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LHC machine status report

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Beams Department

Operation Group

On behalf of the LHC team

LHCC 23.09.2015

outline

- The LHC operation (so far)
- Challenges & limitations
- The rest of 2015

Initial goals for Run II

Energy = 6.5 TeV

Bunch spacing = 25 ns (2800 bunches), estimated pile-up of 40 events per bunch crossing

β*: start with a conservative approach (80 cm) then envisage reduction later in 2015 → 40 cm

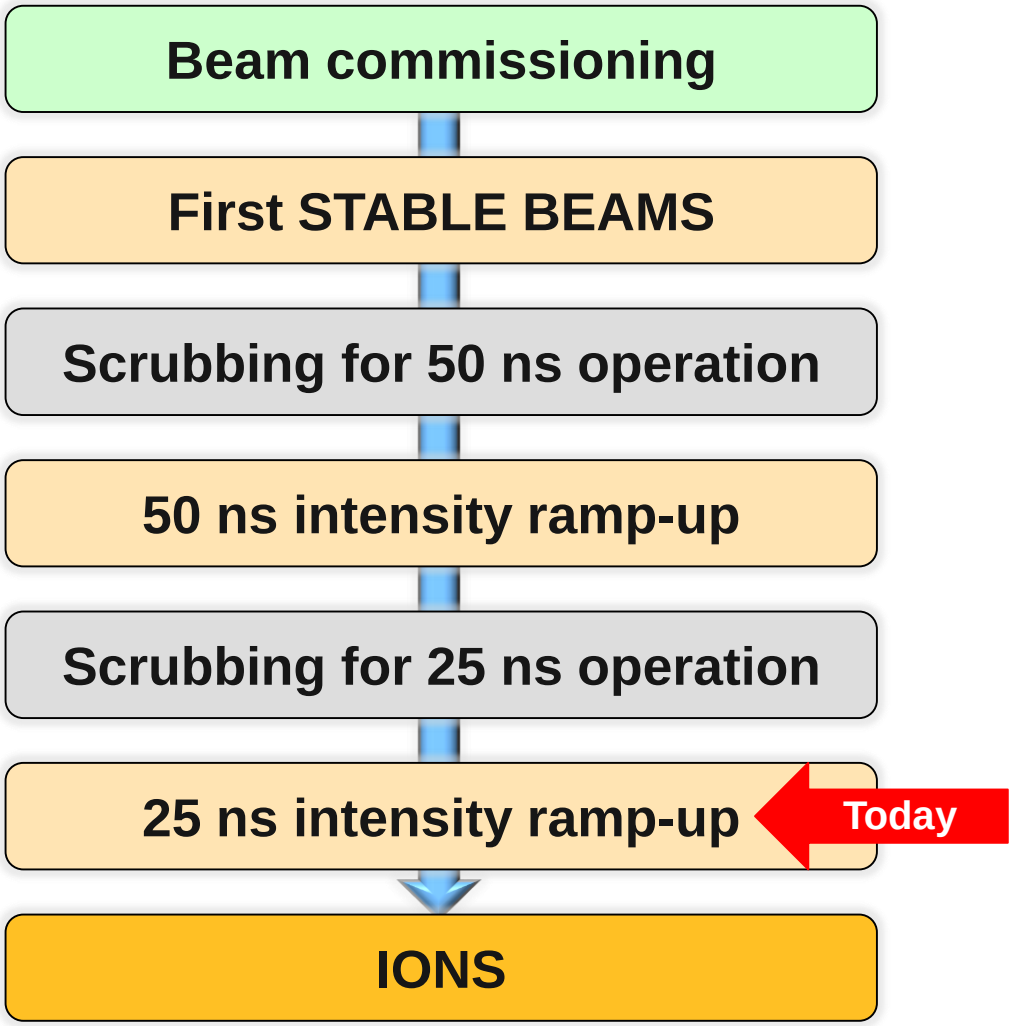
Peak luminosity = 1.3-1.7 x 10^{34} cm^{-2} s^{-1}

Integrated luminosity:

- 10 fb^{-1} for 2015
- 100-120 fb^{-1} until 2018

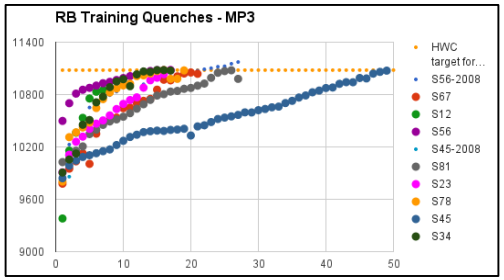
Priority for 2015 is to prepare 2016 as a physics "production run" at 25 ns

2015 planning breakdown

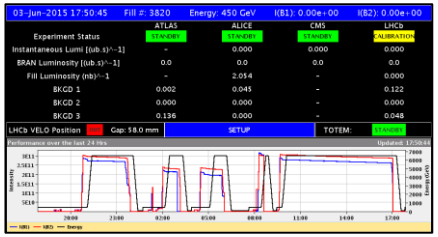


2015 operation at a glance

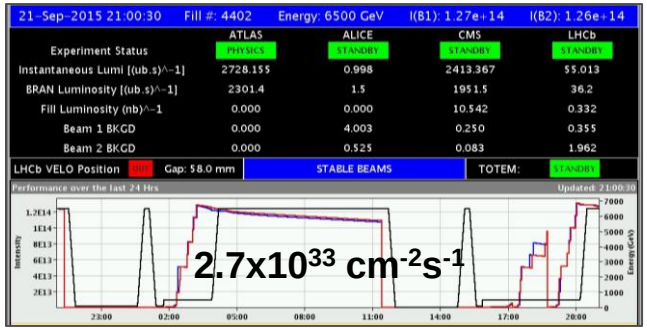
3rd April Completion of PT campaign



3rd June First STABLE BEAMS!

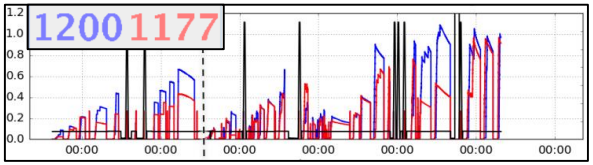


21st September 25 ns STABLE BEAMS with 1177 bunches/beam



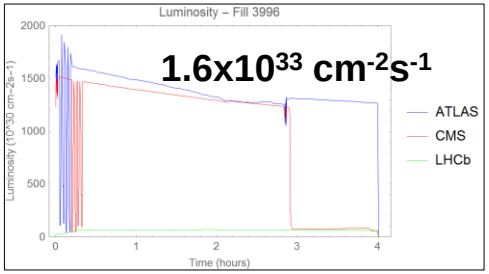
5th April First circulating beam

30th June end of scrubbing for 50 ns

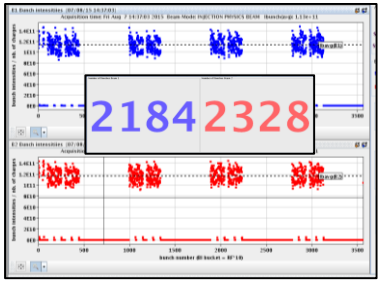


10th April 6.5 TeV for the first time (ever!)

14th July 476b (50 ns)



7th August end of scrubbing for 25 ns



Intense beam commissioning phase

TS#1 MD#1 MD#2 + TS#2

April June July August September

From beam commissioning

Lessons learnt and improvements from Run 1

- **Enhanced** system performance:
  - Beam Instrumentation
  - Transverse feedback
  - RF
  - Collimation
  - Injection and beam dump systems
  - Vacuum
  - Machine protection
- **Improved** software & analysis tools
- **Experience!!!**

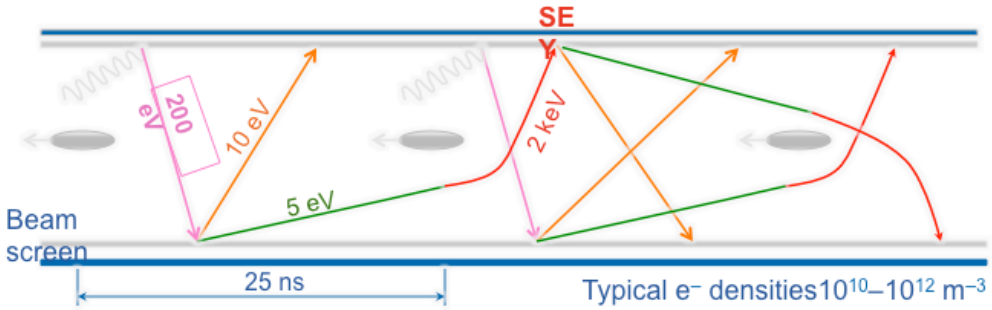
From beam commissioning

Machine status after LS1 and at higher energy

- **Aperture is good** and compatible with the collimation hierarchy
- **Good magnetic reproducibility**
- **Optically good**, corrected to excellent
- **Magnets behaving well** at 6.5 TeV (just 4 additional training quenches since beam operation started)
- **BLM working beautifully** and threshold correctly set (4 beam induced (UFOs) quenches so far)
- **Excellent operation control…**injection, ramp, squeeze etc.

Electron cloud

When operating with small bunch spacing an avalanche-like process, **(Electron Cloud)** can develop in the beam chamber due to the Secondary Emission from the chamber's wall



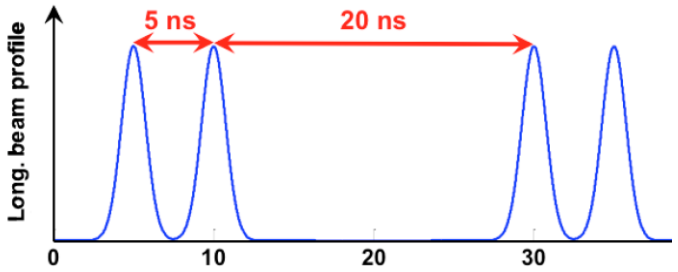
Consequences:

- **impact on beam quality** (instabilities, emittance growth, particle losses)
- **bad vacuum**
- **excessive energy deposition**

Electron bombardment of a surface proved to reduce drastically the **secondary electron yield (SEY)**

This technique **(scrubbing)** provides a mean to suppress e-cloud build-up

Scrubbing



Non adiabatic splitting at SPS injection

Approach with two scrubbing phases

Phase#1

(**50 ns and 25 ns** beam for 50 ns operation)

50 ns beam → ~1000 bunches

- Excellent beam lifetime, no e-cloud

25 ns beams → ~1000 bunches

- Beam degradation important, slow improvement (main limitation was MKI vacuum)

Phase#2

(**25 ns and doublets** for 25 ns operation):

25 ns beam → >2000 bunches

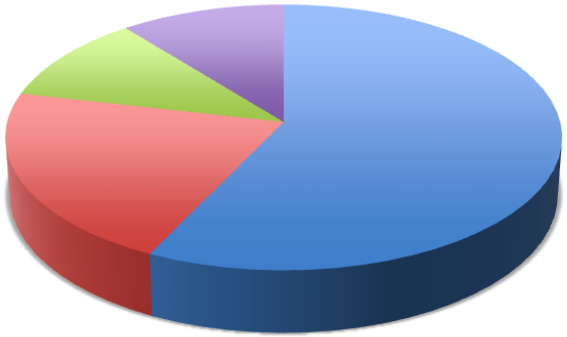
- Injection phase **limited by cryo and vac (TDI and MKI)** for B2

Doublet beams → ~250 bunches

- **Larger e-cloud,** fast beam quality degradation

Observations confirmed a clear improvement of beam quality thanks also to adapted machine settings

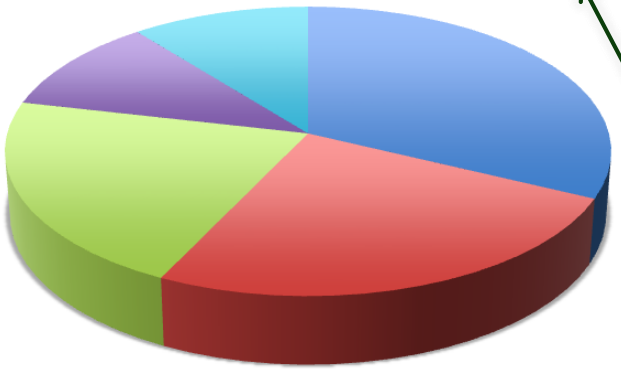
50 ns (> 100 bunches) high energy dumps



- STABLE BEAM (57%)
- RAMP (21%)
- FLAT-TOP (11%)
- ADJUST (11%)

DUMPS vs BEAM MODES

- 2/7 provoked a quenches
- 2/7 @ULO



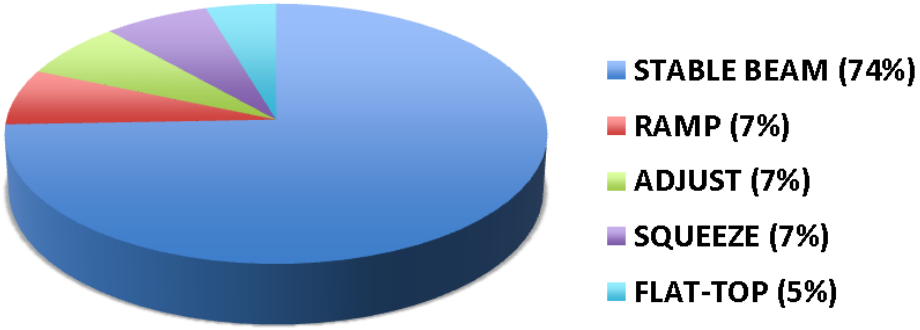
- QPS TRIGGER (32%)
- UFO (25%)
- MISC (21%) *
- PROGRAMMED (11%)
- EARTH FAULT (11%)

DUMP CLASSIFICATION

Integrated SB time = 58 hours

*** MISC contains all dumps that happened only once and that there is no reason to expect again**

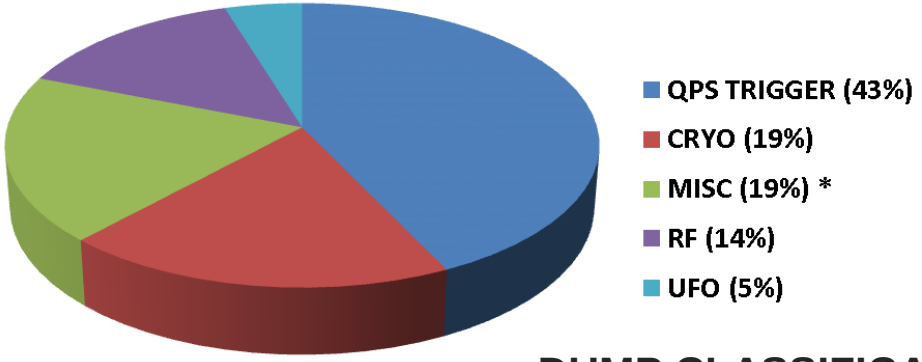
25 ns (> 100 bunches) high energy dumps



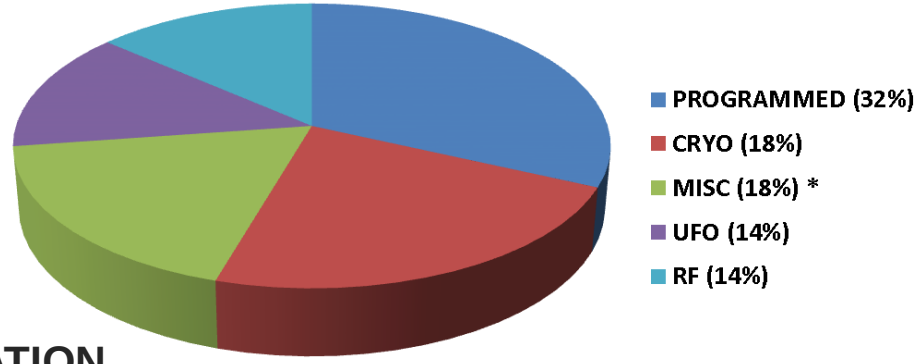
DUMPS vs BEAM MODES

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

Before TS#2



After TS#2

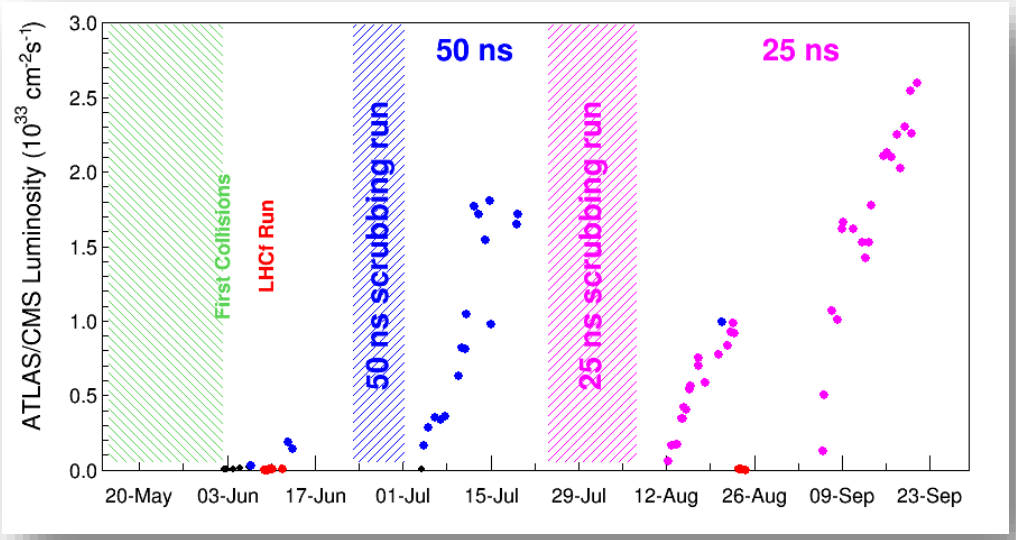


DUMP CLASSIFICATION

Integrated SB time = 151 hours

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

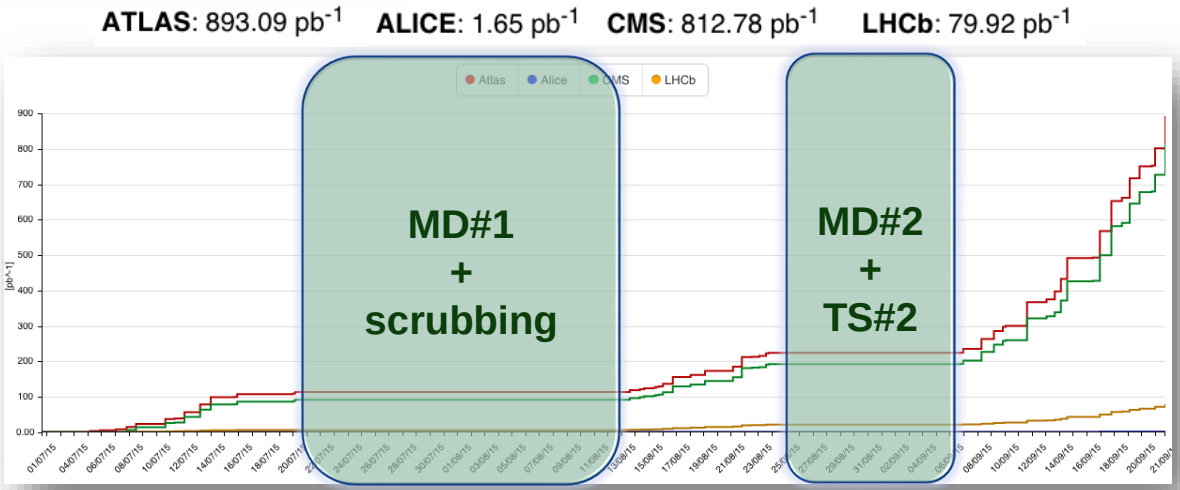
Some statistics



45% luminosity gain wrt 50 ns with 2.4 times number of bunches
(larger emittance and smaller beam intensity)

The integrated L is about 4 times what was before TS#2

…approaching 1 fb^{-1}



outline

- The LHC operation (so far)
- Challenges & limitations
- The rest of 2015

Challenges & limitations

- **QPS**
  - Loss of superconducing circuit - **Recovery time ~3/4 hours**
- **Earth faults**
  - Loss of superconducing circuit - **Recovery time ~ 0.5 to 1 day**
- **TDI**
  - Manufacturing problem - **Preventing >144 bunches injection**
- **UFO**
  - Generation of fast losses – **Recovery time ~1 hour**
- **CRYO**
  - Excessive heat load – **Slowing down Injection&Ramp**

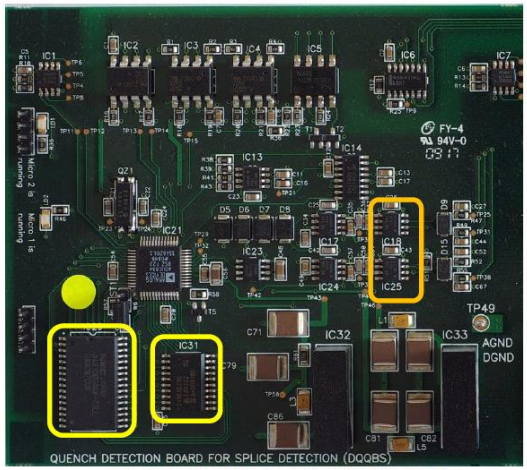
QPS dump triggers (SEU)

SEU due to non radiation hard components installed during LS1

"Old" QPS boards are 4 order of magnitude less sensible to radiation

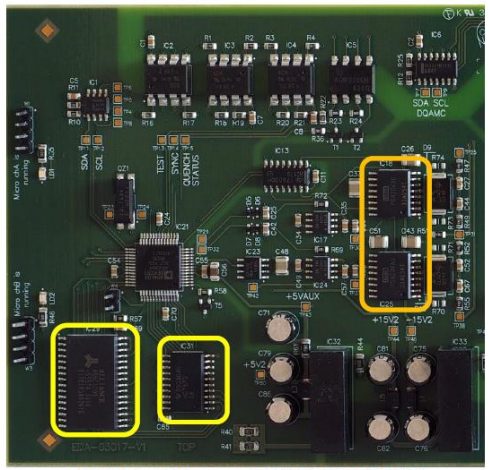
Origin of the SEU problem – recall
Relevant differences between mDQQBS and DQQBS

DQQBS



SRAM: NEC D431000AGW-70LL
D-Latch: NXP 74HCT573
Amplifier: INA141

mDQQBSv2/v3



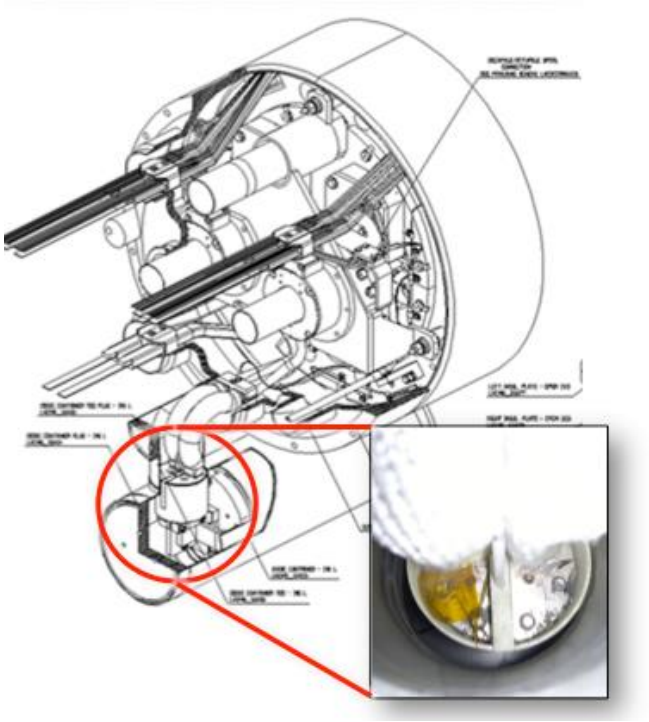
SRAM: Alliance AS6C1008-55SIN
D-Latch: TI 74HCT573
Amplifier: PGA204
Different batch of ADuC834

1248 modified boards have been installed during LS1 to be used for special tests (CSCM) to verify splice quality after consolidation.
All exchanged (1140 during TS#2) and circuits revalidated

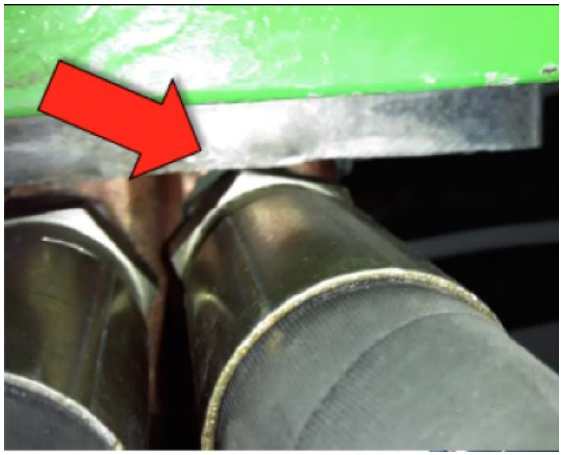
SOLVED!!

Earth faults

An earth faults generates a trip of the circuit with the consequence of (sometimes very) long recovery time for circuit protection and fault investigation



Contact in the cold part



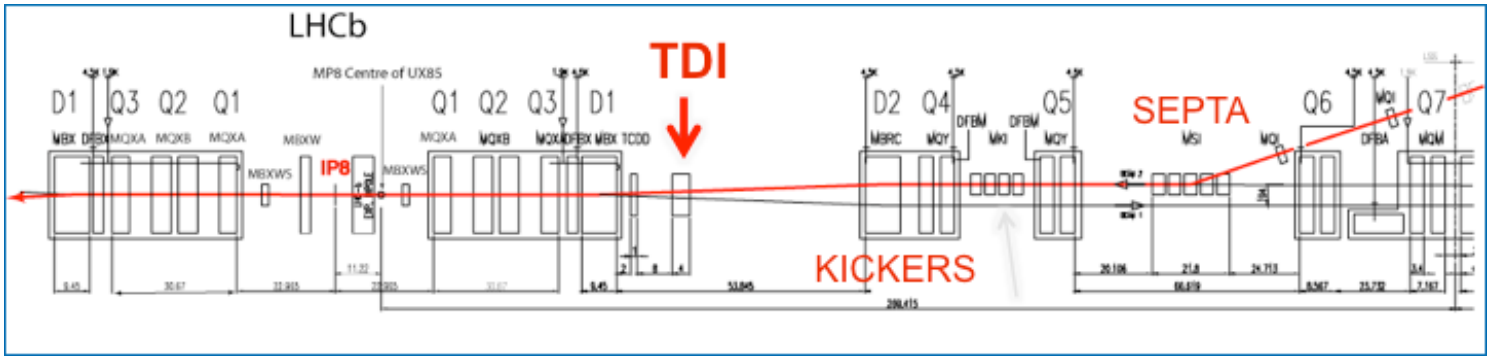
Ex. of warm cable contact

In addition…six occurrences of intermittent earth faults in main dipole circuits. They only last for about 3/4 seconds

Reason unknown…
…faults may appear again!

TDI (injection protection device)

TDI: movable vertical absorbers (4.2 m long) down stream of injection kickers



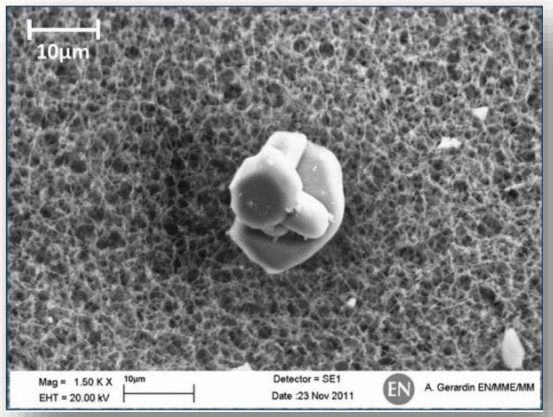
Main blocks are made of hex-boron-nitride. During bake-out tests was discovered that the TDIs cannot withstand temperatures higher than 450 °C (B_2O_3 reactant melting temperature)

This led to the decision of limiting the number of **bunches per injection to 144**.

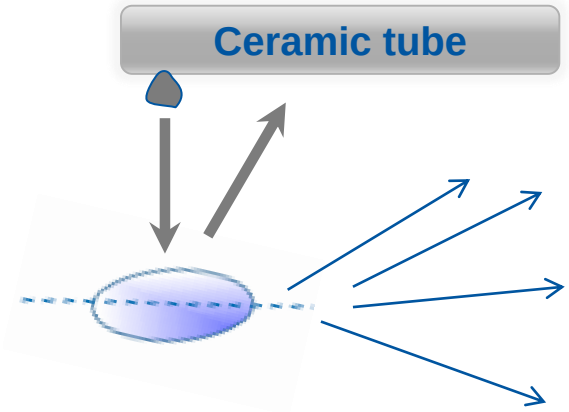
This limits **the maximum number of bunches to around 2400**

Both TDIs will be replaced (graphite jaws) in YETS!!

UFO (*Unidentified Falling Objects*)



1. A **macroparticle** (dust) **falls** from the top of the beam screen
2. The **macroparticle is ionized** due to elastic collisions with the beam
3. The positively charged **macroparticle is subsequently repelled away** from the beam
4. During the above, there may be **significant losses due to inelastic collisions -> beam dump and/or magnet quench!**



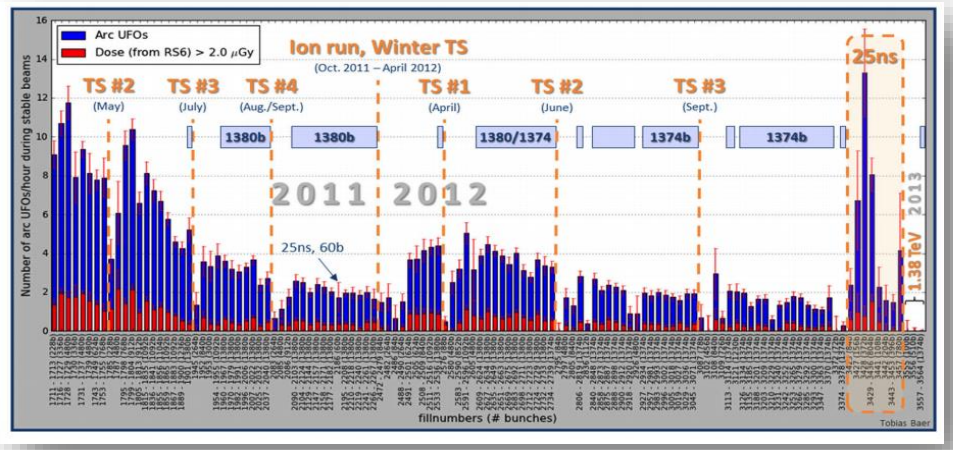
Dust particle dynamics model predicts (among others):

- *Loss duration of a few ms* ✓
- *Losses become faster for larger beam intensities* ✓

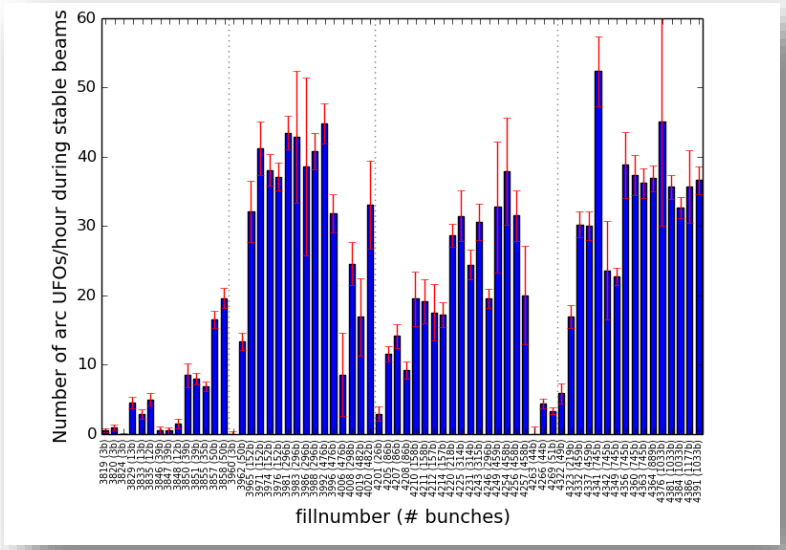
UFO (*Unidentified Falling Objects*)

No. of UFO events exceeded **10+/hour in 2012** with increase after shutdowns and with reduced bunch spacing

Arc UFOs during SB in 2012



Arc UFOs during SB in 2015



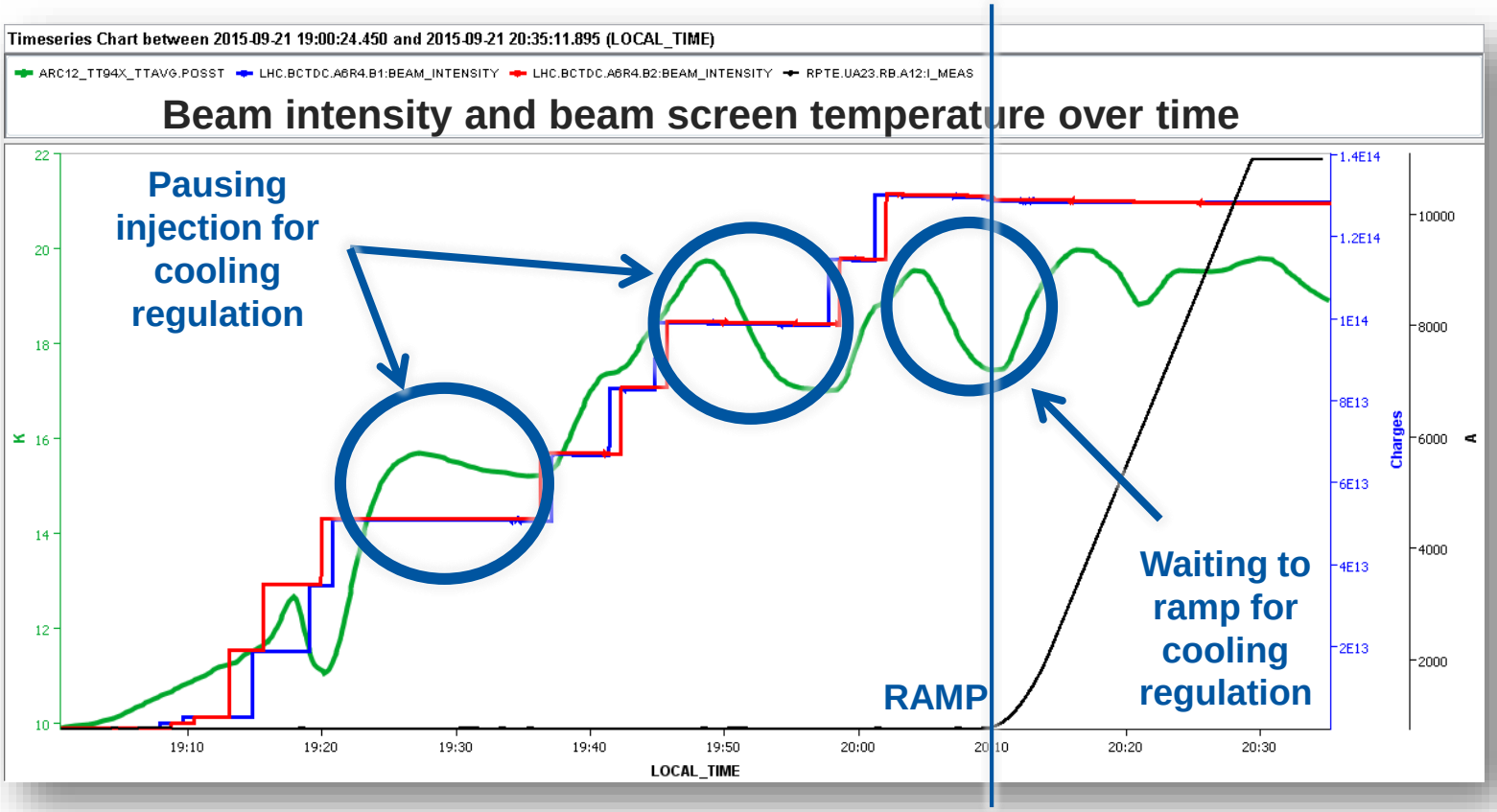
Beam Loss Monitor thresholds set judiciously (only 2 UFO induced quenches), but we **frequently** observe UFOs **close to dump** threshold

We essentially rely on conditioning…

They are with us, there are many of them, they are large !

CRYO

- **Excessive heat load on beam screen circuits during Injection & Ramp**
- **Stability problem following a dump (sudden heat un-load on the system)**



New automatic logic and more relaxed interlock thresholds are being tested!

Challenges & limitations summary

Limitation	Present situation	Perspective
QPS	**SOLVED!!**	
UFO	Many UFOs	Conditioning will help, but will get worse with beam intensity
Earth faults	**LATENT**	**UNKNOWN**
TDIs	Limitation to ~2400 bunches (144 b/inj)	Will be exchanged in YETS 2015
CRYO	Slowing down injection & ramp Stability after beam dump	New logic and threshold change being tested

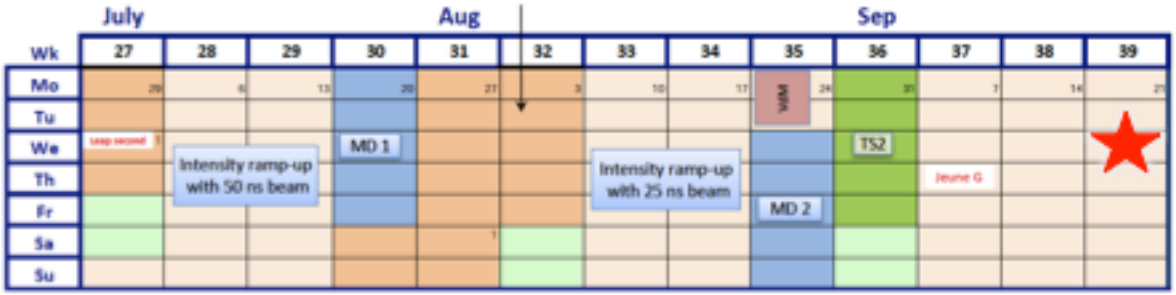
Painful for 2015, they shouldn't be long term issues for Run 2

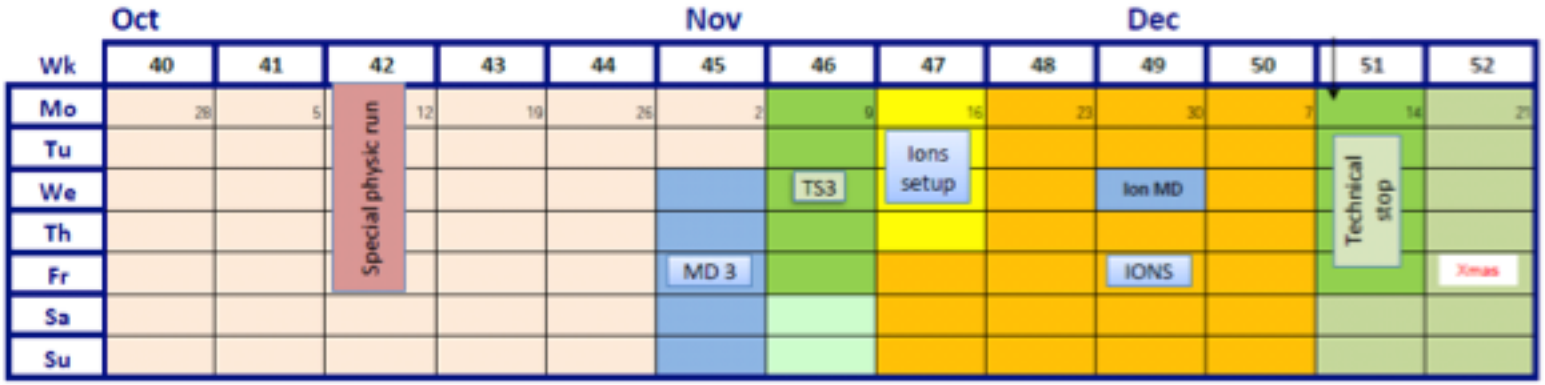
Special LMC on Nov 18th to define actions to be taken during YETS

outline

- The LHC operation (so far)
- Challenges & limitations
- The rest of 2015

LHC planning v1.7





Technical Stop

Recommissoning with beam

Scrubbing

Machine development

Special physics runs (indicative - schedule to be established)

Before the YETS:

35 days pp **low β** physics left
5 days pp **high β** physics left
5 days Machine Development
7 days of Technical Stop (+recovery)
28 days Pb-Pb

Possible performance increase

- **β* reduction**
  - No particular showstopper
  - About 3/4 days needed
- **Emittance reduction**
  - BCMS scheme – smaller emittance from injectors
  - 8b+4e scheme – would turn off e-cloud

BUT

- **Time is limited**
- **Scrubbing for 25 ns is <u>not fully complete</u>**
- **TDI.R8** could provide a temporary limitation on number of bunches (impact on efficiency)

Conclusions

- LHC is presently working at 6.5 TeV with 25 ns bunch spacing. 2015 has been a commissioning year!
- Many problems have been solved and the effect on luminosity production is well visible (longer fills!)
- Some limitations are still present, but there seems not to be any showstoppers for operation in nominal conditions…**2016 looks promising!!**
- The integrated luminosity in 2015 should reach **~4 fb^{-1}**

Thank you for the attention!

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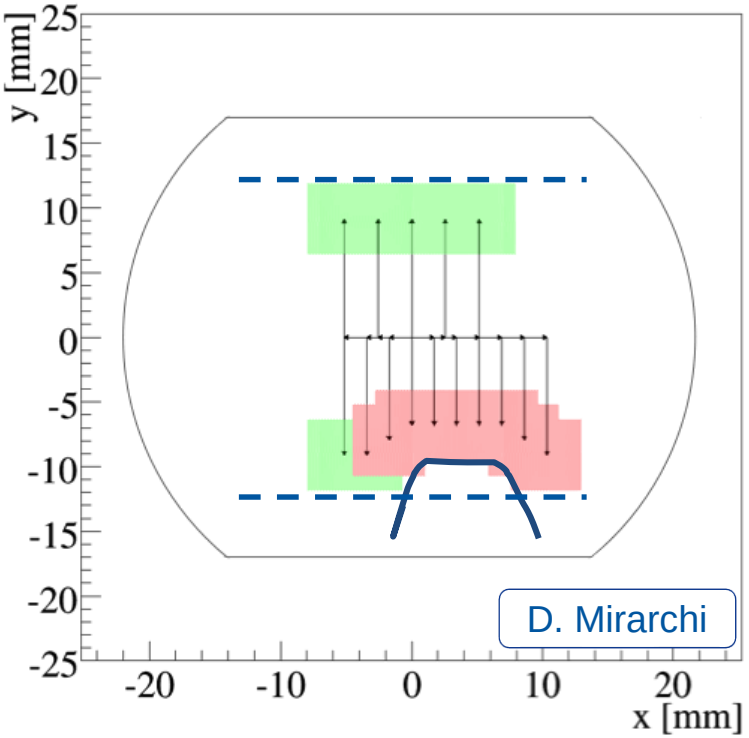
ULO (*Unidentified Lying Object*)

Aperture restriction measured at injection and 6.5 TeV in 15R8

- Presently running with orbit bumps
  - -3 mm in H, +1 mm in V, to optimize available aperture
- UFOs stopped after second beam screen warm-up
- Behaviour with higher intensities looks OK

…stability of the object remains a concern

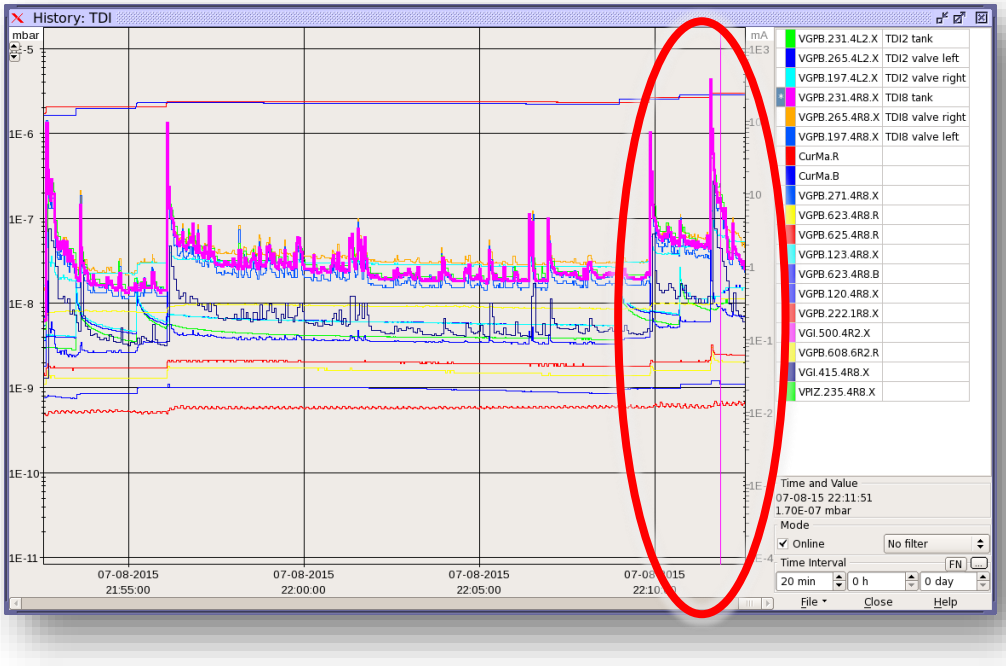


Possible performance increase

	25 ns (nominal)	25 ns (nominal)	25 ns (BCMS)	25 ns (Nominal 8b+4e)
β* [cm]	80	40	80	80
ε*[μm]	3.5	3.5	1.7 – NO!	1.7
Bunch intensity [10^{11} p/bunch]	1.2	1.2	1.2	1.2
N. of bunches with TDI structure limitation (TDI.R8 limitation)	< 2400 (~1200)	< 2400 (~1200)	< 1700 (~1200)	< 2000 (~1200)
Peak luminosity [10^{34} $cm^{-2}s^{-1}$]	0.6	1.6	1.2	1.4
Advantages	Known configuration	High performance	Low emittance	Low e-cloud Low emittance
Disadvantages		Longer setup time	Stability?	Set-up time needed Stability?

TDI.R8

In addition during scrubbing, heating and outgassing of TDI.R8 have been observed, with vacuum spikes above interlock limits



- Investigations of causes and mitigation measures in progress
- We assume a (temporary) limitation of around 1200 bunches. This limitation could be overcome
- Depending on the source, the problem may disappear when exchanging the TDI in YETS