Feedback from the Experiments on the 2017 run

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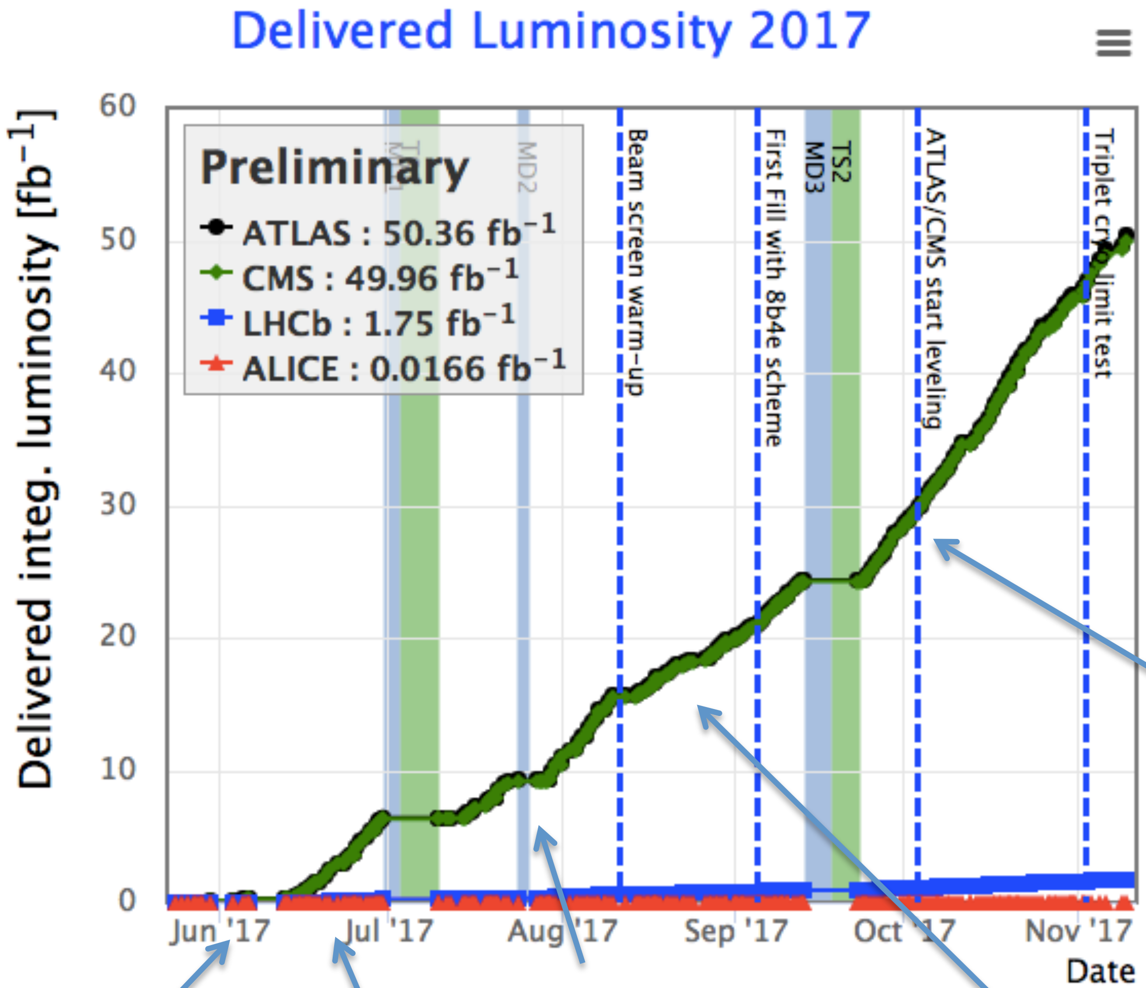
On behalf of the LHC experiments

Evian workshop
12/12/2017

Summary of the year



2017 was a very eventful, "interesting", and eventually successful year. Dominated by 16L2 and related mitigations. Final luminosity numbers very impressive, and year also included a diverse set of special running conditions.

cruising with 8b4e BCS (30cm β*)

Fast ramp-up

Good lumi production upto TS1 (25ns BCMS)

Struggles with 16L2 and magic mitigation

16L2 nightmares after beam-screen warmup

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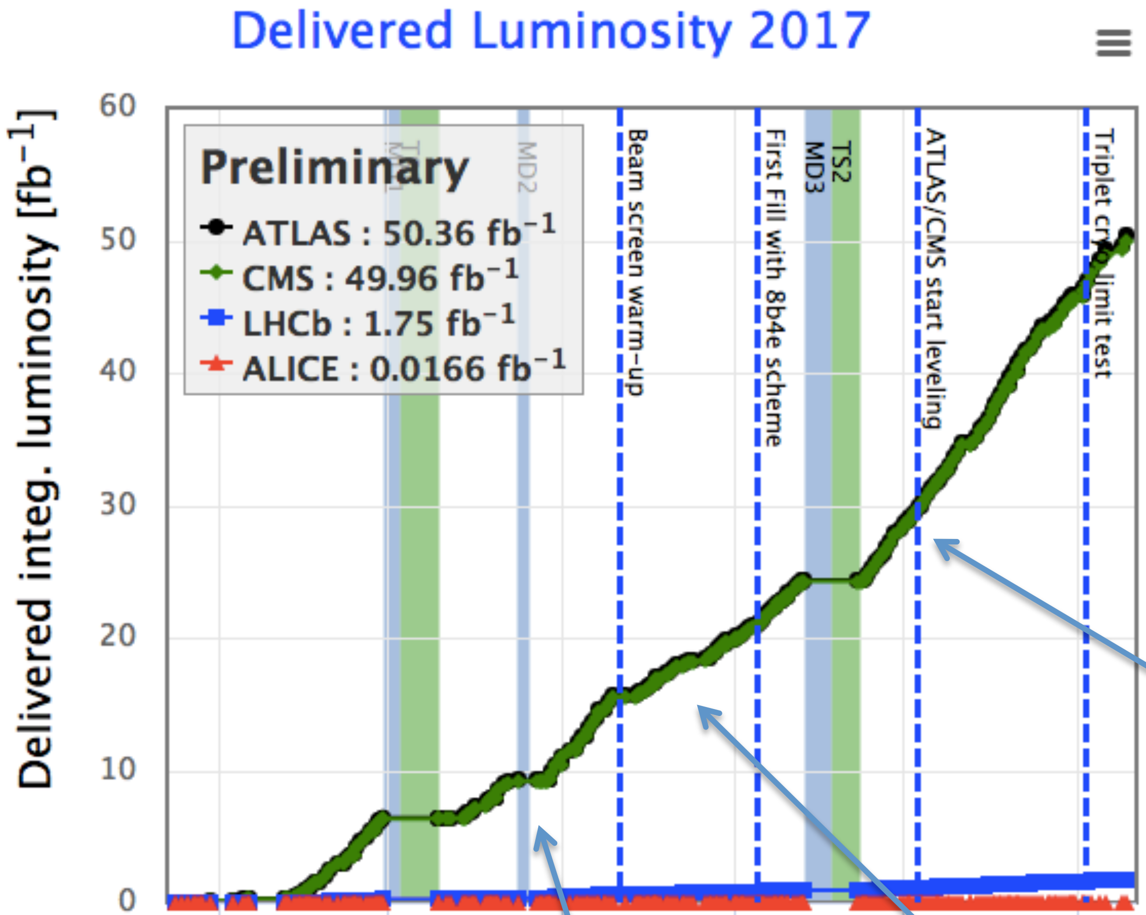


2017 was a very eventful, "interesting", and eventually successful year. Dominated by 16L2 and related mitigations. Final luminosity numbers very impressive, and year also included a diverse set of special running conditions.

cruising with 8b4e BCS (30cm β*)

The experiments would like to ***thank*** the LHC / injector / infrastructure teams for the outstanding performance in 2017.

Good lumi production upto TS1 (25ns BCMS)

after beam-screen warmup

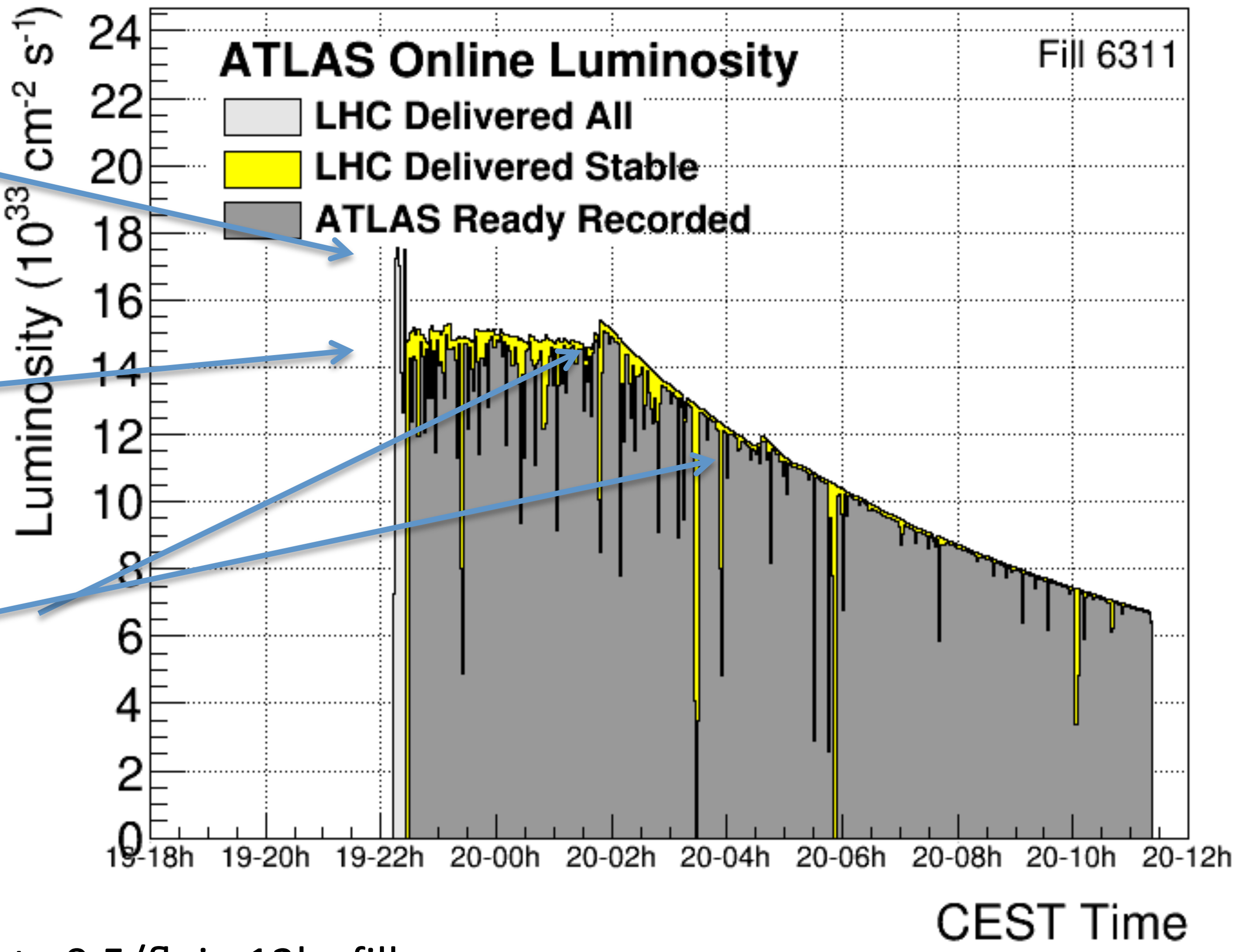
High luminosity data taking

A typical 8b4e, BCS, β*=30cm fill in ATLAS (same for CMS)

Beams head-on at start of fill with very high lumi ~2e34

Lumi levelled at ~1.5e34 with beam separation. Leveled for ~3hrs.

Crossing angle reduction after levelling over, increases luminosity



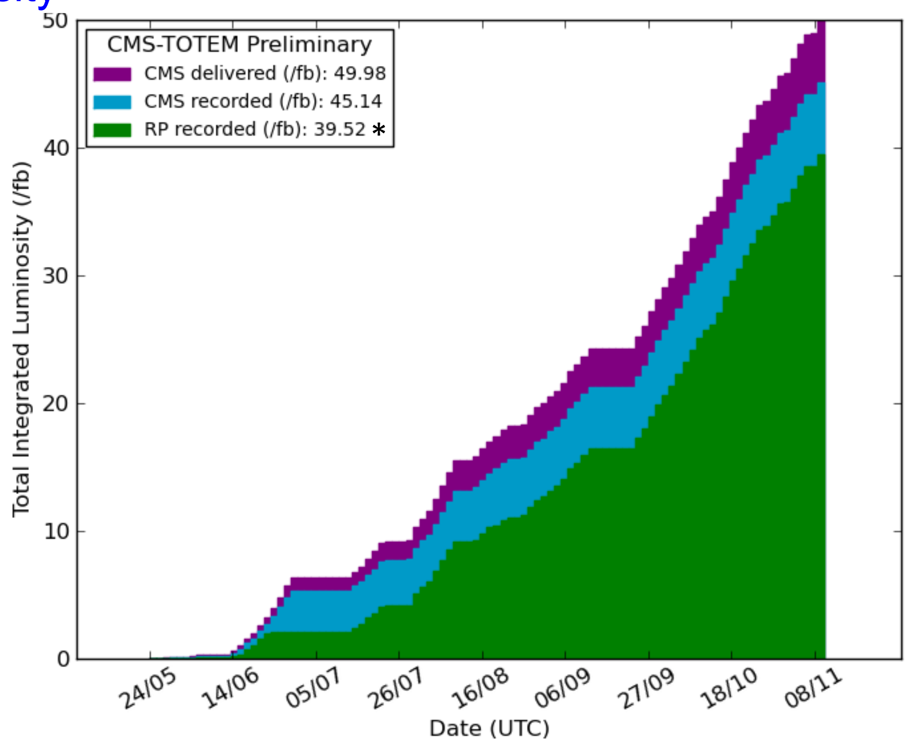
In this configuration integrate 0.5/fb in 12hr fill

Roman Pots at high lumi

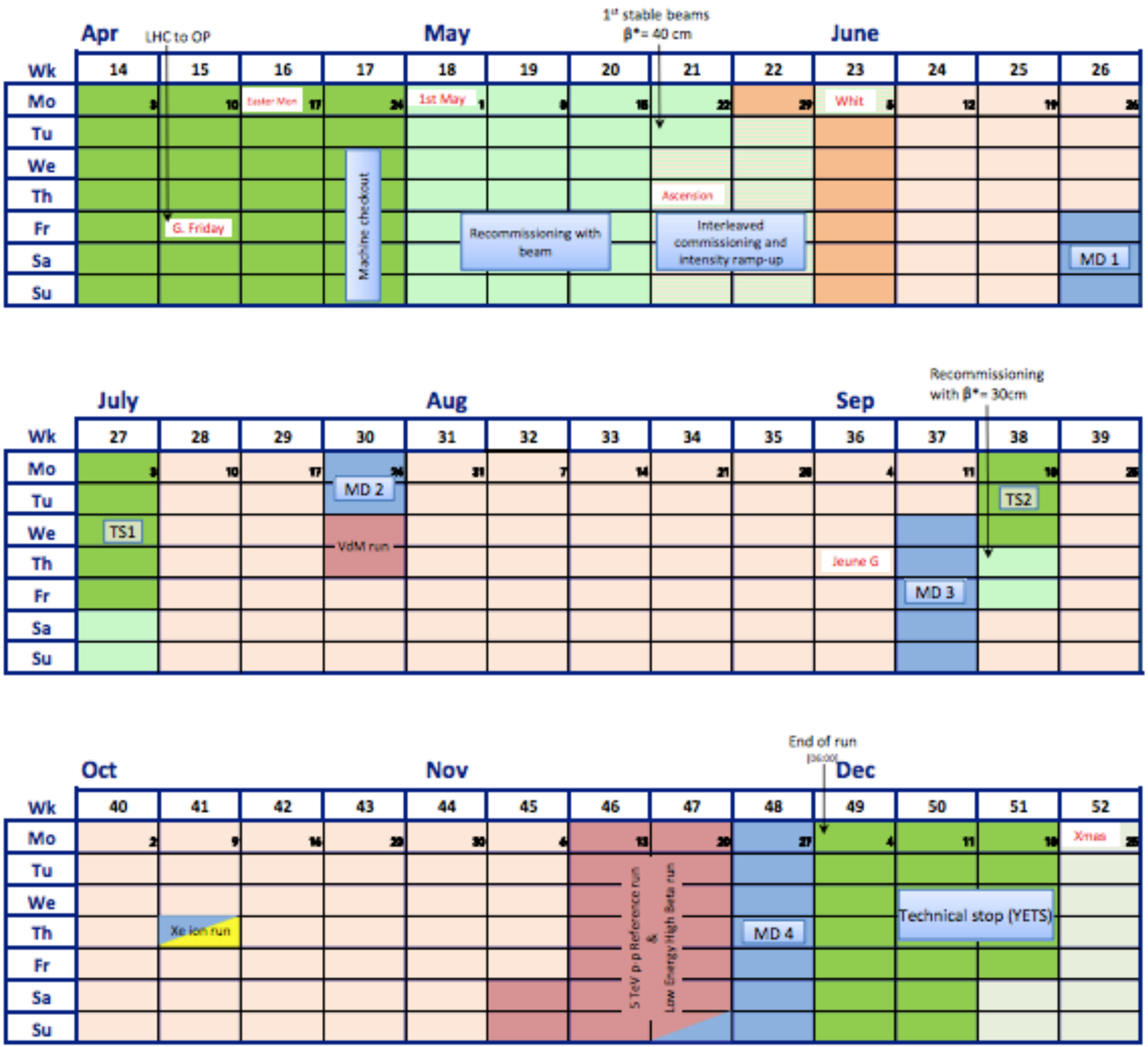
- In 2017 both CT-PPS (IP5) and AFP (IP1) roman pots inserted for nearly all high luminosity fills
- Insertion rules slightly modified wrt 2016 to enhance physics acceptance

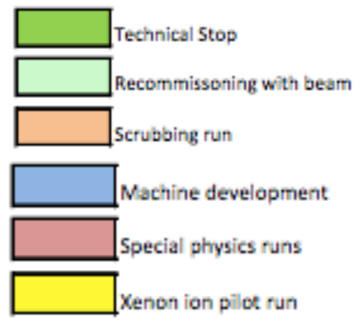
- For both systems, insertions up to highest luminosity ($L \leq 1.6 \times 10^{34}$ cm^{-2} s^{-1}) without problems
  - excellent vacuum
  - benign temperatures
  - no impedance problems
  - no unexpected losses

- For CT-PPS ~40/fb collected with pots inserted
- For AFP ~30/fb collected with AFP+ATLAS combined running
  - AFP under commissioning in 2017



*: Luminosity collected by CMS with RPs inserted in the beam



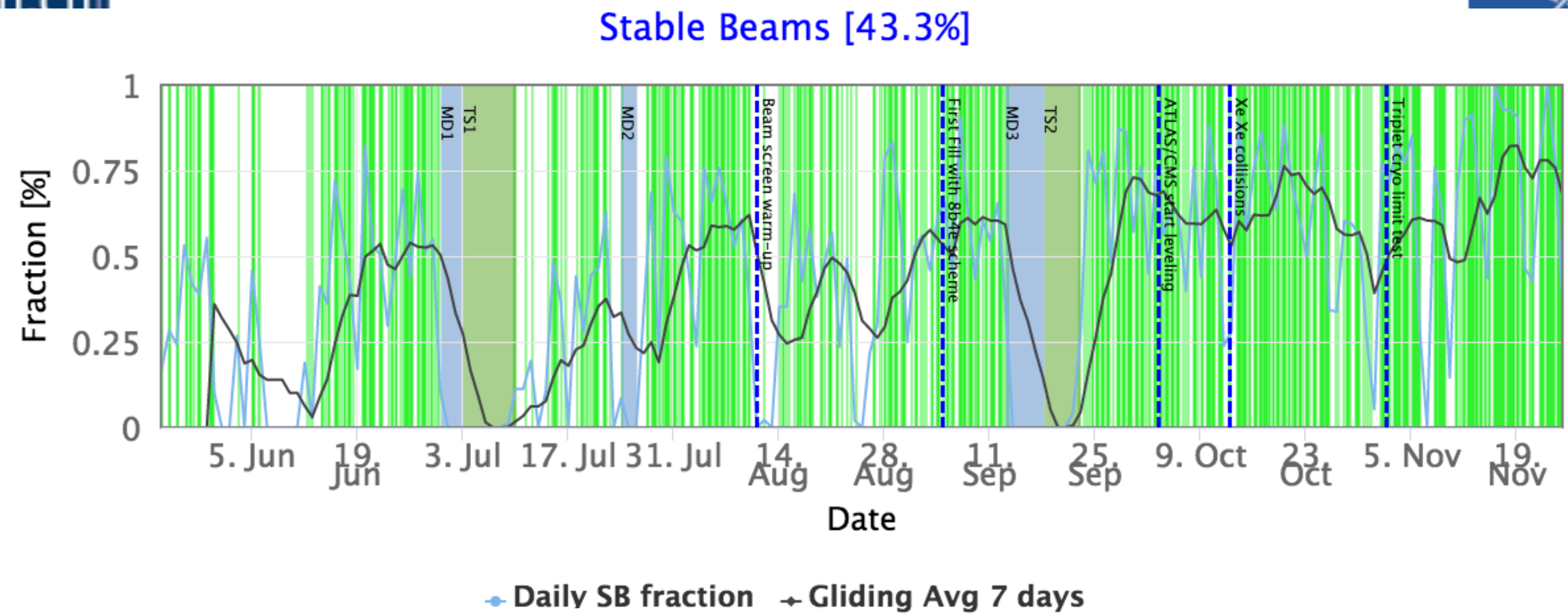


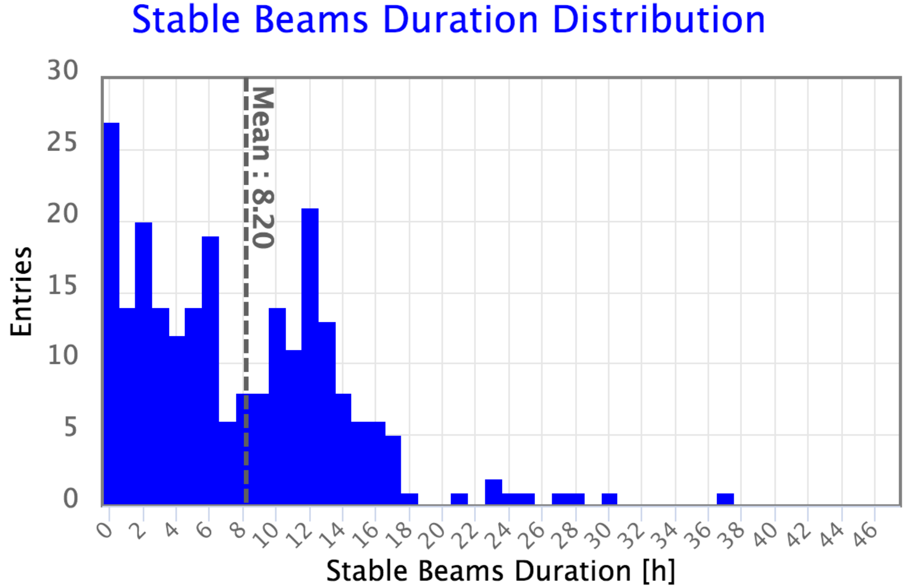
Recap of the 2017 schedule.

Lots of re-arranging at the end of the year:

- Special runs
- CMS pixel

Stable Beams





Numbers for full 2017 run.
Very impressive availability, especially considering rocky period in August (16L2).

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New tools for 2017

- A large number of changes were implemented for or during the 2017 run
  - To improve current performance
  - To mitigate limitations (16L2)
  - To prepare for the future (HL-LHC concepts)
- These will be discussed in the following slides

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RF full-detuning

- Allows significant reduction of power in RF system – needed for HL-LHC intensities
- Introduces a bunch-by-bunch modulation in
  - Timing of collisions (~in 100ps range)
  - Longitudinal position of collision (~1cm range) (IP2/8 only)
  - Size of modulations depends on filling scheme and bunch intensities
- Test fill in 2016 analyzed by experiments, and discussed in LPC meetings at start of 2017
  - No show stoppers identified
- Measured modulations available in DIP for experiment monitoring and/or corrections
- Tool on LPC page to allow estimation of effect for a given filling scheme
- Feedback from the experiments in July showed that:
  - Expected effects observed by experiments
  - No problems expected for operations or physics by this
- Expect to use full detuning in 2018

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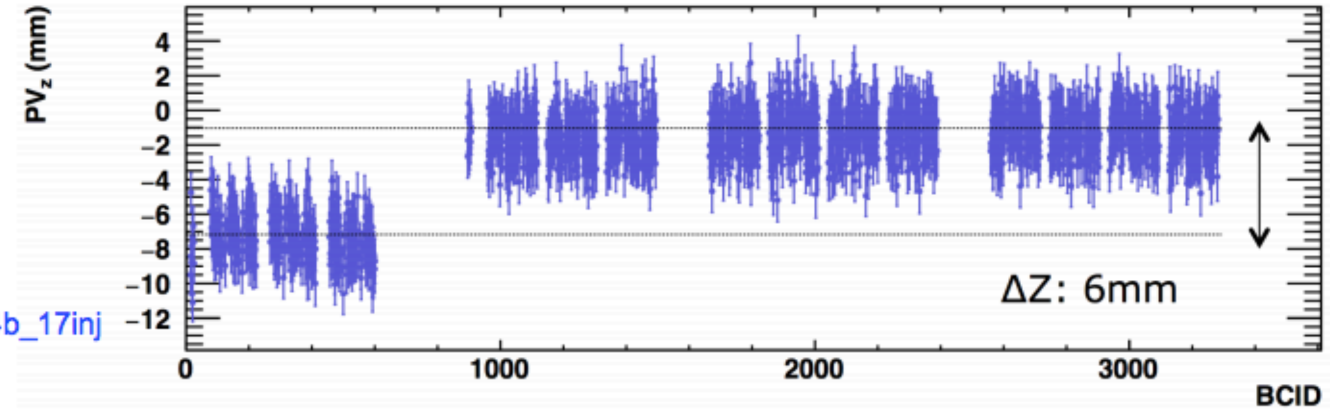
RF full-detuning

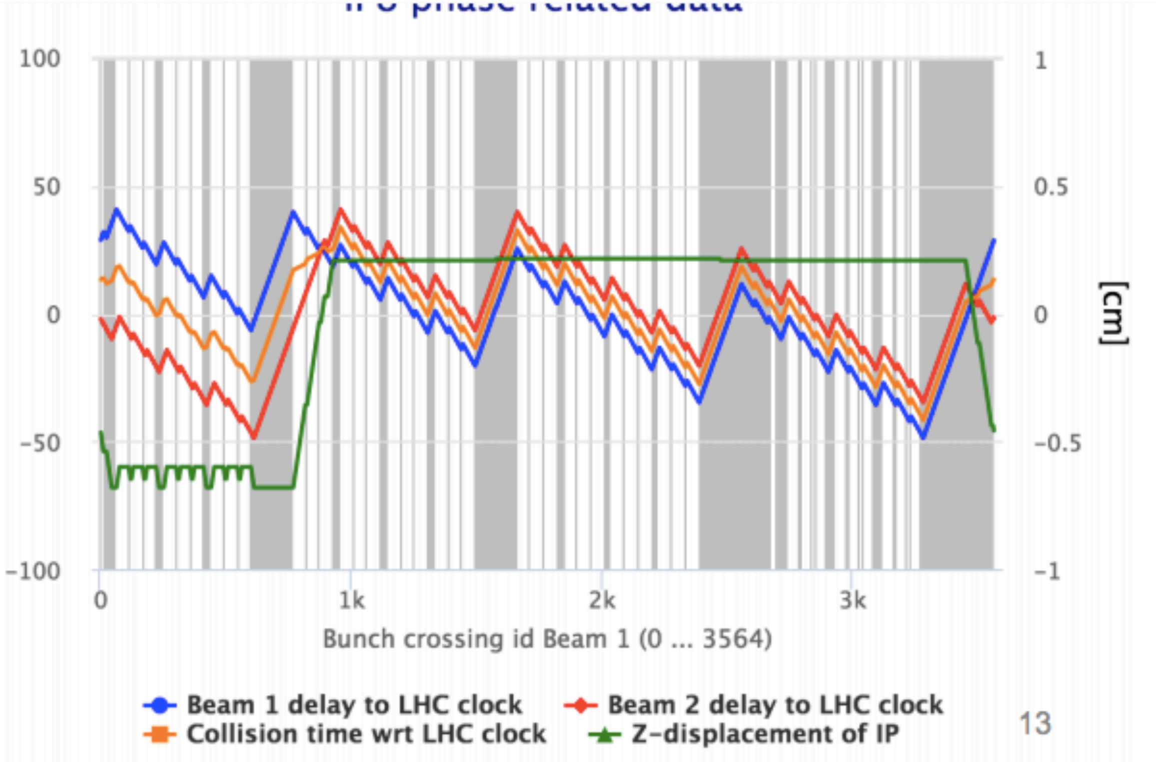
Example feedback from LHCb



Fill 5856

25ns_2173b_2161_1872_1962_144b_17inj

- Initial Intensity: 1.2e11
- Prediction: use 1.1e11
- LHCb measures the shift of the vertex position in z
- Good agreement between measurement and prediction



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Crossing angle changing in stable beams

- Crossing angle reduction tested in MD in 2016
- Long discussions with experiments about using this in operation
  - Worry about detector safety (especially with collimator movements)
  - Managed to convince them that enough levels of protection in place for this to be a safe operation in stable beams
- Validated machine with minimum and maximum crossing angles to allow operation at any intermediate values
- Complication for CT-PPS whose acceptance varies with angle (unlike AFP due to crossing plane)
  - Originally needed a few discrete steps with calibration data for their physics
  - However demonstrated that acceptance effect can be interpolated between calibration data at 3 angles
- For 2018 expected continuous changes to be possible
  - Tested in 1 fill in 2017 with encouraging results
- Flexibility very nice as not only allows the reduction of the angle during stable beams, but also to start with smaller angle (without re-qualification of machine) after studies showed this was feasible
- Indications that with smallest angles probed (~120μrad) parasitic collisions – decided stay with bigger angles to avoid this

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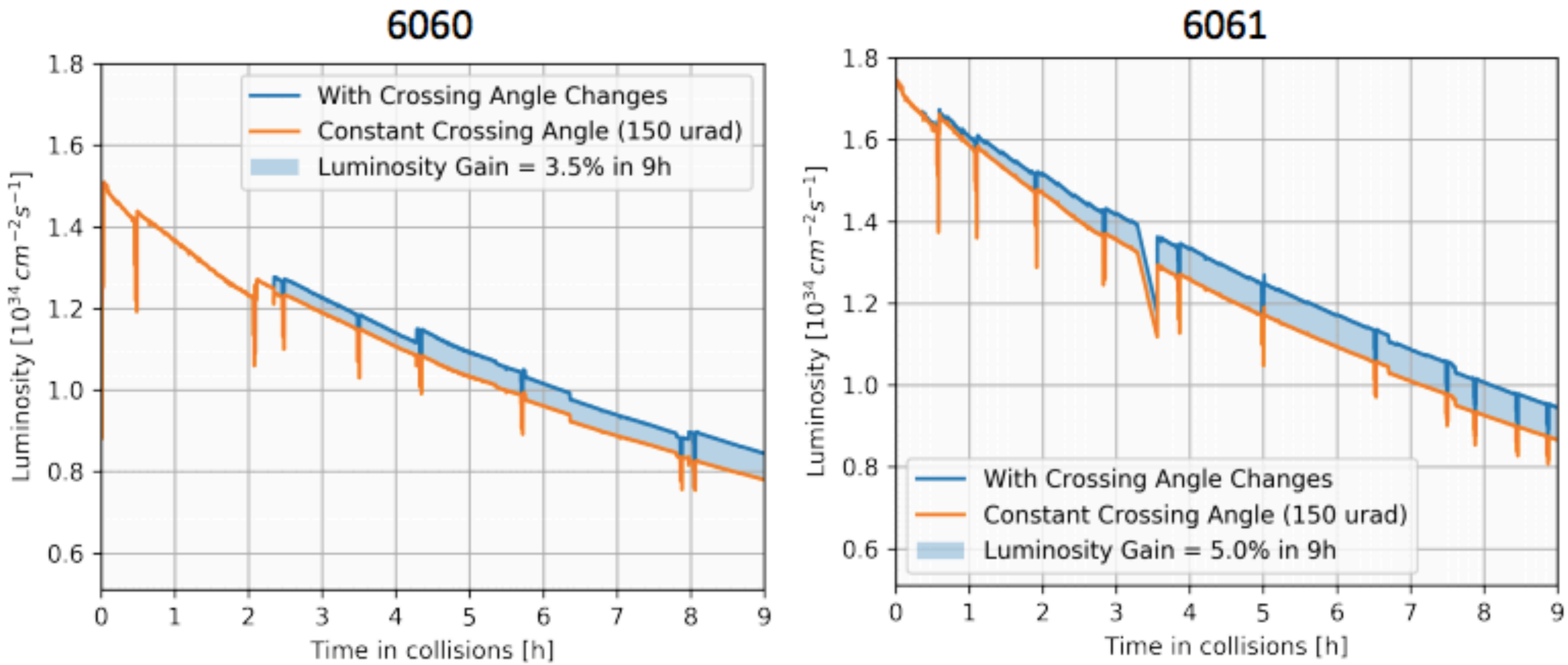
Crossing angle changing in stable beams



Expected gain of 1.5% in integrated lumi in 9h SB by reducing crossing angle in small steps of 1 urad. Effect on beam also less violent.
Would be worth pursuing such a strategy for 2018. Requires CT-PPS can use such data for physics.

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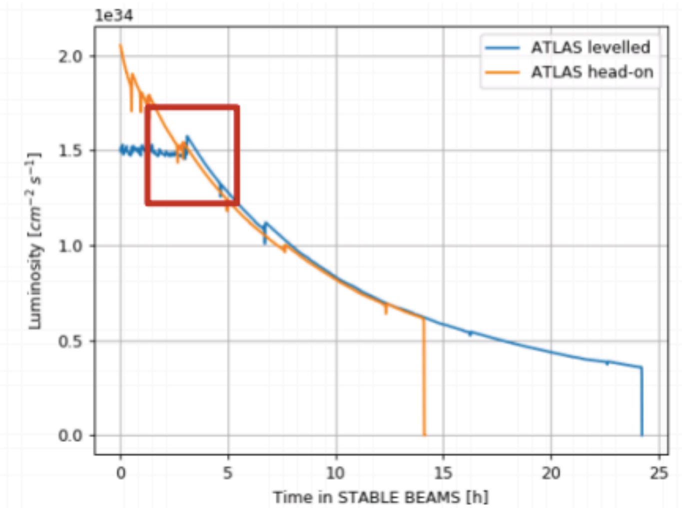
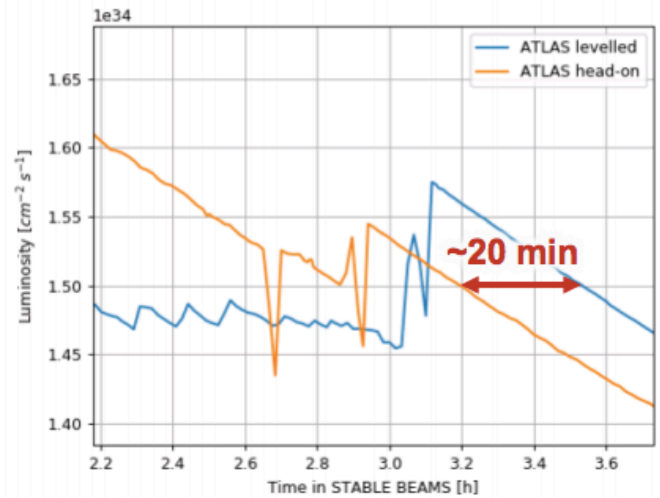
ATS optics / β*=30cm

- ATS
  - ATS optics baseline for HL-LHC
  - Worse acceptance for CT-PPS, but a lot of effort from the optics team to improve this as much as possible for the 2017 run
  - No complaints from the experiments about ATS in 2017
  - One small complication is that non-standard optics need to adapt to ATS, not easy to use old configurations
    - VdM, high B* etc…
- β*=30cm
  - Switched from 40cm => 30cm after TS2
  - Partly motivated by poor production due to 16L2, and commissioning further squeeze for 2018
    - Also allows first use of telescopic ATS optics (preparation for the future)
  - Experiments were not pushing for this
    - (prefer stable configuration, worried about possible risk, and loss of luminosity)
  - Proved to be very successful
    - Commissioning/validation in estimated time and with no issues
    - Significant gain in integrated luminosity
      - Expected gain ~8%, actual gain higher due to more aggressive crossing angle
    - Sets us up well for 2018 running

Separation levelling (IP1/5)

- Levelling ATLAS/CMS with separation was used in operation after we moved to 8b4e/BCS in order to limit the pileup in the experiments
- Worked very smoothly
  - Benefitting from a couple of test fills in 2016
- Some small issues related to step size, tolerance needed to be ironed out at the start for optimal operation, but no complaints
  - We assume that levelling separation will be an operational tool for 2018 if needed
- Levelling ATLAS/CMS to very low-mu values (~2-3) at the end of the year also worked very successfully. Originally it was somewhat unclear if there would be instabilities due to the lack on head-on collisions but no problems were observed
  - May also want to run like this for a few days in 2018





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8b4e (& BCS)

- Experiments already have experience from 8b4e filling scheme from test in 2015
  - Generally not favoured as gives more pileup/lumi
  - Originally ATLAS did not like the short trains as causes problems with their out-of-time pileup compensation – however online and offline corrections implemented to deal with this
- As an emergency mitigation for 16L2 8b4e worked extremely well
  - It saved the year!
- Original 8b4e filling scheme used was particularly bad for LHCb in terms of number of collisions, however changing abort gap keeper allowed a more fair distribution of collisons
  - Of course LHCb still suffered from less bunches compared to 25ns schemes
- BCS scheme for 8b4e also gave a nice gain in performance
  - Demonstrates incredible flexibility of the injectors, and super smart thinking by the experts!

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No complaints about any of the new tools!

Special runs in 2017

- VdM scan (13 TeV)
  - Scan programme went well
  - complication with last minute change of filling scheme due to unexpected long range effects (zero crossing angle at injection)
- 5 TeV run
  - Well planned
  - Machine setup and validation extremely fast and smooth
  - Incredible machine availability allowed to reach all (ambitious) experiment goals 1 day ahead of schedule
- 900 GeV high β*
  - see next slide
- Low-pileup data taking
  - Last minute addition to schedule
  - Ran very smoothly, separating all IPs did not cause problems
  - Very good availability, and long fills meant data set exceeded expectations

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900 GeV high β*

- Challenging run, requested by TOTEM/ALFA
- Converged on basic setup (energy, β*) (18/8)
- Always said would need early tests with beam, but difficult to schedule with 16L2
- Took sometime to converge on acceptable optics for physics
  - Plan to also take data with 11m β* to cover full needed *t* range
- First test with beam (25/10) showed could directly inject into physics optics, with acceptable lifetime and emittance growth
- Second test (8/11) showed large beam backgrounds in detectors, different scraping strategies tried but none effective enough for physics
  - Decided here to cancel run in 2017, running out of time due to change of LHC schedule
- Third test (22/11) tried different way to control background. Off momentum particles shown to play a significant role
- Run will probably be requested for 2018 if can be shown to be feasible in acceptable time
- Lessons learnt
  - Hard to rush setup and tests for these challenging runs
  - Not a good idea to schedule special runs right at end of year, as run out of contingency if problems occur

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Miscellaneous

- Non-colliding bunches
  - Try to have non-overlapping trains of 12b in filling scheme to give ‘isolated’ non-colliding bunches (not polluted by collision afterglow)
  - When we moved to 8b4e this was no longer possible, still non-colliding bunches in each beam, but not isolated
  - Limited the ability for ATLAS to monitor the beam backgrounds in 1-beam
  - This issue depends on details of filling scheme, but could be nice to have some more flexibility here (shorter trains?)
- Instabilities
  - Instabilities triggered by 16L2 events that caused the beam to be lost, were of course a significant problem in 2017 running
  - However other instabilities did not cause problems for the experiments
- Beam backgrounds
  - In general beam backgrounds in 2017 were similar/better than in 2016 and not problematic for the experiments

Communication

- Generally things worked very well in the communication between machine and experiments (with LPC in the middle!)
  - Big thanks to all relevant experts and especially machine coordinators!
- A few examples where things were not perfect:
  - Experiments would like to be pre-warned when large push in beam parameters (and therefore luminosity). One fill in 2017 where intensity pushed without warning to experiments caused some problems
  - Not perfect communication related to ATLAS BCM masking during MDs
  - Not perfect communication related to beam-mode for machine-tests/ commissioning, can be problematic for CMS as beam-mode can directly drive their state-machine
  - Scheduled last high β^* test clashing with SPS MD, inefficient, and frustrating for SPS experts
    - Should be avoided in the future with better communication
- In general it is not completely clear to us how the best communication with the injector teams should work (LPC or machine coordinators main channel?)

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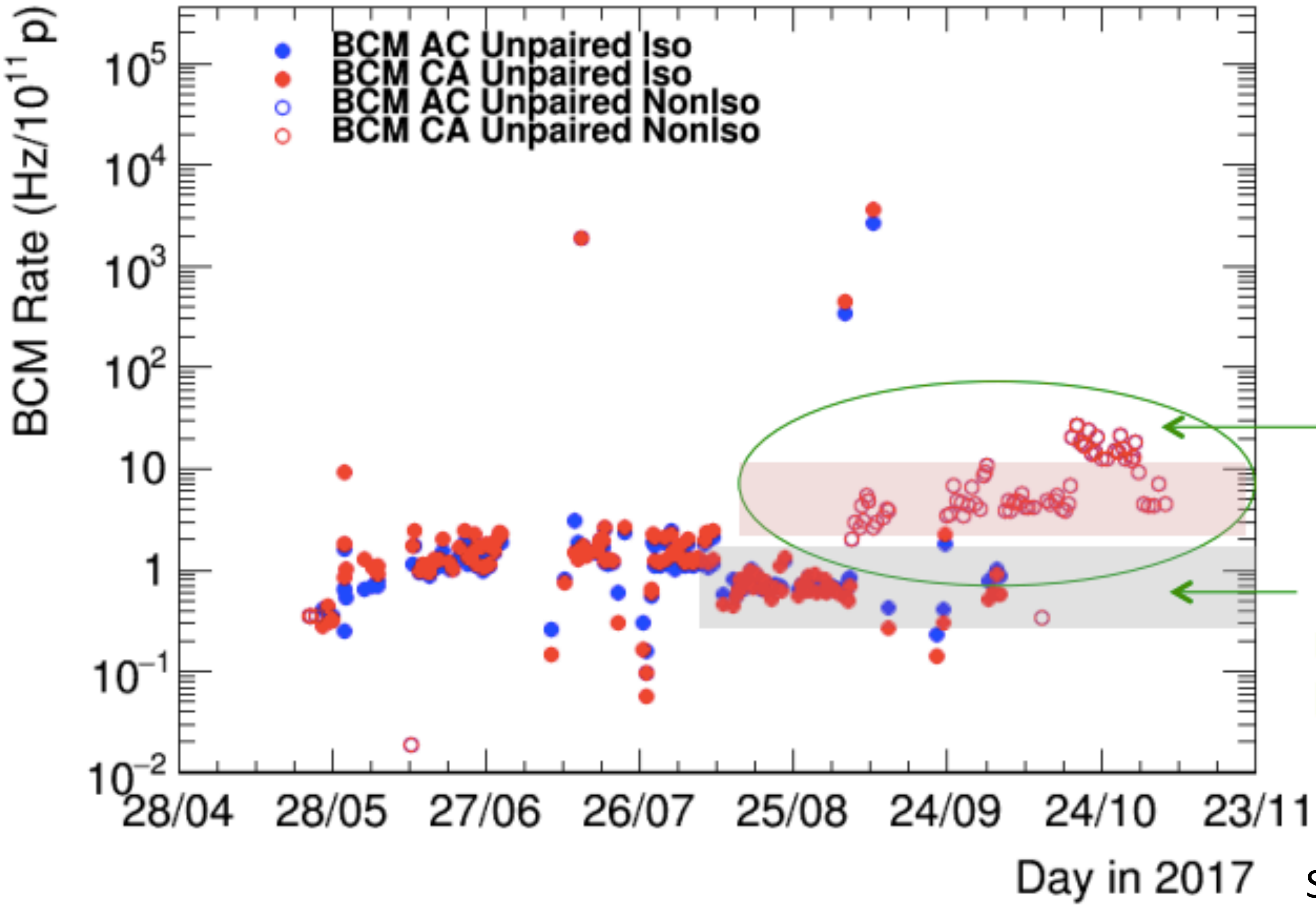
Conclusions

- 2017 proved to be a very successful year for the LHC experiments
  - 50/fb to ATLAS/CMS
  - 1.86/fb to LHCb
  - 170hrs at 5 TeV to ALICE
  - low-pileup data for ATLAS/CMS
- Solution to mitigate 16L2 and still deliver relied on flexibility of injectors/LHC and intelligence of experts
  - 8b4e, BCS, 30cm and levelling
- New tools introduced in 2017 were big successes, allow more flexibility and improved performance in the future
- Experiments looking forward to even more data in 2018!

Beam backgrounds

Second part of the 2017 data taking with 8b4e scheme (empty circles)
Standard DataSummary plots dominated by afterglow in both beams.

- We can display the correct measurement for one beam only… in a forthcoming plot



Not only it is afterglow,part is an artifact effect, probably due to BCM. Under investigation.

Expected order of magnitude of the real background level

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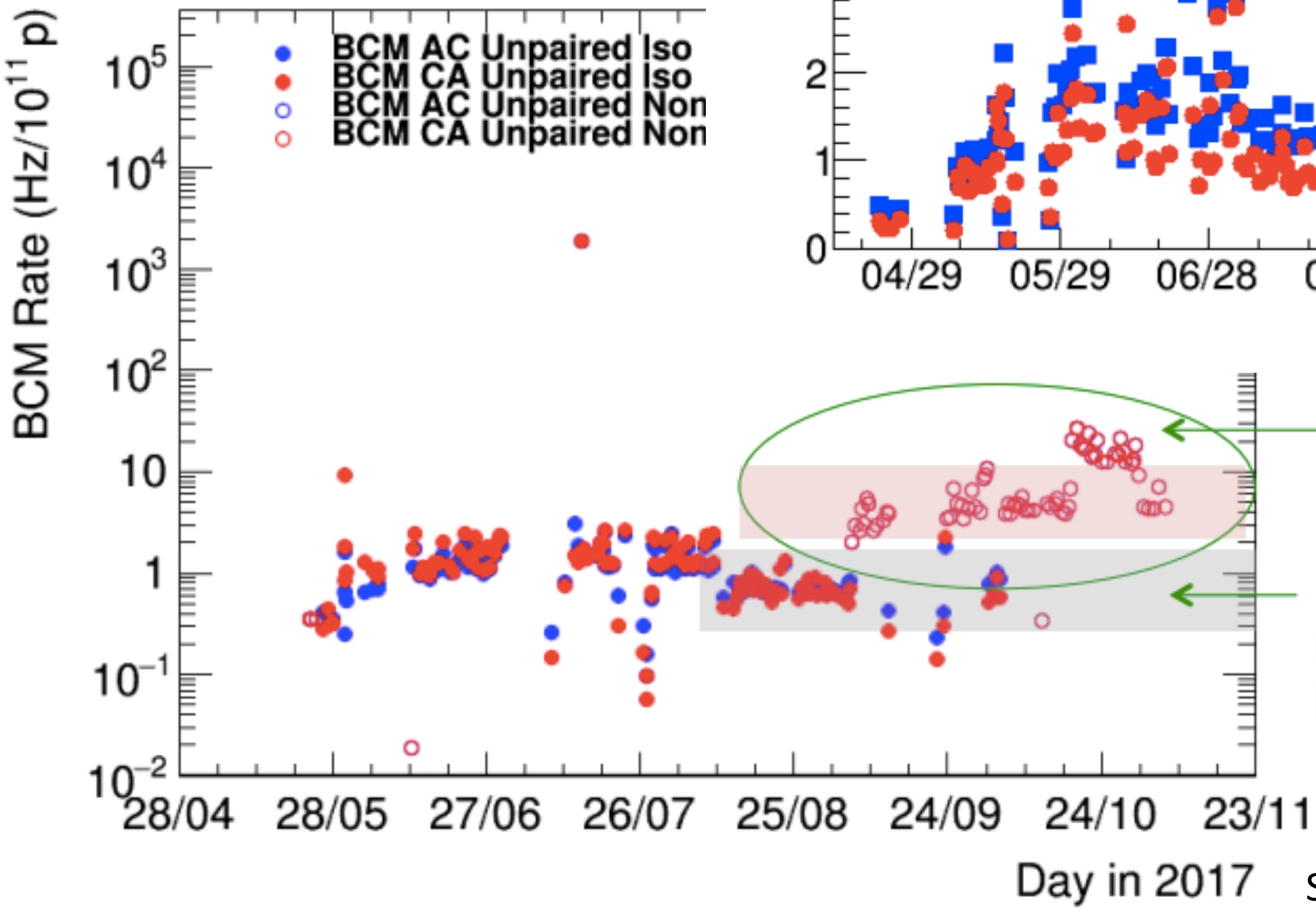

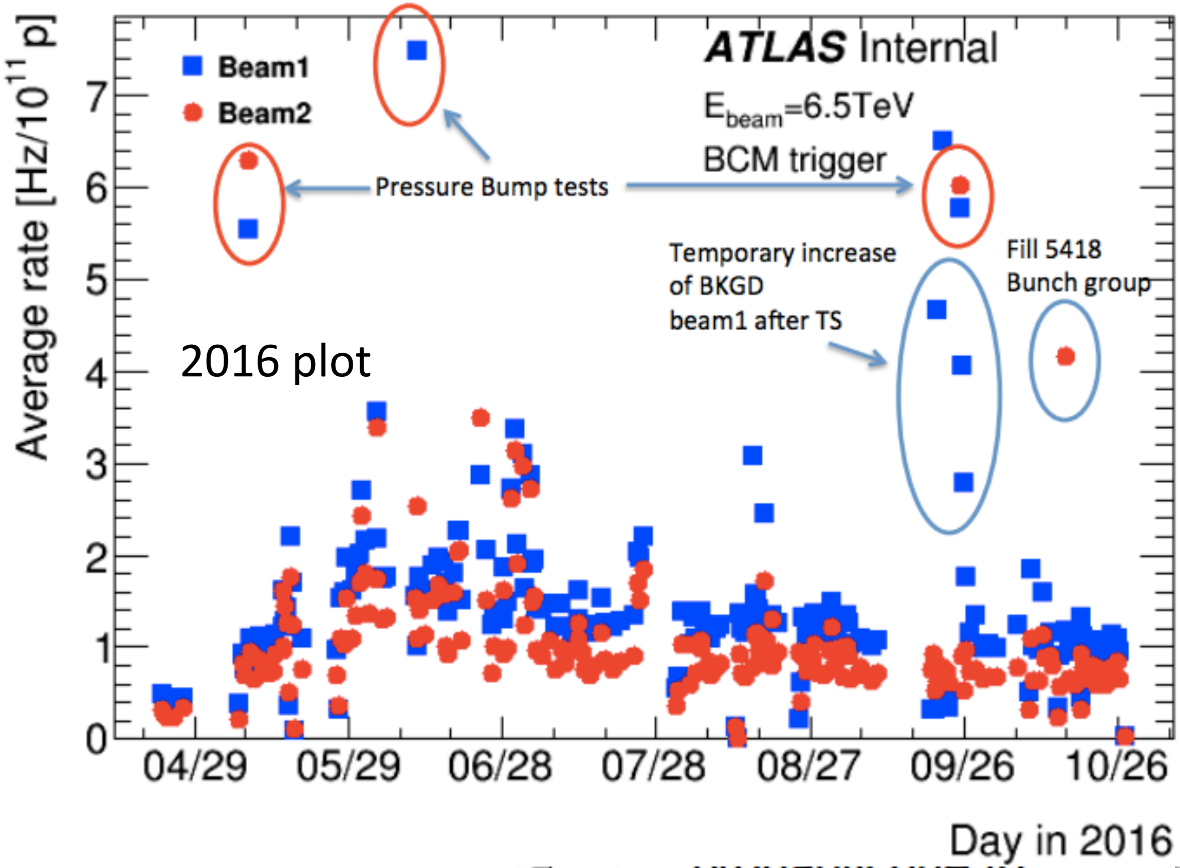

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