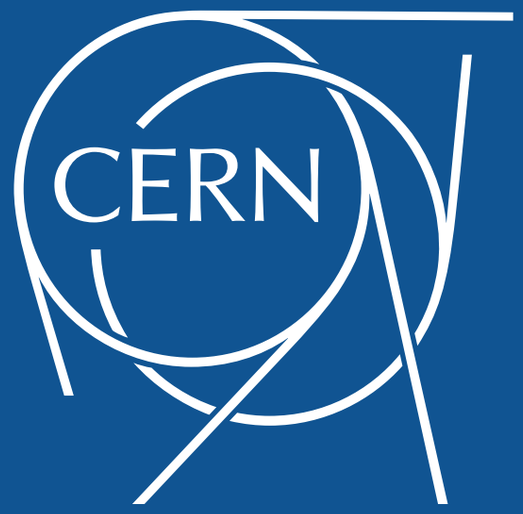

CERN

Status and Outlook of the LHC

Enrico Bravin - CERN BE/BI
for the LHC team

2016 Annual US LHC Users Association Meeting
2-4 November 2016
Lawrence Berkeley National Laboratory

Outline

- Objectives for 2016 and run2
- Parameters for 2016 and differences w.r.t. 2015
- Summary of commissioning and operation
- Performance and achievements
- Peek at 2017 and 2018

Objectives for Run 2

- Run 2 main objective: 100 fb^{-1} p-p for ATLAS and CMS at $E_{cm} \geq 13TeV$

- 2015: Recommission the machine after LS1 at E_{beam}= 6.5TeV. Target 5 fb^{-1}

- 2016: p-p production + Pb-p run. Target p-p 25 fb^{-1}

- 2017-2018: p-p (+ HI in 2018). Target p-p 35 fb^{-1}/y

Changes 2015 → 2016

$$L = \frac{N_b^2 f_{rev} k_b}{4\pi \varepsilon \beta^*} \cdot \frac{1}{\sqrt{1 + \left(\frac{\phi_{xing}\sigma_s}{2\sigma_{xing}}\right)^2}}$$

- New combined ramp & squeeze→ shorter cycle
- Better handling of e-cloud effects→ mitigate transients,
- Changed BLM thresholds → minimise dumps due to UFOs
- Smaller beta* from 80cm to 40cm → higher luminosity
- BCMS beams → smaller transverse emittances → higher luminosity
- Reduced crossing angle 185 μrad → 140 μrad (1/2 angle)

Commissioning milestones

YETS - Many interventions on many systems

Ended on March 4

Powering tests

Start March 4
End March 21

HW check out

BIS loop closed March 23

Low intensity injection

First beam March 25

Low intensity combined ramp and squeeze

First CR&S March 26

Low intensity squeeze

First squeeze March 26

Corrections of Optics, Q, Q`, C-

Nominal intensity

Started operation with nominals March 29

Injection

Combined ramp and squeeze

CR&S on April 6

Squeeze

First collisions

First collisions April 8

Collimators setup

First stable beams

April 23 3b+3b
April 24 12b+12b

Bunch trains injection

72b April 21

Physics
Intensity ramp-up

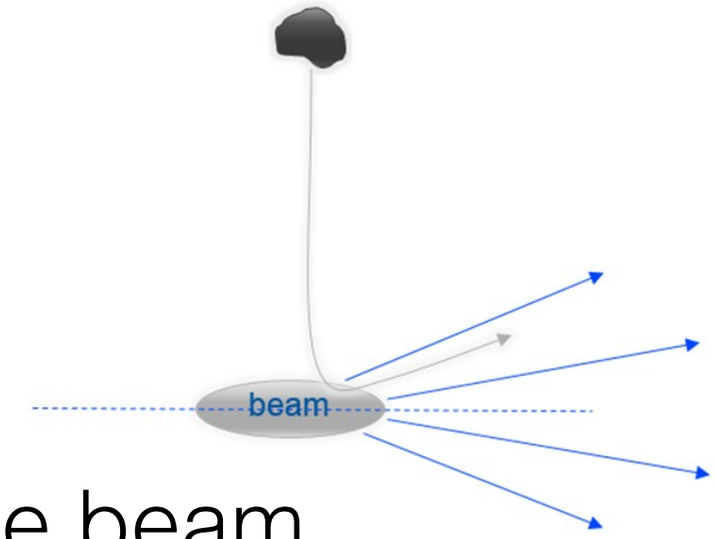
2040b June 1

Included special bump in IP5 to increase dispersion in TOTEM

Possible performance limitations

- Unidentified laying object (ULO)
  - Reduces available aperture
- Unidentified falling objects (UFO)
  - Trigger beam dumps and magnet quenches
- Electron cloud
  - Limits number of bunches (vacuum, thermal load)
  - Instabilities: losses, degraded beam quality
- Hardware faults rate
  - Fault tracking tools (identify critical systems)
  - Consolidations (using fault tracking as input)
  - R2E project (SEU almost gone)

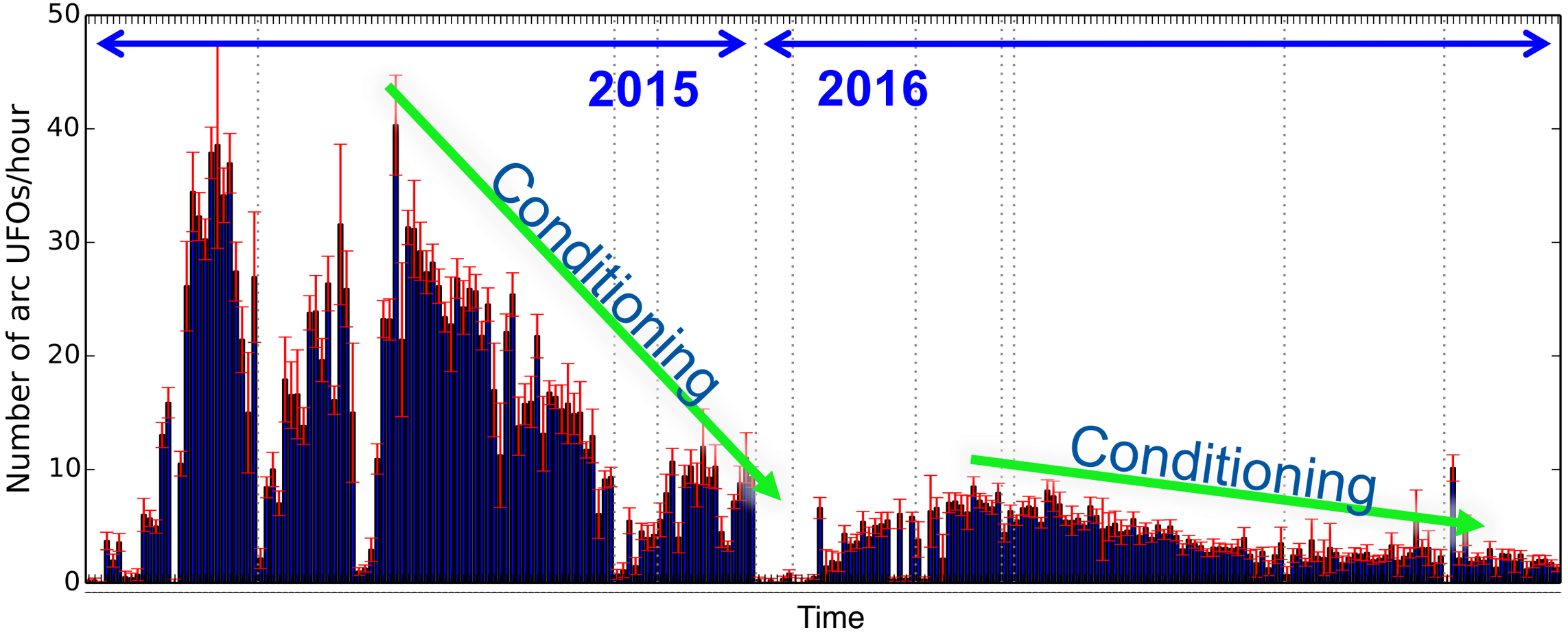
UFOs



- Small particles (~10μm) falling onto the beam generating showers
- Source and mechanism not fully understood yet
- **2015**: 21 UFO-related dumps, including 3 quenches (ULO events not included)
- In 2016 increased threshold of BLMs
  - Expected increase of UFO-induced quenches (~+1)
  - Expected decrease of UFO-induced dumps(~-10)
- **2016**: 20 UFO-related dumps including 3 quenches

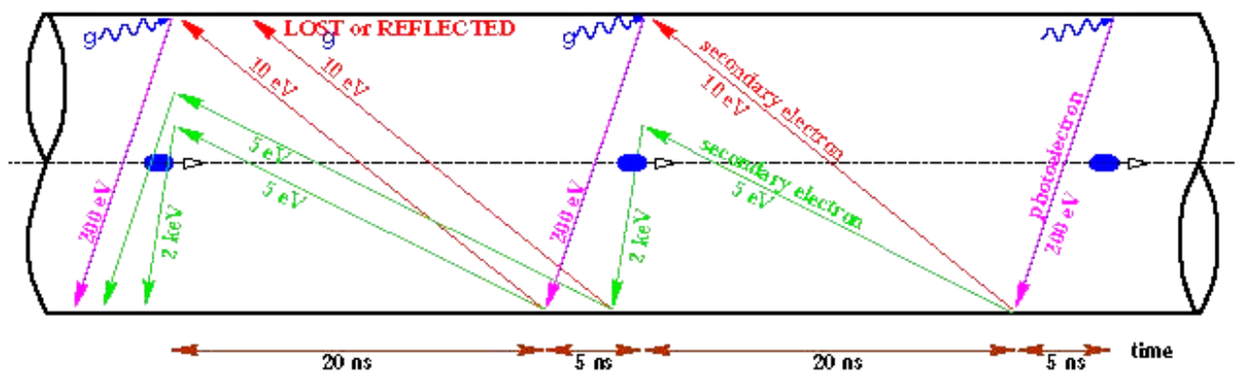
Evolution of UFOs

- There is a clear conditioning effect
- Not known if conditioning will be lost after venting
- At the present rate UFOs are under control



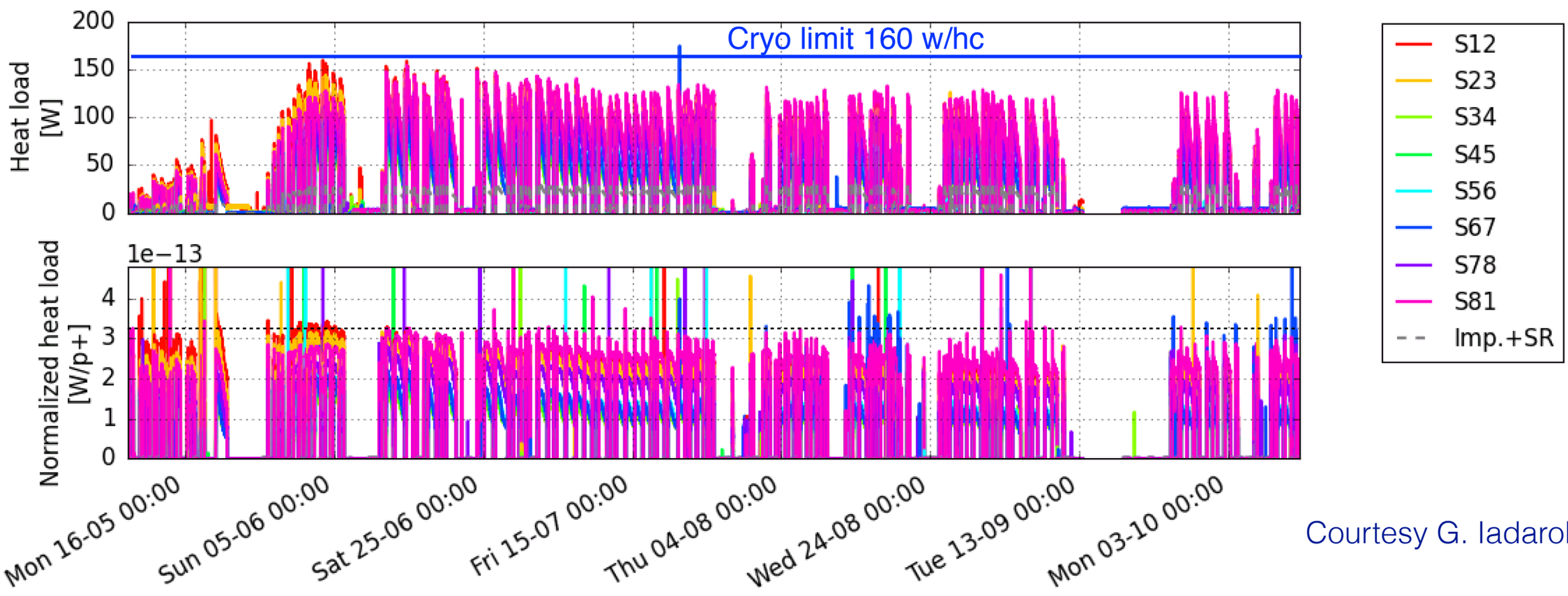
Electron cloud

- Electron liberated on the vacuum chamber are accelerated by the p+ beam
- Accelerated electrons impact on the vacuum chamber liberating more electrons
- If the SEY is high, and the bunch spacing short, it turns into an avalanche producing heat load on the cold beam screens and trigger beam instabilities
- electron bombardment reduces the SEY (scrubbing)



e-cloud in 2016

Modest effects of e-cloud during 2016 due to the limitation in bunch current and short batches

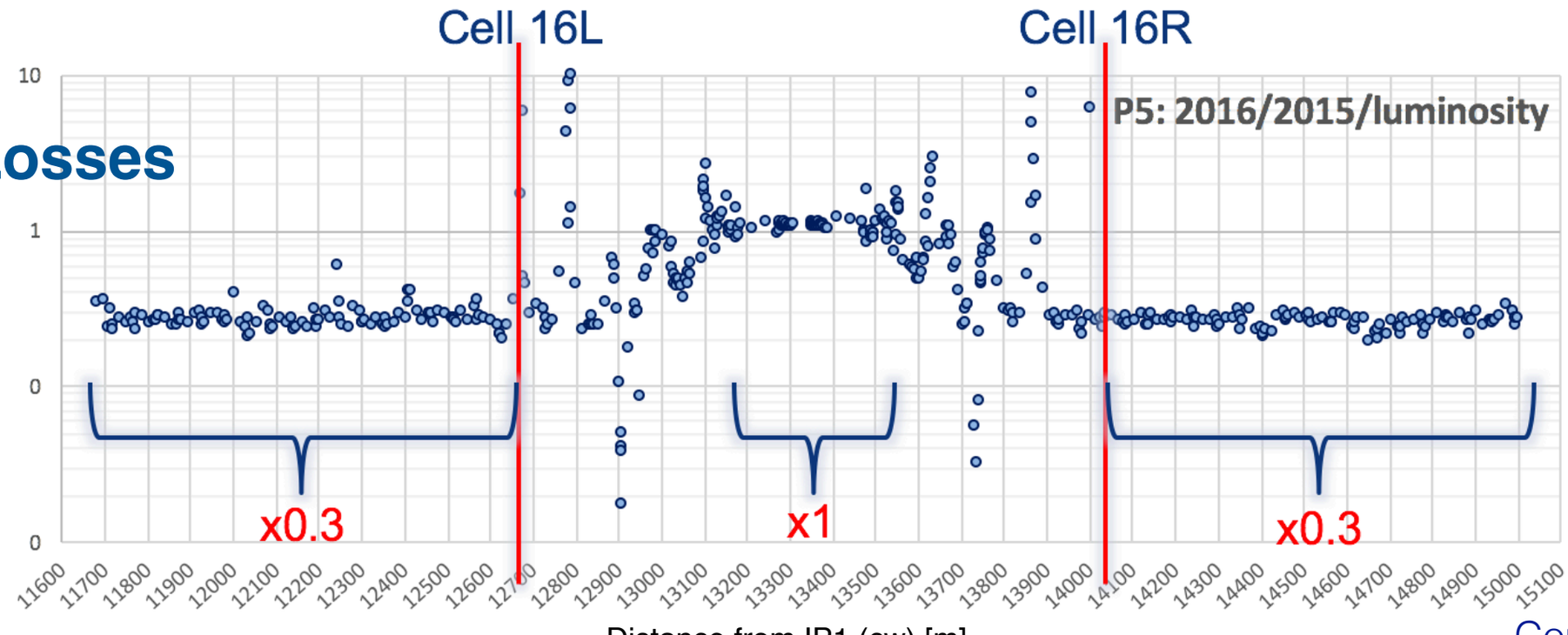


Courtesy G. Iadarola

Radiation effects

Equipment	Dumps 2015 (After TS2)	dumps 2016 35fb-1 (Expected)	dumps 2016 20fb-1 (22.07)
QPS	3	0-5	0
Power Converter	3	~13	2
Cryo	0	0	0
EN/EL	0	0	0
TE/ABT	0	0	1*
Vacuum	0	0	0
Collimation	0	0	0
RF	4**	0	0

Beam Losses



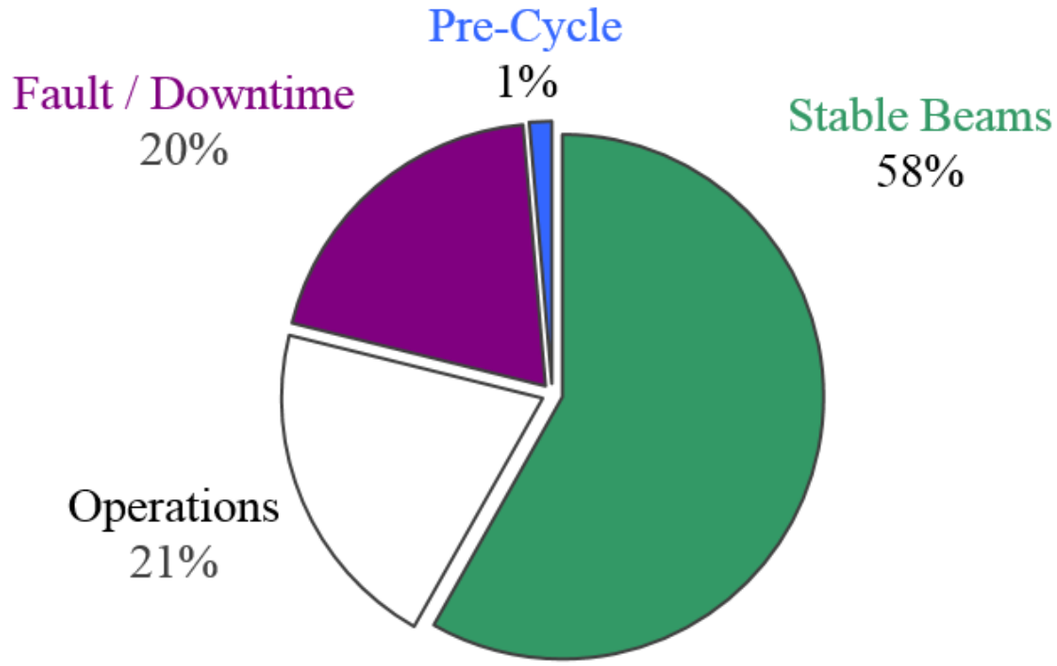
Courtesy S. Danzeca

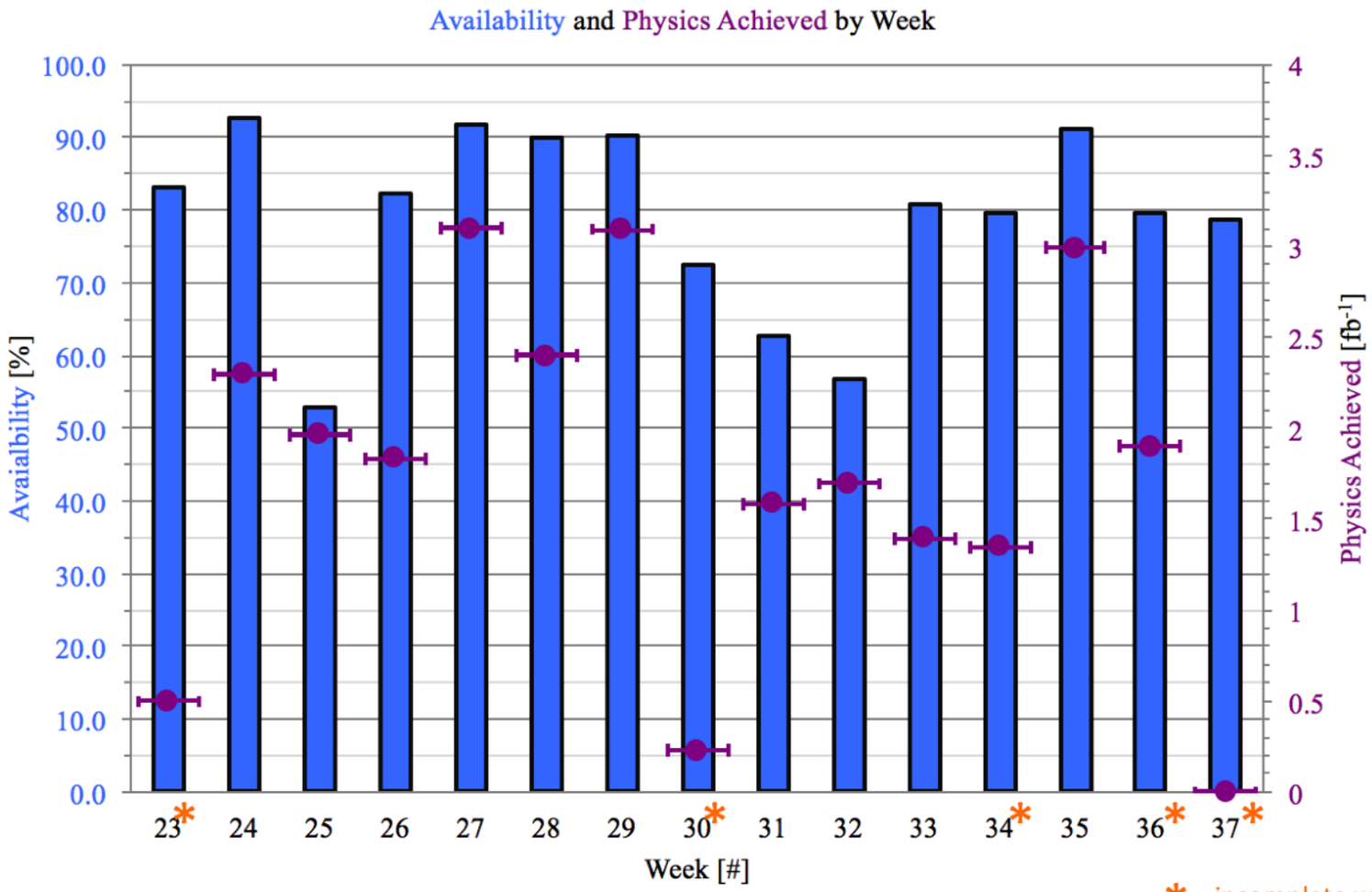
Availability

6 June → 18 September

Excellent availability!

Almost 50% of fills dumped by OP



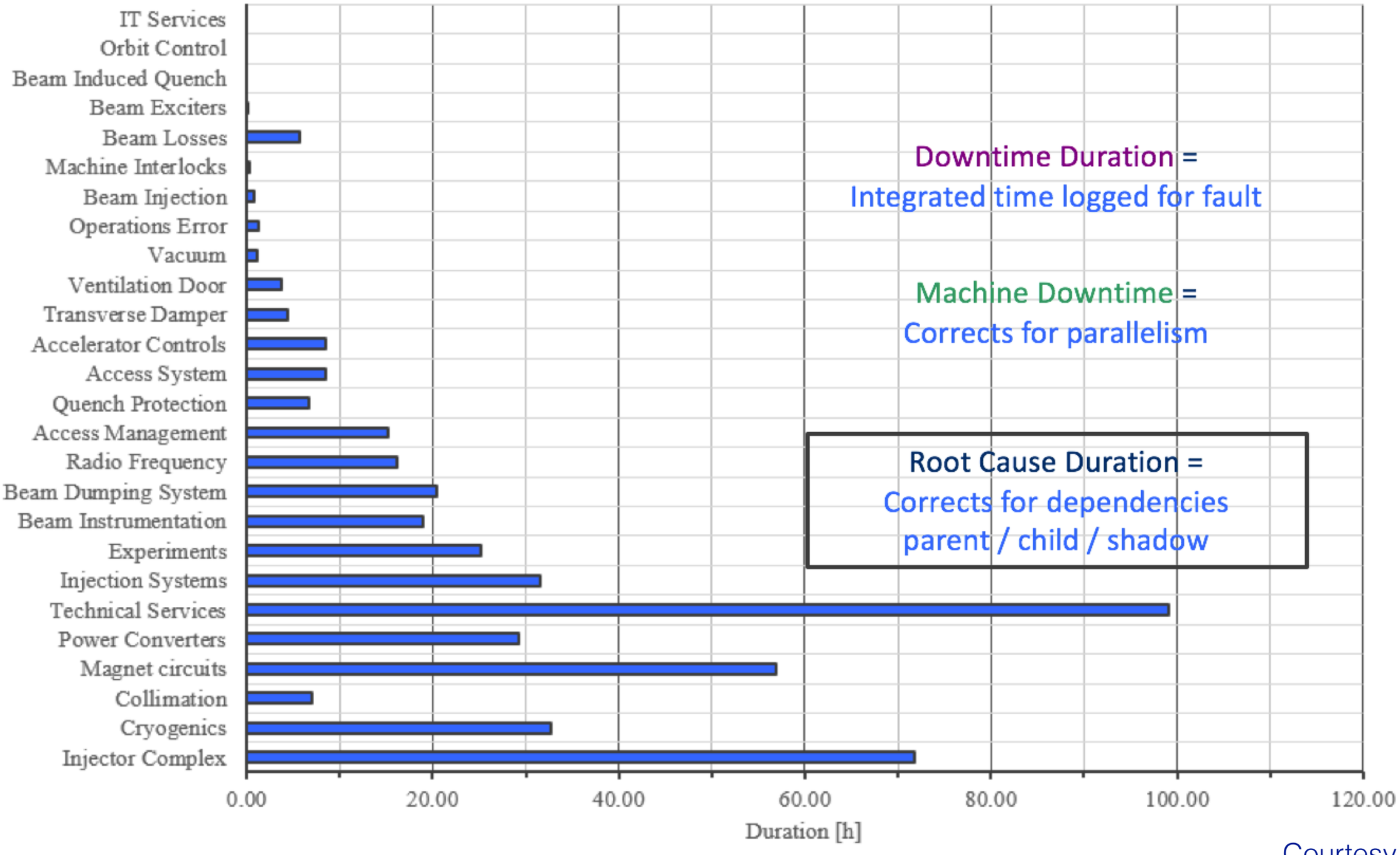


Mode	Duration [h]
Stable Beams	1112.0
Operations	384.6
Fault / Downtime	377.5
Pre-Cycle	26.4
Total	1910.5

79 days physics ≈ 1910.5 hours

Courtesy B. Todd

Fault analysis

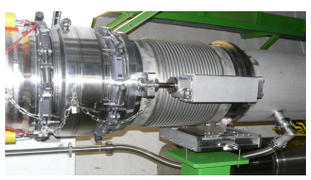


Courtesy B. Todd

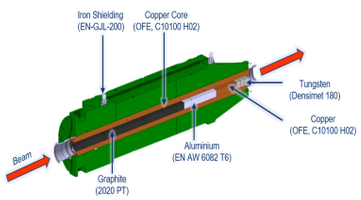
Other limitations in 2016

- Start of the run affected by few important faults
- Some generated long downtimes
  - 66kV transformer IP8, POPS, PS MPS, water flooding Pt.3
- Some imposed limitations throughout the year
  - LHC dump B1 N_2 leak (in the shadow of other limitations)
  - SPS internal dump (TIDVG) (no 144b/288b trains, max 2040b/2220b)
  - Bad vacuum around injection kicker of B2
    - max total current for B2 limited to ~2.4E14p (e-cloud)

14 April - LHC dump B1



25 April - SPS dump



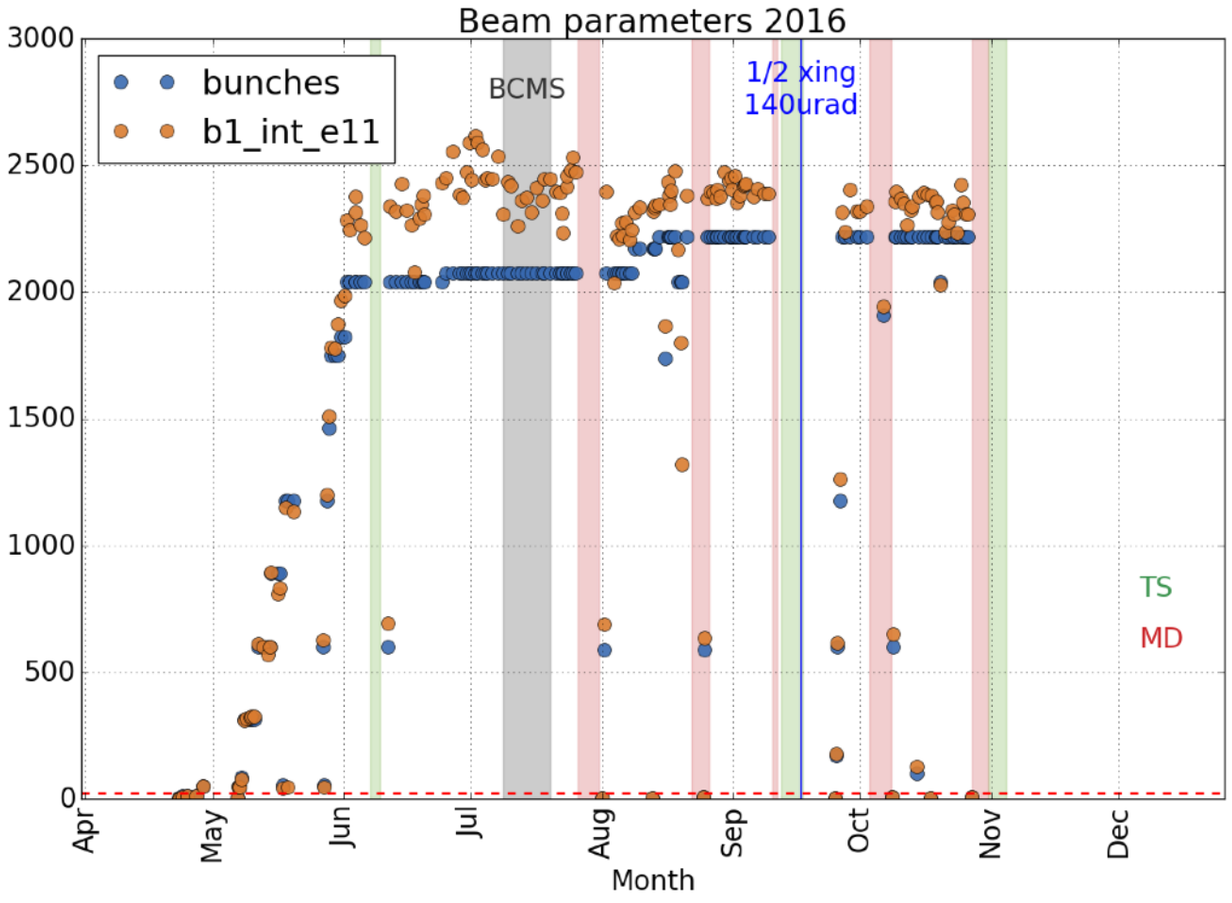
27 April – POPS down

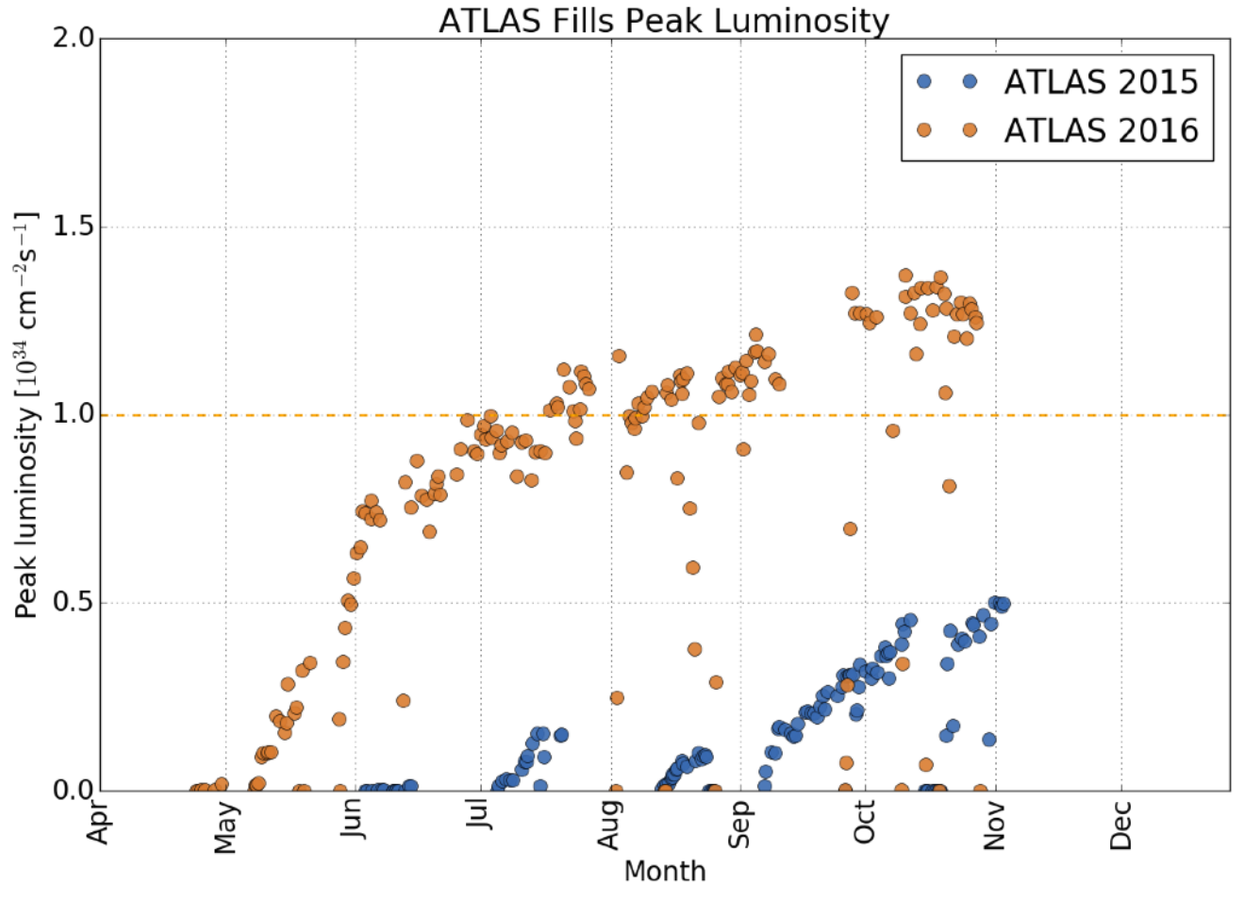
29 April marteen

20 May - PS MPS

21 June - Water Pt. 3

LHC performance 2016

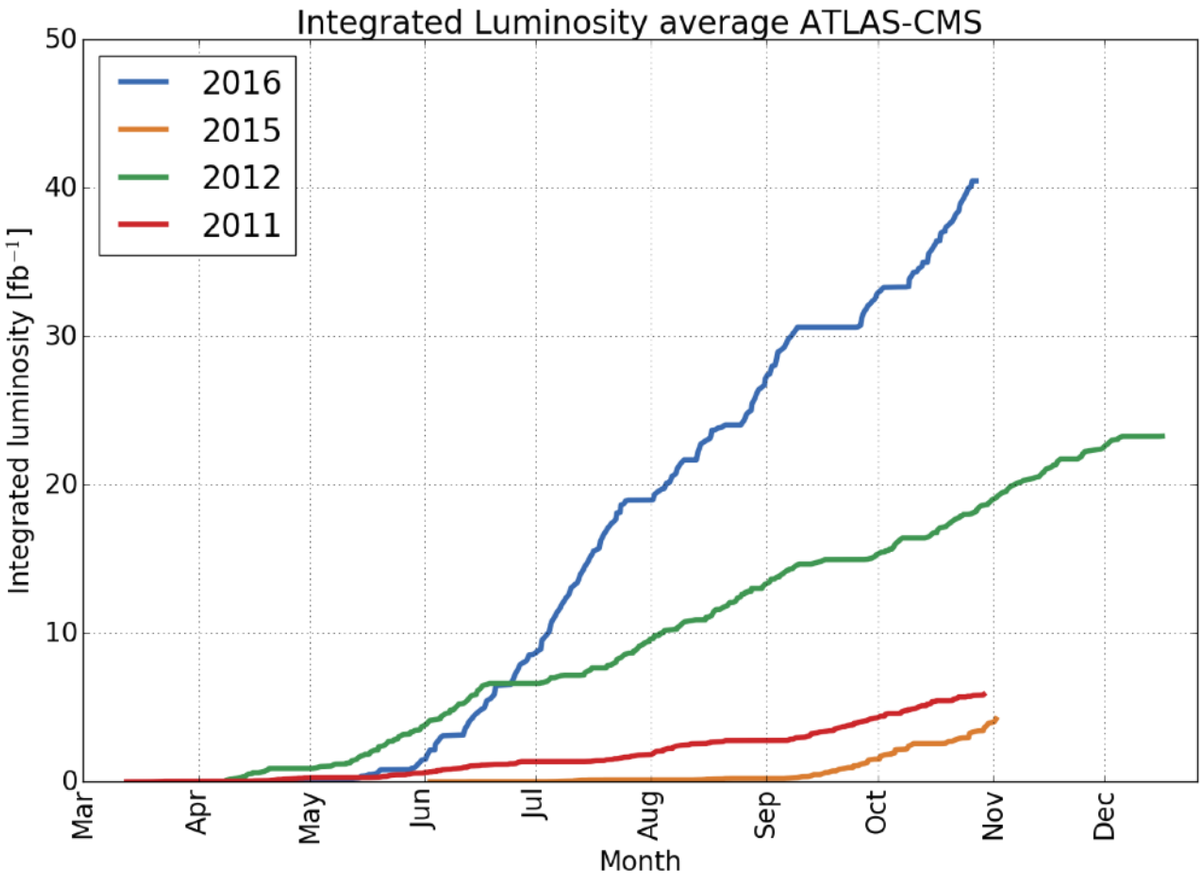




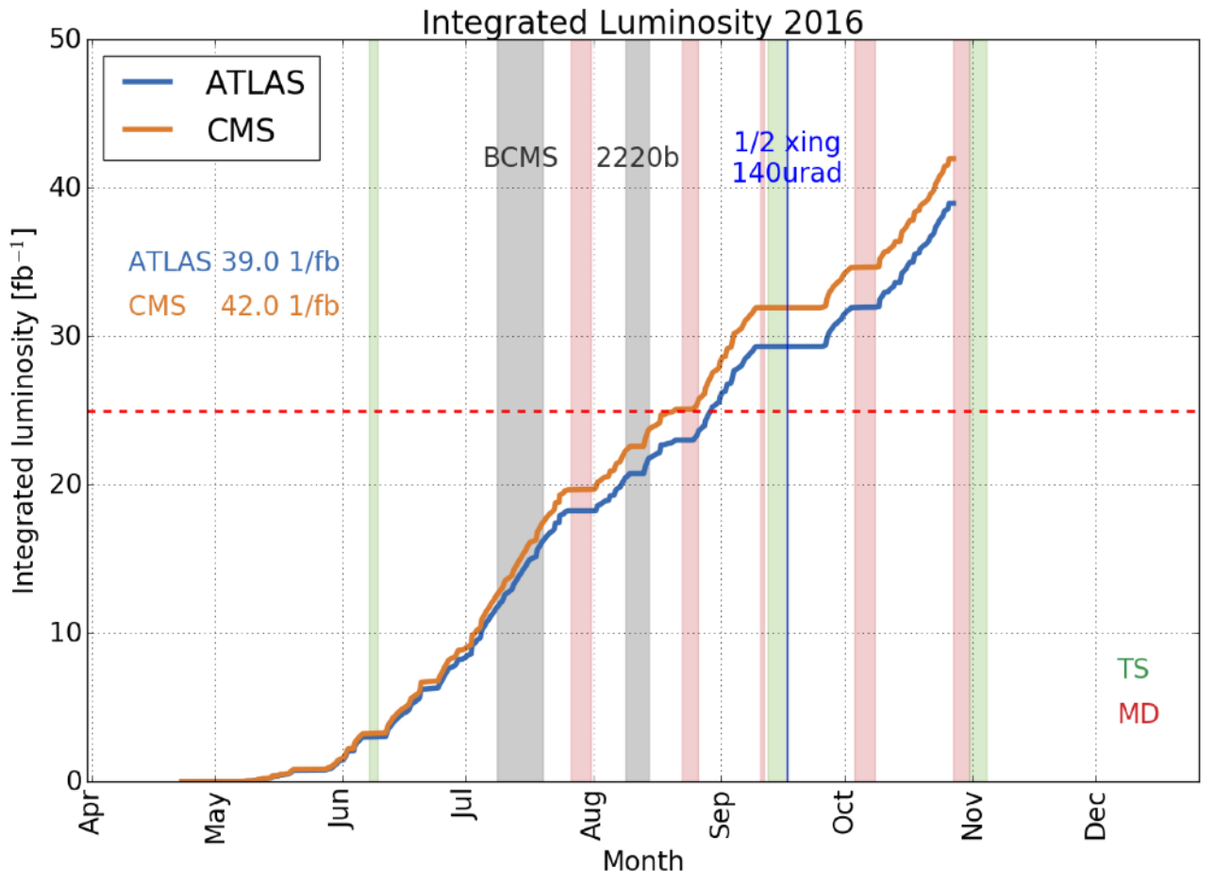
Steady production from beginning of June

From end of June LHC operated consistently above design peak luminosity

Production 2016



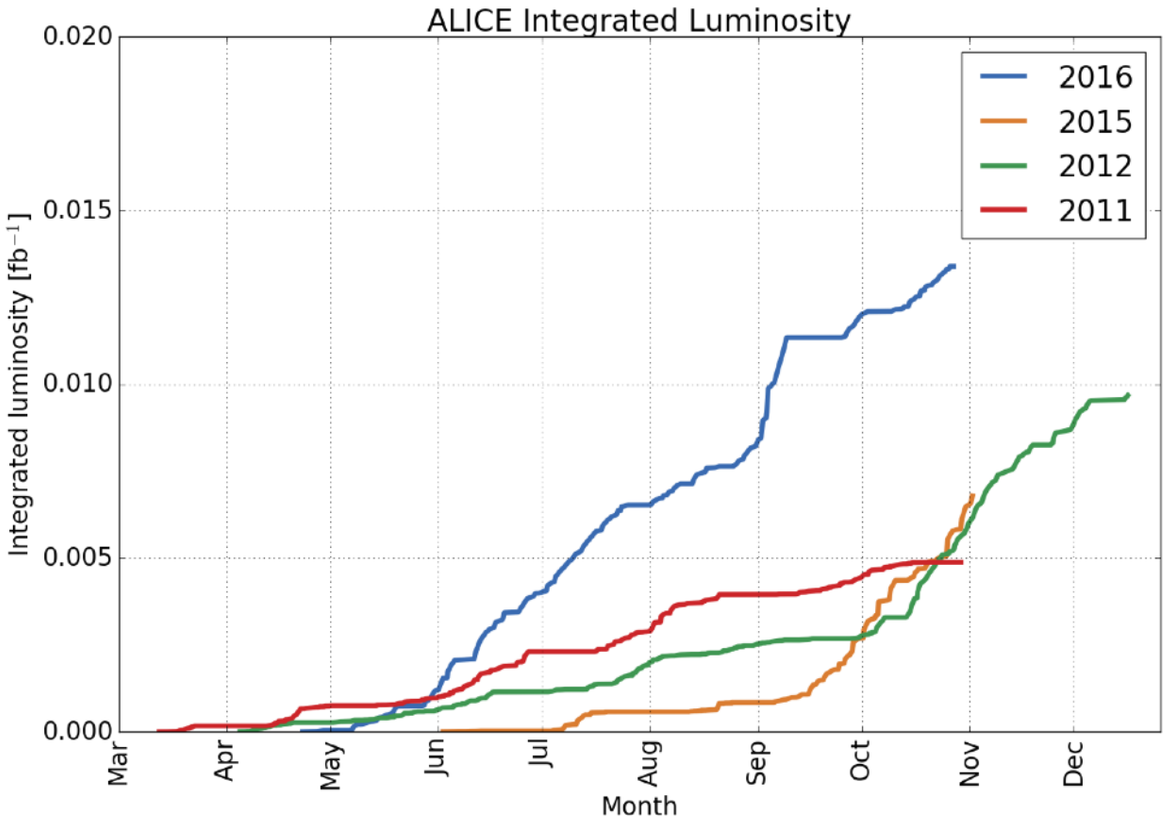
Astonishing integrated luminosity achievement



Fast ramp-up after each configuration change

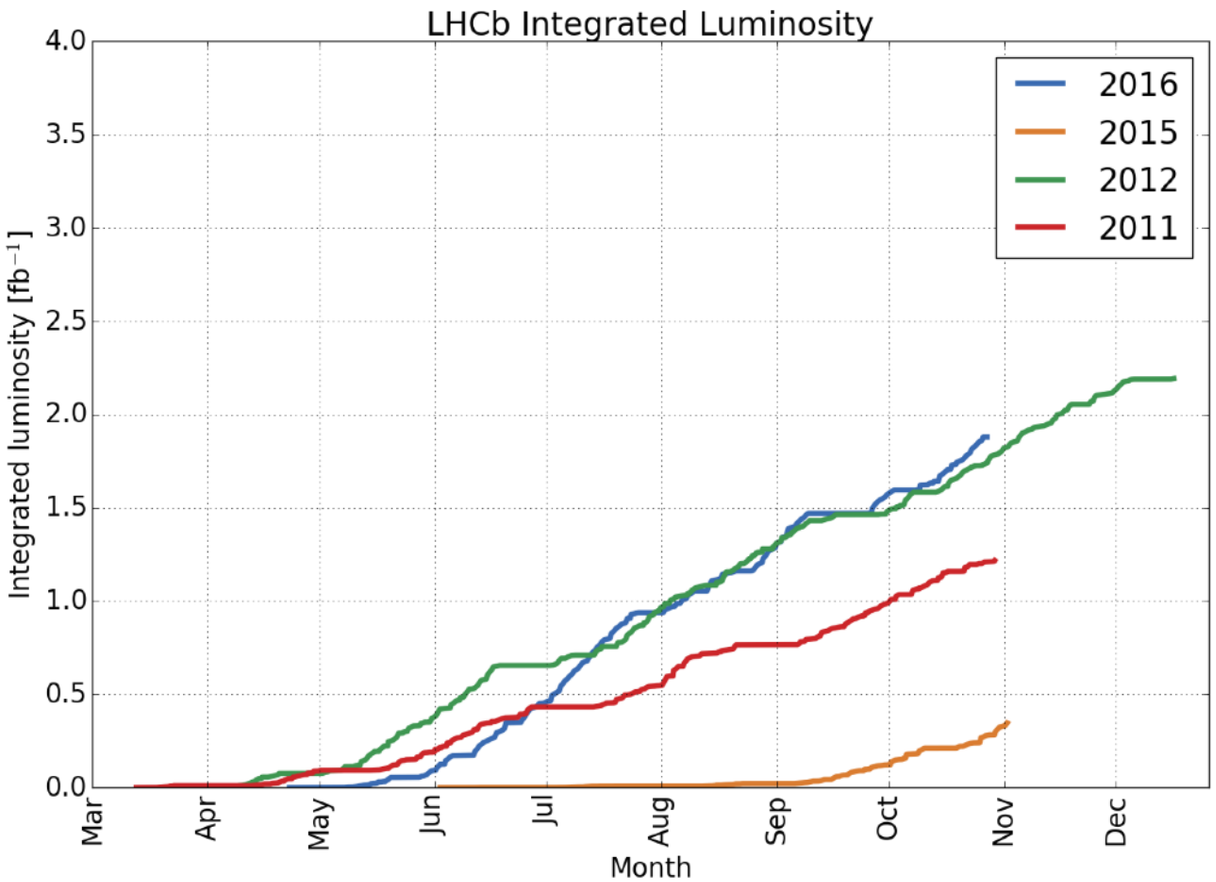
Steady peace through the year

Not only ATLAS and CMS



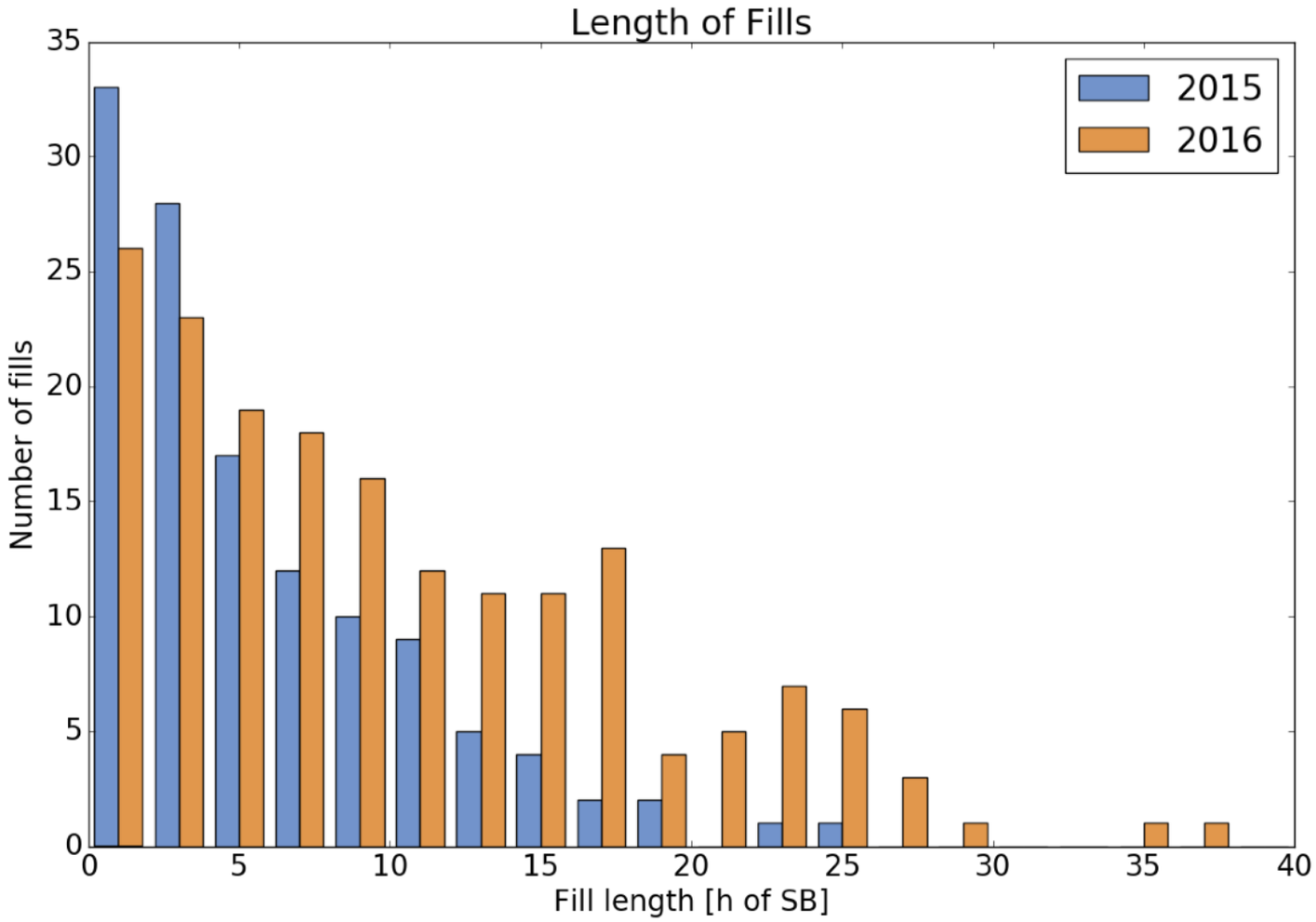
ALICE ~13.5 nb^{-1}

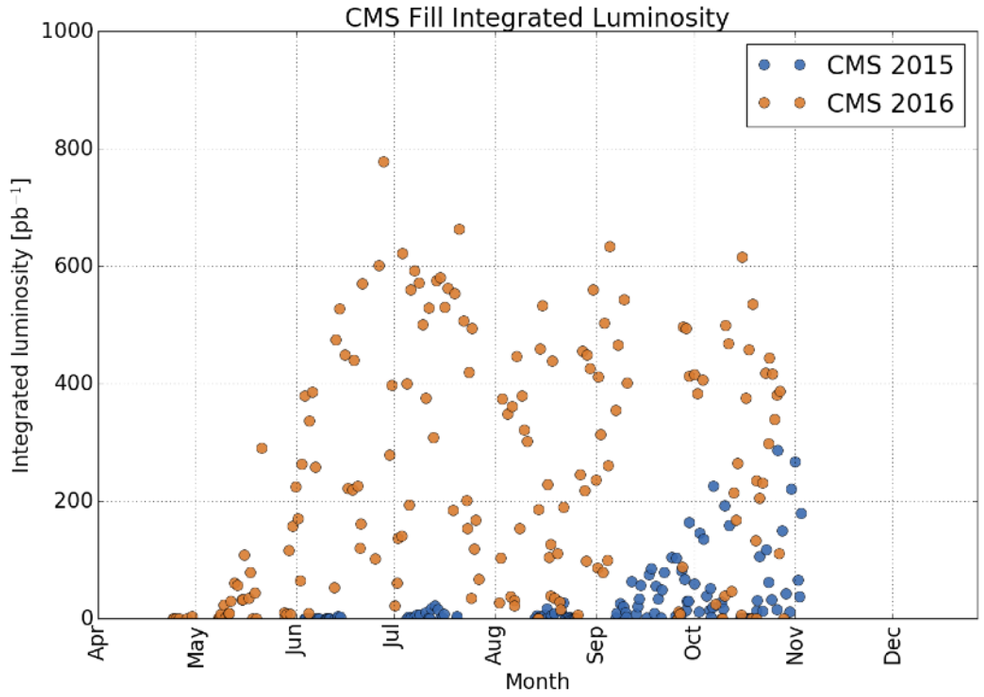
LHCb ~1.9 fb^{-1}



Both profit from the long fills

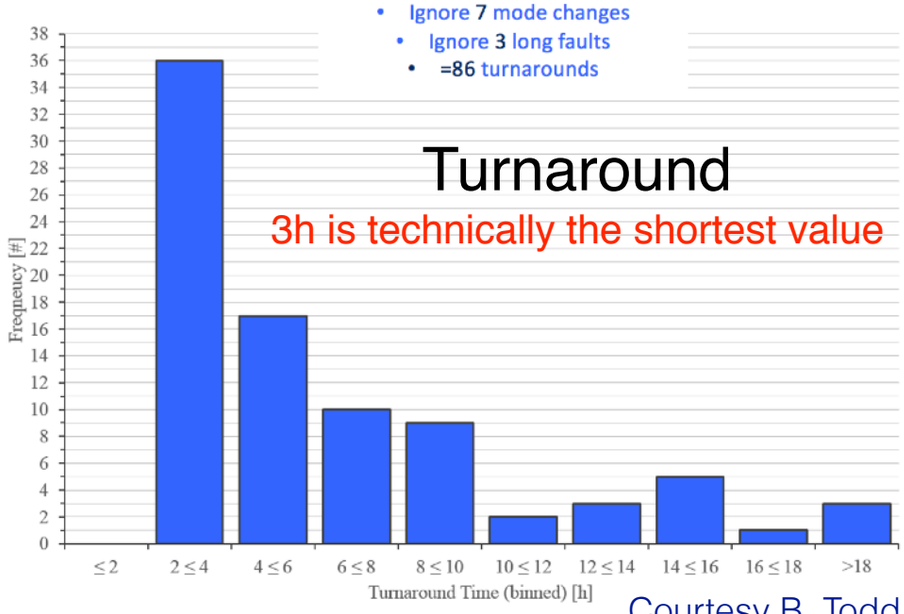
Operation cycle





96 fills with stable beams, time to get to fill # from previous fill

- Ignore 7 mode changes
- Ignore 3 long faults
- =86 turnarounds



Courtesy B. Todd

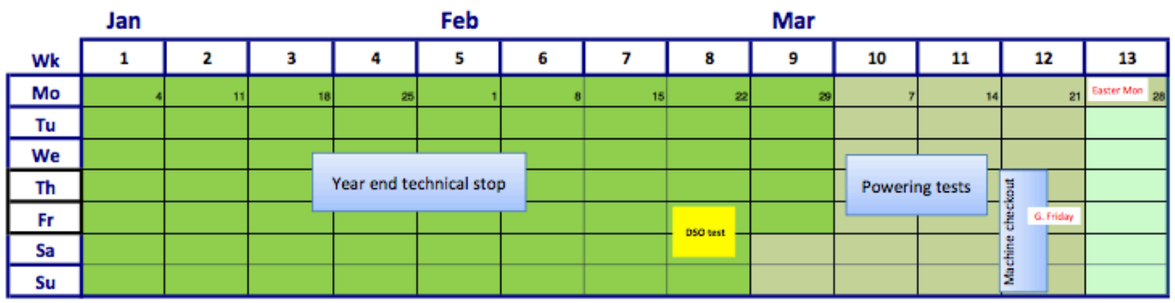
Almost half of the fills ended by operators

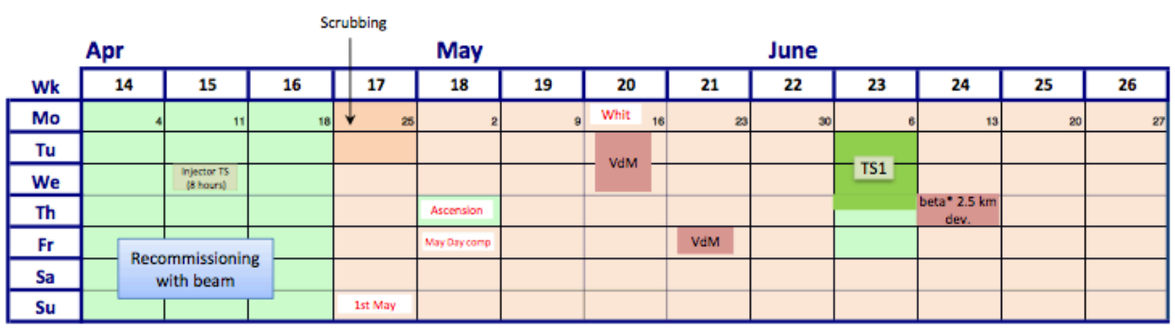
We can finally decide the length of fills!

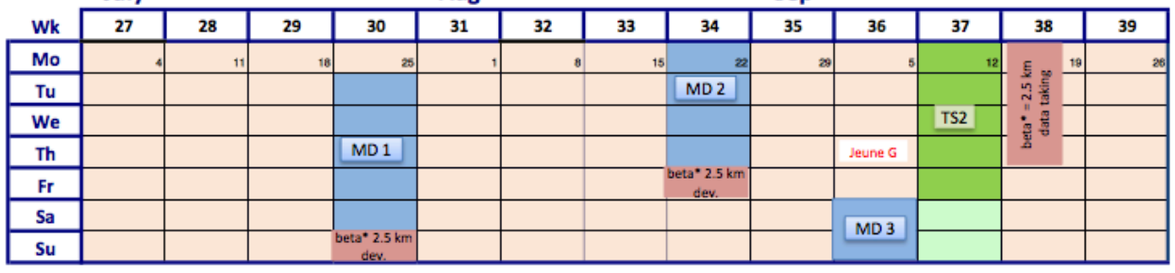
Special operation

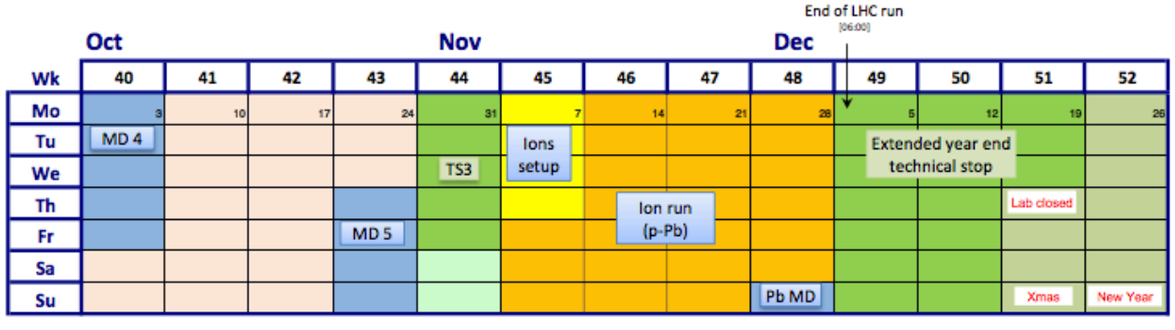
- Van der Meer scans for luminosity calibration
  - Full VdM scans on 17, 18, 27 May fro all experiments
  - Partial scans and studies here and there
- Large beta* run for forward physics (ALFA and TOTEM)
  - 19-22 September, very successful
- Proton-Lead physics
  - Next! Ambitious and dense program just starting
  - Commissioning of required cycles partially done
- Plus many ad hoc cycles during the 20 days of MDs
  - Partially with HL-LHC in view, partially to test improvement already applied

2016









Technical Stop

Machine development

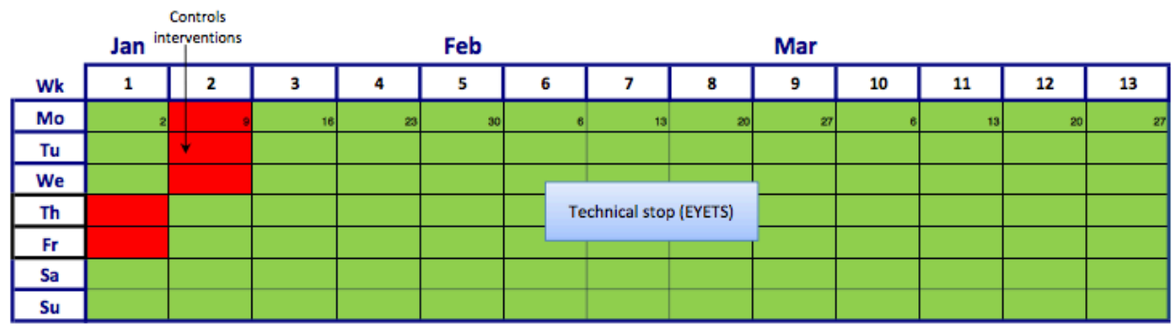
Recommissoning with beam

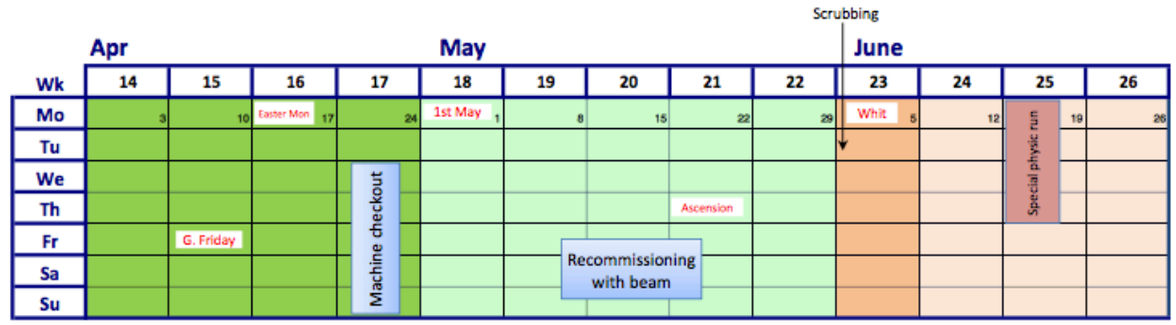
Special physics runs

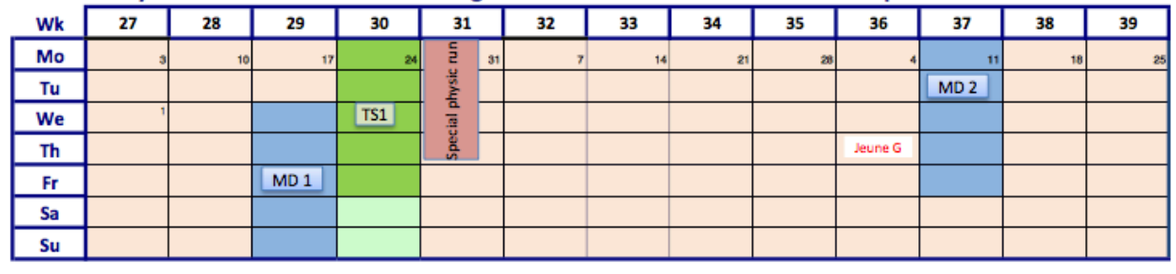
Scrubbing

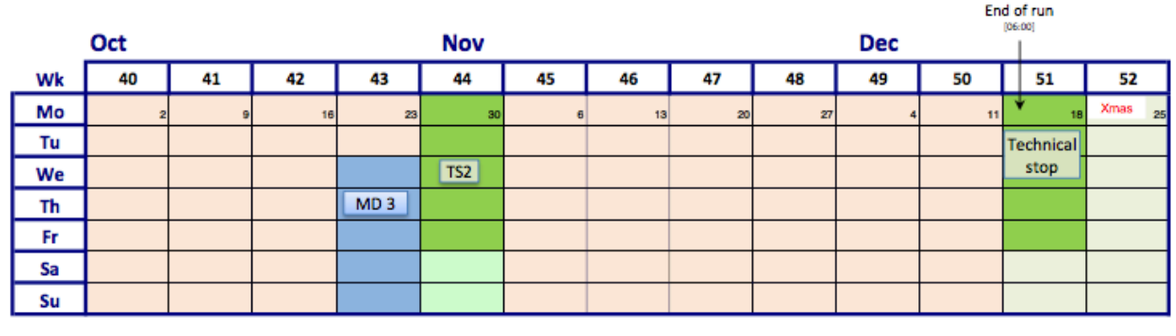
146 days p-p physics

2017 DRAFT









Technical Stop

Machine development

Recommissoning with beam

Special physics runs (indicative - schedule to be established)

Scrubbing (indicative - dates to be established)

152 days p-p physics

Beam parameters for 2017

	2016	2017
I bunch [E11]	1.1	1.1 - 1.25
Emittance (SB) [μm]	3.2 - 2.5	3.2 - (2.5 BCMS)
Number of bunches	2040 - 2220	2748 (2448 BCMS)
β* (IP1&5) [cm]	40	40 (33)
Crossing angle [μrad]	185 - 140	185 (140)(170)(205)
Peak luminosity [E34 cm^{-2} s^{-1}]	1.4	1.4 - (1.9)
Peak pileup	45	45 - 56
Integrated luminosity [fb^{-1}]	40	40 - ?

- Many decisions to be taken at next Chamonix
  - BCMS or standard?
  - Beta* 40cm or 33cm
  - ATS optics or standard optics
- Fate of SPS dump will be revised in March
- Inner triplet maximum heat load to be re-evaluated (present limit at 1.7E34 $cm^{-2}s^{-1}$ peak luminosity)
- Sector 1-2 will be warmed up → UFOs and e-cloud may come back

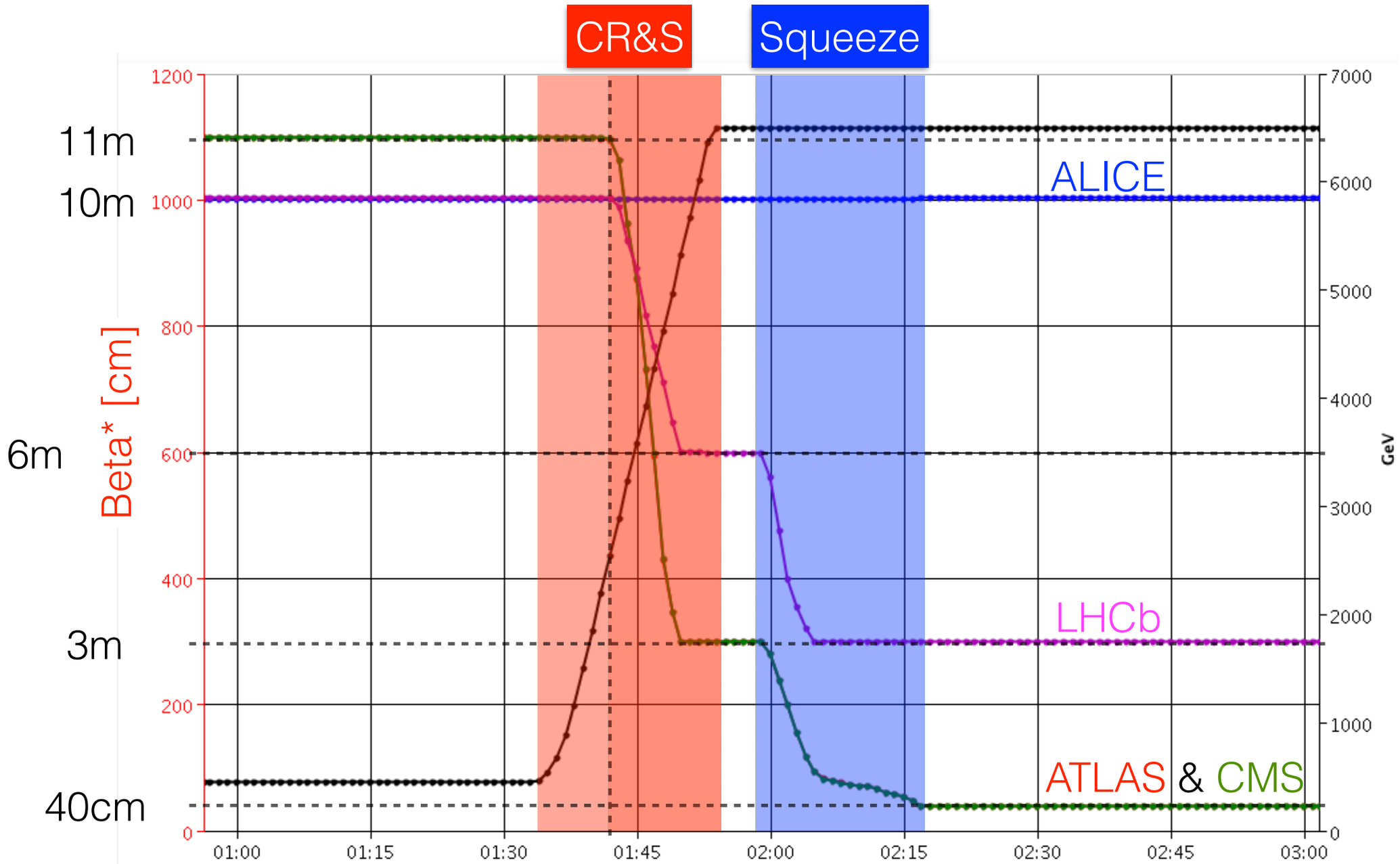
Luminosity levelling at IP1 and IP5 may be needed

Conclusions

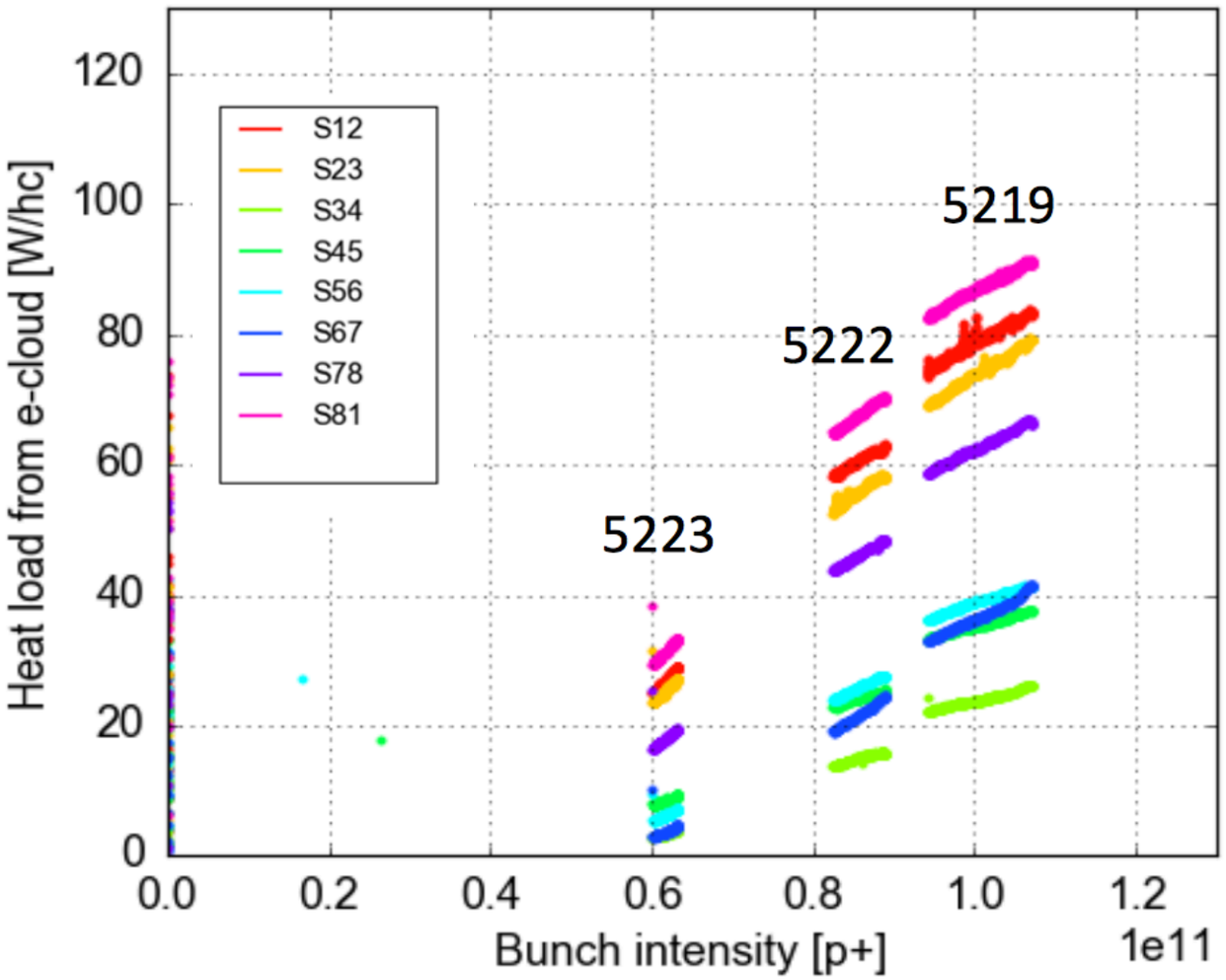
- Despite some troublesome events it has been a wonderful year at the LHC
- Excellent machine availability/reliability as never before
- UFO, e-cloud, faults under control
- Despite (thanks to?) not pushing parameters too hard due to limitations delivered more than 40fb-1 to ATLAS and CMS
- Big progress in understanding and controlling the beast
- Lot of work ahead for the EYETS
- Established a solid base for the coming years


The End

Combined Ramp & Squeeze



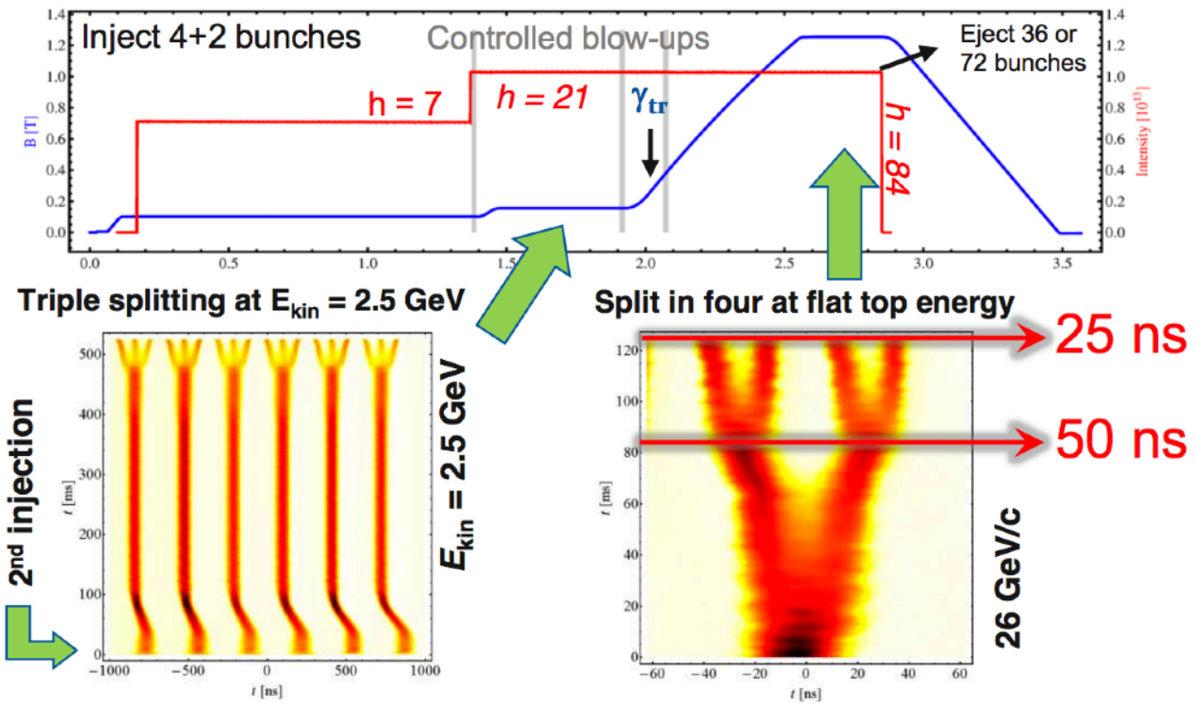
e-cloud studies



- Several fills with same conditions during the year to quantify conditioning (modest)
- 3 fills with 72bpi and increasing bunch intensity
- Large differences between sectors not understood

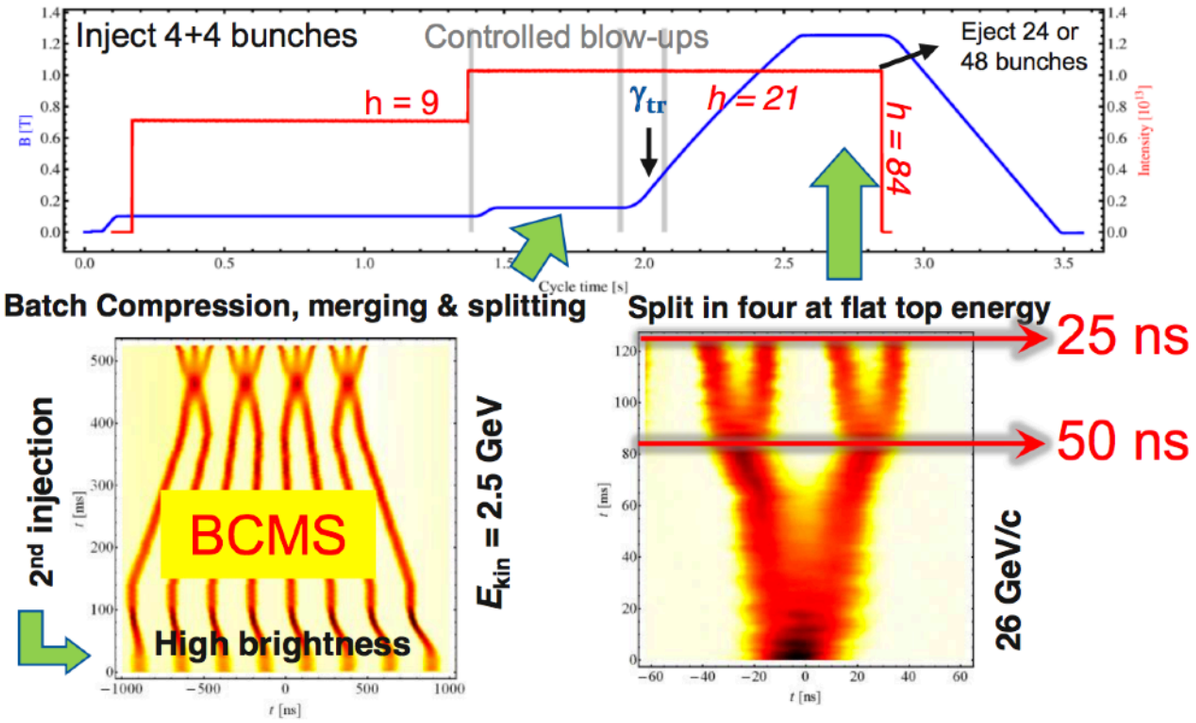
Standard vs BCMS beams in the PS

Standard 72b batch ε_{xy}~2.5µm
I_{bunch} < 1.3E11



25 ns: Each PSB bunch divided by: 12 → 6 x 3 x 2 x 2 = **72**
50 ns: Each PSB bunch divided by: 6 → 6 x 3 x 2 = **36**

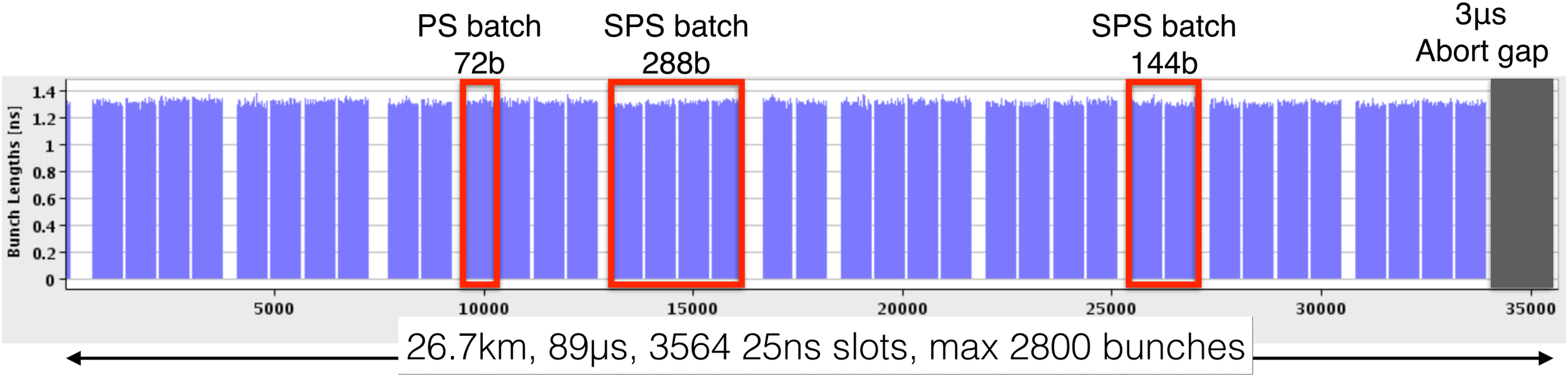
BCMS 48b batch ε_{xy}~1.5µm
I_{bunch} < 1.3E11



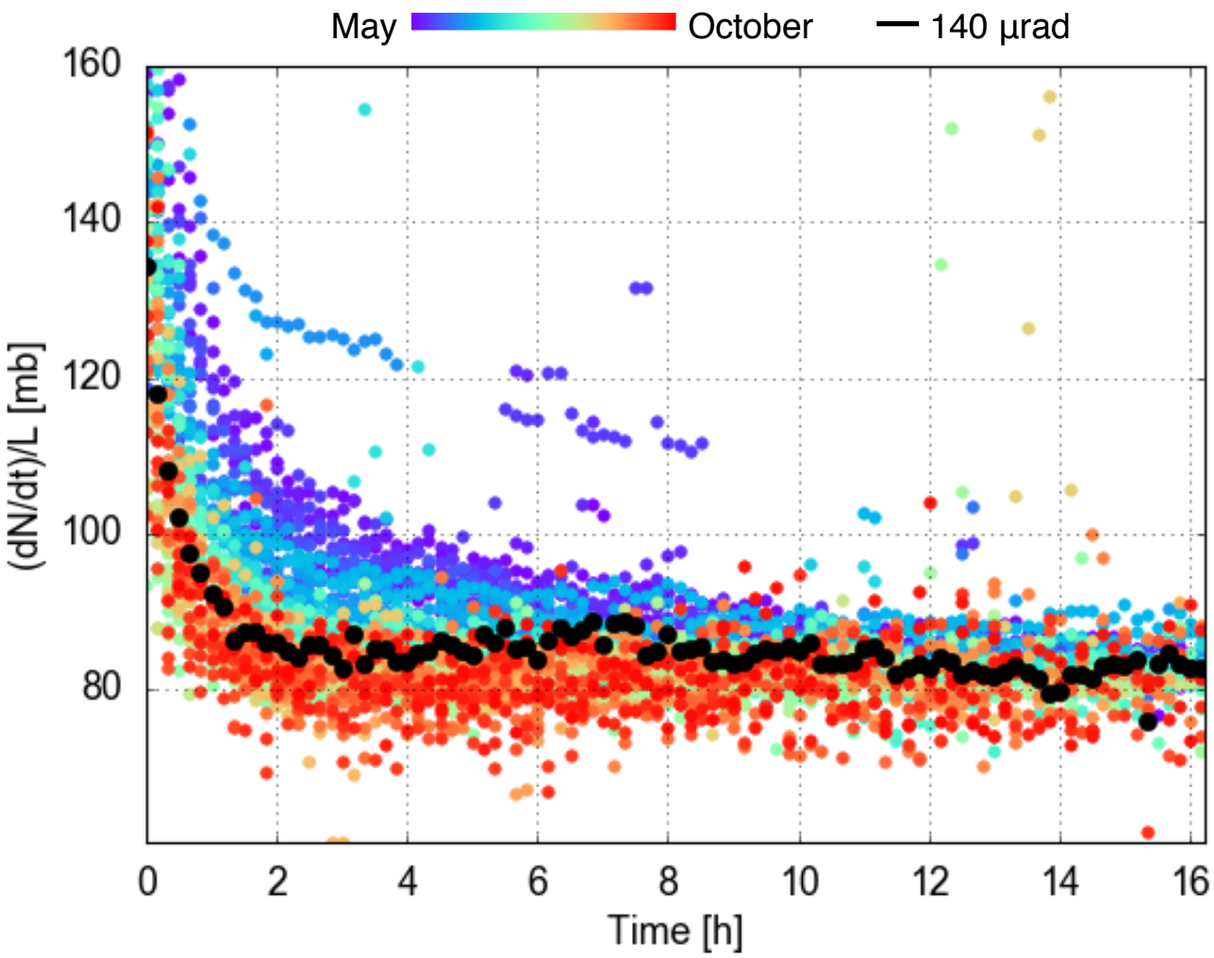
25 ns: PSB bunches 'divided' by: 6 → 8/2 x 3 x 2 x 2 = **48**
50 ns: PSB bunches 'divided' by: 3 → 8/2 x 3 x 2 = **24**

Beam structure

- The LHC injection gap is ~900ns while the SPS injection gap is ~200ns
- The maximum number of bunches in the LHC depends on the number of batches per SPS injection
  - 72b / inj. → max 2040b
  - (2 x 48b) / inj. → max 2220b (2076b)
  - (4 x 72b) / inj. → max 2800b



Losses in collisions



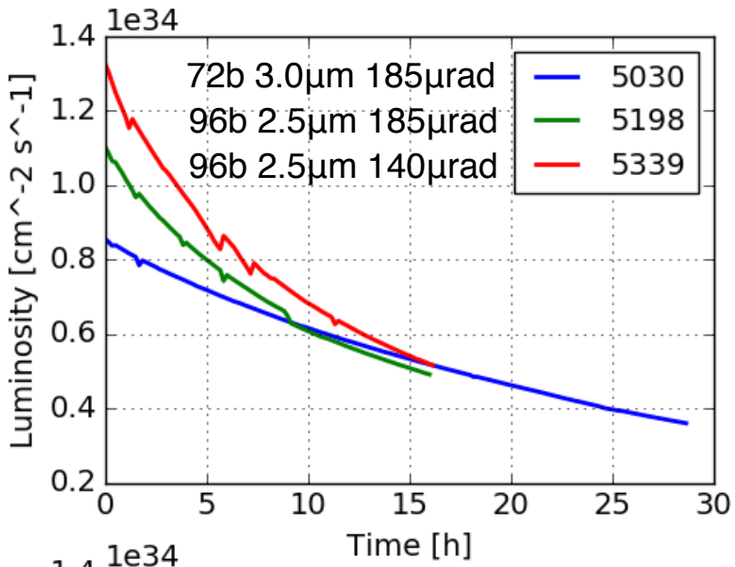
Courtesy
F.Antoniou, G. Iadarola, Y.Papaphilippou

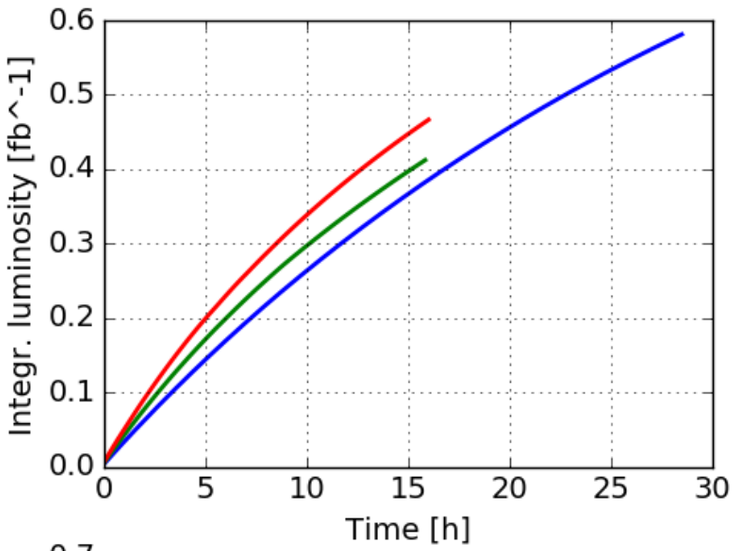
- During the first few hours in collisions losses well in excess of the burn-off
- After ~3h losses become dominated by luminosity burn-off
- Situation improved during the year (BCMS)
- Reduction of crossing angle has no effect

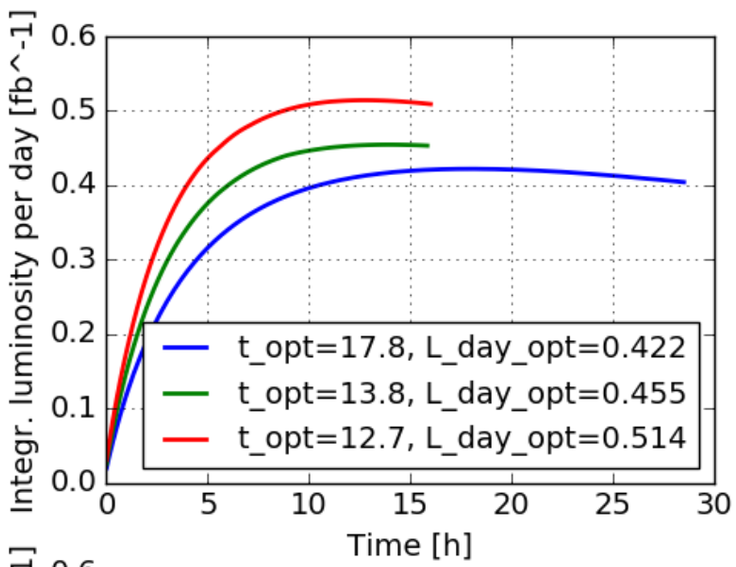
Luminosity lifetime

6h turnaround

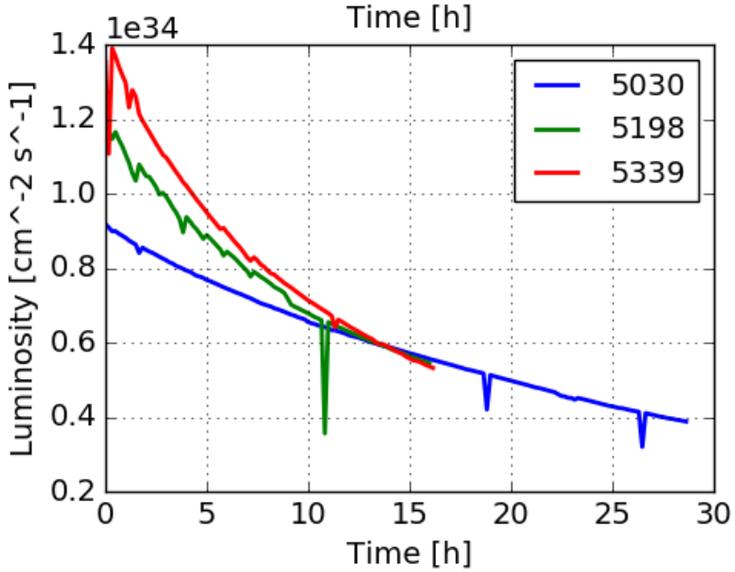
ATLAS

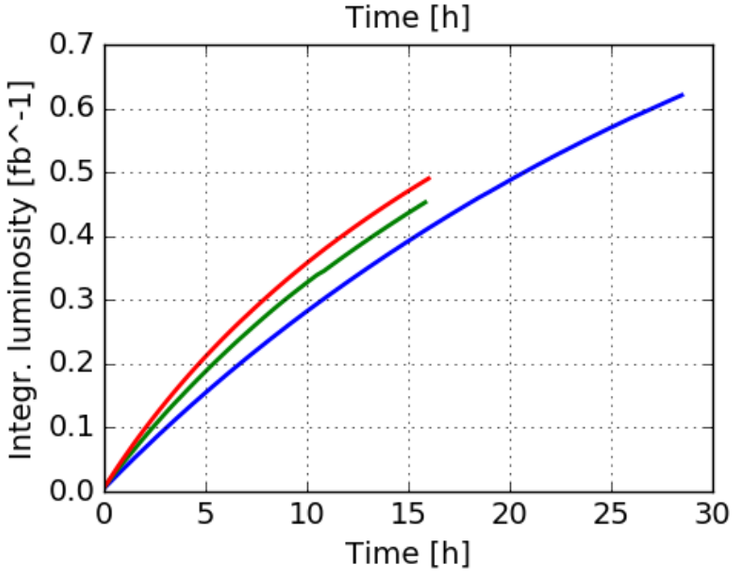


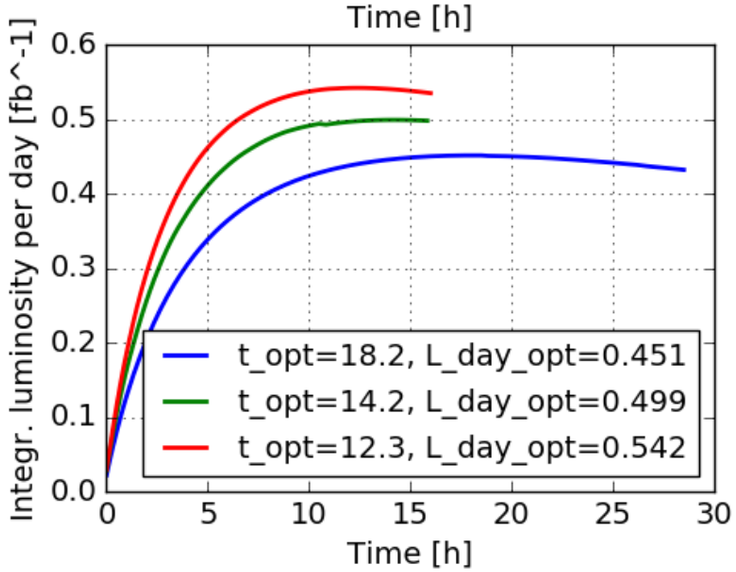




CMS







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