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CERN

Experiments
- experience and future

J. Boyd, C. Schwick (LPC)

Evian 2016

13/12/2016

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Overview

- 2016 feedback
- 2017 running
  - nominal running
  - special runs
- Issues
  - luminosity imbalance
  - CT-PPS acceptance
  - CMS beam-line re-alignment

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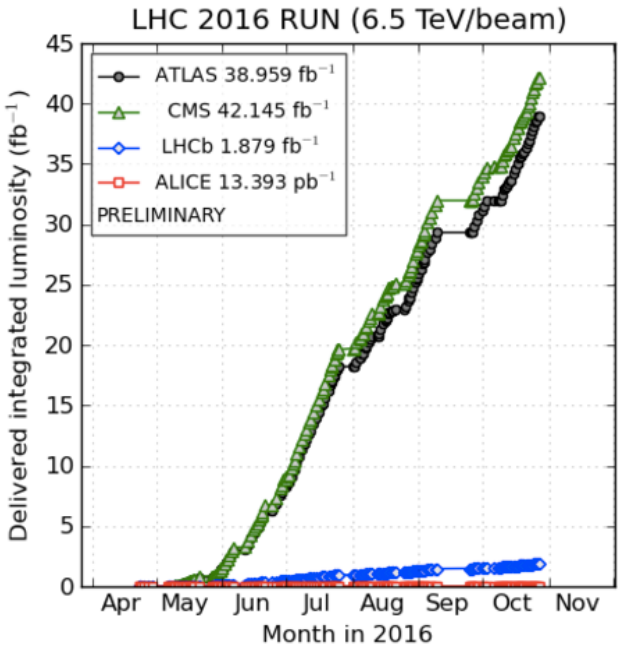
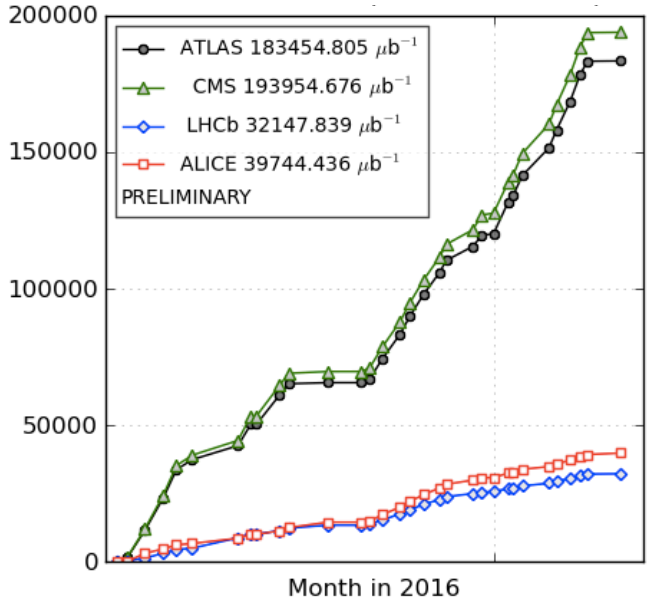
2016 performance

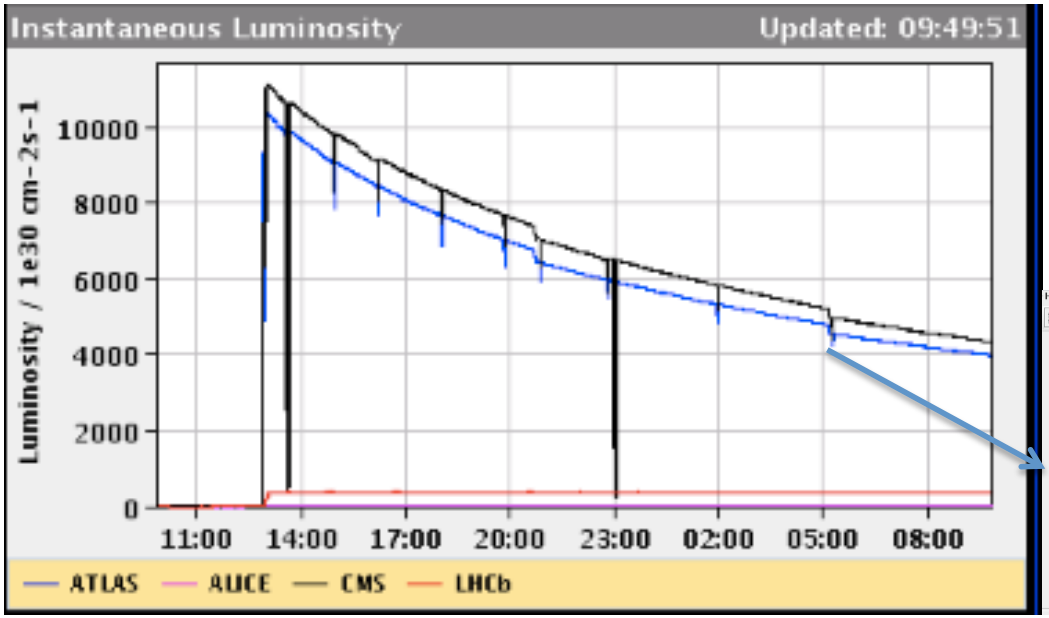
- 2016 was a great year!
  - Excellent availability and high peak lumi
  - Experiments could cope with the high lumi/PU (just)
    - Routinely inserting CT-PPS pots to 15σ for first time, without problems!
  - In general experiments not worried by
    - beam backgrounds (better than in 2015)
    - instabilities (except if they lost the fill)
  - Very successful 2.5km β* run for TOTEM/ATLAS(ALFA)
  - Proton-Lead run was great success despite very challenging plan, after conflicting requests from experiments

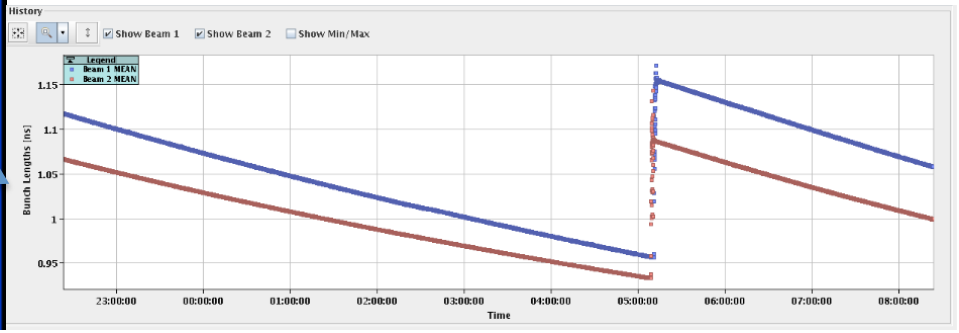




2016 performance

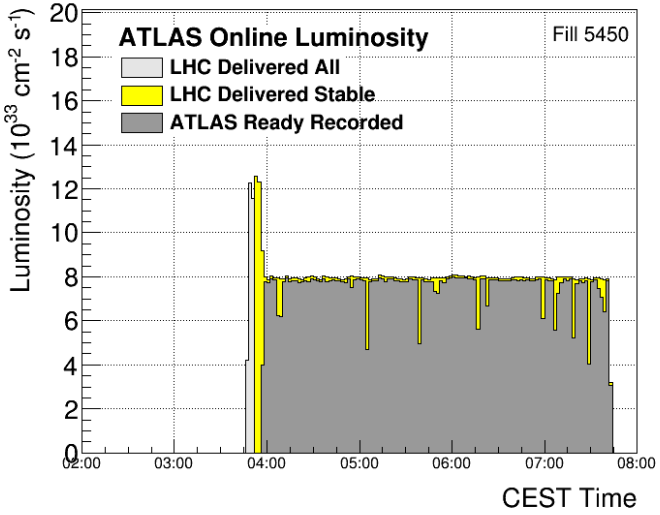
- Bad losses at injection for a short period which caused problems for ALICE
  - fixed when additional RF 40 MHz cavity used in PS
- Bunch length levelling for +ve LHCb dipole polarity worked well for them
  - will run 2017 (unless IP8 crossing plane changed?)
  - Could be improved to to run at slightly lower bunch lengths (~0.9ns) to increase lumi to IP1/5
- ATLAS/CMS lumi imbalance is an issue
  - Need to try to address this for 2017

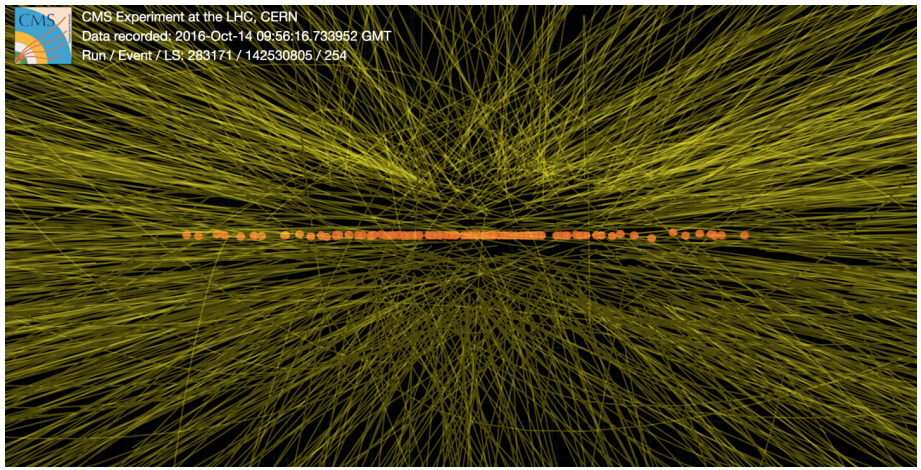




2016 test runs

- A number of useful test fills were carried out in 2016:
  - Tests of luminosity levelling by separation in IP1/5 demonstrated this works, and can be operational in 2017 if needed
  - High pileup fill for ATLAS/CMS very useful for preparing the experiments for higher luminosity running in the future
    - Experiments would like this again in 2017 (>10% higher pileup in 25ns trains if possible)
  - Crossing angle reduction test to understand ATLAS/CMS luminosity difference
    - Very useful likely want to repeat in 2017
  - Test of HL-LHC RF scheme (full detuning)
    - Seemed to work well, so far no reasons from experiments why this cant be used in standard operation in 2017+





Nominal running in 2017

- ATLAS/CMS would prefer to run with BCMS in 2017 to maximize integrated luminosity
    - 2017 seen as a luminosity production year
- Both experiments:
    - expect to be able to cope with pileup up to 60, and 2e34
        - LHC not expected to go beyond this – see next slide
    - are studying if levelling below 2e34 would be beneficial to their physics programme
- We consider leveling by separation at IP1/5 (either or both) will be operational in 2017
    - Maybe needed also for triplet cooling limit (1.75e34 mentioned this week)
- We think choice of β* and ATS/standard-optics is not important for experiments as long as it does not effect setup time, or machine availability
    - Exception - ATS less good for CT-PPS physics reach – see later
- Experiments very much hope that SPS beam dump will be replaced to allow to inject 144b with BCMS (2400b in total compared to 2200 in 2016)
- New for 2017 AFP pots to be inserted to 15σ for regular high lumi running

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2017 planning: running conditions

M.Lamont

	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}

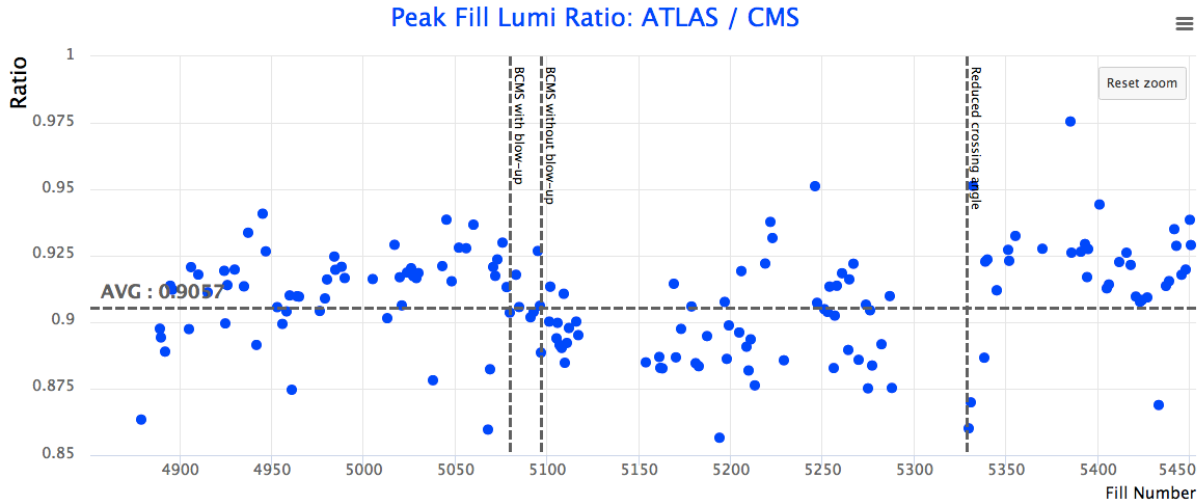
Final configuration following discussion at Evian and Chamonix

Special runs in 2017

- In the period 2017/2018 we had requests for:
  - 90m-like β* run with maximum lumi (TOTEM – glue balls, missing mass search…)
    - LHCC suggest to do in 2018 (~1-2 weeks including setup)
    - Optimization of machine setup to give highest lumi (μ=1) has started with Helmut
  - 5 TeV pp reference run (needed for Pb-Pb and p-Pb physics analysis)
    - requested by ALICE, ATLAS/CMS – but time will be driven by ALICE request
    - ALICE want 6.7days in SB at low lumi – should try to come up with a configuration to do this as efficiently as possible – e.g. very long levelled fills (c.f. 5 TeV p-Pb) – what β* etc..?
    - LHCC suggest to do either at end of 2017 (cool-down?) or end of 2018 depending on schedule – good to have a configuration ready for end of 2017 running
  - LHCC also support idea of having a high β* run at low energy (900GeV/2TeV?)
    - Not clear when, could be 2018 or in Run-3 depending on machine performance
    - We could schedule 1 day of machine time to investigate this possibility in 2017?
- VdMs with same configuration as in 2016 will be scheduled
- Possible baseline plan to have 5 TeV pp reference run at end of 2017
  - With option to postpone to 2018 based on delays with the start-up after the EYETS, and/or machine performance during the year
- Start planning configuration for the 5 TeV pp reference run, and also 90m-like β* run to happen before end of Run-2

Luminosity Imbalance

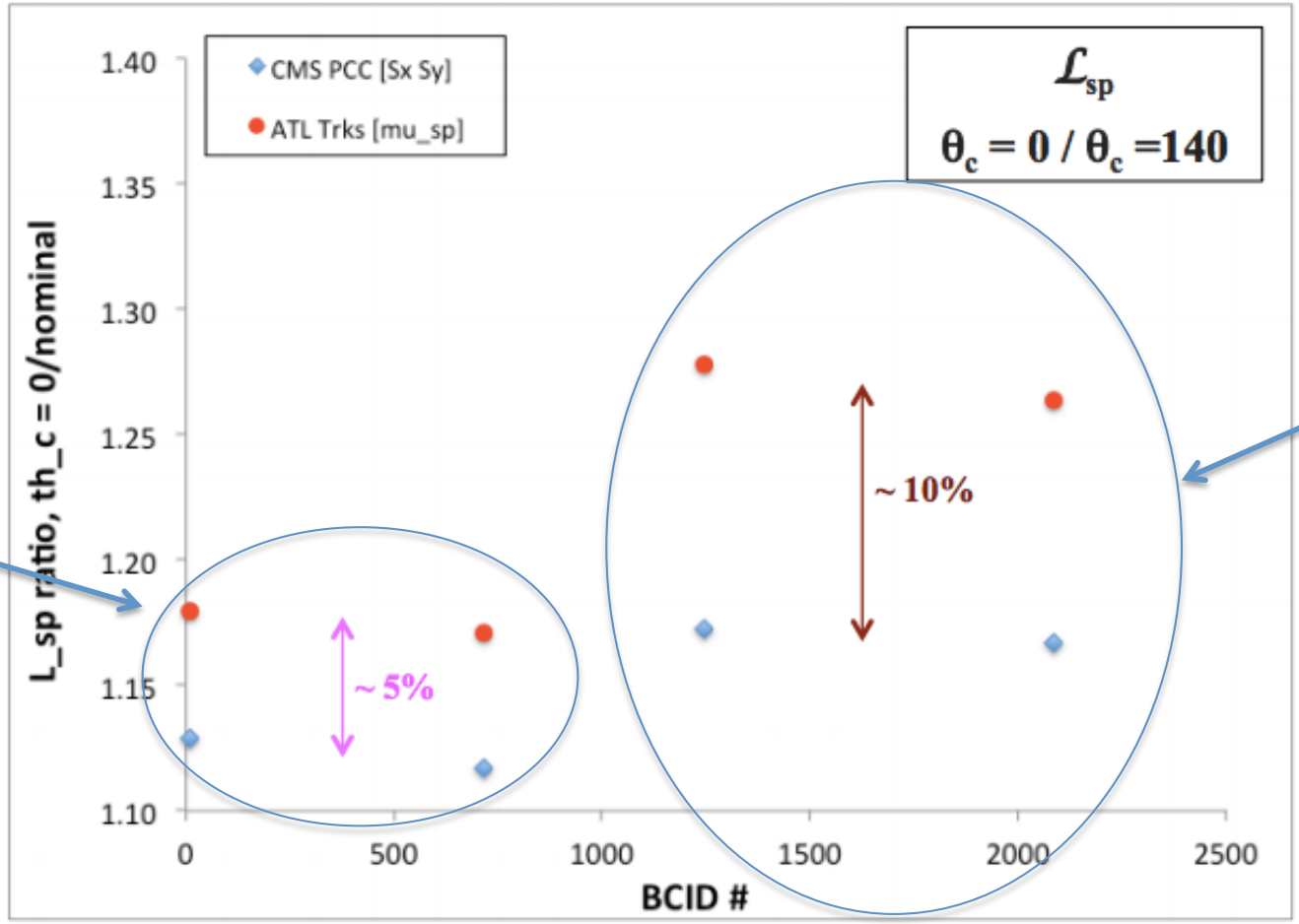
- Significant ~10% difference in lumi to ATLAS/CMS
- Seems to be (mostly) due to different H/V emittance coupled with different crossing planes in IP1/5
  - Analysis of crossing angle reduction test support this hypothesis
  - Very preliminary Z-counting analysis (independent of lumi measurement) also suggests ATLAS received less luminosity than CMS
  - H/V emittance evolution plot shown by Michi in contradiction to this for last period of running
  - More studies needed to confirm the understanding of this effect
- If confirmed preferred solution in 2017 is to run with crossing angle normalized by emittance in relevant plane
  - Gives better cancelation of beam-beam effects, and gives correct separation in beam sigma
  - Difficulty is reliable measurement of emittance
- Open question – how to choose the normalized crossing angle?
  - Do not want to update this often, but could change at TS if choice shown to be non-optimal
  - Need to understand flexibility (or not) in small changes to crossing angle with out long (re-)validation



Detailed analysis, results broadly consistent if luminosity determined from width of VDM or from lumi detector rates.

θ_c-dependence of the geometric factor at IP1 & IP5: F [$\mathcal{L}_{sp}$]

W.Kozanecki et al
LPC 5/12/16



Large emittance bunches (~4.5um)

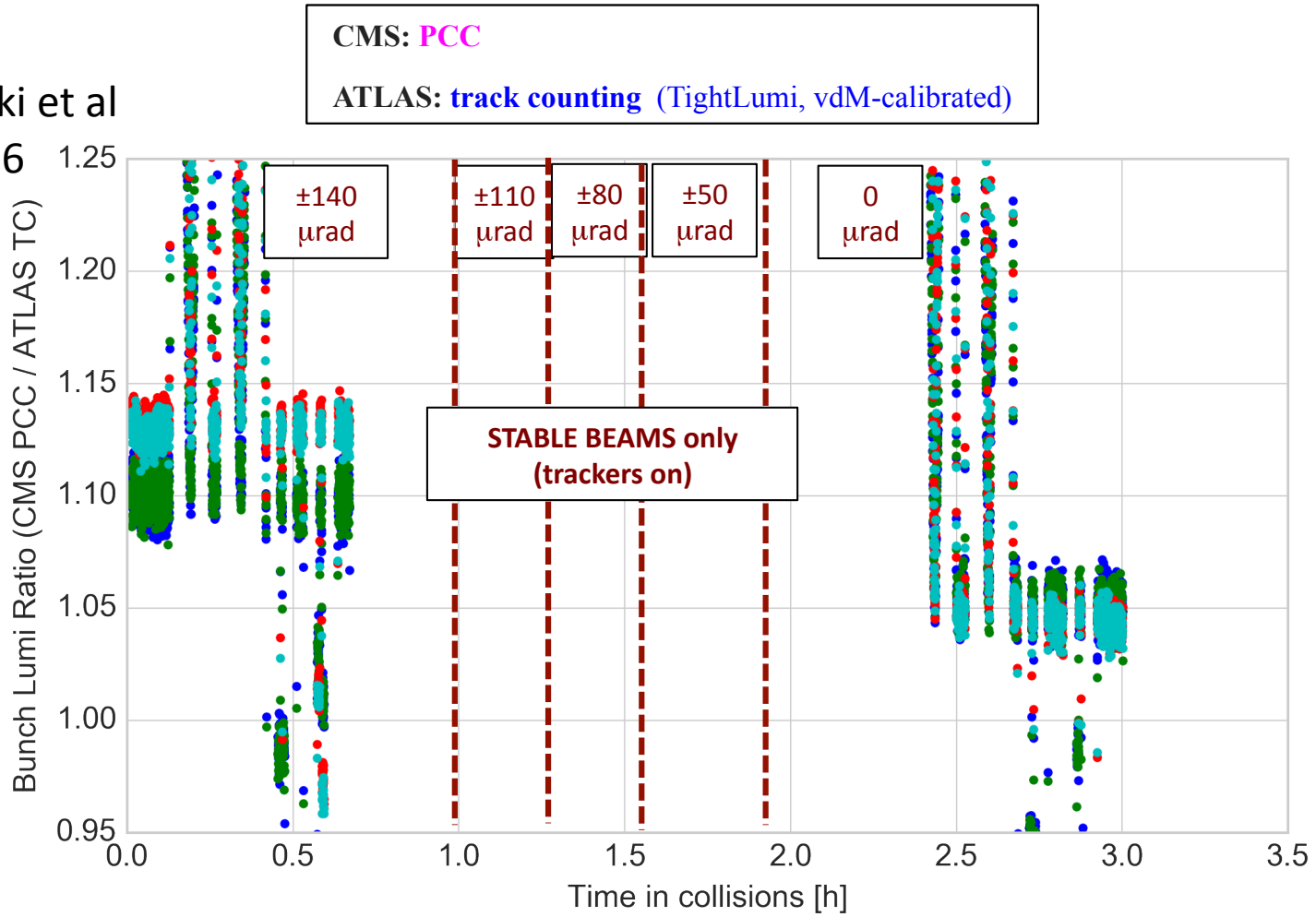
small emittance bunches (~2um)

- *At IP1, the geometric factor F varies from ~ 1/1.17 to 1/1.28, depending on the emittance*
- *At IP5, F varies from 1/1.12 to 1/1.17, depending on the emittance*
- ***The geometric factors** are ε-dependent as expected, **and significantly different at IP1 & IP5***

These conclusions are insensitive to the still-to-be-determined length-scale calibrations.

θ_c-dependence of the CMS/ATLAS ratio: 2nd update

W.Kozanecki et al
LPC 5/12/16



θ_c from ±140 μrad → 0: CMS/ATLAS ratio decreases by ~ 5 (~ 9) % for the high- (low-) emittance bunches

- *further improvement in consistency between low- and high-ε bunches at both $\theta_c = 0$ and $\theta_c = 140$*
- ***CMS/ATLAS $\mathcal{L}$ ratio ~ 1.11 (1.03) at $\theta_c = \pm 140$ (0) μrad***

The ~ 3 % difference at $\theta_c = 0$ may be due to imperfect vdM calibration and/or to β^* differences btwn IP1 & IP5

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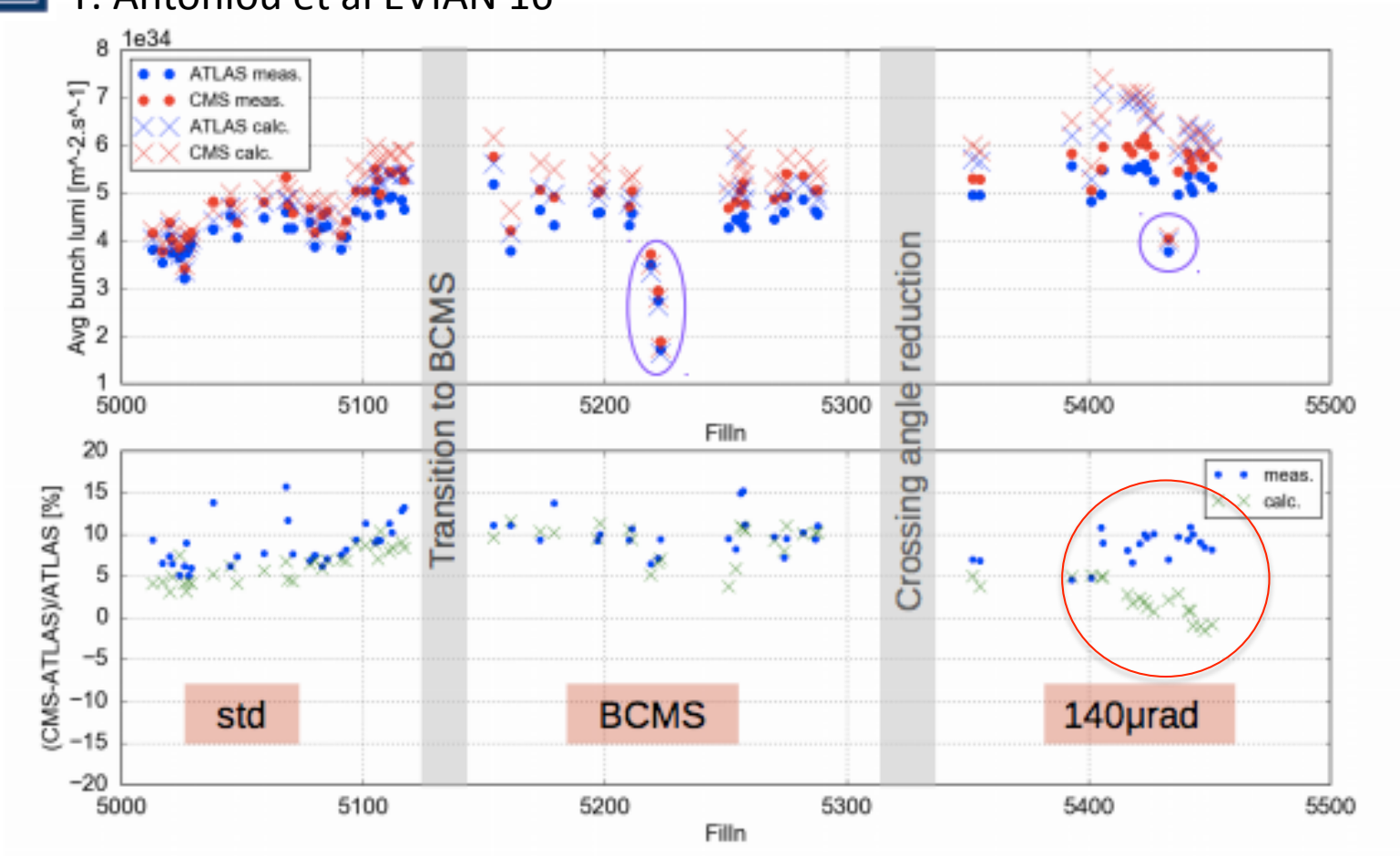
Luminosity Imbalance

F. Antoniou et al EVIAN 16



Good agreement between model to predict luminosity imbalance (using BSRT measured emittances) and measured luminosity difference. Except for last set of fills (>5400) (crossing angle reduction test in this period, shows disagreement between BSRT emittance and observed geometric factors in IP1/5).

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CT-PPS acceptance

CT-PPS acceptance reduced with larger crossing angle (cancellation of dispersion from crossing angle and D1 magnets). In 2016 a dedicated orbit bump was introduced (after a late request) to improve the acceptance.

For 2017 the plan was to optimize optics (reduced beam size at pots so they can be inserted closer to beam) so bump would not be needed. However acceptance still worse than 2016 and CT-PPS requesting a bump to improve this. Available corrector strength for bump depends on beam-line re-alignment bump in IP5.

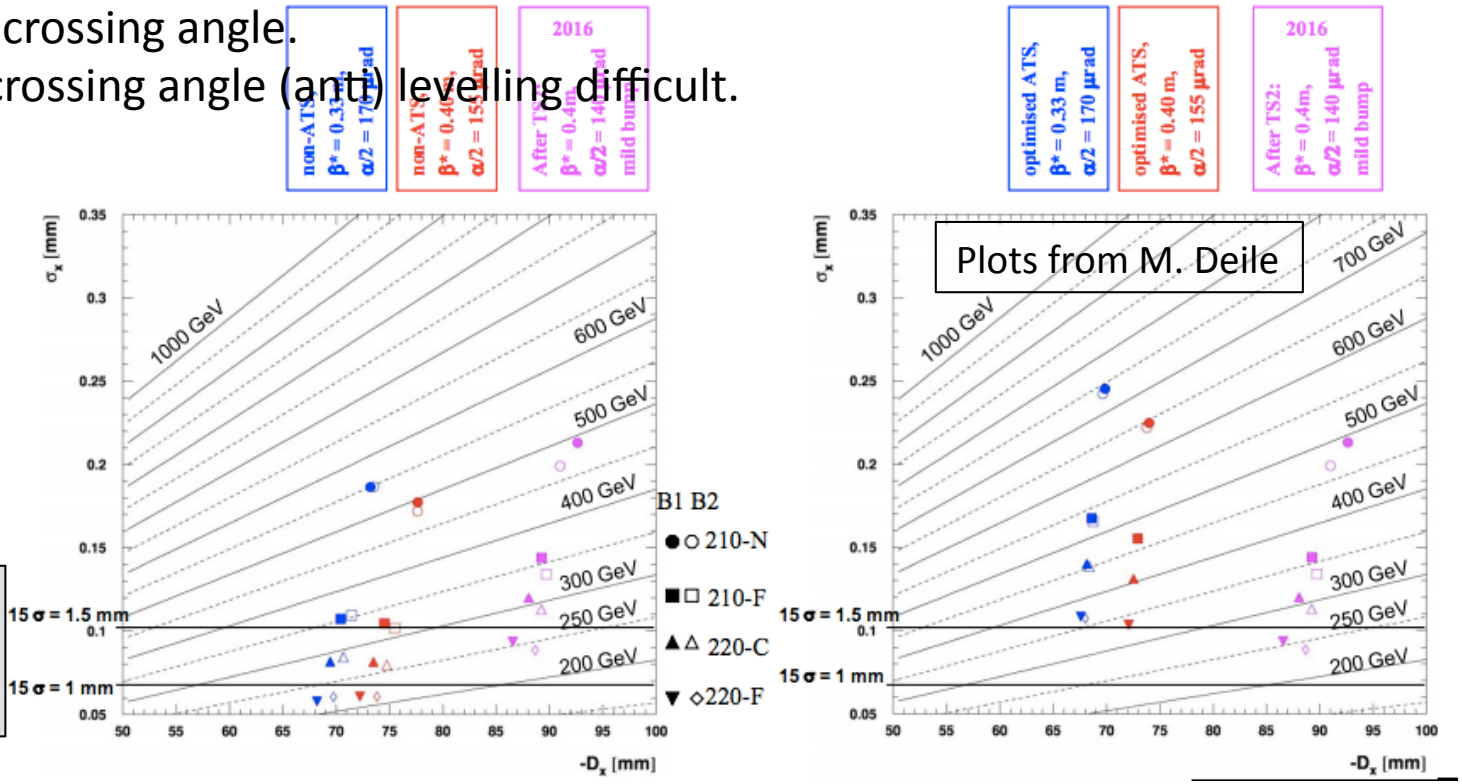
CT-PPS acceptance worse for ATS optics.

CT-PPS prefer a smaller crossing angle.

CT-PPS may also make crossing angle (anti) levelling difficult.

CT-PPS pots inserted to 15σ in 2016 but 1.5mm from beam, closer than this may be problematic.

Situation much simpler for AFP as pots not in crossing plane.



CMS beam-line re-alignment

Request from CMS to re-align the beam-line in IP5 :

LMC 02 Nov 2016 AB

Beamline re-alignment request (-2mm)

Technical Coordination

w.r.t. nominal beam axis:
Central yoke wheel of CMS is set concentric (not adjustable).

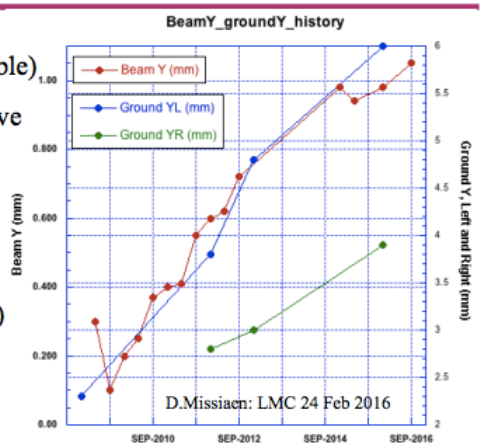
Rail system supporting pixel tracker 3 mm low (cumulative tolerances from support off yoke wheel).

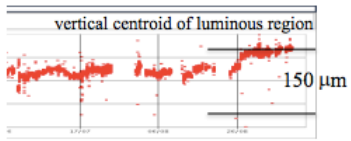
Beam is 1mm high – presumably due to continuing ground movement of tunnel wrt expt. cavern (trending upwards ~ 3.5 mm over last 7 years, L5 side).

Bpix centre currently just 0.8mm low (shimmed upwards) but little margin for further adjusting because no more headroom to support tube.

Uniform illumination of the pixel is important to assure uniform illumination/occupancy and by inference longevity

Therefore asking for beam axis to be lowered by 2mm in EYETS (set at y=-1mm overcompensate to account for anticipated future motion before LS2 – based on observed trend for 2016).
[will re-set beampipe to +0.5mm wrt new nominal beam axis].





Trend continuing in 2016 : 150 µm May-Aug

slide from A. Ball
LMC 2/11/16

Discussion on various options (our understanding):
-full mechanical re-alignment very heavy, risks delaying start up after EYETS – postpone to LS2
- re-align beam with local orbit bump – possible without limiting β*, but at limit of corrector strengths (effects any CT-PPS bump)
- hybrid mechanical/magnetic approach – mechanical re-alignment within TAN + magnetic bump (maybe best to allow a CT-PPS bump?)

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Summary

- LHC machine and injectors worked exceptionally well in 2016
  - Excellent availability (~50% of scheduled time in stable beam) and high peak luminosity (~50% higher than design)
  - Delivered 40/fb to ATLAS/CMS and ~1.9/fb to LHCb
  - Experiments coping well with the high pileup data
  - Very successful high β* and proton-ion runs completed
- ATLAS/CMS luminosity discrepancy remains a concern
  - Can be (mostly) explained by differences in emittance in crossing planes
  - But more work needed to understand this
- For planning the setup for 2017
  - Nominal running:
    - Experiments favour BCMS running to get maximum luminosity
    - Expect to be able to cope with the high pileup from this
    - Luminosity levelling expected to be operational if needed
    - Request to improve CT-PPS acceptance with bump, depends on IP5 re-alignment strategy
  - Special runs
    - Requests for 90m-like run (2018), and 5 TeV pp reference run (2017 or 2018)

Backup slides

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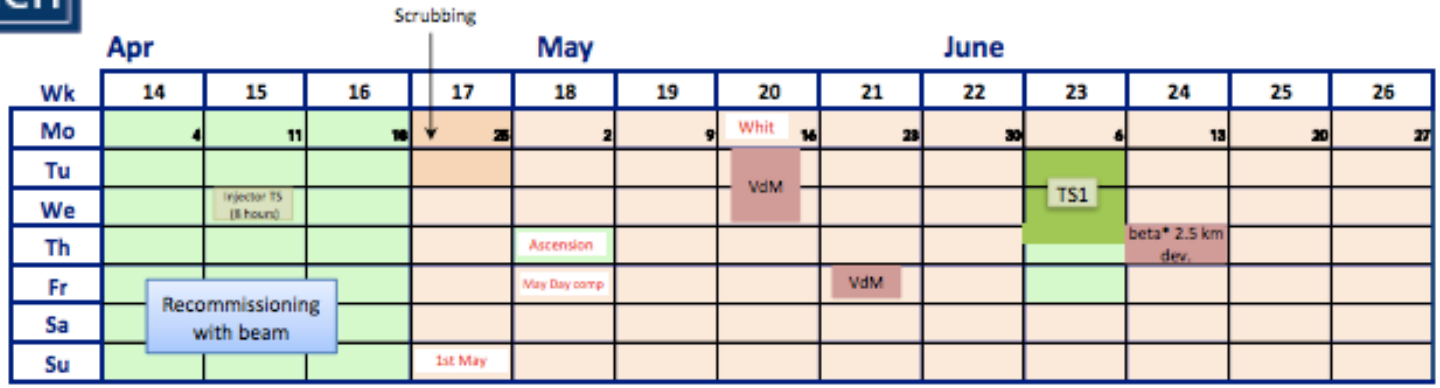
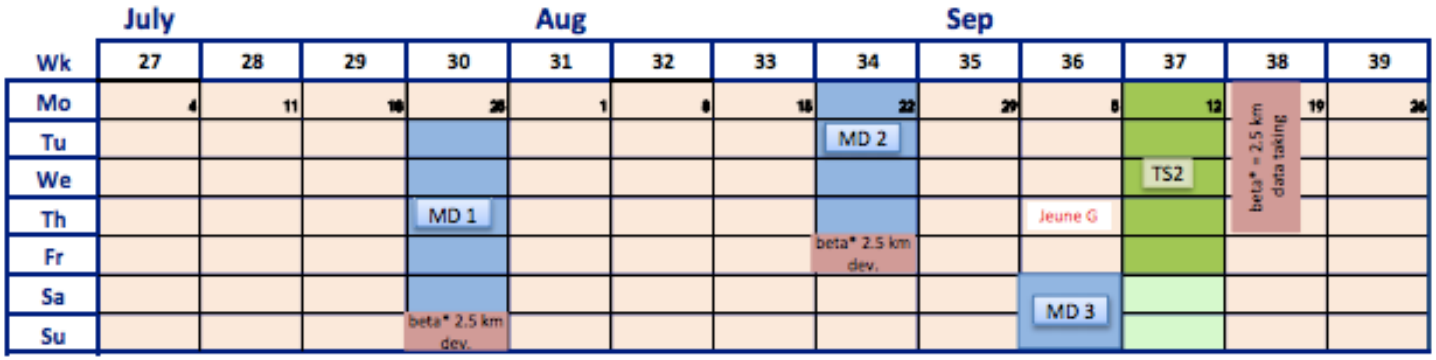
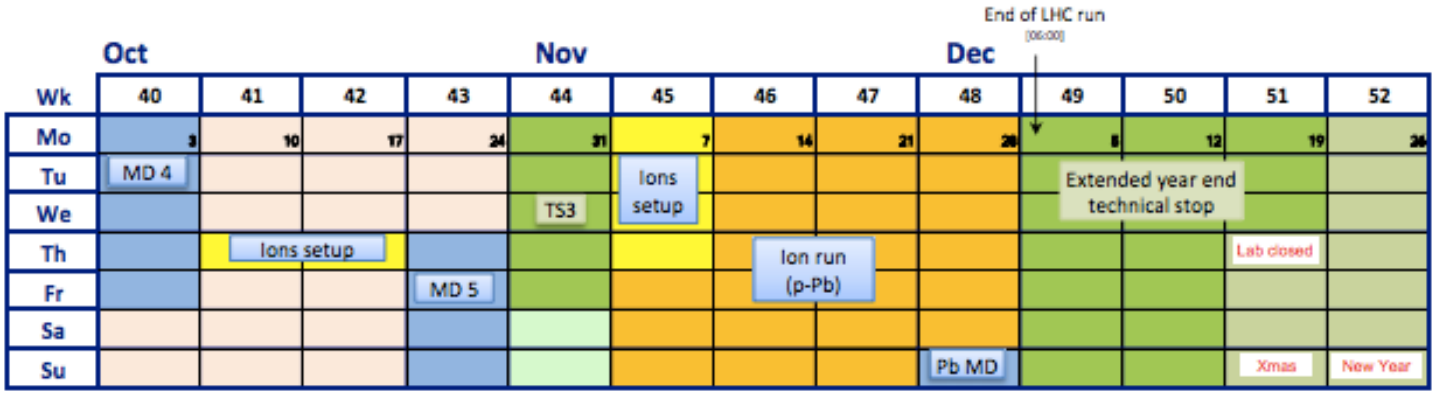
2016 overview







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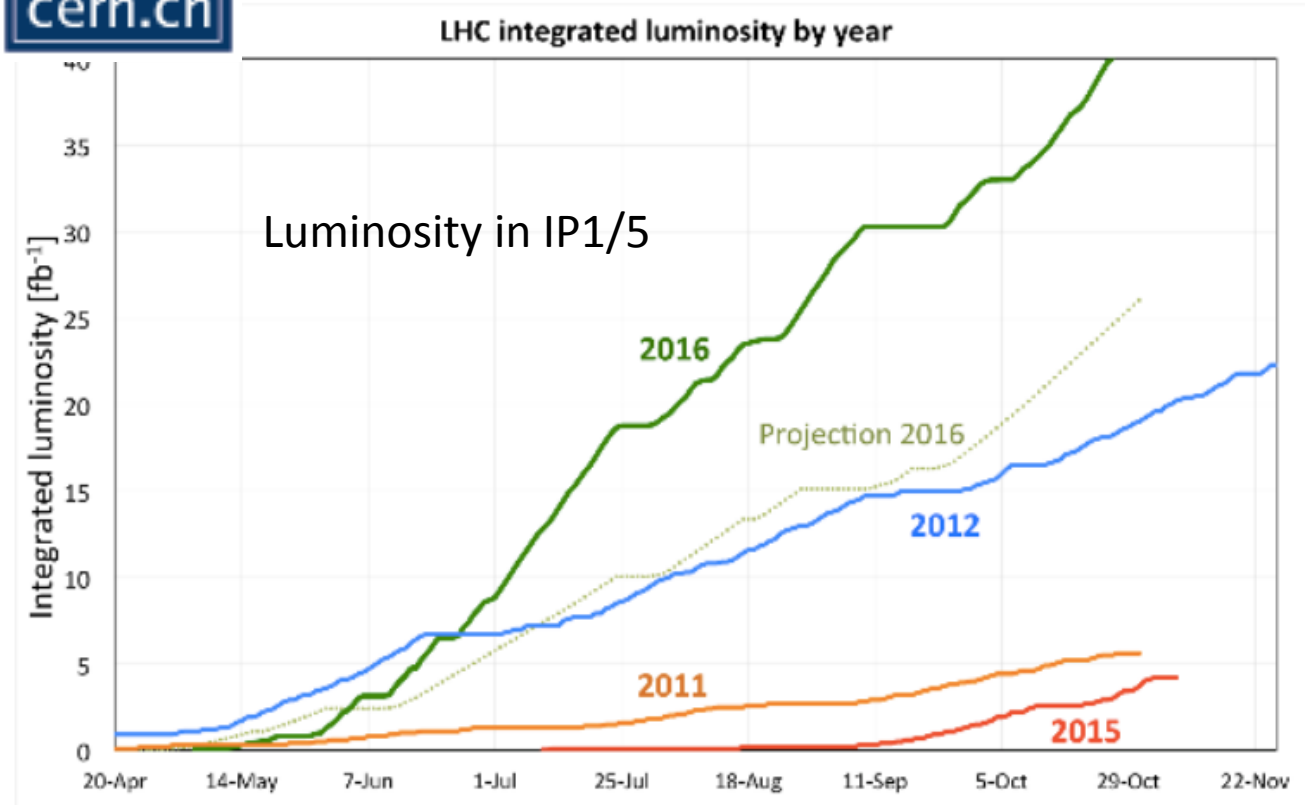
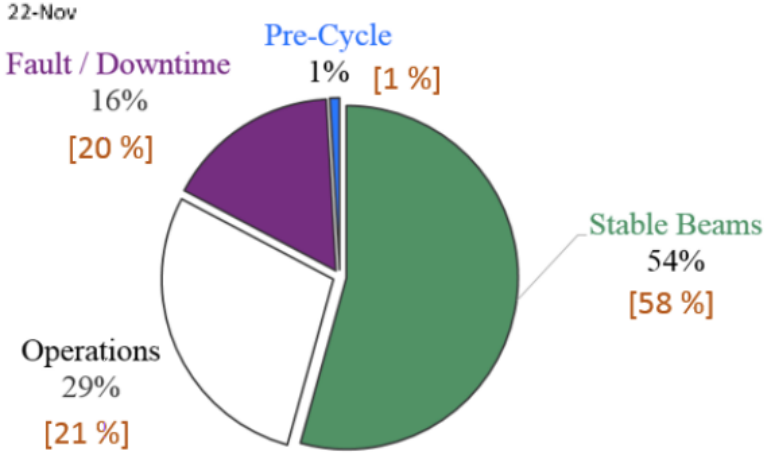
LHC performance



Excellent luminosity production throughout the full year.
Availability exceptional
More scheduled activities (MD, TS, special runs) at end of year, which effected luminosity, but taking these out the slope of curve similar throughout year.



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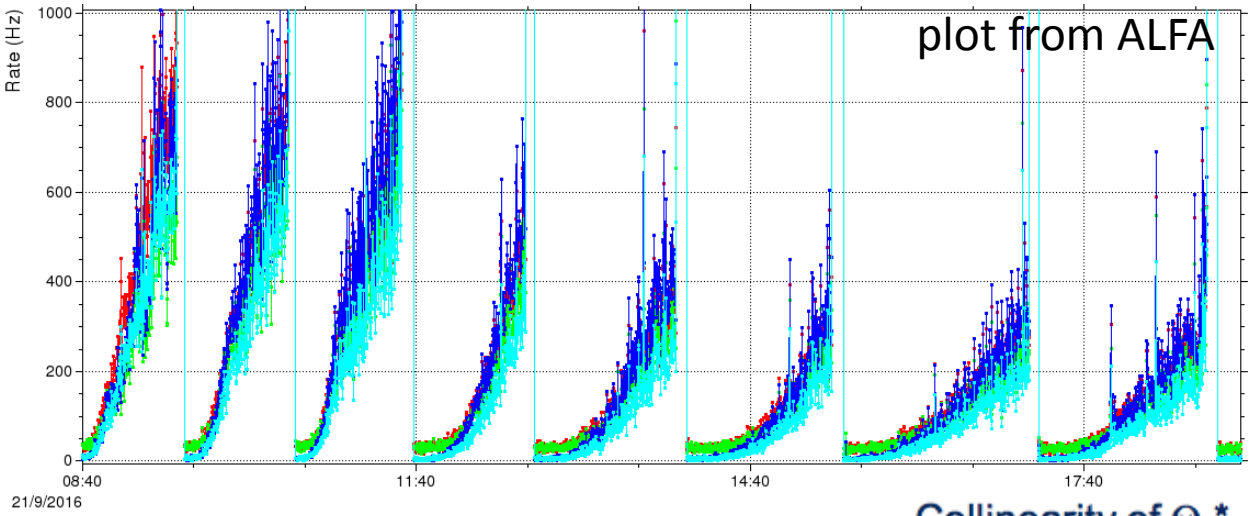
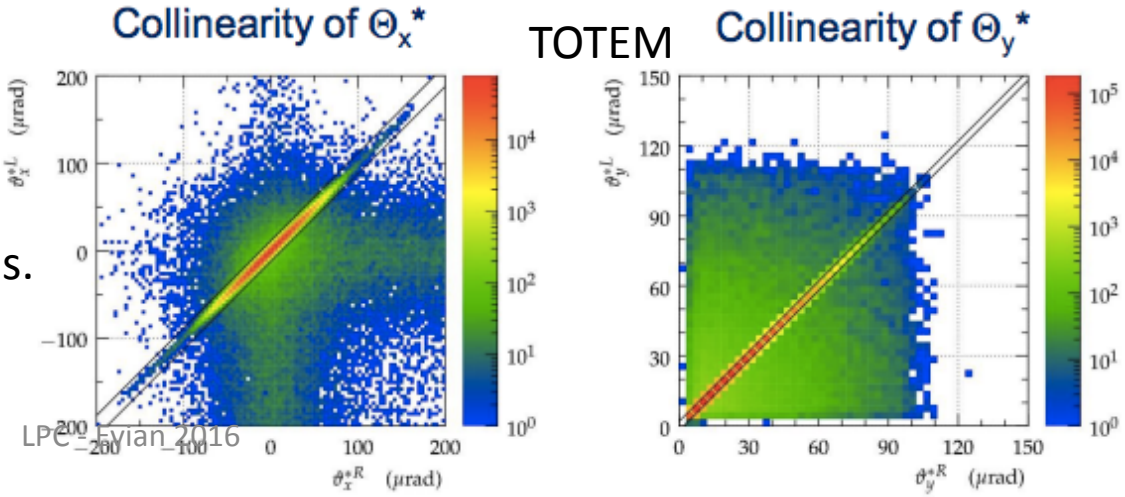
2.5km β* physics

2.5km β* physics data taking for TOTEM/ALFA for 4 days at the end of September.
Very challenging configuration, pushing machine to its limits.
Well prepared with 3 days of setup before the run.
Re-population of background after collimator scraping significant, but improved during the run.



Run successful : ~350/ub delivered in 4 fills.

TOTEM



Reminder of Heavy Ion plan

LPC/LPCC proposed plan:

	M	T	W	T	F	S	S
week1	set up 5	set up 5	set up 5	5 TeV	5 TeV	5 TeV	5 TeV
week2	5 TeV	5 TeV*	set up 8	set up 8	set up 8	set up 8	8 TeV
week3	8 TeV	8 TeV	8 TeV	8 TeV	8 TeV / LHCf run*	LHCf run* / reversal	reversal
week4	reversal / 8 TeV	8 TeV	8 TeV	8 TeV	8 TeV	8 TeV	MD

operation	days
5 TeV setup	3
8 TeV setup (both directions)	4
direction reversal	2
MD	1
LHCf run	1 (hopefully less than 12hrs)
5 TeV data taking	6
8 TeV data taking	11 days (5.5 for each direction)
Total	28 days (= 4 weeks)

*-source re-fill

Shorthand:
5 TeV = $\sqrt{s_{NN}}$ = 5.02 TeV
8 TeV = $\sqrt{s_{NN}}$ = 8.16 TeV

3

Assuming no large problems expect:
700M – 1B evts @5 TeV for ALICE
~70/nb @ 8 TeV for ATLAS/CMS
~10/nb @ 8 TeV for ALICE/LHCb
1-day for LHCf @ 8 TeV
(beam reversal @ 8 TeV)
+ outlined simple de-scoping scenarios

Always considered to be very ambitious!

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Ion-run status to date

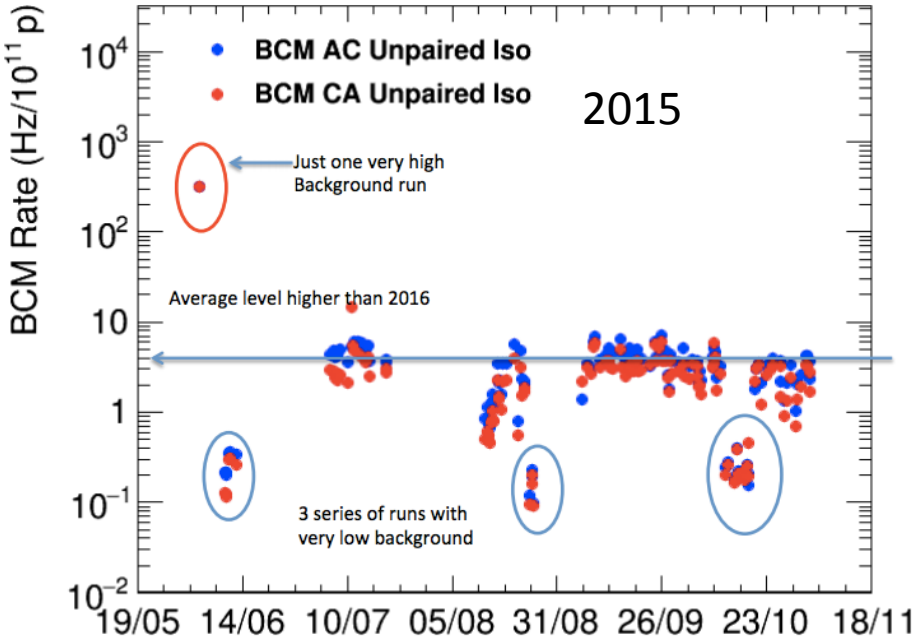
J. Jowett

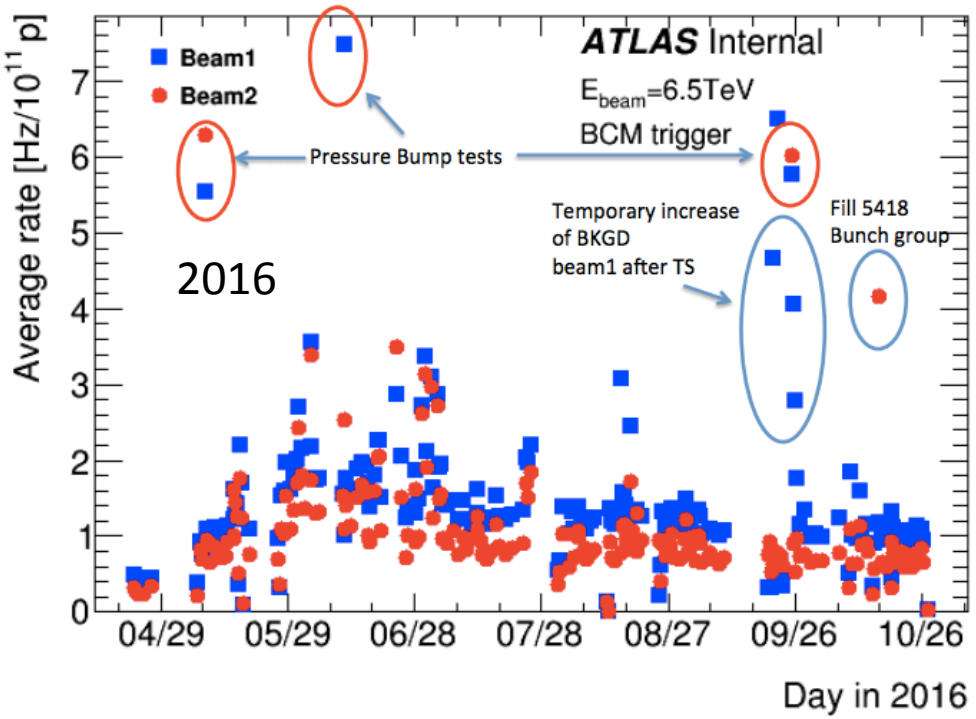
	Experiment	Primary goal	Achieved	Additional achieved
5 TeV p-Pb	ALICE (priority)	700 M min bias events	**675 M**	
	ATLAS/CMS			0.36 /nb min bias
	LHCb			SMOG p-He etc
8 TeV p-Pb	ATLAS, CMS	50 /nb	**66,70 /nb**	Min-bias in LHCf run
	ALICE, LHCb	10 /nb	**14,13 /nb**	Min-bias in LHCf run
	LHCf	9-12 h @ 10^{28} $cm^{-2}s^{-1}$	**9.5 h @ 10^{28} $cm^{-2}s^{-1}$**	
8 TeV Pb-p	ATLAS,CMS	50 /nb [100 /nb total at 8TeV]	**50,52 /nb [116, 122 /nb]**	
	ALICE, LHCb	10 /nb	**13,12 /nb**	

Benefiting from excellent LHC and injector performance. Luminosity >x6 the design!

Beam background

Plots from LBSG 21/11/16





Beam background measured in 2016 ~3x less than in 2015, and stable with time

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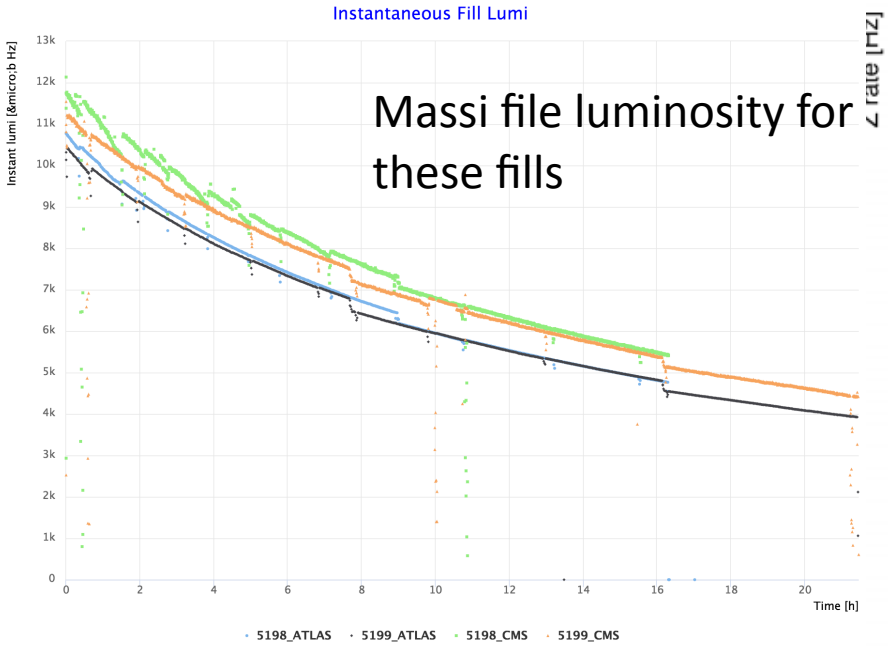
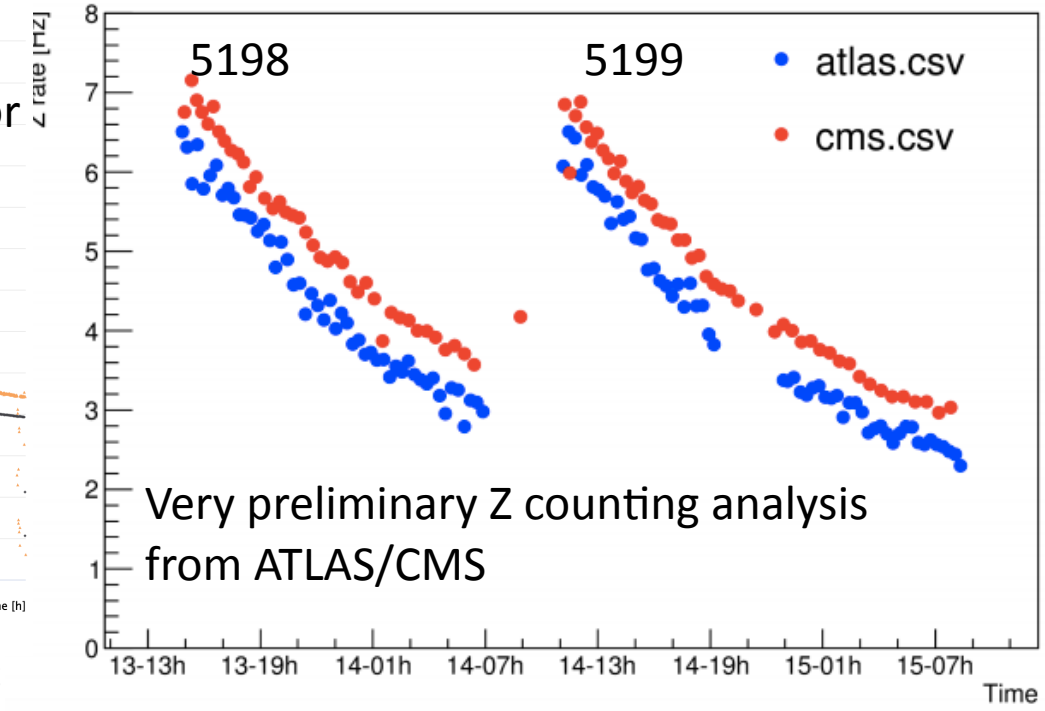
Z-counting

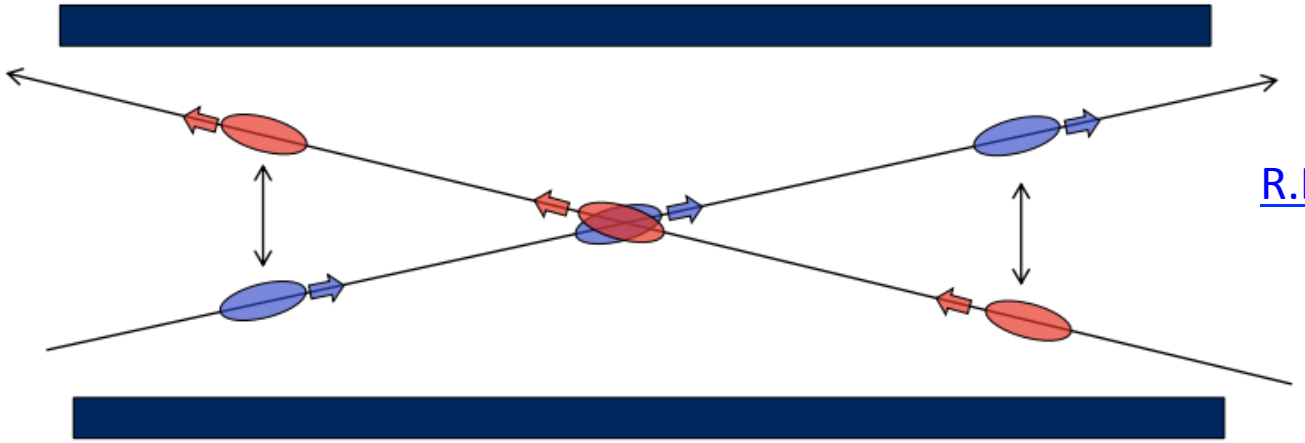
- ATLAS/CMS working on comparison of the number of produced Z bosons
  - Gives an important independent test of the delivered luminosity
- Compare Z->μμ rates in 2 defined fiducial volumes (barrel, and barrel+endcap)
- Correct observed number for trigger and reconstruction efficiency
  - Determined from data with tag+probe
- Aim for few % accuracy
- Currently comparing 4 fills
  - Still work in progress, but initial studies show Z rate consistent with experiment luminosity measurements
- Pushing strongly for this to be operational for all fills with short latency in 2017





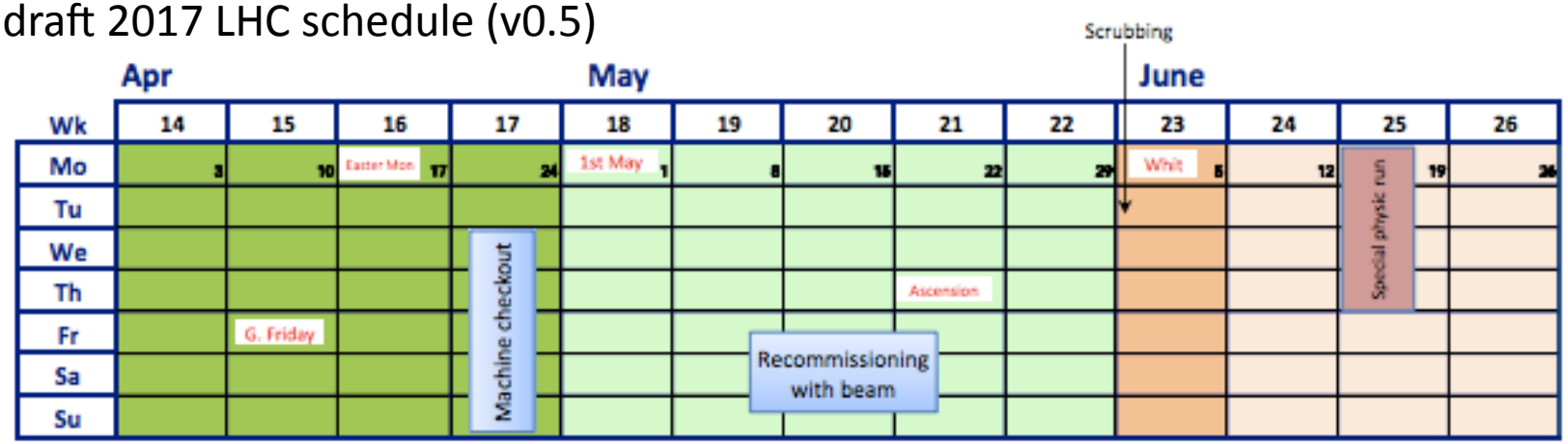
Luminosity Imbalance

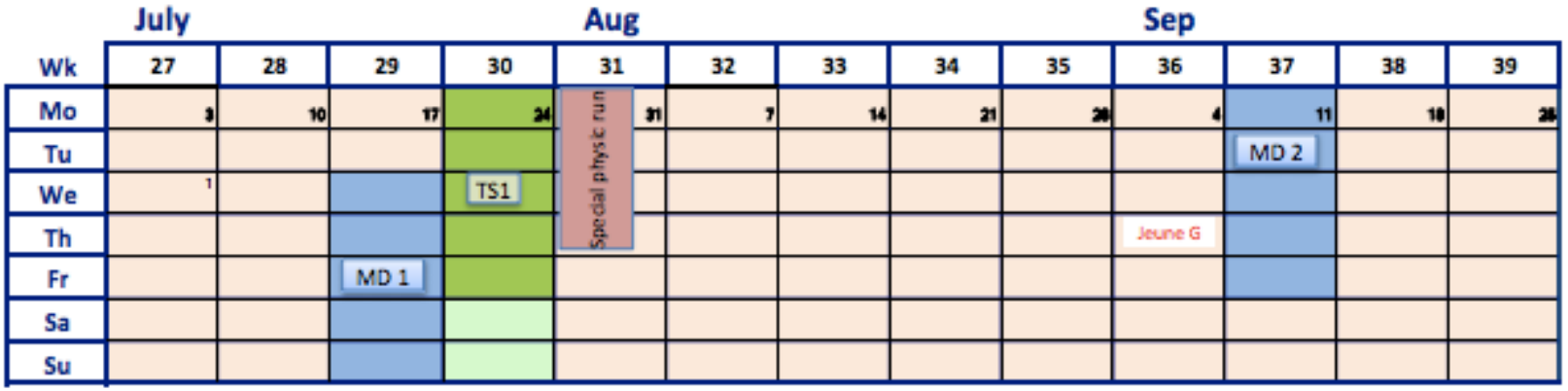
Crossing angle set to number of beam σ at position of first parasitic crossing.
If different H/V emittance then $\sigma_{H/V}$ are different, and σ from crossing plane should be used.
Allows better compensation of LRBB effects, and equalizes luminosity, and bunch length.

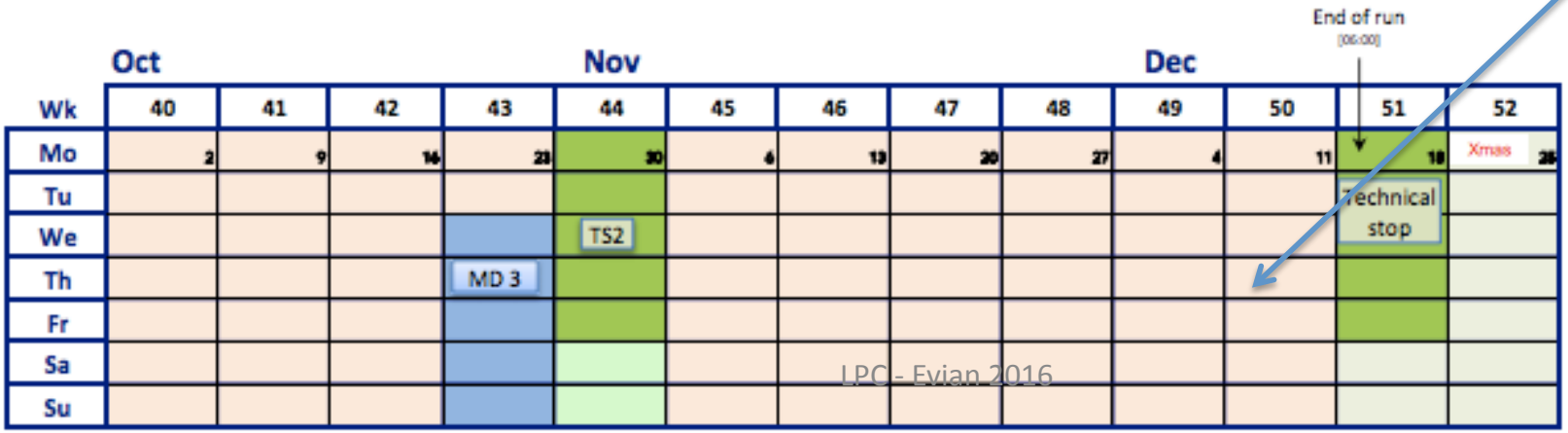


R.Bruce

draft 2017 LHC schedule (v0.5)







could schedule ~1.5 weeks of 5 TeV pp reference data here

from Mike Lamont
17/10 LPC

2017 version v0.5

Phase	Days
Initial Commissioning post EYETS	35
Scrubbing (assuming machine stays cold)	7
Proton physics 25 ns	**152**
Special physics runs	8
Machine development	15
Technical stops	10
Technical stop recovery	4
Total	**231 days (33 weeks)**

- Machine development scaled down
- Might debate: initial commissioning; scrubbing; effect of magnet exchange

Given the large amount of work planned in the EYETS (LHC and CMS) it is probably not unlikely that the start up could be delayed by 1-2 weeks. This maybe a reason to limit special runs in 2017.

Main EYETS work

- LHC/Injector work:
  - Replaced dipole in sector 12 (requires warming up this sector)
  - Replacing SPS beam dump
  - Additional pumping for MKI injector kicker (does not drive schedule)
  - Re-align beam-line around CMS (~500-1000m of beam-line!) – under discussion

- Experiment work:
  - Installation of new CMS pixel detector
  - CMS hadronic calorimeter upgrade
  - Refurbishment of CT-PPS pots (CMS/TOTEM)
  - Installation of shielding for ALFA electronics (ATLAS)
  - Installation of AFP second arm (ATLAS)

Detailed discussion on main work:
https://indico.cern.ch/event/579222/

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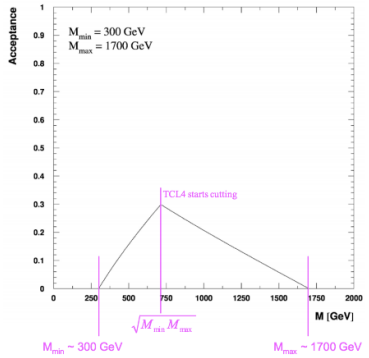
CT-PPS acceptance

Minimum mass with >0 acceptance shown.
Best acceptance for considerably higher mass.



non-ATS, β* = 0.33 m, α/2 = 170 µrad

non-ATS, β* = 0.40 m, α/2 = 155 µrad

2016 After TS2: β* = 0.4m, α/2 = 140 µrad mild bump

With no bump minimum mass with 3 pots
non-ATS ~300-350 GeV
ATS ~450-500 GeV
2016 with bump ~350 GeV

optimised ATS, β* = 0.33 m, α/2 = 170 µrad

optimised ATS, β* = 0.40 m, α/2 = 155 µrad

2016 After TS2: β* = 0.4m, α/2 = 140 µrad mild bump