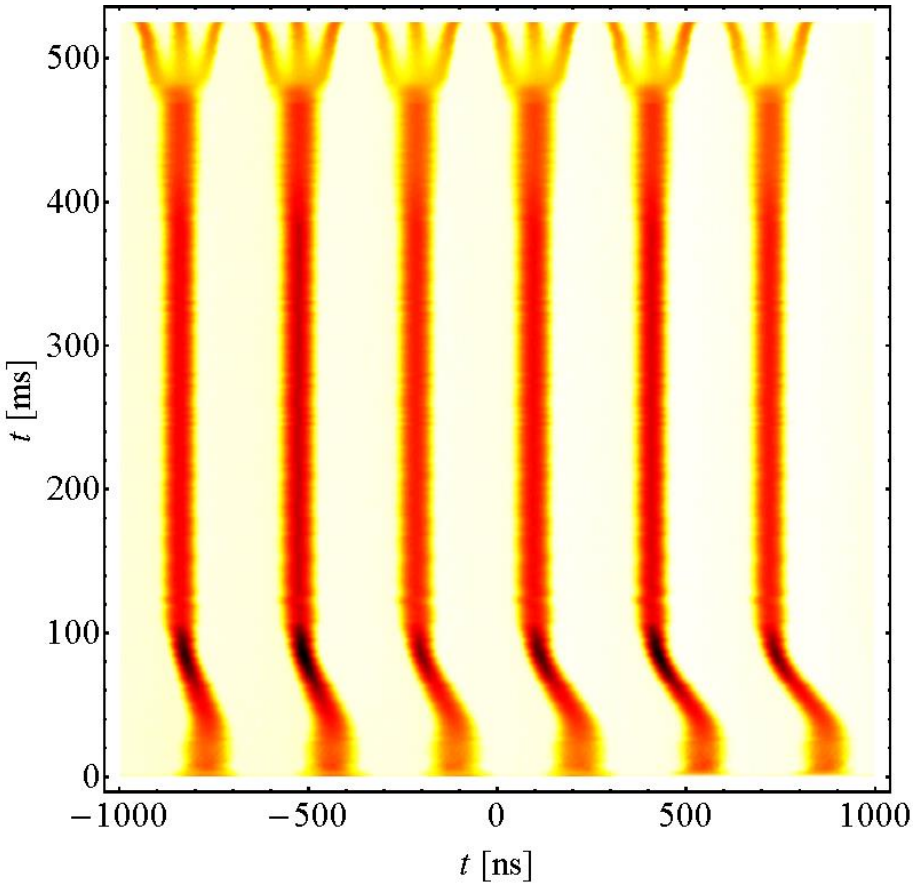
Reduced beta* and lower transverse beam sizes from the injectors compensating the lower number of bunches

Acknowledgements to Steve Hancock

Beam from injectors

Lower than nominal emittance taken a step further

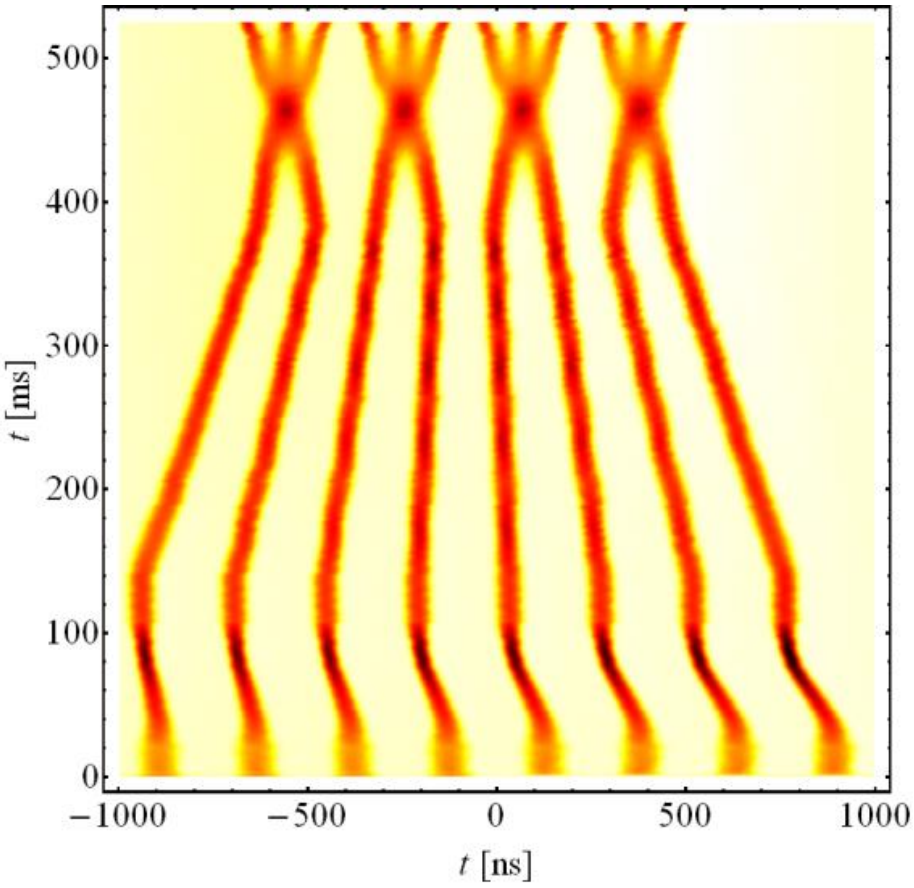
Standard 25 ns scheme



PS circumference

BCMS

(**B**atch **C**ompression, **M**erging & **S**plitting)



Lower intensity, **smaller** bunches from PSB

Good peak performance

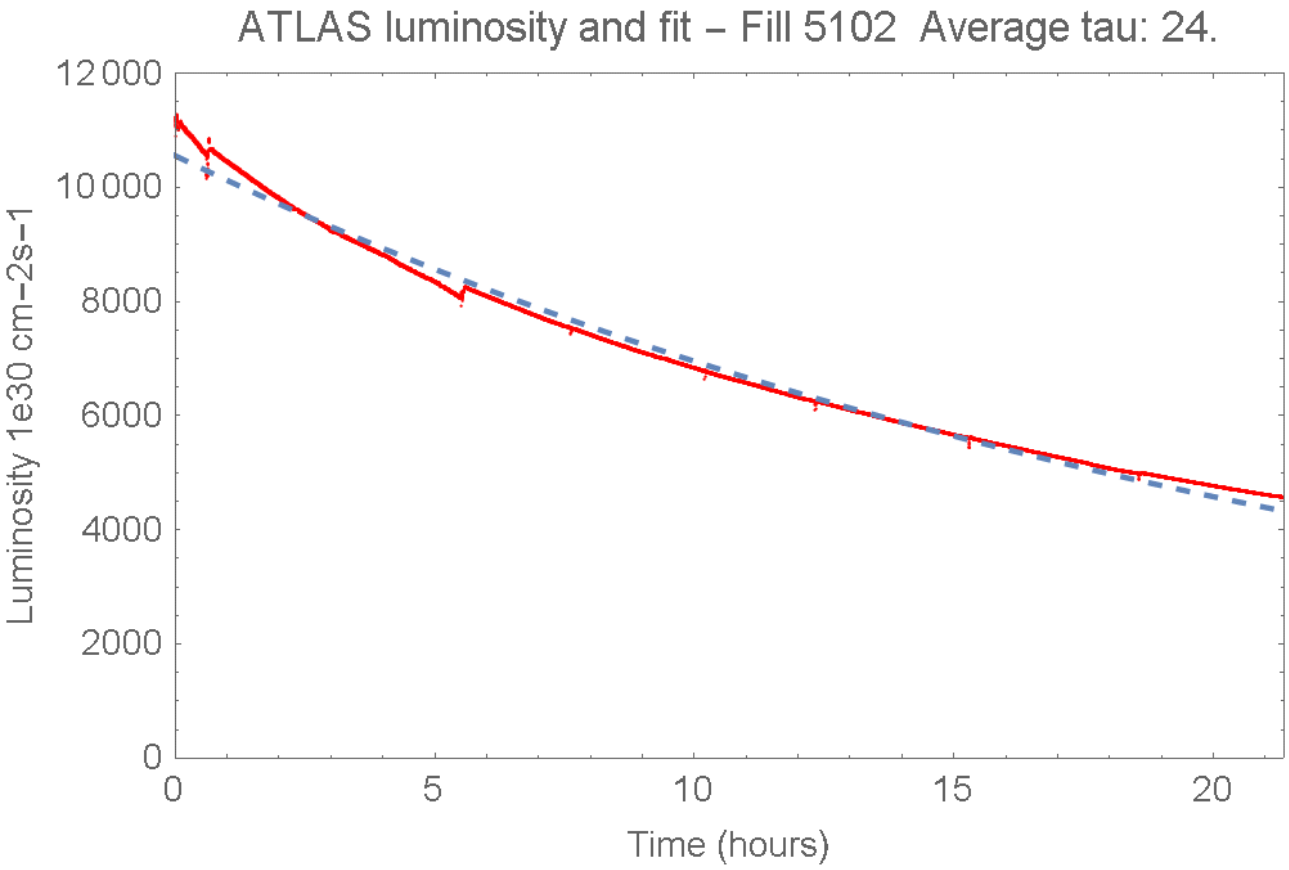
- Beta* = 40 cm
- BCMS
- Reduced crossing angle, bunch length
- Limited in number of bunches
- Limited in bunch intensity (injection kicker vac.)

Crossing angle reduced end September

X-angle [urad]	F
370	0.59
280	0.7

Bunch population	~1.1e11
Number of bunches	2220
Beta*	40 cm
Crossing angle	280 urad
Emittance (BCMS)	~2.0 um
Peak (CMS)	**~1.5e34 $cm^{-2}s^{-1}$**

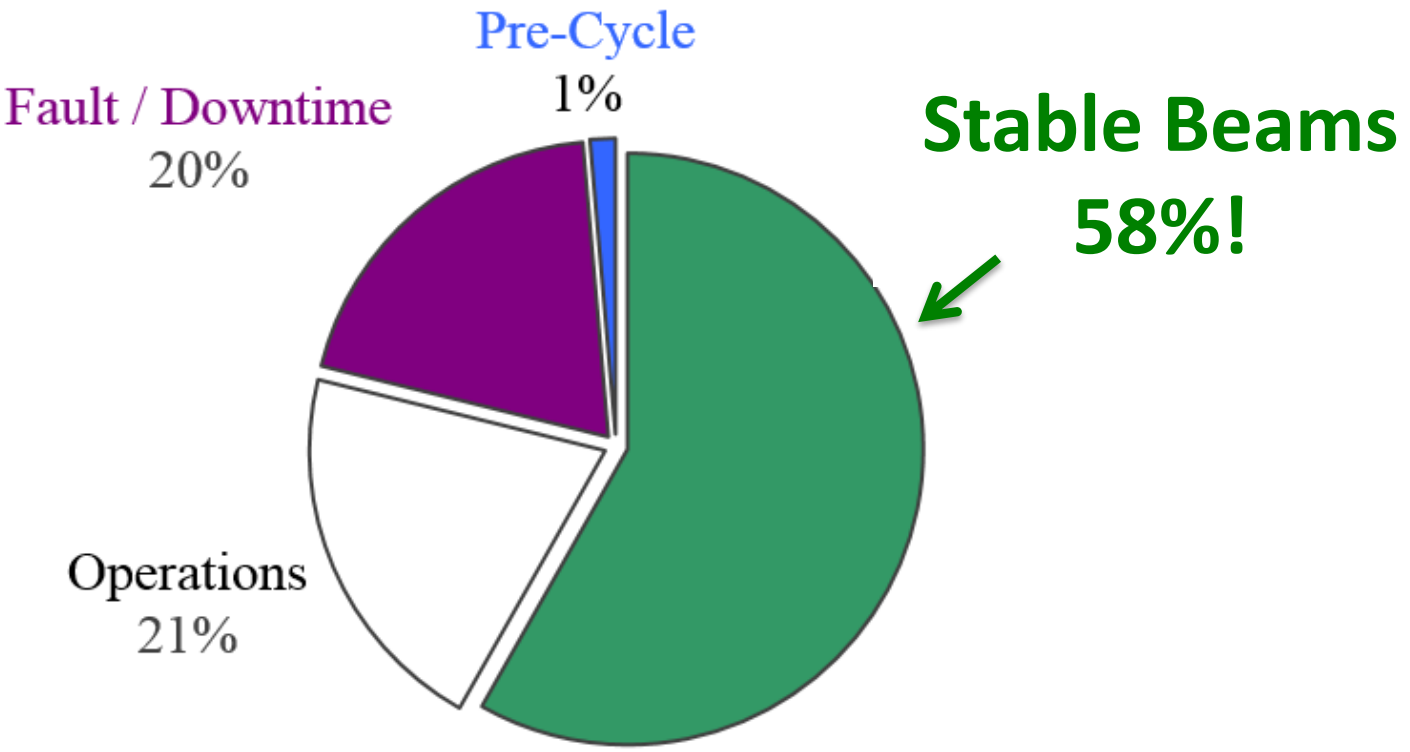
Luminosity lifetime



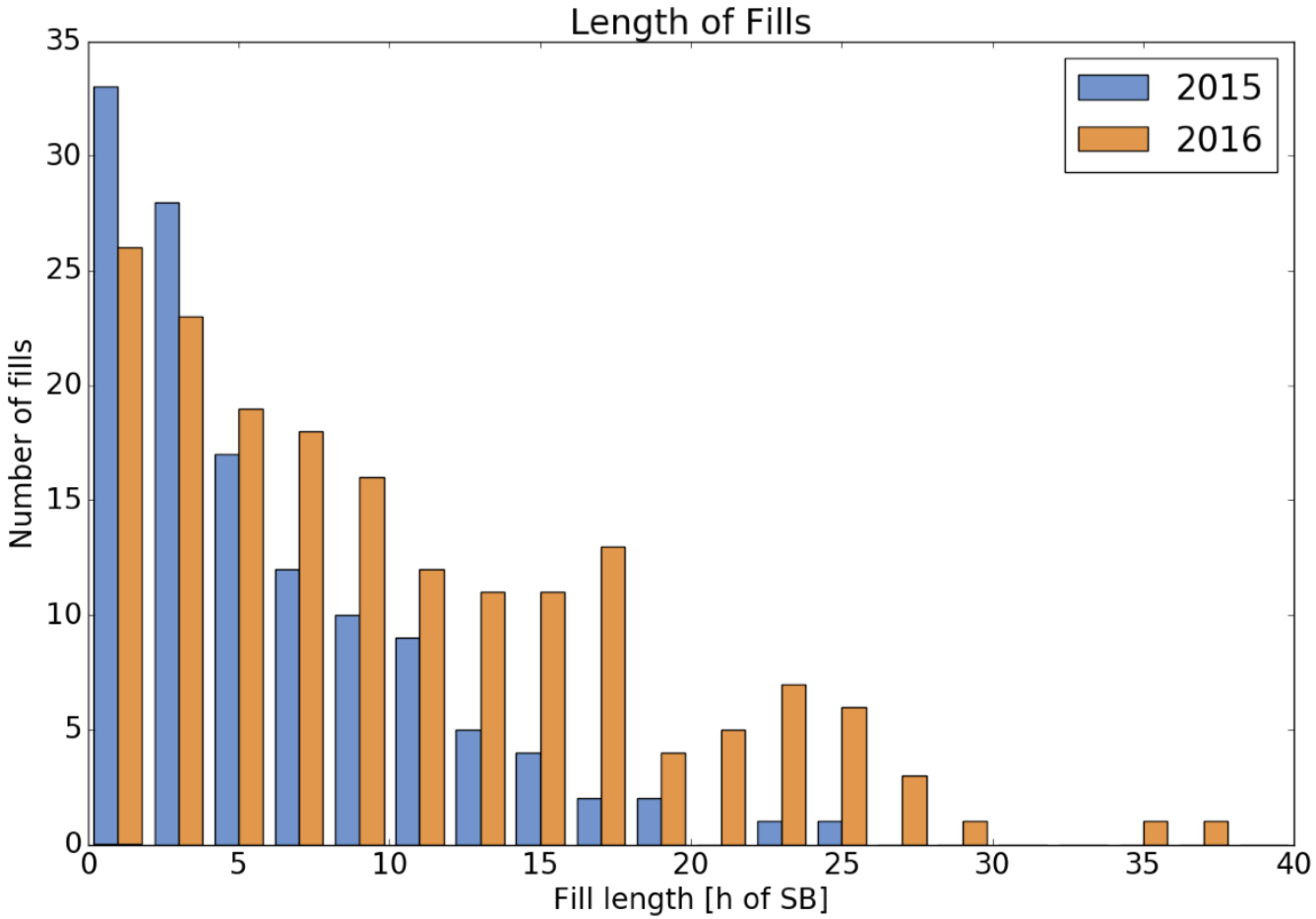
- Excellent luminosity lifetime – main component - proton loss to inelastic collisions in ATLAS, CMS and LHCb
- Enjoying effects of synchrotron radiation damping

Availability: 11th June – 8th September

79 days proton physics



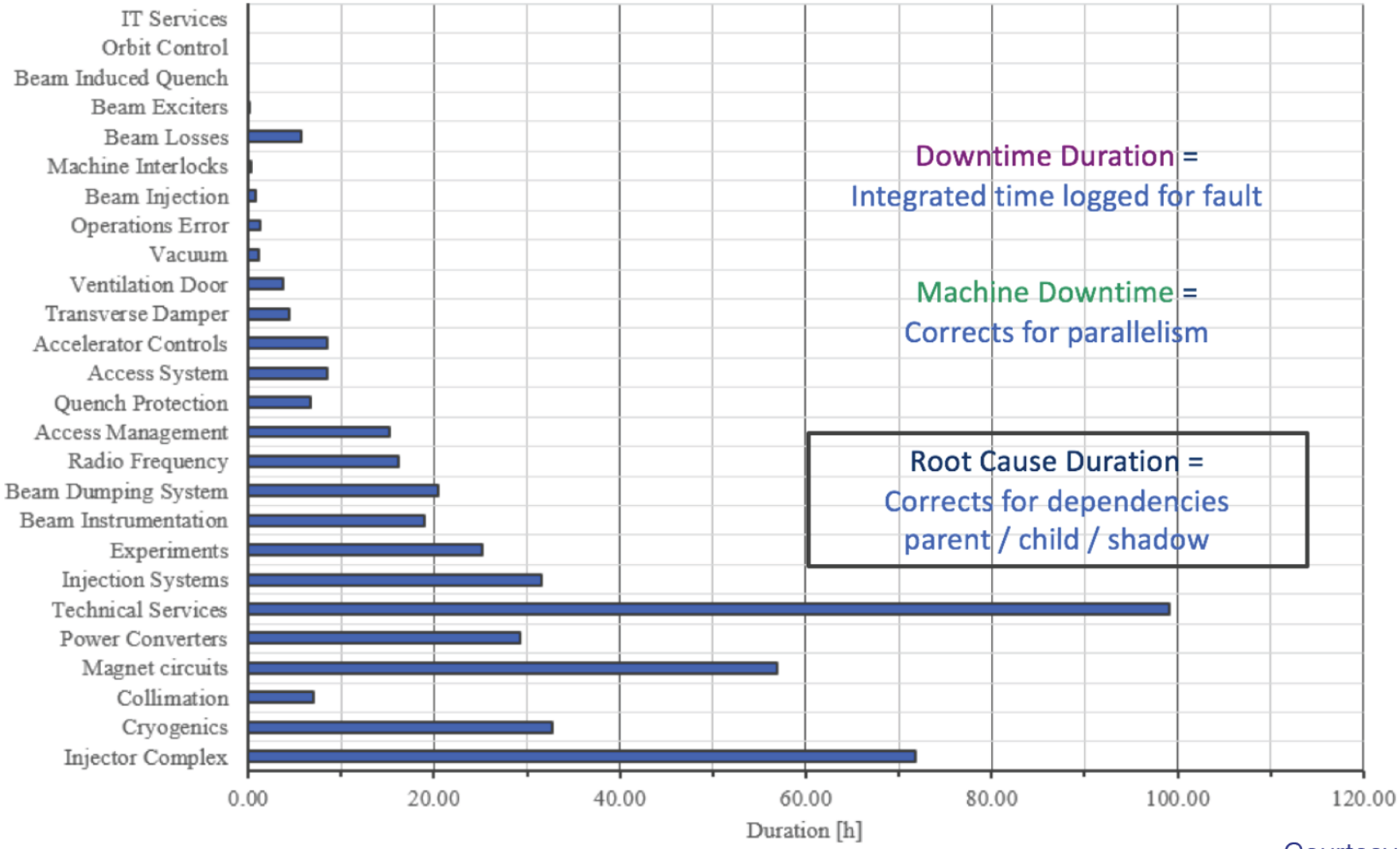
Premature dumps



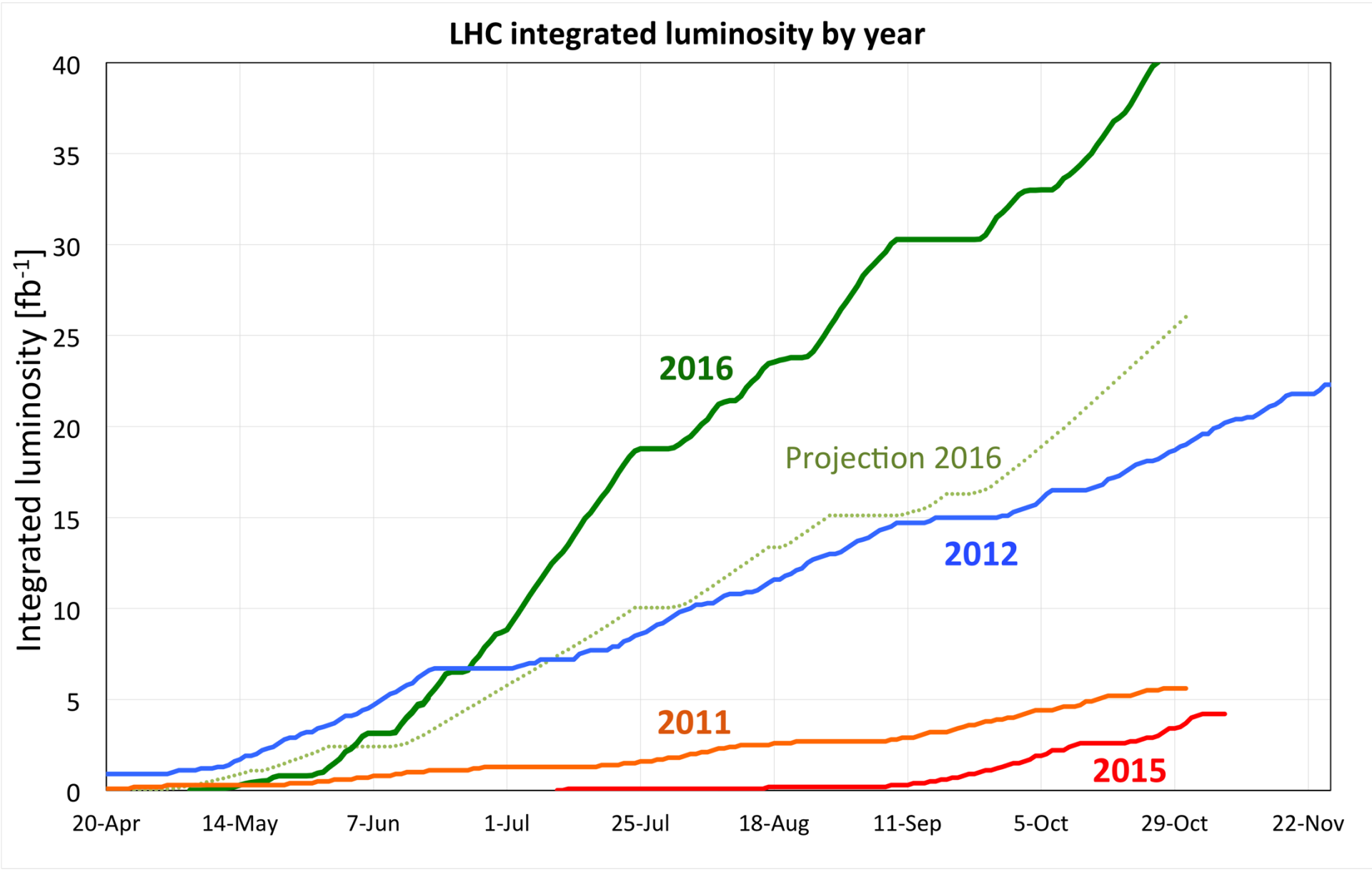
Almost half of the fills ended by operations

Start to worry about optimum fill length!

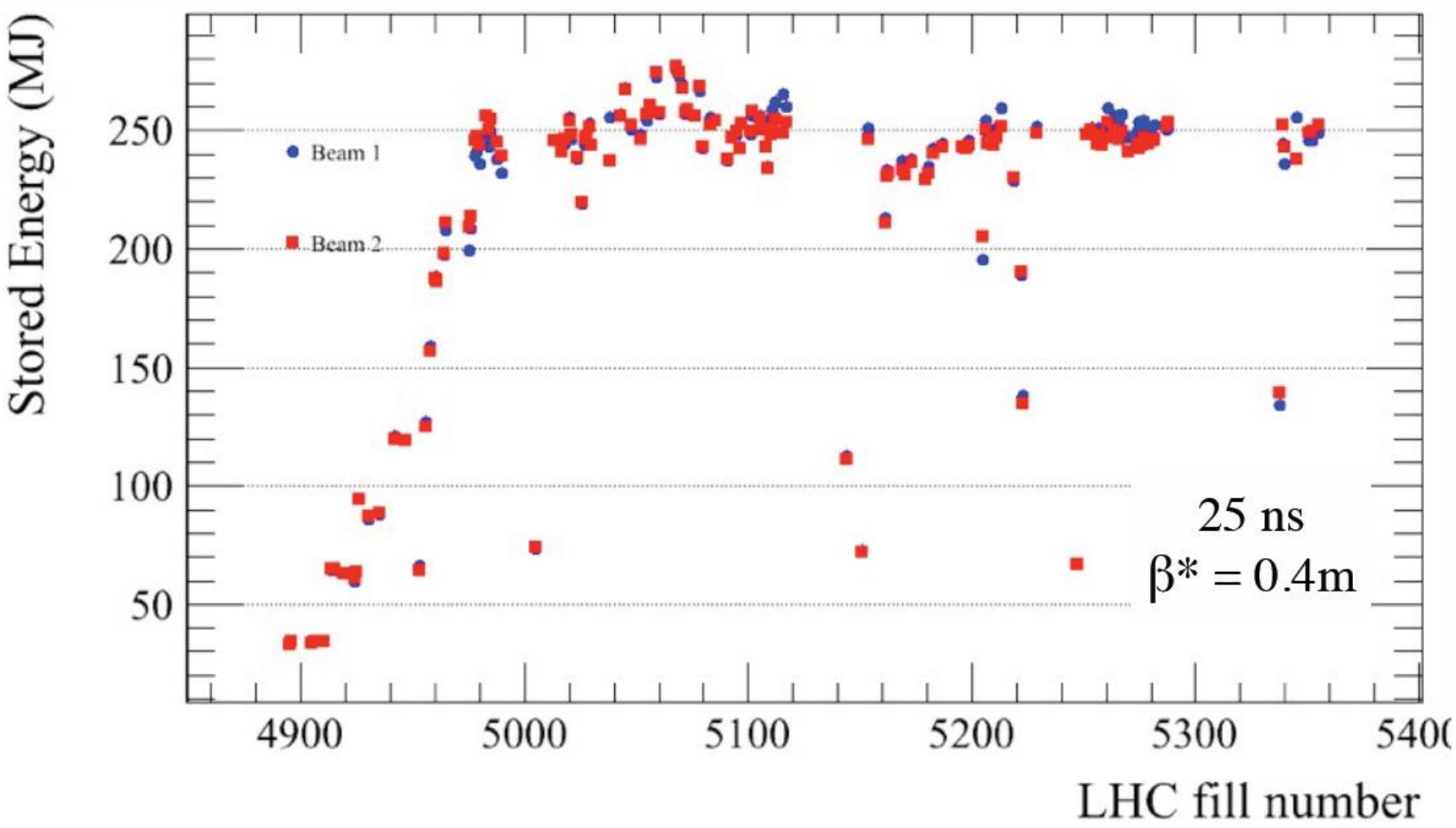
Fault analysis



Courtesy B. Todd


LHC integrated luminosity by year
Integrated luminosity [fb-1]
40
35
30
25
20
15
10
5
0
20-Apr
14-May
7-Jun
1-Jul
25-Jul
18-Aug
11-Sep
5-Oct
29-Oct
22-Nov
2016
Projection 2016
2012
2011
2015

This with > 250 MJ per beam

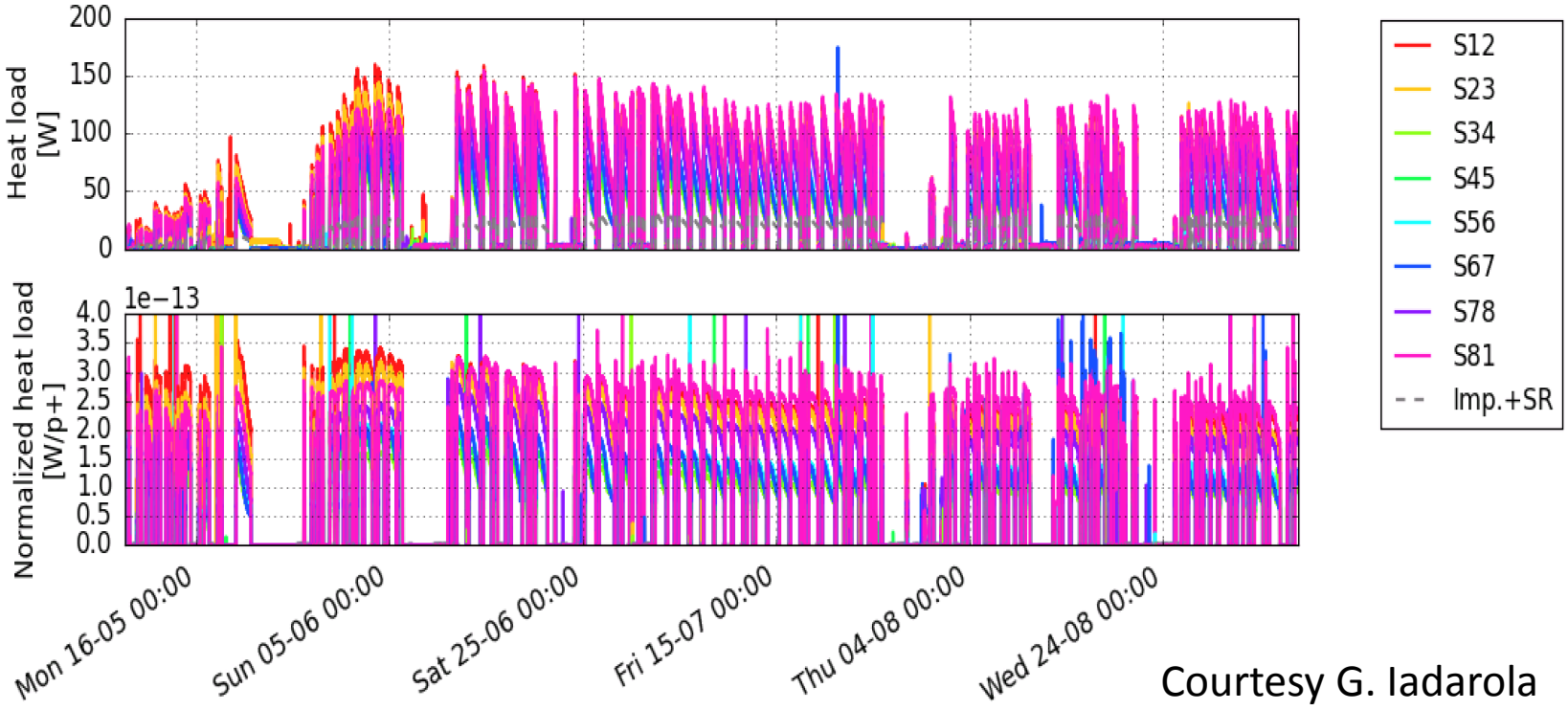


Operations underpinned by superb performance of the machine protection system

Limitations

- SPS beam-dump
  - No of bunches per injection limited to 96
  - Total number of bunches: 2200
- Injection kicker
  - Outgassing from ceramic connection (MKI8D-Q5)
  - Bunch population limited to around 1.1 x 10^{11}
- Electron cloud
  - Still significant heat-load within cryogenic limits
- UFOs
  - Frequency has happily conditioned down

Electron Cloud - Heat Loads

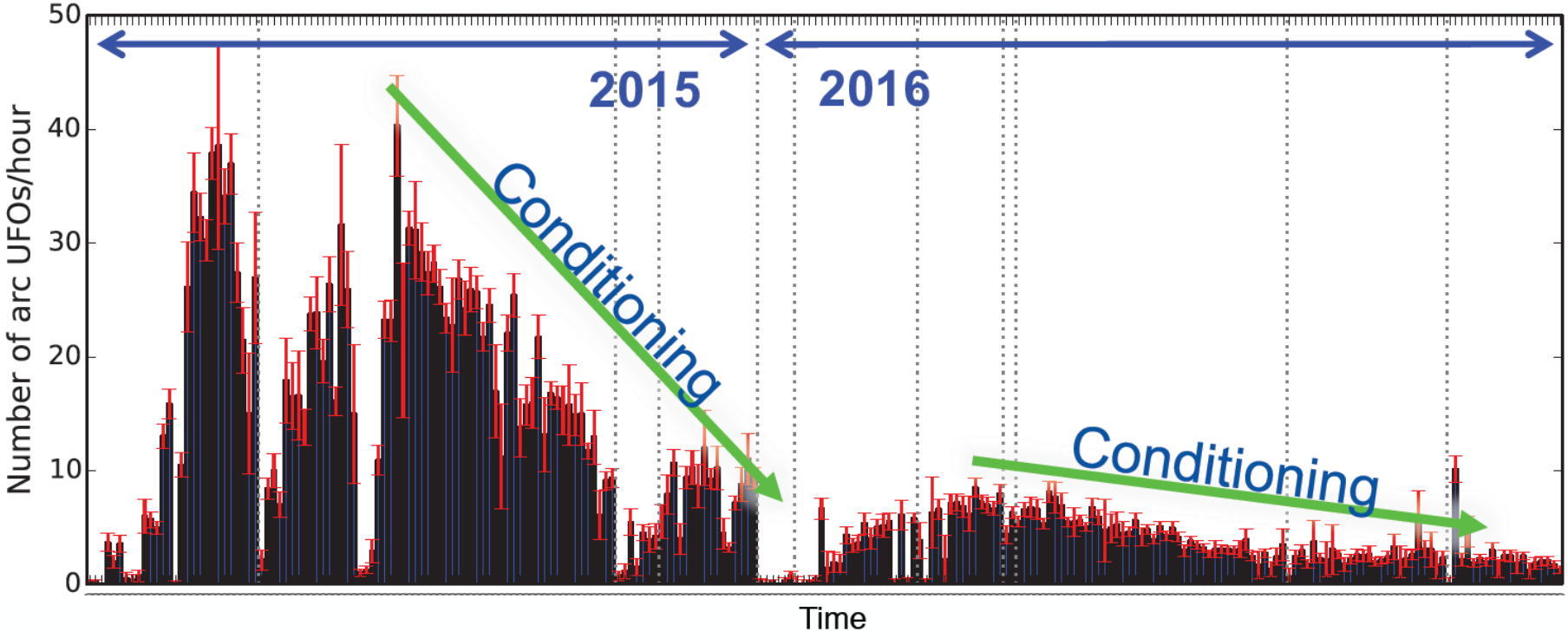


Courtesy G. Iadarola

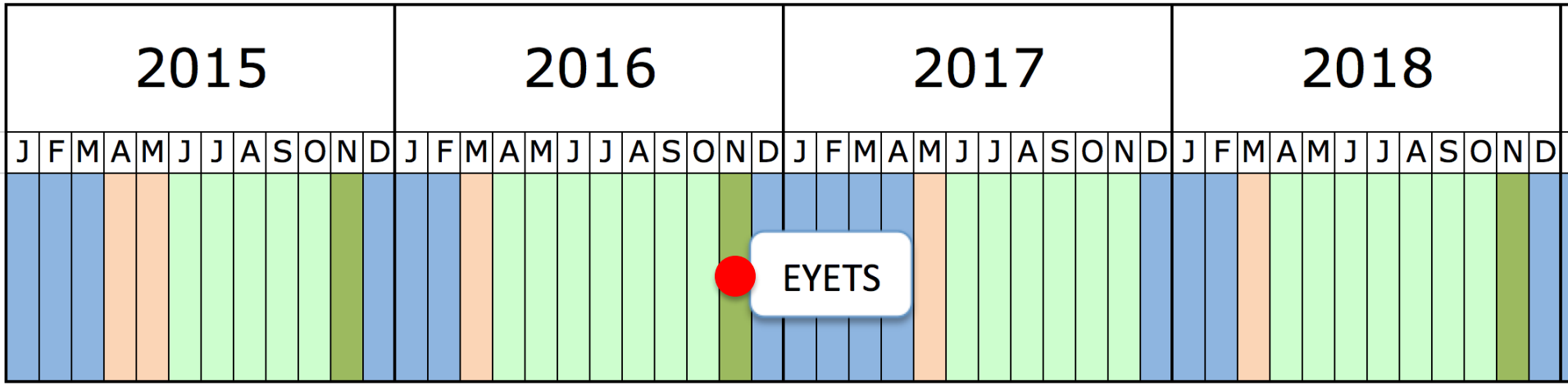
- Very slow electron cloud reduction despite significant doses
- Improved handling of dynamics by cryogenics
- Drives instabilities – running with high chromaticity, octupoles and damper gain to successfully counter

UFOs

- Clear conditioning effect
- Not known if conditioning will be lost after venting
- At the present rate UFOs are at a very acceptable rate



Run 2



Shutdown/Technical stop
Protons physics
Commissioning
Ions

Extended Year End Technical Stop – 20 weeks
- CMS pixel upgrade
- **dipole exchange in sector 12**

Complementary objectives:

- Prepare for HL-LHC and post-LS2 LIU era
- Prepare for 7 TeV operation - operation at over 6.5 TeV in 2018 being explored – see Chamonix

Main Options 2017

- Optics
  - ATS versus nominal
  - From a performance perspective nothing to choose between them (beta*, squeeze length etc.)
  - Might worry about commissioning time – strategic choice
- Squeeze
  - 40 cm or lower (33 cm seems popular)
  - Luminosity levelling options being explored
- Nominal 25 ns versus BCMS

Limits from SPS beam dump and LHC injection kicker vacuum should be lifted

Possible 2017/18 parameters

	Nominal	BCMS	BCMS+
Beta* (1/5) [cm]	40	40	33
Half crossing angle [urad]	185	155	170
No. of colliding bunches	2736	2448	2448
Proton per bunch	1.25e11	1.25e11	1.25e11
Emittance into SB [um]	3.2	2.3	2.3
Bunch length [ns]	1.05	1.05	1.05
Peak luminosity [$cm^{-2}s^{-1}$]	**~1.4e34**	**~1.7e34**	**~1.9e34**
Peak pile-up	~37	~51	~56
Luminosity lifetime [h]	~21	~15	~14

Naively applying 2016's overall Hübner factor gives between 45 and 60 fb^{-1}

Final configuration following discussion at Evian and Chamonix

Machine status - summary

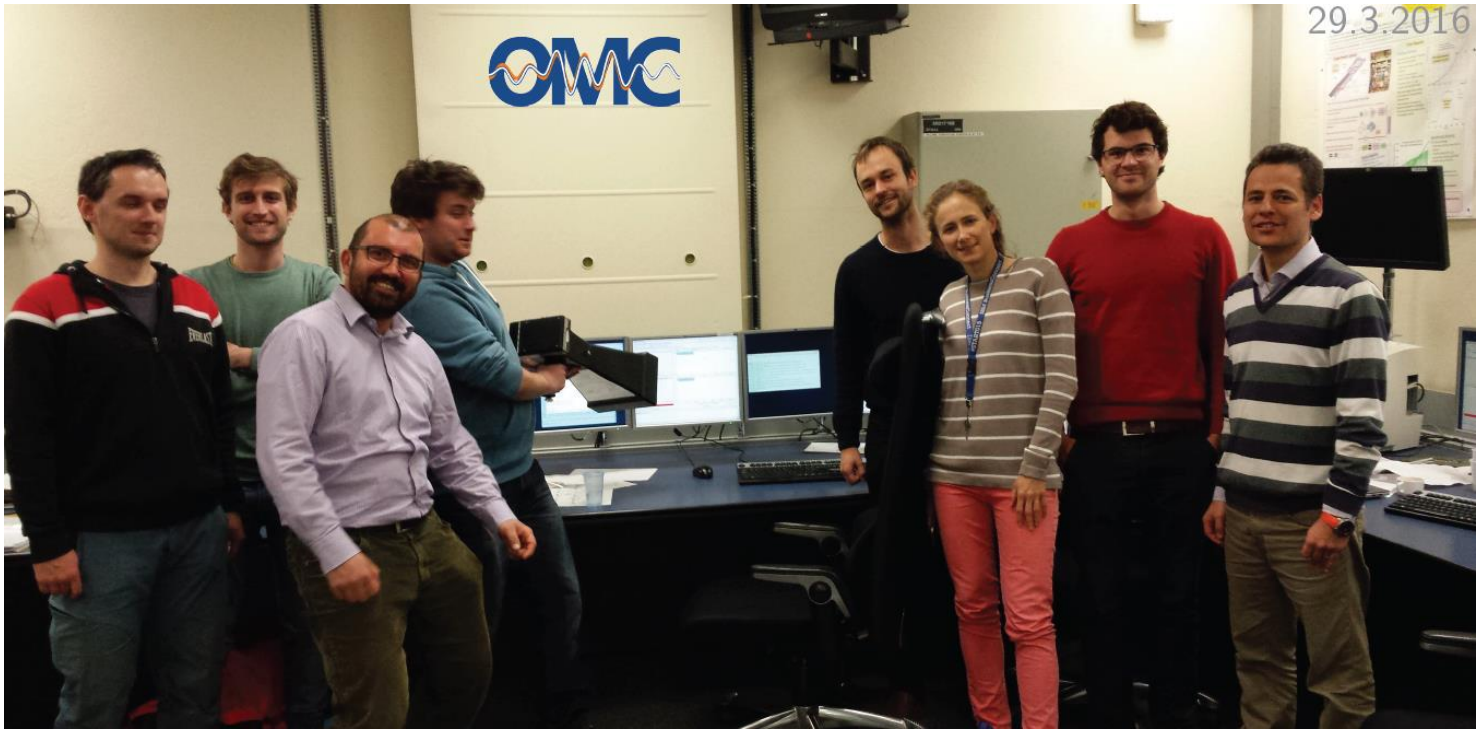
- Excellent and improved system performance
- Magnets behaving well at 6.5 TeV
- Good beam lifetime through the cycle
- Operationally things well under control
- Magnetically reproducible as ever
- Optically good, corrected to excellent
- Aperture is fine and compatible with the collimation hierarchy.
- Collimation can take anything that's thrown at it

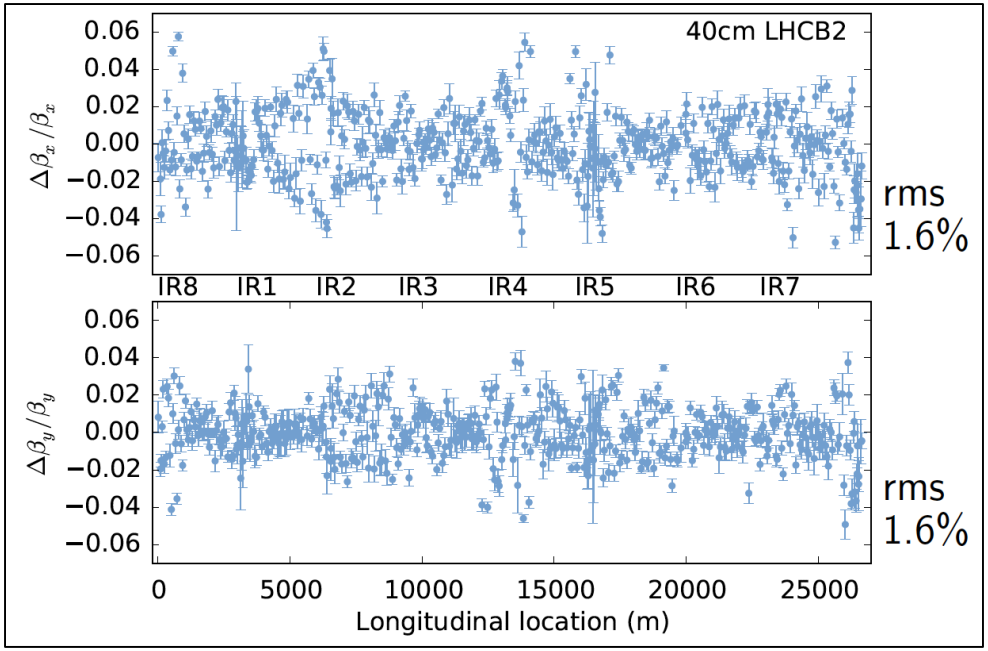
Conclusions

- **Reasonable peak performance**
  - Well above design luminosity (squeeze, beams from injectors)
  - Still margin for improvement in Run 2
- **Good integrated delivery**
  - Excellent availability (normal caveats apply)
  - Electron cloud conditioning slowly
  - Fortunate that UFOs have conditioned down

Interesting to note that a machine of this complexity with such a challenging operational regime can work pretty well!

Looking good	Keep an eye on
Availability and R2E	Electron cloud
Injectors	Instabilities
Optics	Losses at start of fill
Magnet model, magnets at 6.5 TeV	Beam-beam, DA
Aperture	Emittance growth
Reproducibility, stability	Earth faults
Nominal cycle++, turn-around	Robustness of protection devices
Losses through cycle	
Machine protection, QPS	
ADT, RF, Power converters	
Beam instrumentation, feedbacks	
Collimation, beam cleaning	
LBDS, Injection	
Cryogenics	
Vacuum, UFOs, Beam induced heating	





2016: 1% rms beta-beating, C- of 0.0002 and lot more to celebrate!

ADT offers a complete solution for virtually any measurements in the transverse plane across the whole machine:

- Excitation synchronous with the beam
- Can target anything from individual bunches within a 25ns train to a full turn
- Coherent excitation by sin/cos and modulated sin/cos signals
- Noise-like signals, ADT-AC dipole, DC dipolar kick, skipping turns
- Excitation strength from very gentle to very powerful
- A dedicated bunch by bunch observation system (ADTObsBox)
- Machine-wide synchronization and triggering through timings or instability trigger network

```
0.4 ADT gain
exciting again 6 trains = 144 bunches

last point before dump on the power load 14.7 kW

~steady state power load estimated: 12.4 kW

Quench!
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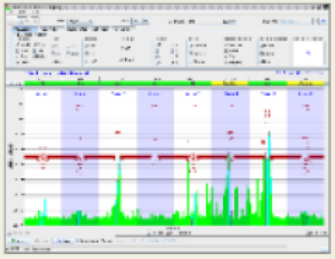

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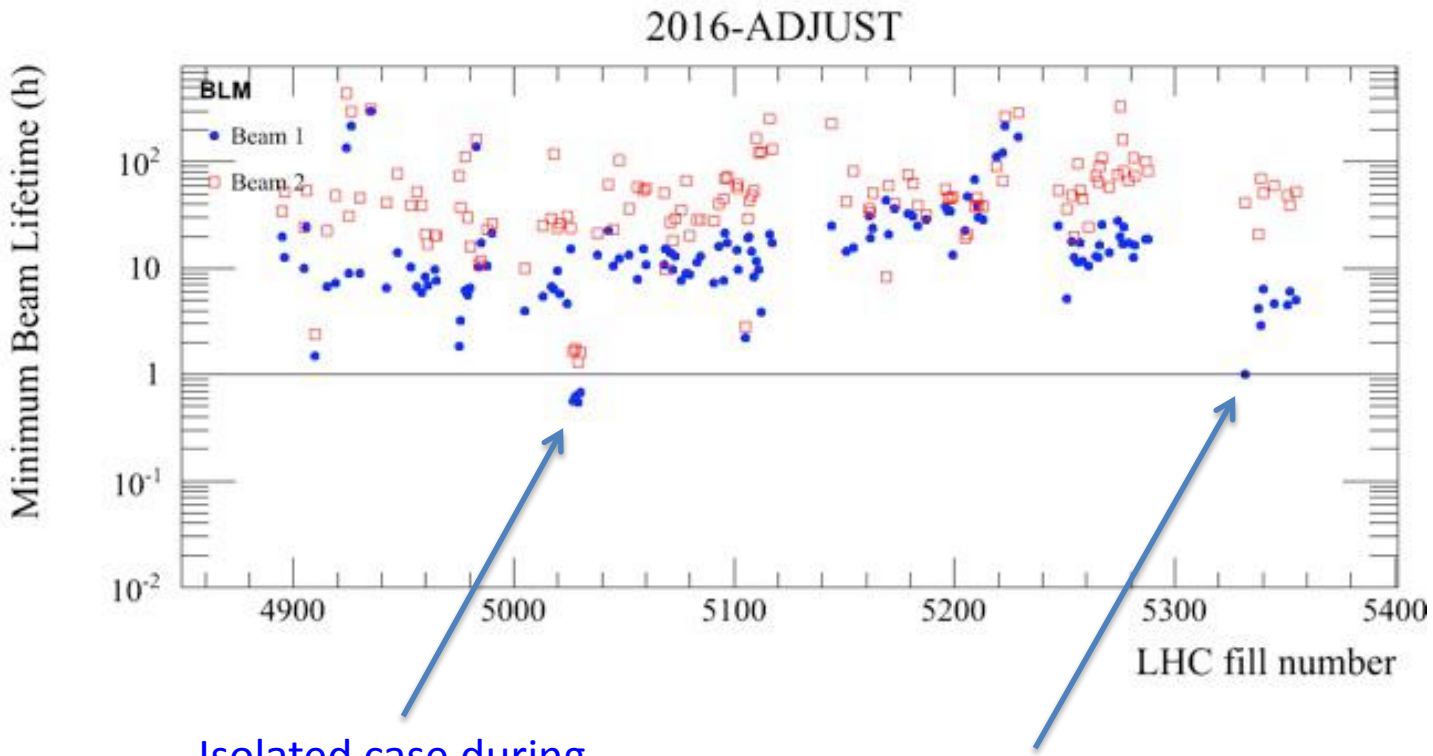
desc:

Courtesy Daniel Valuch

Lifetime

Lifetime very good in Run 2. Not clear how to scale to HL-LHC.

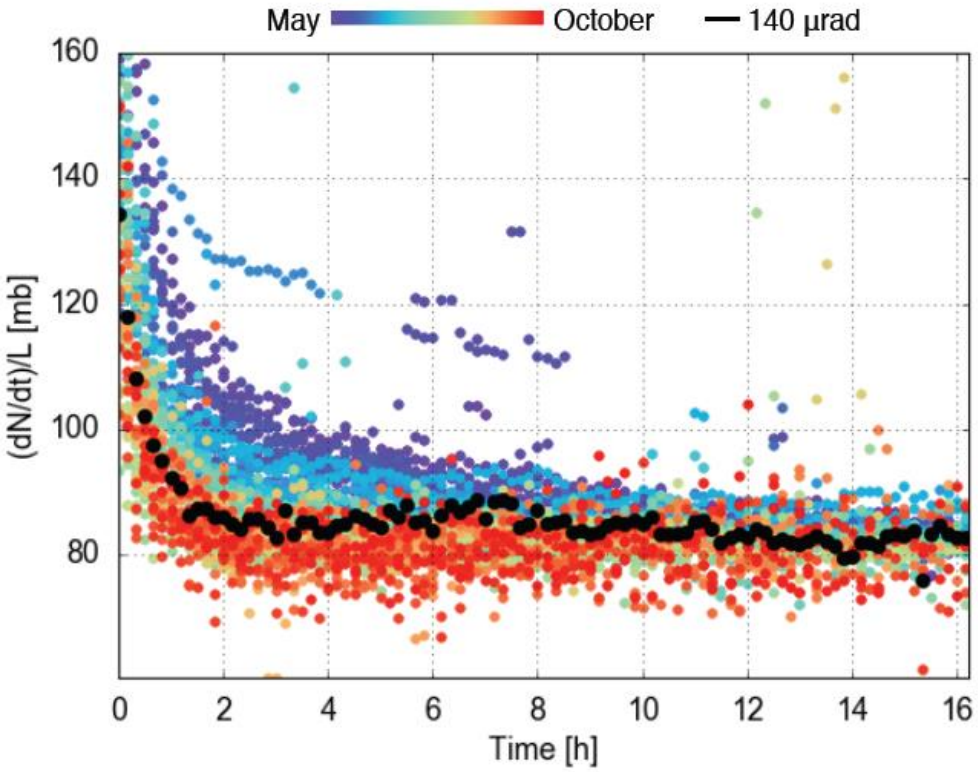


Isolated case during intensity ramp up

After reduction of crossing angle. Mitigation deployed

Belen

Lifetime in Stable Beams



Courtesy
F.Antoniou, G. Iadarola, Y.Papaphilippou

NB first hour – was worse with higher bunch population in 2012