LHC Machine Status report

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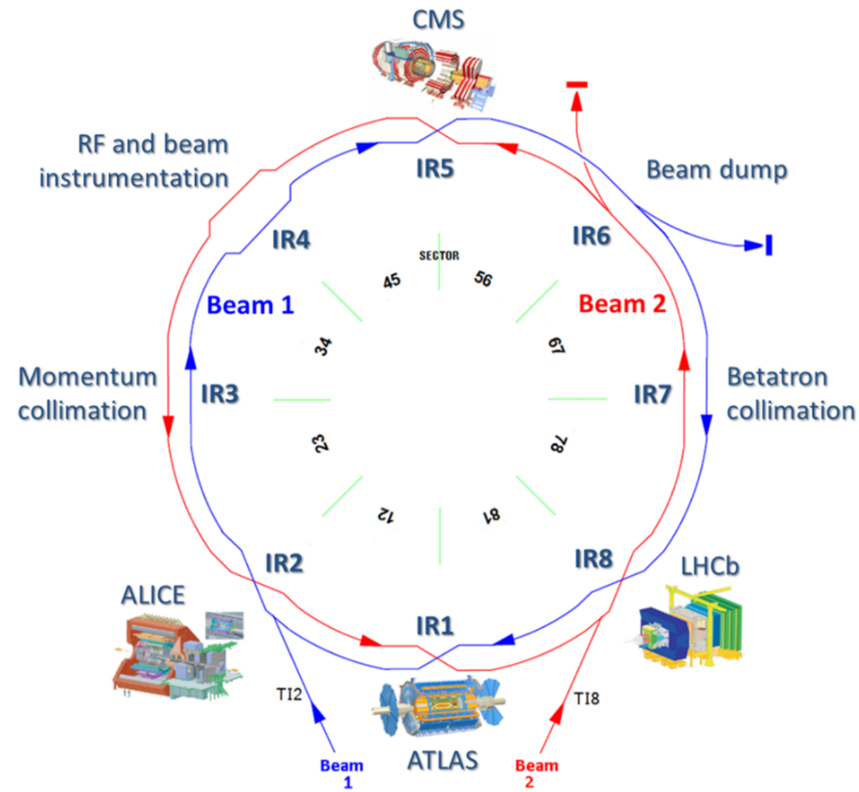
On behalf of the LHC Team

Outline

- Performance in 2015
- High intensity related issues
- Lead-Lead run
- Performance after YETS



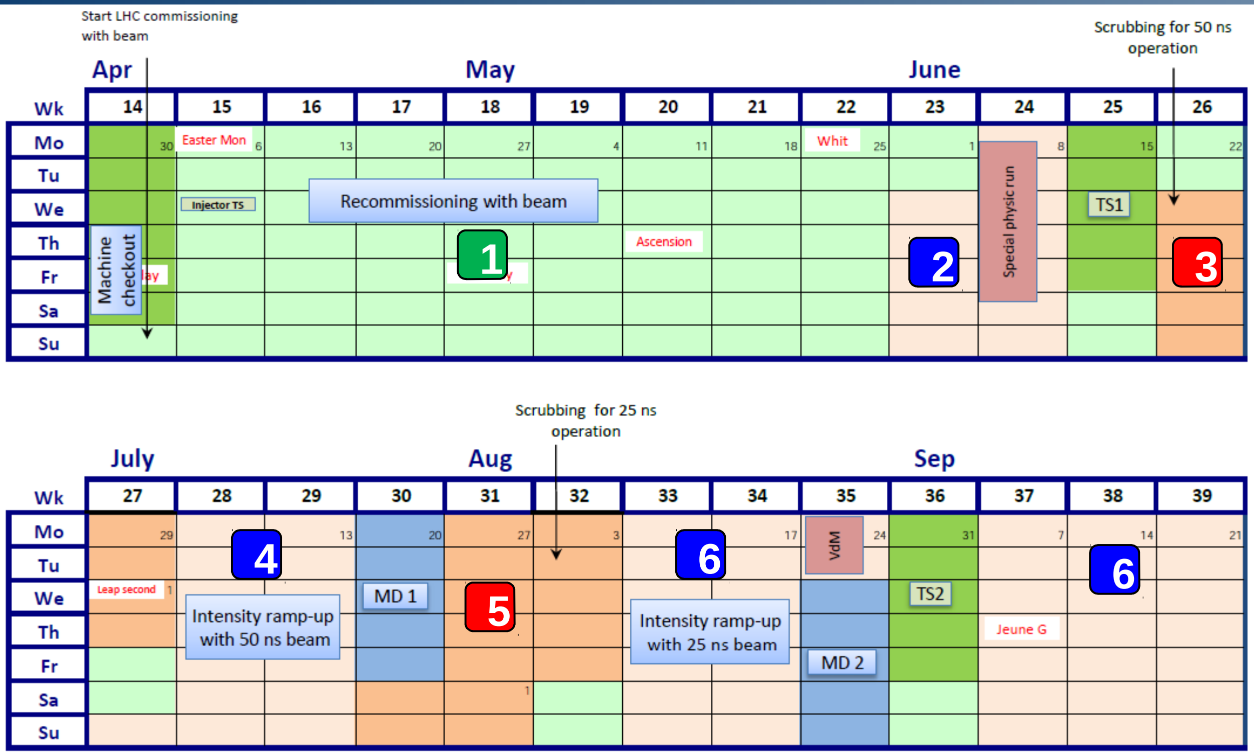
LHC Run 2 goals (2015 - 2018)

- Operate the LHC at 6.5 TeV (or higher).
- Operate with 25 ns bunch spacing.
  - *For Run 1 operated with 50 ns spacing (e-cloud).*
- Maximize the integrated luminosity & collect ≥ 100 fb^{-1}.

Objectives for 2015:

- Learning year of Run 2 (6.5 TeV, 25 ns bunch spacing)
  - *Energy: lower quench margins, lower beam loss tolerance*
  - *25 ns: electron cloud, UFOs, larger crossing angle*
- Achieving reliable operation with 25 ns spacing is top priority.
  - *β^* at the IPs were relaxed to ease operation: $\beta^* = 80$ cm was selected while 60-40 cm was in reach. We plan to move to <u>40</u>-50 cm in 2016.*

2015 commissioning strategy



1. Low intensity commissioning – 8 weeks
2. First physics – low number of bunches, LHCf run
3. Electron cloud scrubbing for 50 ns (e-cloud)
4. Physics - intensity ramp-up with 50 ns

   Characterize high intensity operation (≈ repeat 4 TeV @ 6.5 TeV)

5. Electron cloud scrubbing for 25 ns (e-cloud)
6. Physics - ramp-up intensity for 25 ns operation

Machine status in 2015

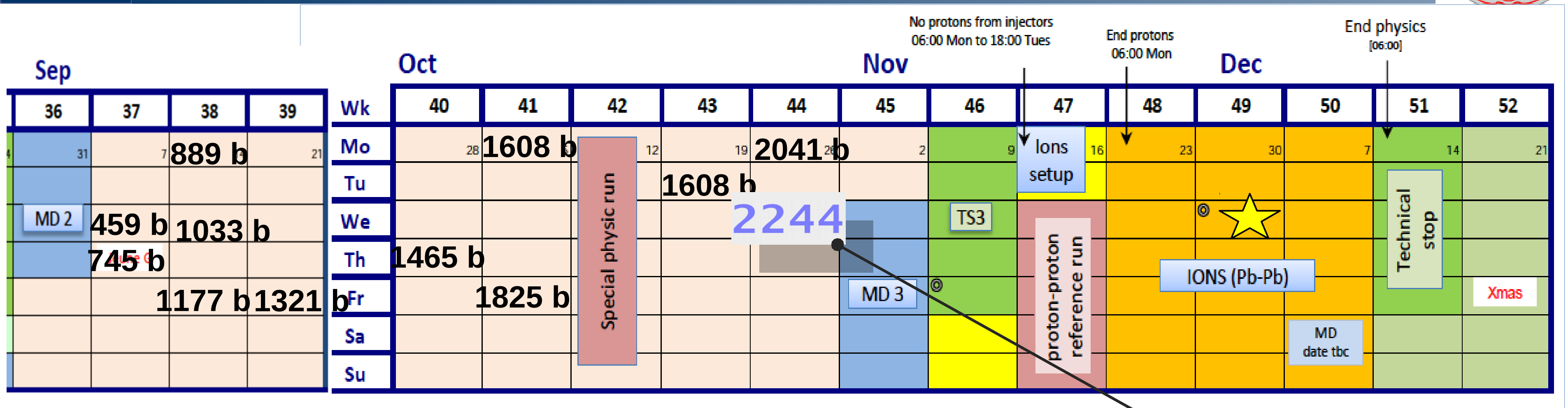
Operation could rely on a solid experience from run 1 (2010-2013) to startup the LHC – back in business in 2 months, followed by intensity ramp up since early summer.

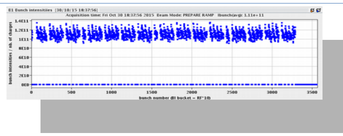
Status:

- Excellent magnetic reproducibility,
- Optics well corrected, 5-10% β-beating,
- Aperture is good and compatible a further reduction of β*,
- Magnets behaving well at 6.5 TeV (just 3 additional training quenches since beam operation started),
- Good & improved instrumentation,
- Excellent operation control:
  - Injection, ramp, squeeze etc.

- The main point of concern is called e-clouds.

End of 2015: 25 ns physics run





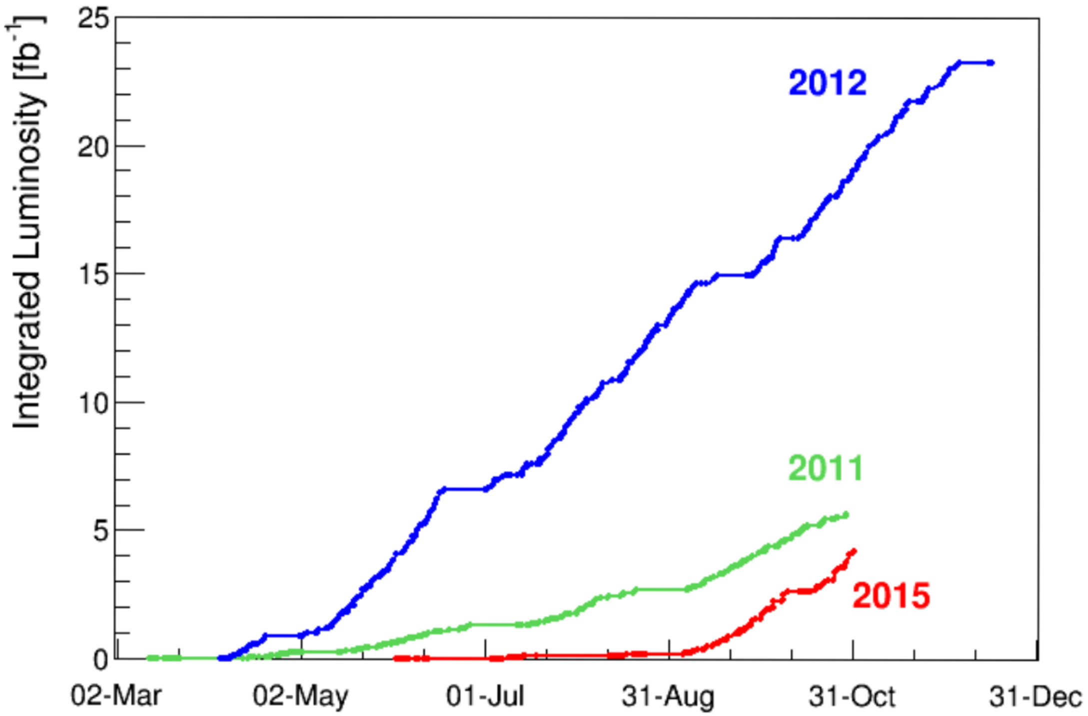
October 28, Record no. bunches

2244

- Resume of the intensity ramp up after TS2
  - *First driven by machine protection validation*
  - *Then driven by cryo system operation (> 1600 bunches)*
- Special physics run (90 m optics)
  - *back to lower beam intensity for commissionning and production → step down for 25 ns physics run*
- Ions run to conclude the year:
  - *Including intermediate energy run with proton at 2,51 TeV*

Integrated luminosity

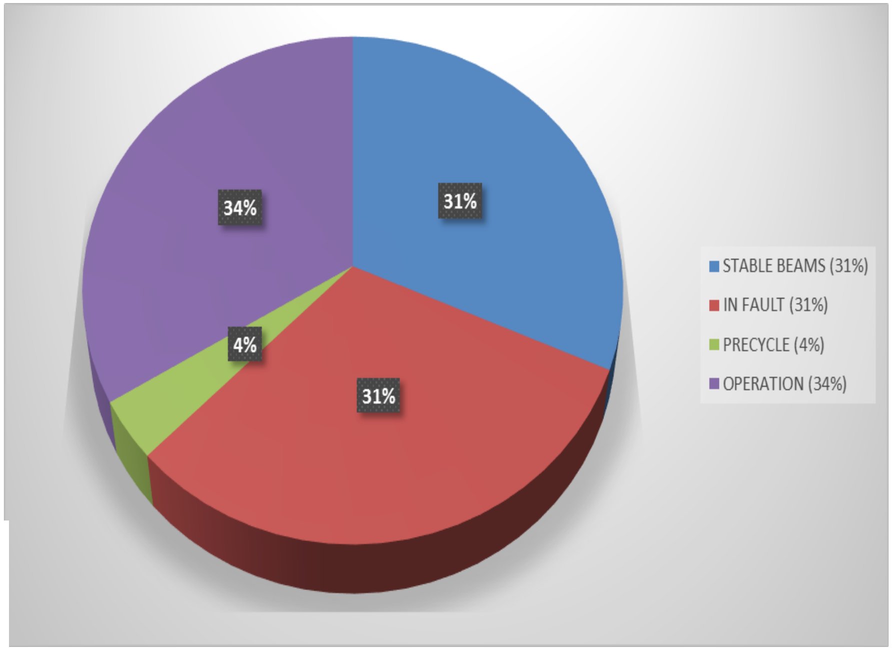
- The initial projections of integrated luminosity for 2015 were ~8-10 fb^{-1}.
- Finally achieved > 4 fb^{-1} for ATLAS and CMS
- Slope at the end of the run better than in 2011, and not far from 2012 slope
  - *More than 1 fb^{-1} produced last week of proton-proton operation*
- The main reasons for the lower value:
  - Start-up delays (~6 weeks)
  - Availability issues (radiation failures on the quench protection tunnel electronics – solved now)
  - Difficulties to master electron clouds → slower intensity ramp-up

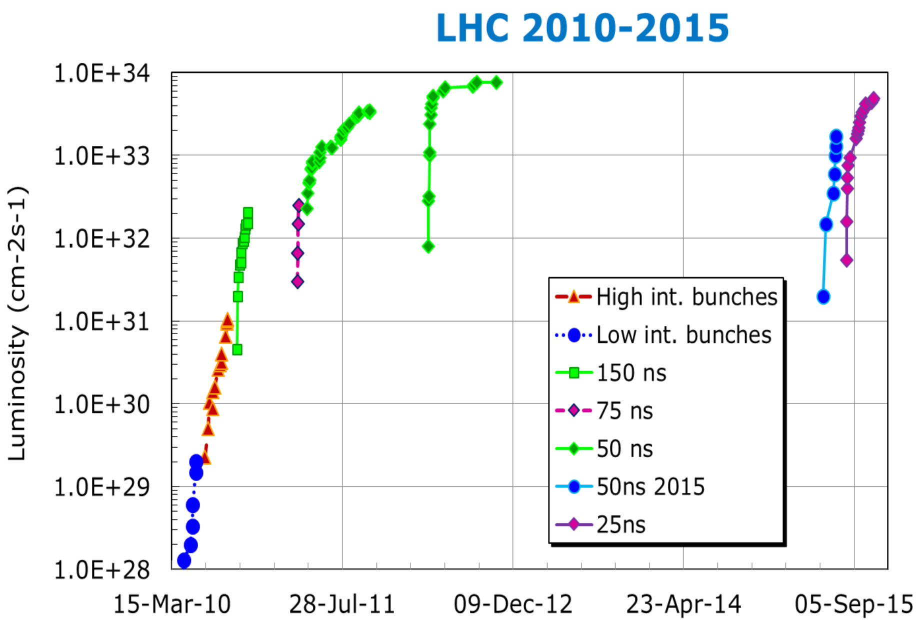


The 2015 proton run is finished now, this year will close with a 4 week lead ion run.

Luminosity production 2015

- **Luminosity production:**
  - We spend 31% of the scheduled time delivering collisions to experiments
  - (compared to 33 % in 2011 and 37% in 2012)



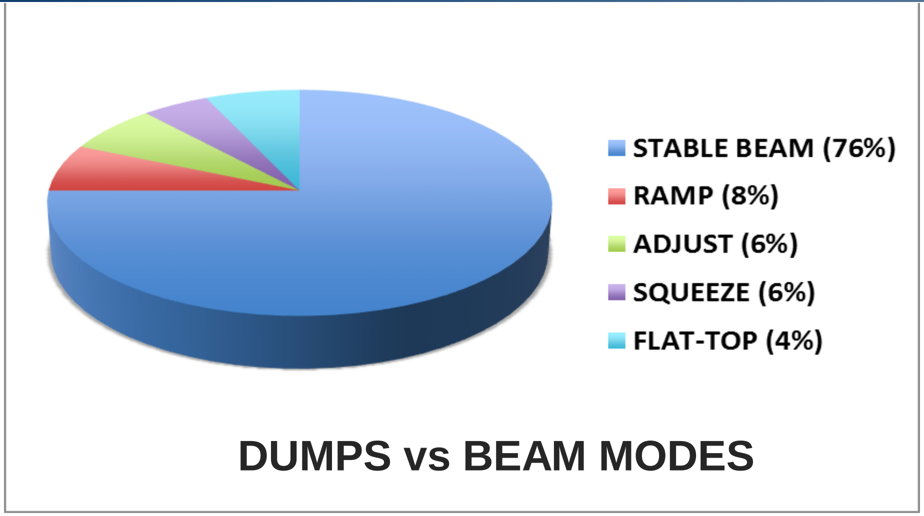


- **Peak Luminosity**:
  - Run 1: 7.6×10^{33} cm^{-2}s^{-1}
  - Run 2: 5.1×10^{33} cm^{-2}s^{-1}

Design lumi:

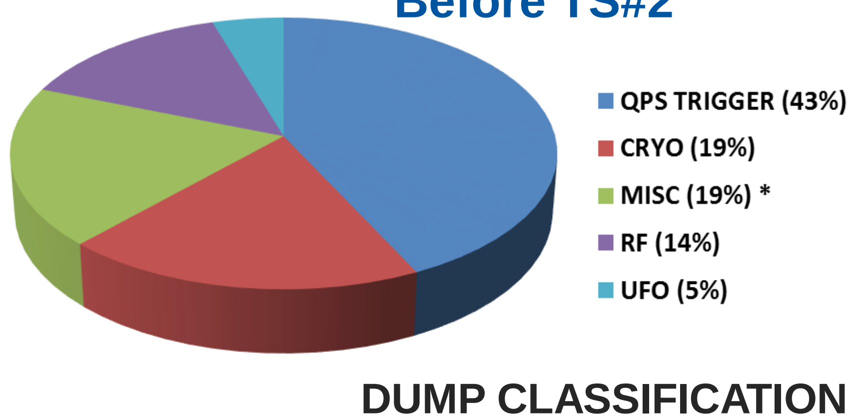
1×10^{34} cm^{-2}s^{-1}

High energy dumps (25 ns run > 100 bunches)

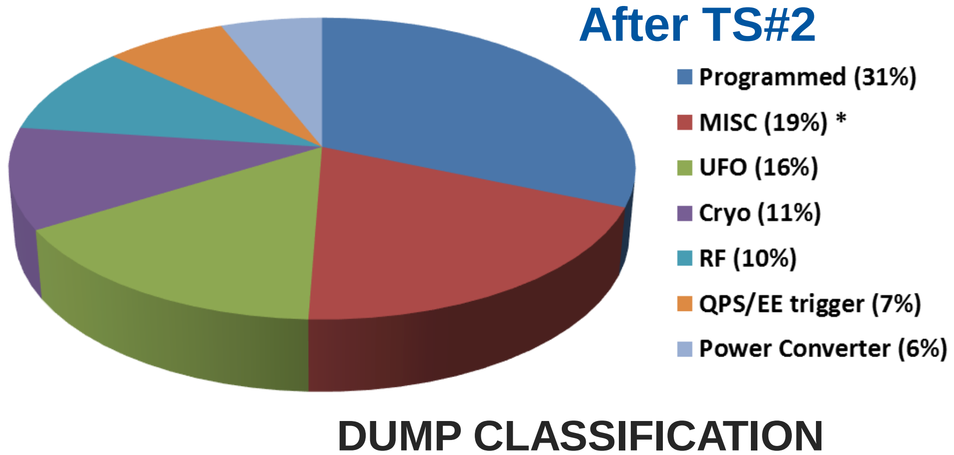


No more Earth fault
No QPS trigger after TS#2
Higher load on Cryo and RF

Before TS#2



After TS#2



Integrated SB time = 490 hours

* MISC contains all dumps that happened less than 2 times and that there is no reason to expect again

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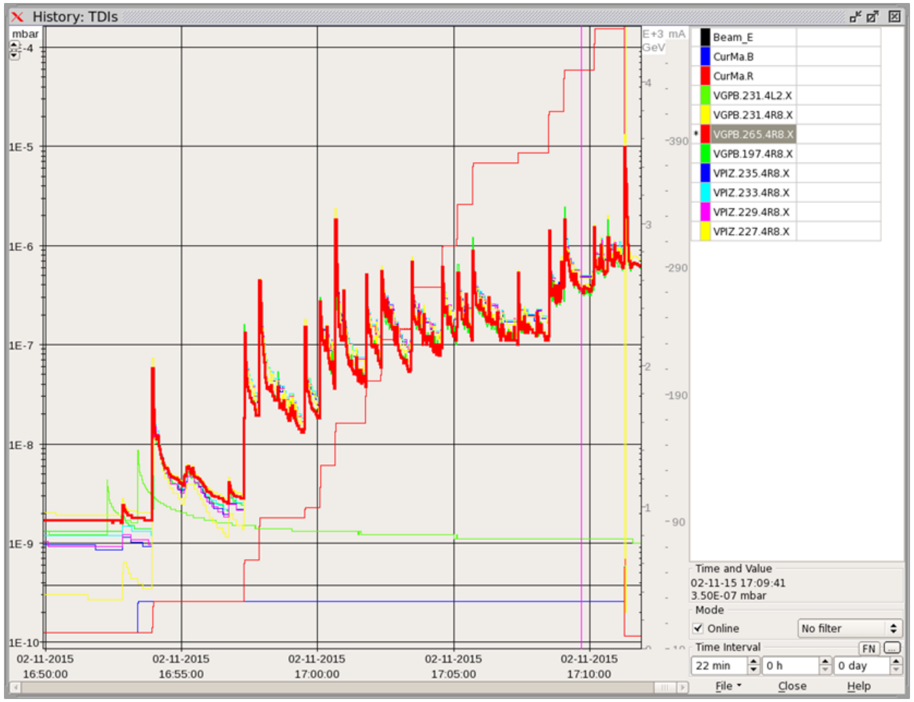
Issues with TDI

- A protection device against injection failures (**TDI**) that must withstand the impact of a nominal beam injection is limited to due a weakness of the material (**Boron Nitrite**) – exchange planned during winter stop.
  - *Decided to limit the number of bunches per injection to 144 to avoid potential damage*
  - *Limiting the maximum number of bunches to around 2400 for 2015*

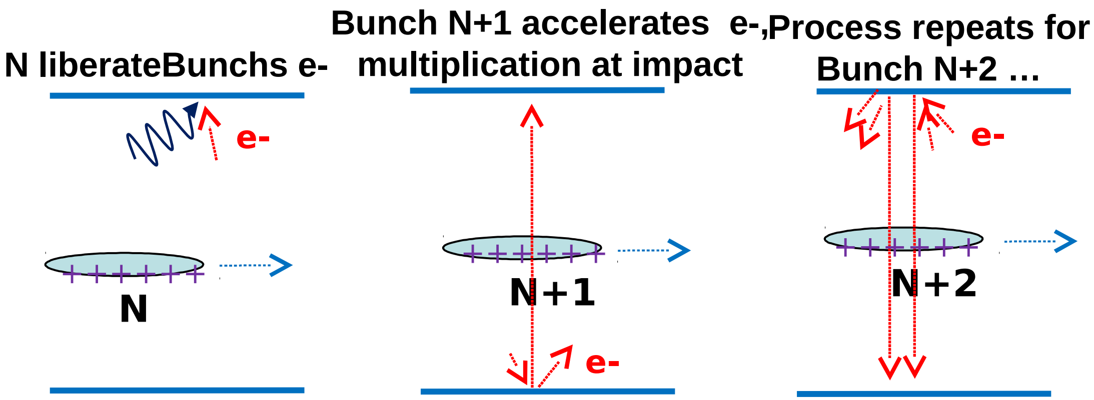
- Vacuum problem shown by one of the blocks during srubbing with 25 ns beam.
  - *Reducing scrubbing efficiency*
  - *Slowing down injection process*
  - *7 beam dumps at injection → downtime*



- Exchange planned during winter stop

Electron cloud challenge

- When operating with positively charged beams and closely spaced bunches electrons liberated on vacuum chamber surface can multiply and build up a cloud of electrons.

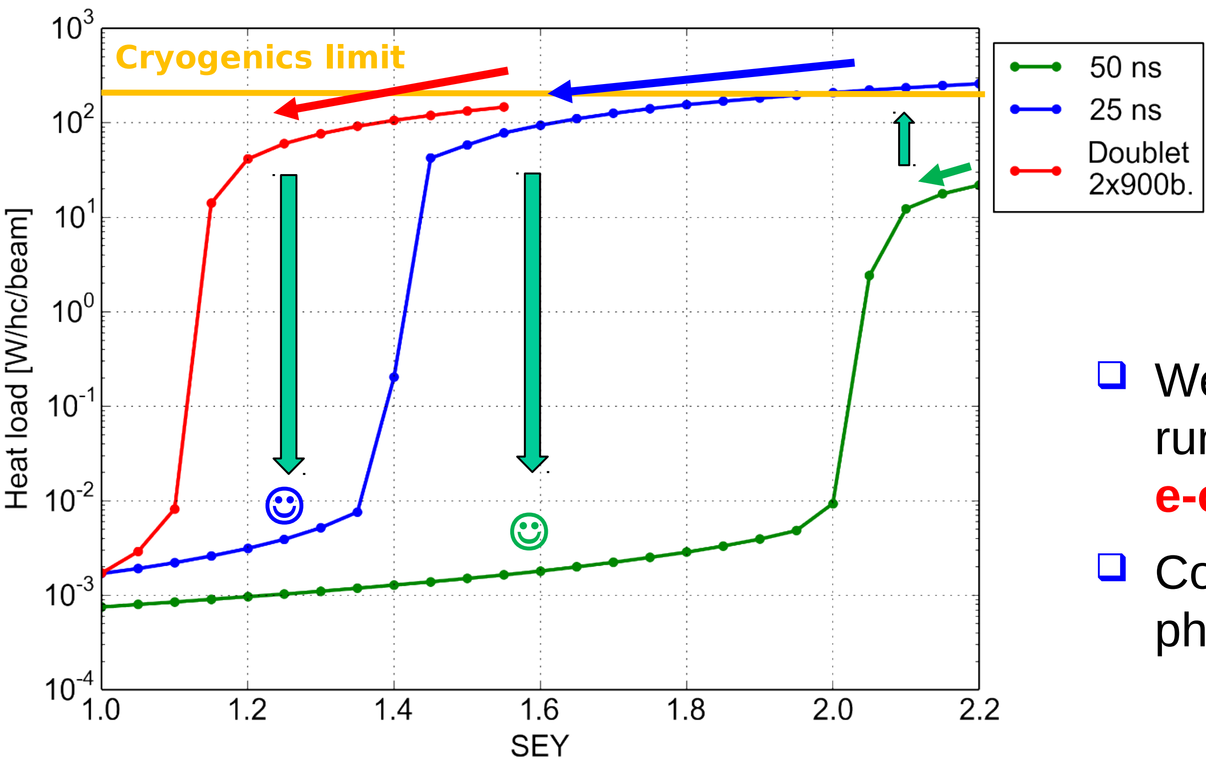


- Consequences of e-cloud build-up:
  - *Vacuum pressure increases → interlocks triggered*
  - *Impact on beam quality (emittance growth, instabilities, particle losses)*
  - *Excessive energy deposition → cryogenic cooling capacity and stability*

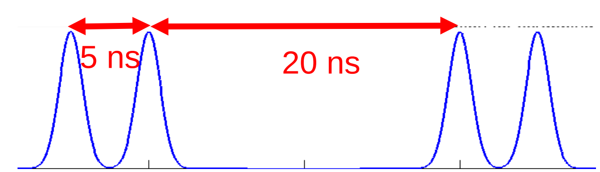
- The key parameter for e-clouds is the **Secondary Emission Yield (SEY)** of electrons from the vacuum chamber surface.
  - *SEY reduced by electron bombardement of the surface (SCRUBBING)*

Scrubbing strategy

- There is a strong dependence of e-cloud build up on bunch spacing:
  - ***Conditioning requires a beam that is <u>more powerful</u>*** *(->more electron generation) than the beam used for operation !*
- <u>For 50 ns</u>: scrubbing with 25 ns, then revert to 50 ns for operation.
- <u>For 25 ns</u>: try the same strategy -> *invented* a new ***doublet beam*** to enhance the e-cloud further.
- Doublet beam could not be used, too unstable beam – SEY too high.



Doublet beam

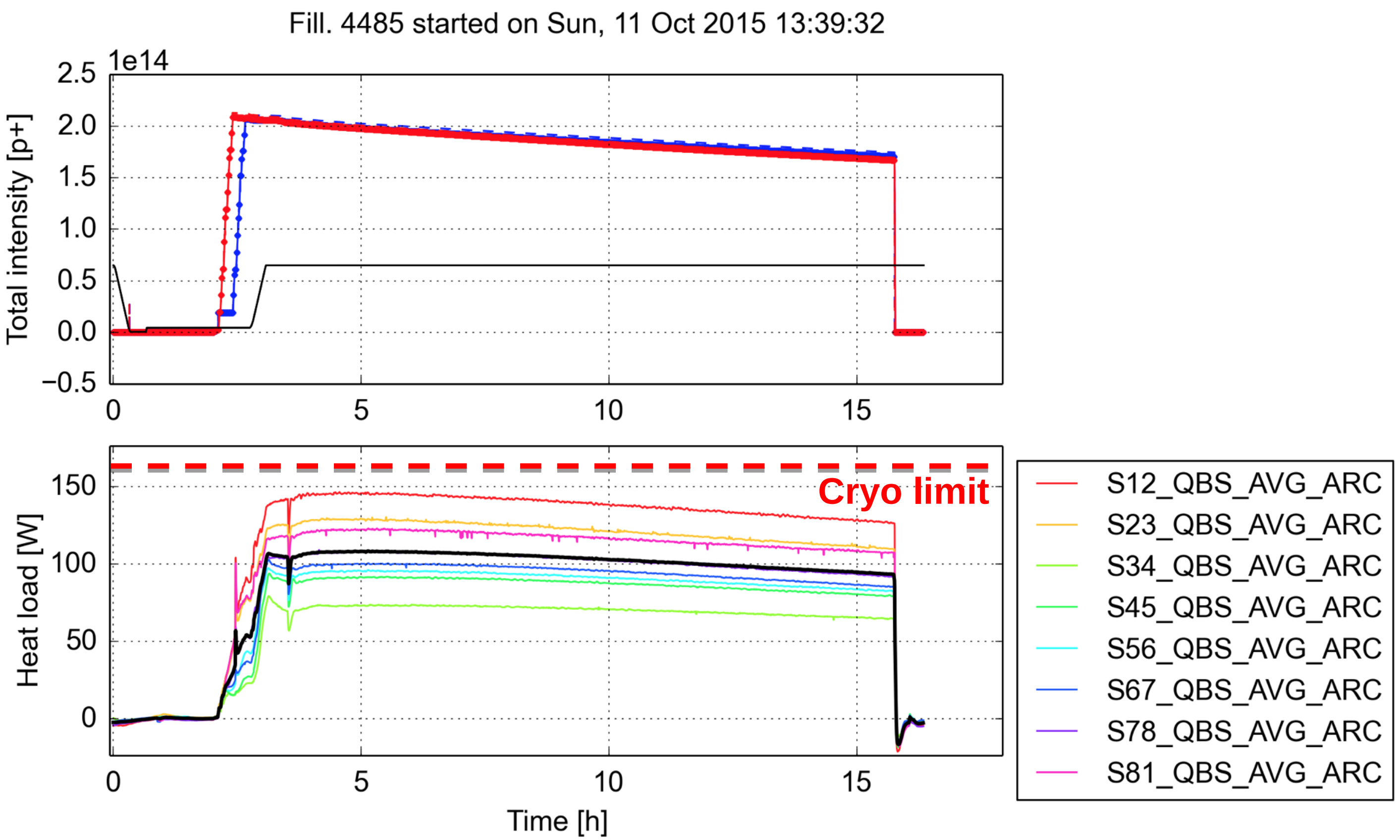


- We **came out** of the scrubbing runs with an **important residual e-cloud activity**.
- Conditionning continued during physics production

Heat load evolution

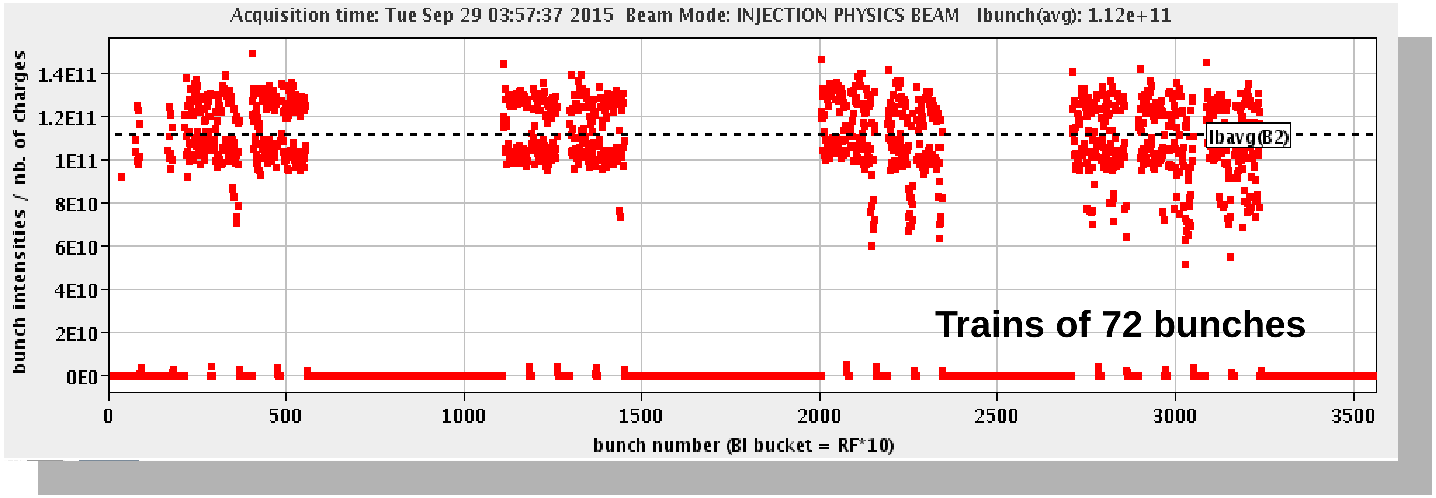
- Heat load on cryo system higher than expected due to e-cloud activity
- As number of bunches increased, operated closer and closer to the limit of cryogenic coling capacity

  => The intensity ramp-up was limited by the cryogenics: we can only step up intensity when we gain on the e-cloud front.

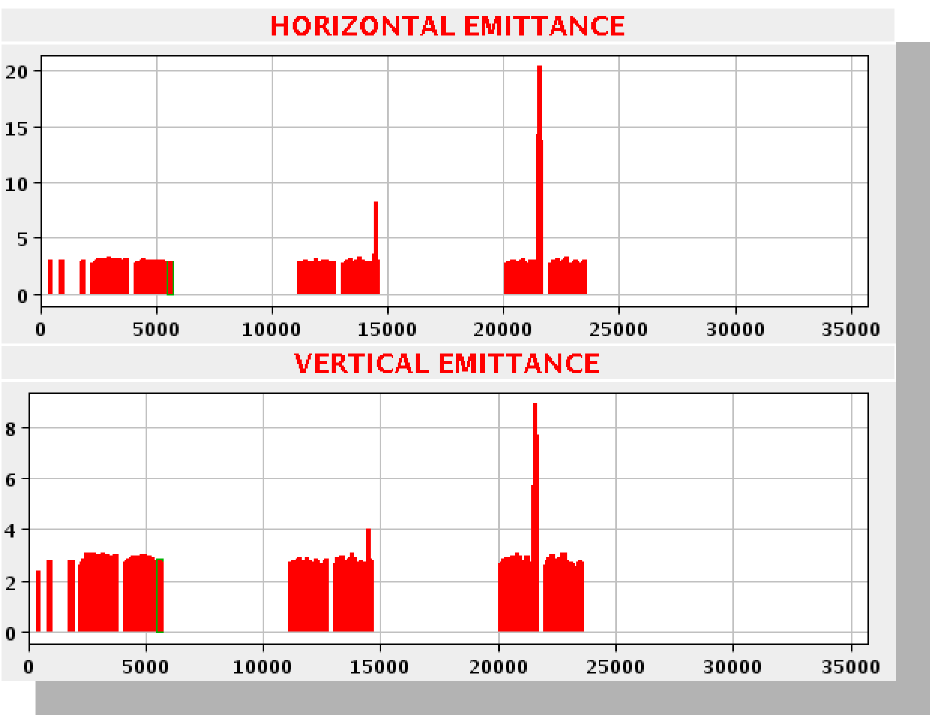


25 ns beam quality

Bunch intensity



Bunch emittance (µm)



The 25 ns beams are operated with trains of 36 or 72 bunches (nominal 288), the signature of electron clouds are visible:

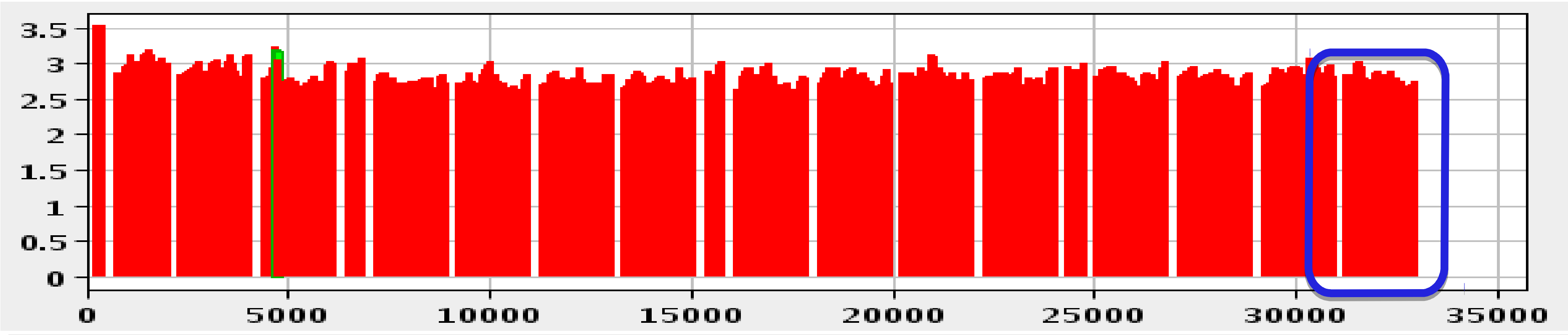
- *Intensity spread along the trains.*
- *Blown up bunches.*

Scrubbing has not completely removed e-clouds. The conditioning has to continue in parallel to physics operation.

Optimized beam parameters

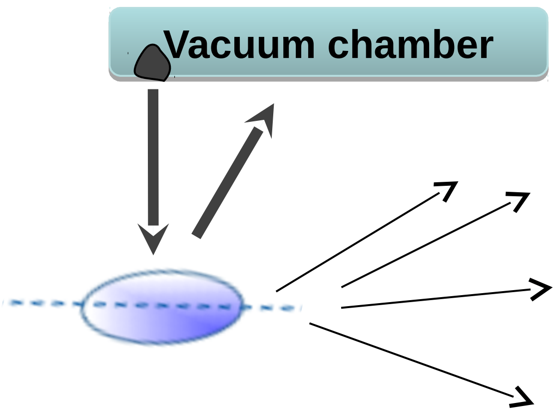
- Filling procedure optimized to cope with heat load and TDI pressure spikes
  - *Pause at injection for cryo stabilization*
  - *Improved interlocking logic and automatic feedback for cryo operation*
- Change of working point to cope with beam instabilities:
  - *Optimization of tune /chromaticity during injection*
- Optimization of the bunch trains structure to cope with TDI limitation and limit the e-cloud build-up:
  - *Introducing gaps- reducing heat load for a given number of bunches*
  - *2244 bunches per beam with 36b-gap-36b*
  - *Nominal bunch intensity: 1.15 x 10^{11} protons per bunch*

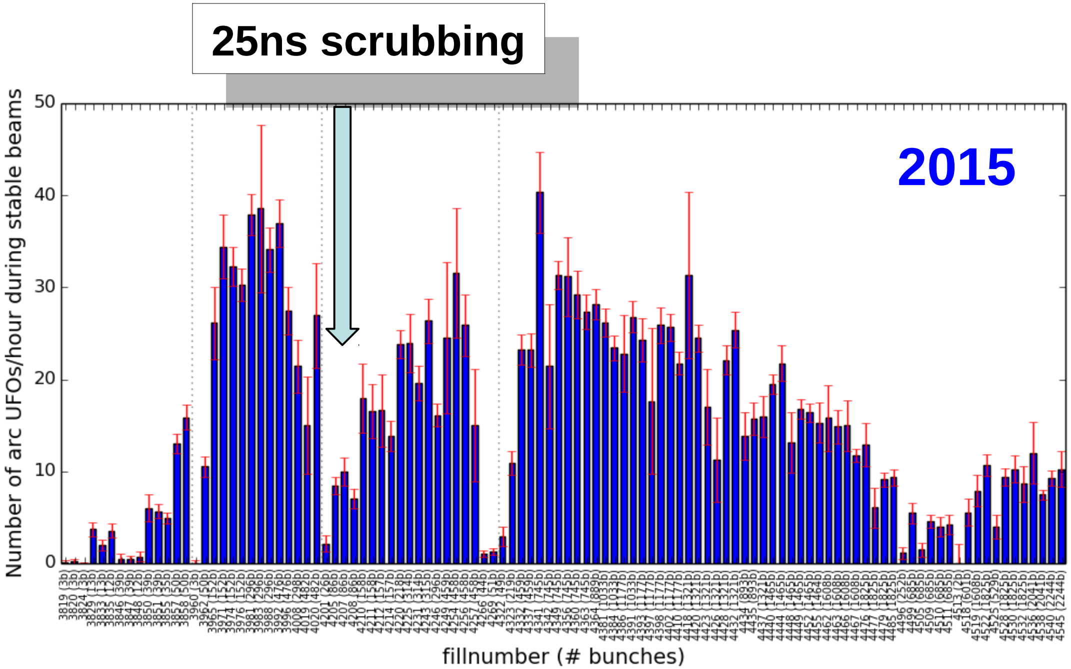
4 PS batches with enlarged gap



Unidentified Falling Objects - UFOs

- **Dust particles falling into the beam** – '**UFOs**' – have interfered with operation since Run 1.
  - *If the induced losses are too high, the beams are dumped to avoid a magnet quench (20 times / year in Run 1).*
- UFOs have also present at 6.5 TeV – 17 beams were dumped by UFOs and 2 magnets were quenched.





- Fortunately the rate decreases with time – significant condition is observed (also in Run 1).
- Further fine tuning of the beam loss monitor thresholds for such short losses (millisecond scale) is possible.

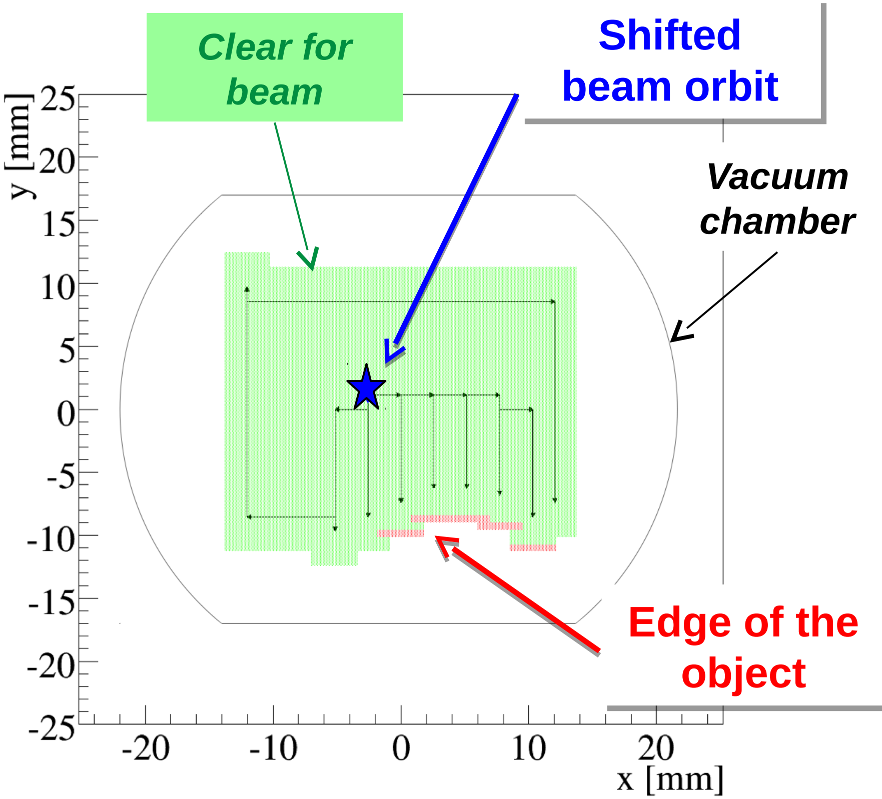
  ⇔ number of quenches

The bad ‘surprise’ : aperture restriction

- A position with anomalous beam losses was located on beam 2 in the arc between LHCb and ATLAS only few days after commissioning.
- An aperture restriction due to an obstacle was found by scanning the beam position.

- The beam orbit was shifted upward and sideways to avoid the ULO (Unidentified Lying Object).
  - -3 mm in H, + 1 mm in V
- **So far operation** – even at high intensity – **does not suffer from this object.**
- Opening the magnet to remove this object would take 2-3 months !

=> Not planned for YETS



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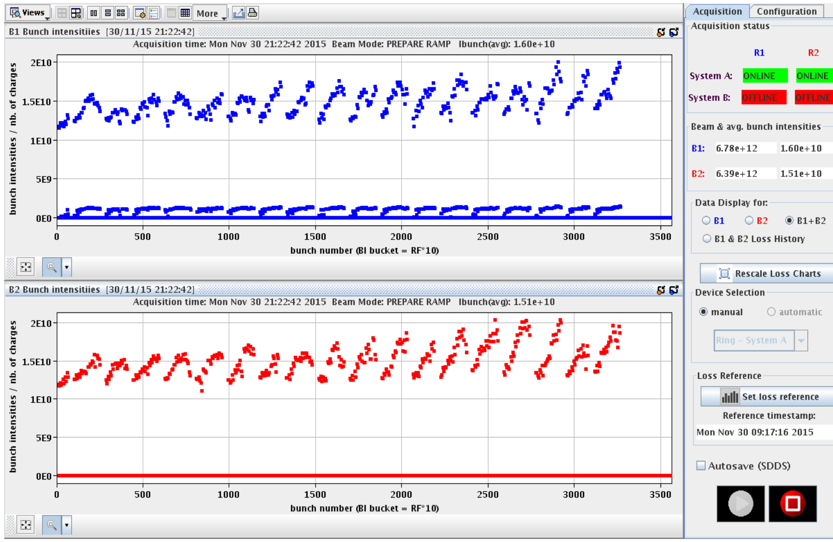
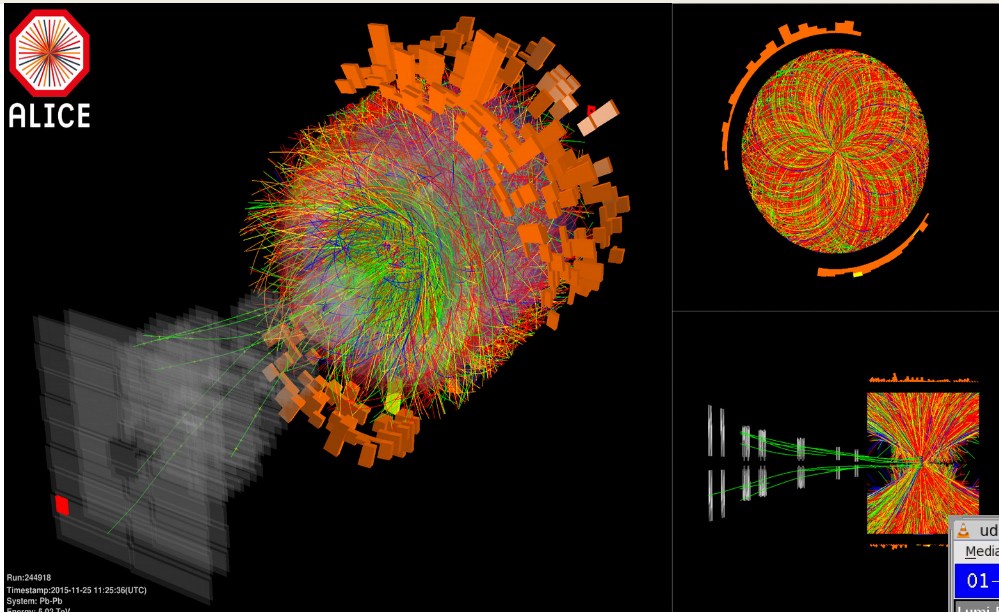
Lead-Lead physics run

- After TS3, restart for ions physics run
- Intermediate energy run with protons at 2.51 TeV slotted in:
  - *Full cycle commissioning: combined ramp and squeeze, optics, Machine protection validation....*
  - *Intensity ramp up: up to 1800 bunches per beam*
- 3 weeks of Ions run:
  - *Again full validation of a new cycle at 6.37 ZTeV: Alice presqueeze, squeeze, ALICE crossing reversal + displacement of the collisions point....*
  - *After 5 days of Stable Beams, operating with 426 bunches per beam*



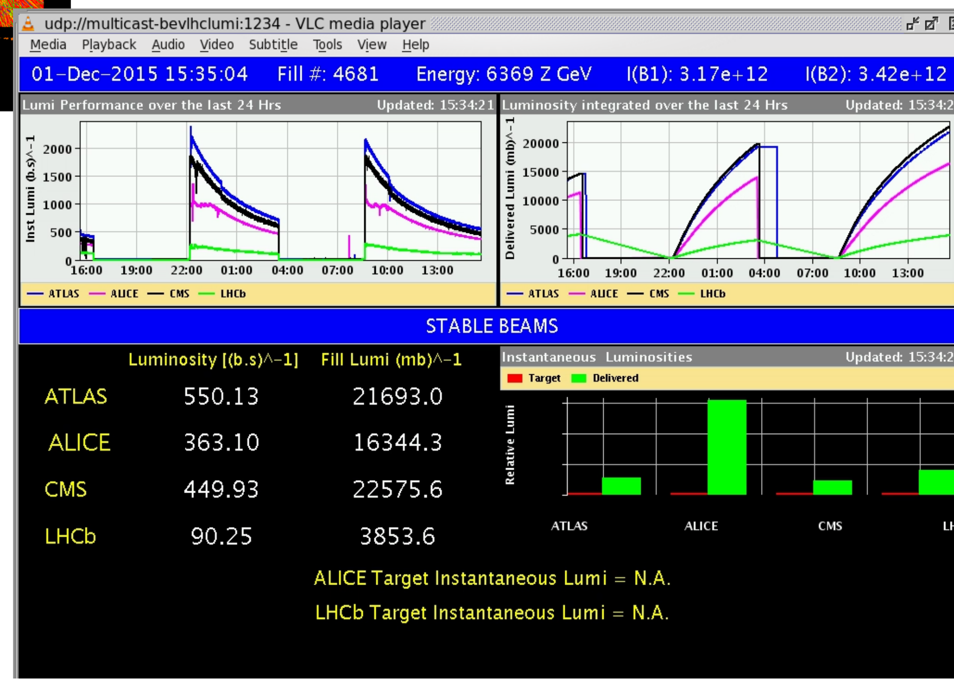
25 Nov – First Pb-Pb STABLE BEAMS

First Pb-Pb Stable Beams at 5.02 *A* TeV = 1.045 PeV



ALICE event with TPC and muon spectrometer

- **Design peak lumi:** 1×10^{27} cm^{-2}s^{-1}:
  - *ALICE already leveled at design lumi*
  - *ATLAS/CMS aready beyond*
- Delivered lumi so far (1 week of SB):
  - *Around 150 ub^{-1}*
  - *Target for 2015 ions run :300- 500 ub^{-1}*



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- Proton-Lead
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Possible performance after YETS

- Exchange of Injection absorbers should allow nominal train injection (288 bunches per injection)
  - *Could help to complete scrubbing*
- 2016 – Production year, setting stage for Run 2:
  - *6.5 TeV*
  - *β* reduction to 40 cm in ATLAS and CMS*
  - *Not yet fully scrubbed for 25 ns*

  => Re-establish present conditions, good for operations up to ~2000 bunches, continue pushing

	Peak lumi E34 $cm^{-2}s^{-1}$	**Days proton physics**	**Approx. int lumi [fb^{-1}]**
2015	~0.5	~50	4
2016	1.2	160	~35

=> All options to be discussed at Evian and Chamonix Workshops

Summary

- 2015 has been a (good) commissioning year
  - *After 2 month of commissioning and after curing some initial teething problems, operation at 6.5 TeV is now stable and quite robust.*
- Many different cycles have been fully commisionned and validated for high intensity in very limited beam time:
  - *High beta optics, Van Der Meer fills, 2,51 TeV run, 6.37 ZTeV*
- The integrated luminosity delivered in 2015 is finally > **4 fb^{-1}**
  - *Operation with high intensity beams of 25 ns spacing is limited by the available cryogenics power due to strong electron cloud activity.*
- With the improvements that are anticipated for 2016 we should reach the required performance for Run 2.
  - *Even with the same number of bunches than 2015, at 40 cm β* , we can reach design peak lumi: 1×10^{34} $cm^{-2}s^{-1}$.*