# LHC Machine Operational Status and Plans

Uppsala University, 27th September 2010

(Prospects for Charged Higgs Discovery at Colliders)

Steve Myers

(On behalf of the LHC team and international collaborators)

# Topics

- Recap of last two years or so (brief)
- Summary of luminosity performance this year
- Very Recent Progress

# LHC: Some Technical Challenges: Recap

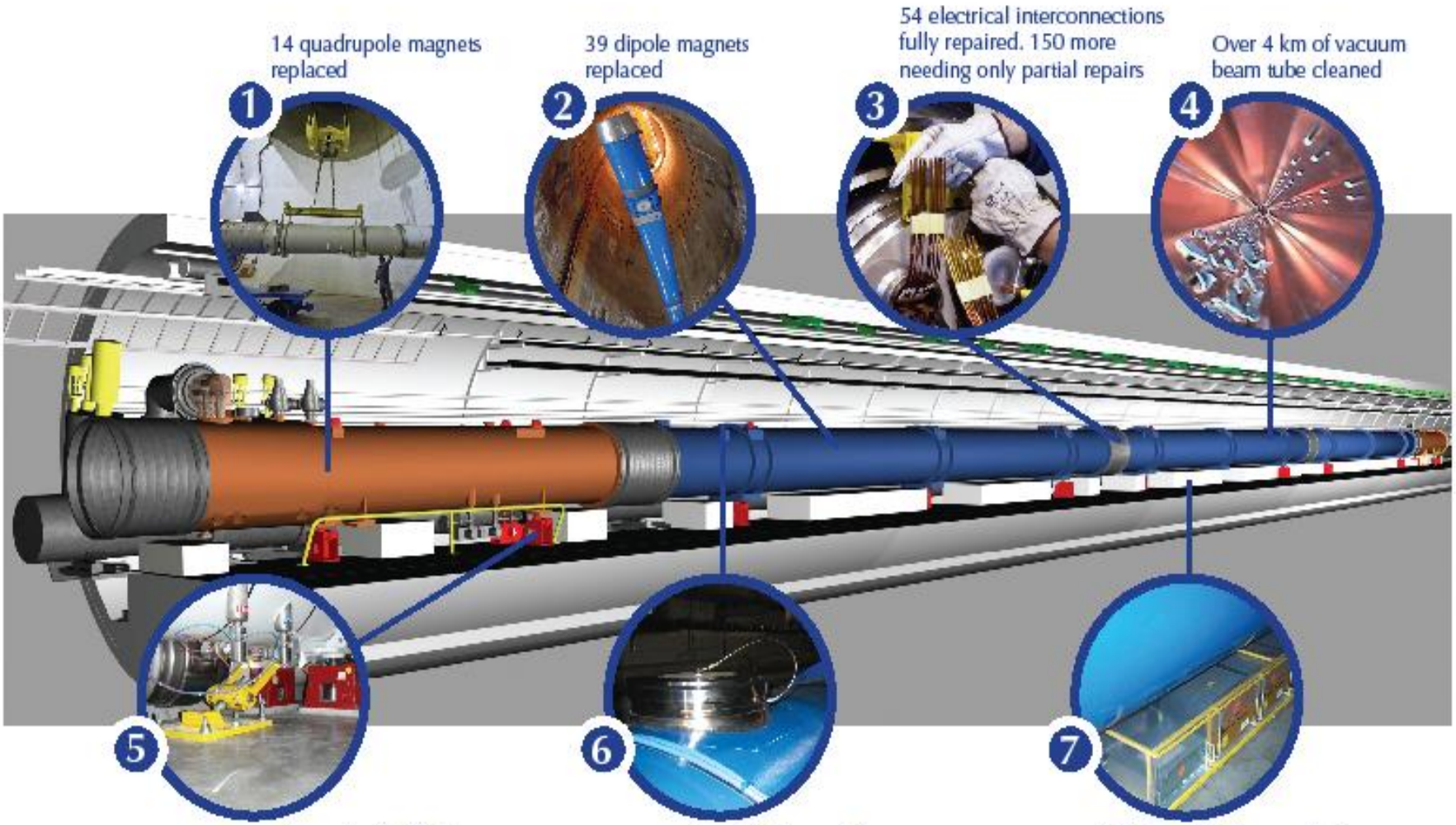
| | | |
|---|---|---|
| Circumference (km) | 26.7 | 100-150m underground |
| Number of superconducting twin-bore Dipoles | 1232 | Cable Nb-Ti, cold mass 37million kg |
| Length of Dipole (m) | 14.3 | |
| Dipole Field Strength (Tesla) | 8.4 | Results from the high beam energy needed |
| Operating Temperature (K) (cryogenics system) | 1.9 | Superconducting magnets needed for the high magnetic field<br>Super-fluid helium |
| Current in dipole sc coils (A) | 13000 | Results from the high magnetic field<br>1ppm resolution |
| Beam Intensity (A) | 0.5 | $2.2.10^{-6}$ loss causes quench |
| Beam Stored Energy (MJoules) | 362 | Results from high beam energy and high beam current<br>1MJ melts 1.5kg Cu |
| Magnet Stored Energy (MJoules)/octant | 1100 | Results from the high magnetic field |
| Sector Powering Circuit | 8 | 1612 different electrical circuits |

# LHC Commissioning: Recap

- 2008
  - Accelerator complete
  - Ring cold and under vacuum
- September 10th 2008
  - First beams around
- September 19th 2008
  - The incident
- 2008 – 2009
  - 14 months of major repairs and consolidation
  - New Quench Protection System for online monitoring and protection of all joints.

Phase 1 +2

# The LHC repairs in detail




+ 8 cryogenics!

# Summary of LHC Commissioning

- November 20th 2009
  - First beams around again
- November 29th 2009
  - Both beams accelerated to 1.18 TeV simultaneously
- December 8th 2009
  - 2x2 accelerated to 1.18 TeV
  - First collisions at 2.36 TeV cm!
- December 14th 2009
  - Stable 2x2 at 1.18 TeV
  - Collisions in all four experiments

LHC - highest energy collider

Limited to 2 kA in main circuits (1.18 TeV) during deployment and testing of new Quench Protection System

# Decided Scenario 2010-2011

Following the technical discussions in Chamonix (Jan 2010) the CERN management and the LHC experiments decided

- Run at 3.5 TeV/beam with a goal of an integrated luminosity of around $1fb^{-1}$ by end 2011
  - Implies reaching a peak luminosity of $10^{32}$ in 2010
- Then consolidate the whole machine for 7TeV/beam (during a shutdown in 2012)
- From 2013 onwards LHC will be capable of maximum energies and luminosities

Primary Goal for 2010

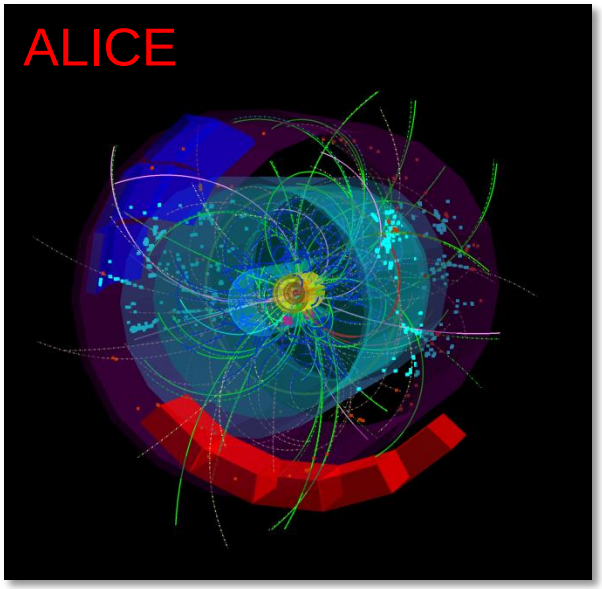
# Why do we limit the beam energy to 3.5TeV in 2010-2011?

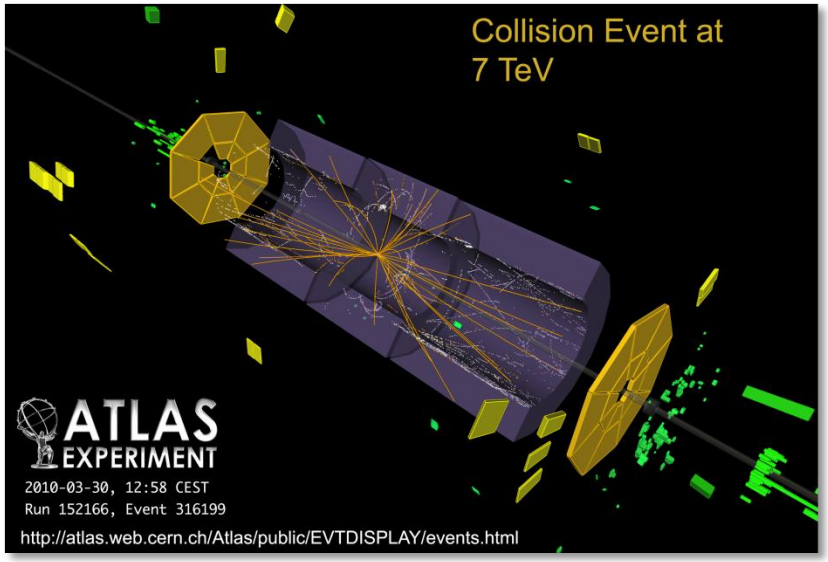
All the work we have done since November 2008 makes us certain that a repeat of September 19 can NEVER happen.

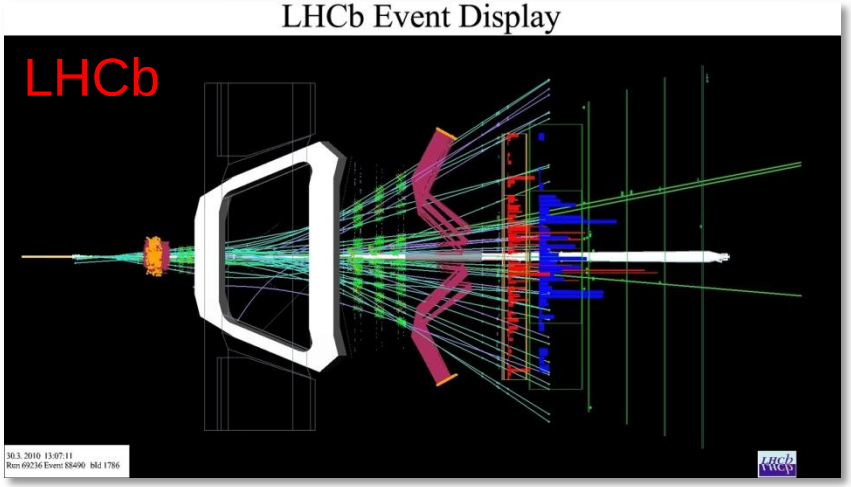
The offending connector in this incident had an estimated resistance of 220nΩ. We have measured all 10,000 inter-magnet connectors and the maximum resistance we have seen is 2.8nΩ.

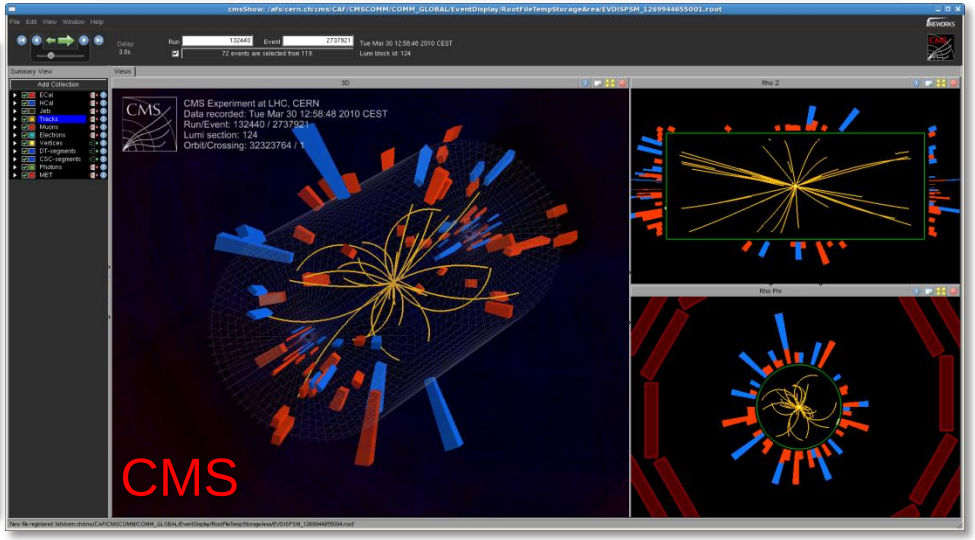
BUT in April 2009, we have uncovered a different possible failure scenario which could under certain circumstances produce an electric arc in the “copper stabilizers” of the magnet interconnects

# LHC: First collisions at 7 TeV on 30 March 2010



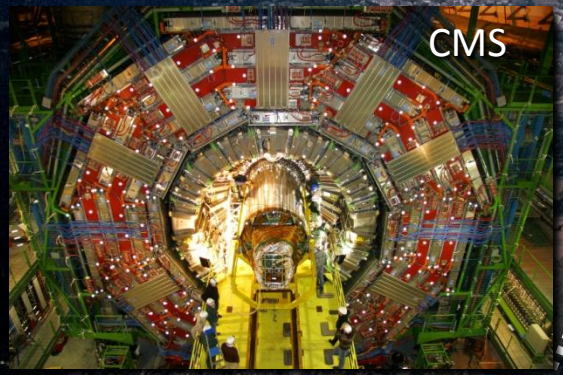



# Have Entered a New Era in Fundamental Science

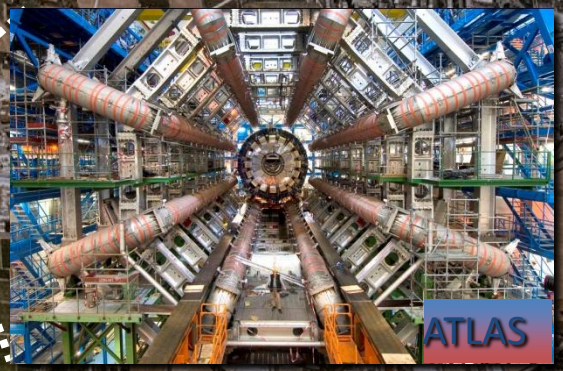
Start-up of the Large Hadron Collider (LHC) is a very exciting turning point in particle physics.





Exploration of a new energy frontier





# Summary of Luminosity progress

calculated

| Event | TeV | OEF | β* | Nb | Ib | Itot | MJ | Nc | Peak luminosity | Date |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.5 | 0.2 | 10 | 2 | 1.00E+10 | 2.0E+10 | 0.0113 | 1 | 8.9E+26 | 30 March 2010 |
| 2 | 3.5 | 0.2 | 10 | 2 | 2.00E+10 | 4.0E+10 | 0.0226 | 1 | 3.6E+27 | 02 April 2010 |
| 3 | 3.5 | 0.2 | 2 | 2 | 2.00E+10 | 4.0E+10 | 0.0226 | 1 | 1.8E+28 | 10 April 2010 |
| 4 | 3.5 | 0.2 | 2 | 4 | 2.00E+10 | 8.0E+10 | 0.0452 | 2 | 3.6E+28 | 19 April 2010 |
| 5 | 3.5 | 0.2 | 2 | 6 | 2.00E+10 | 1.2E+11 | 0.0678 | 4 | 7.1E+28 | 15 May 2010 |
| 6 | 3.5 | 0.2 | 2 | 13 | 2.60E+10 | 3.4E+11 | 0.1910 | 8 | 2.4E+29 | 22 May 2010 |
| 7 | 3.5 | 0.2 | 3.5 | 3 | 1.10E+11 | 3.3E+11 | 0.1865 | 2 | 6.1E+29 | 26 June 2010 |
| 8 | 3.5 | 0.2 | 3.5 | 6 | 1.00E+11 | 6.0E+11 | 0.3391 | 4 | 1.0E+30 | 02 July 2010 |
| 9 | 3.5 | 0.2 | 3.5 | 8 | 9.00E+10 | 7.2E+11 | 0.4069 | 6 | 1.2E+30 | 12 July 2010 |
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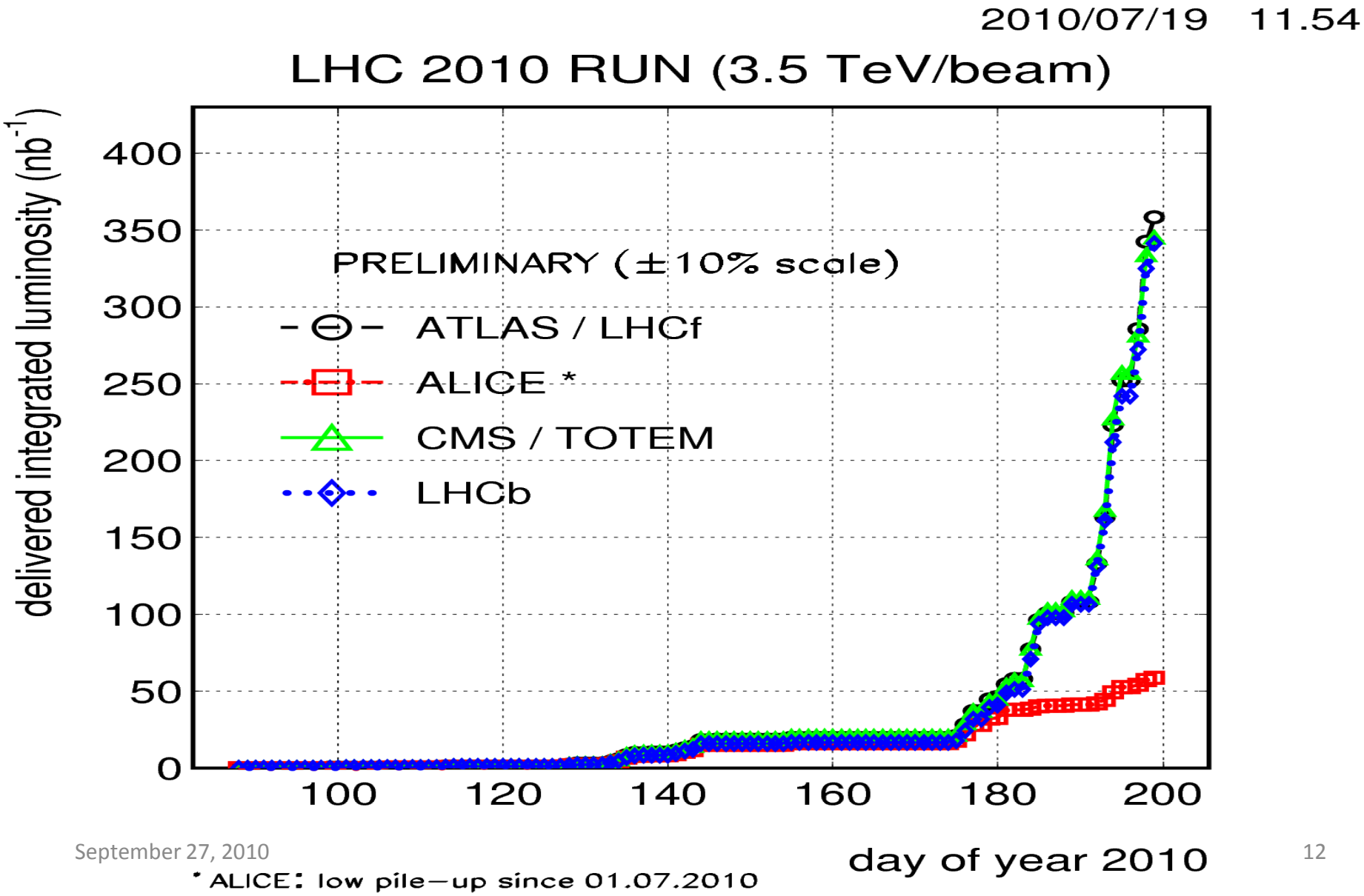
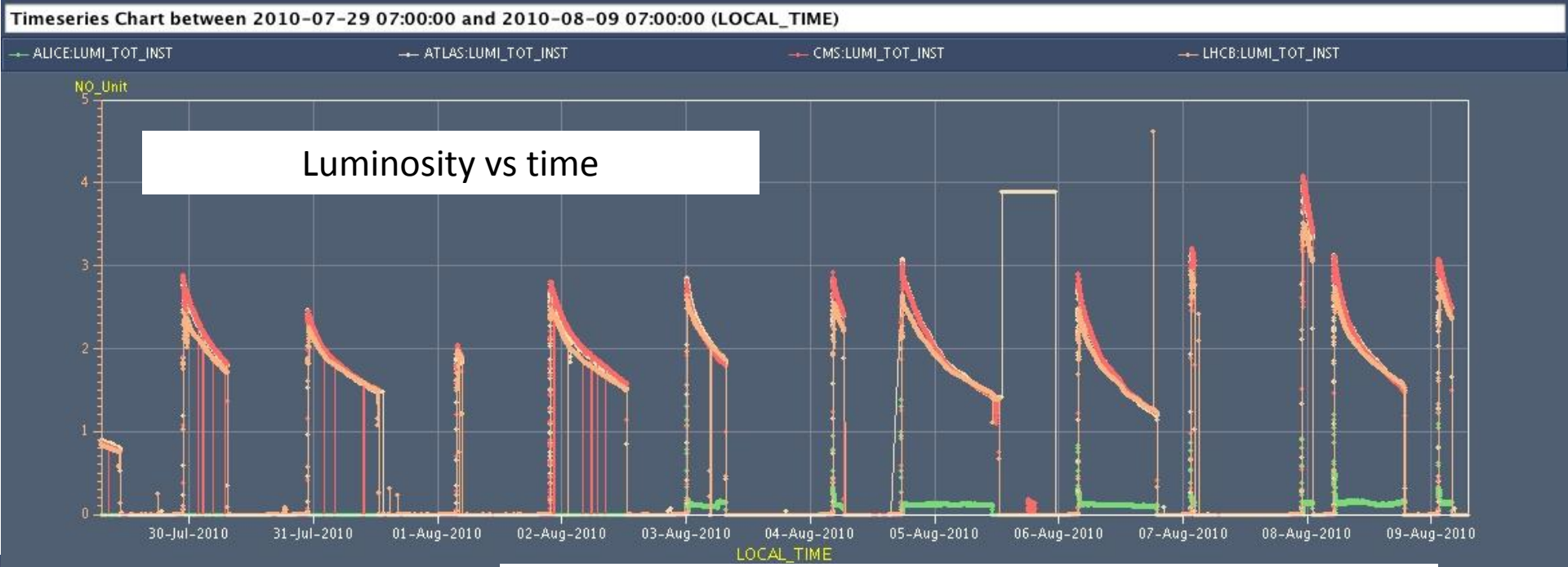
| 11 | 3.5 | 0.2 | 3.5 | 25 | 1.00E+11 | 2.5E+12 | 1.4129 | 16 | 4.1E+30 | 30 July 2010 |
| 12 | 3.5 | 0.2 | 3.5 | 48 | 1.00E+11 | 4.8E+12 | 2.7127 | 36 | 9.1E+30 | 19 August 2010 |

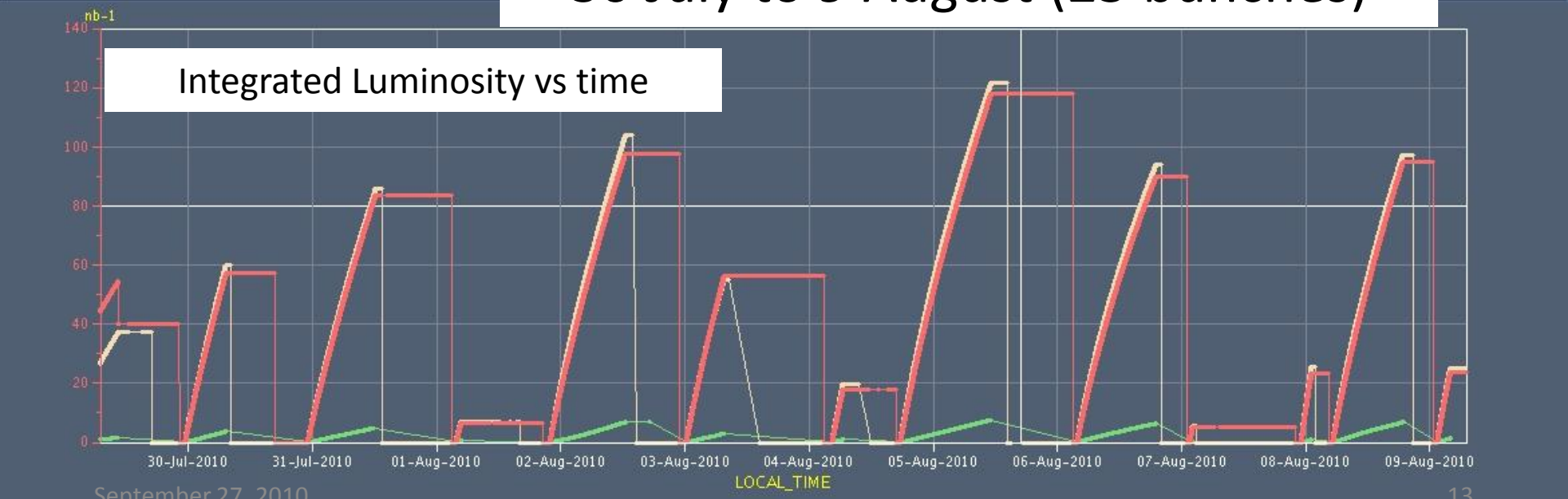
Maximum reached is $10.7 \times 10^{30}$ cm$^{-2}$s$^{-1}$

# Integrated Luminosity ICHEP10 (350nb-1)

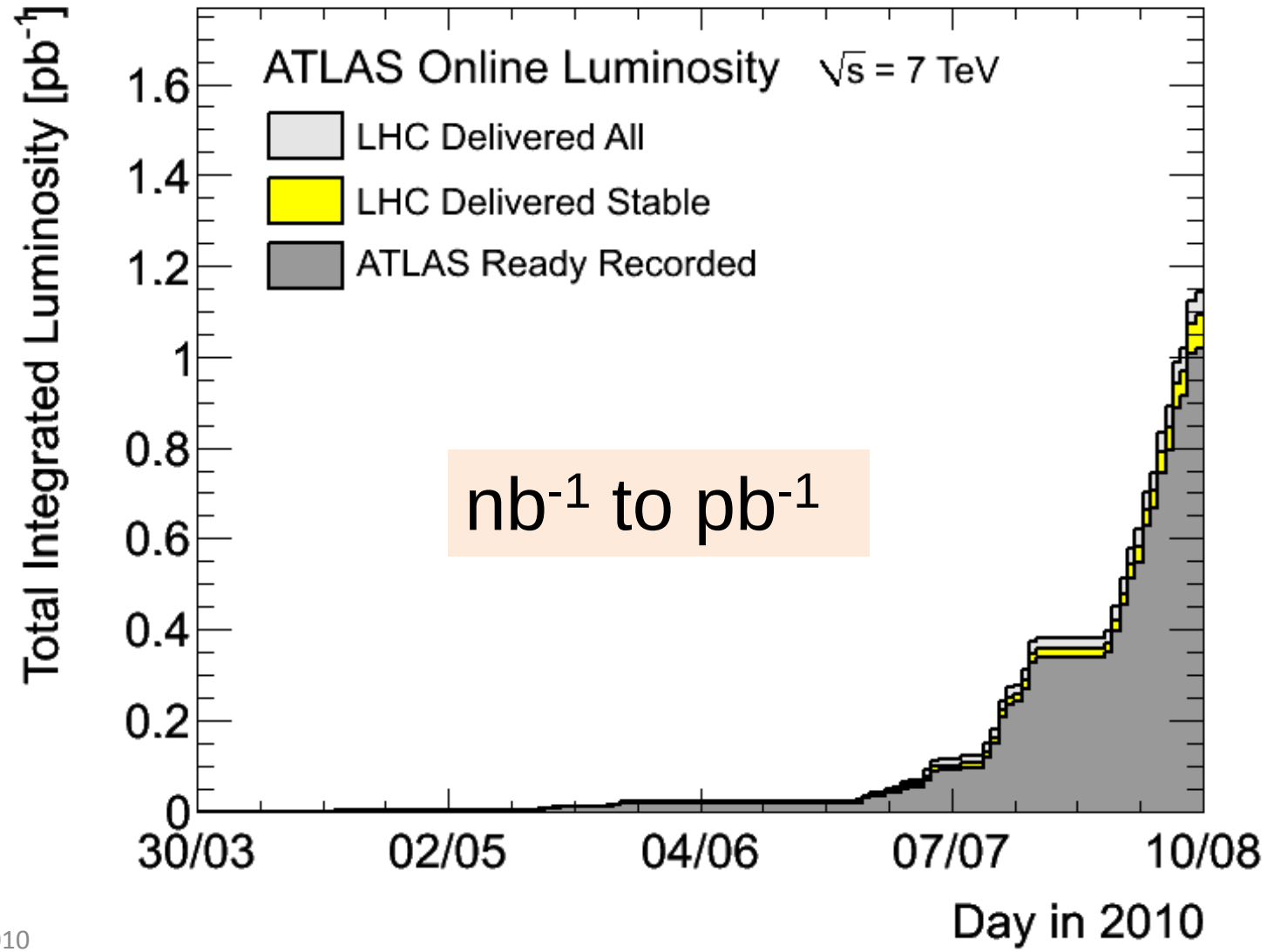


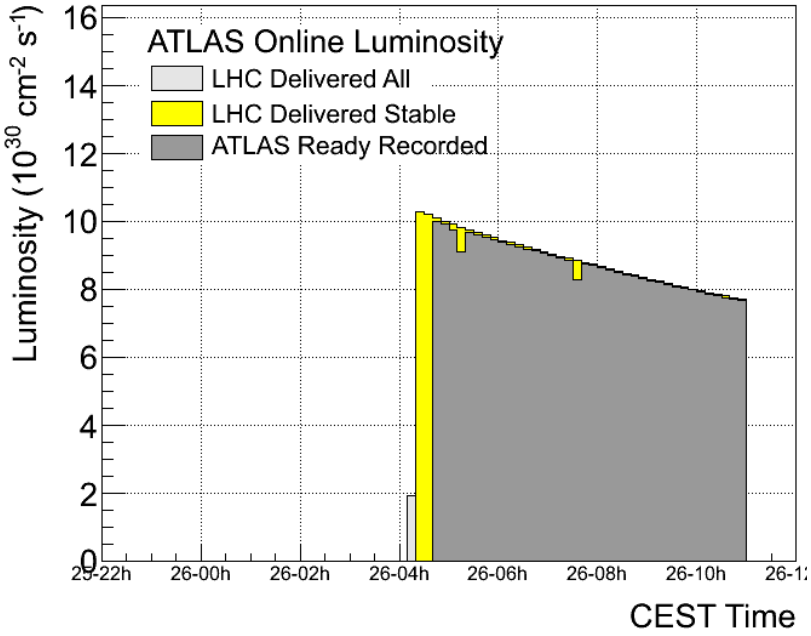



30 July to 9 August (25 bunches)



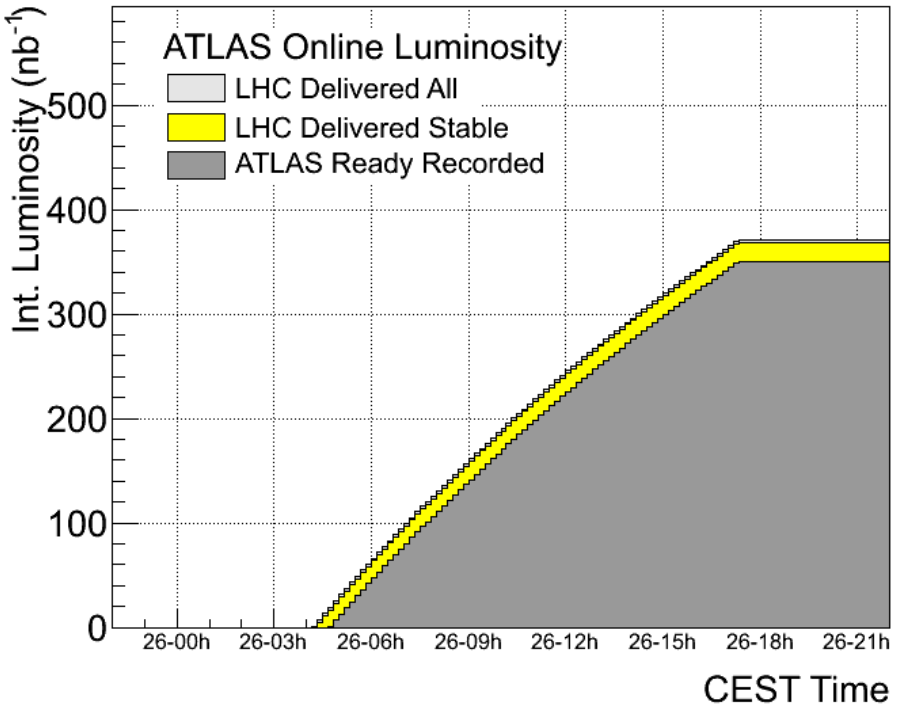
# Change of units Friday 6.8.



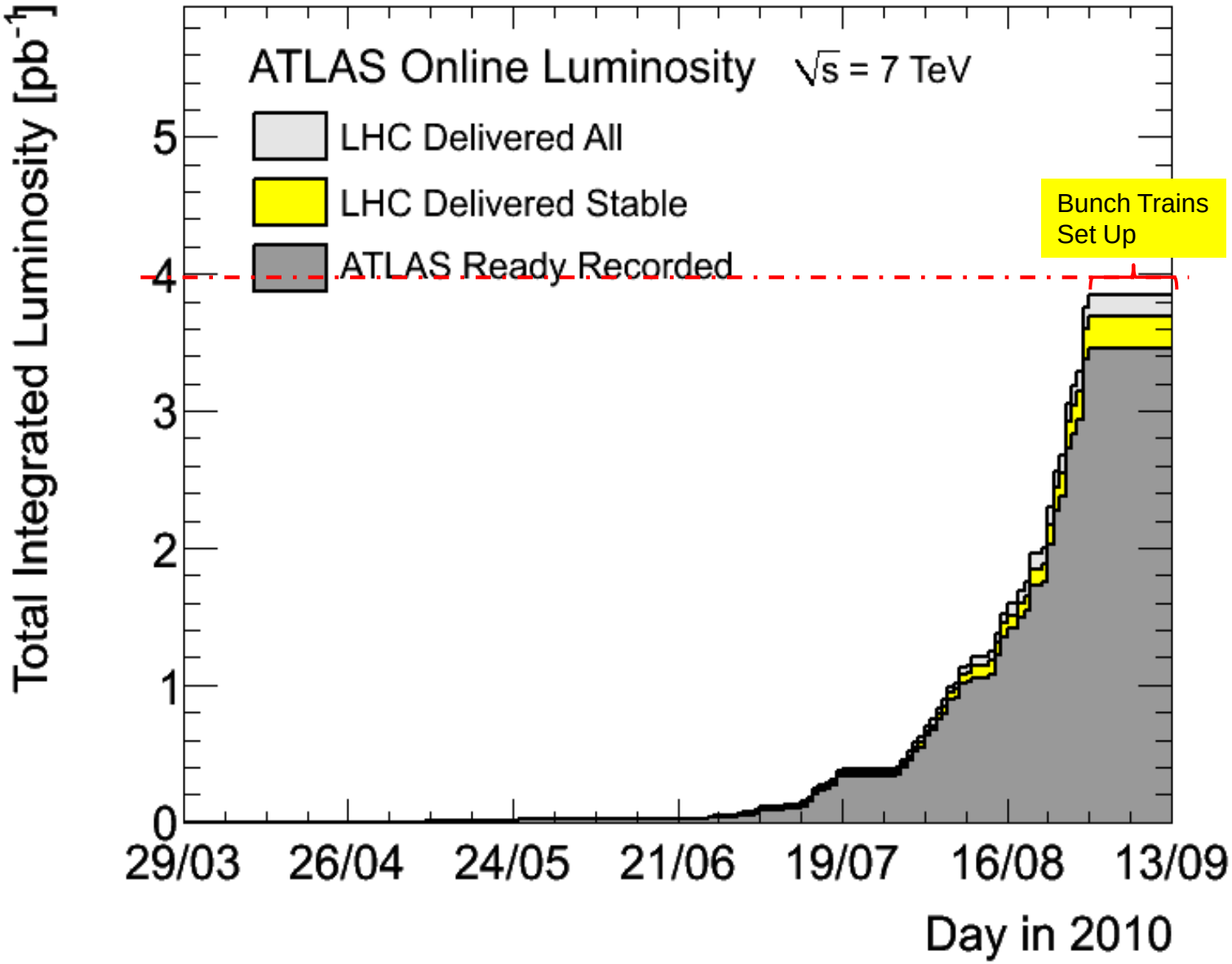



# 1303 (Aug 26) best fill so far

This fill gave integrated luminosity exceeding what was shown in ICHEP Paris



# Approaching 4pb$^{-1}$ (move to bunch trains)



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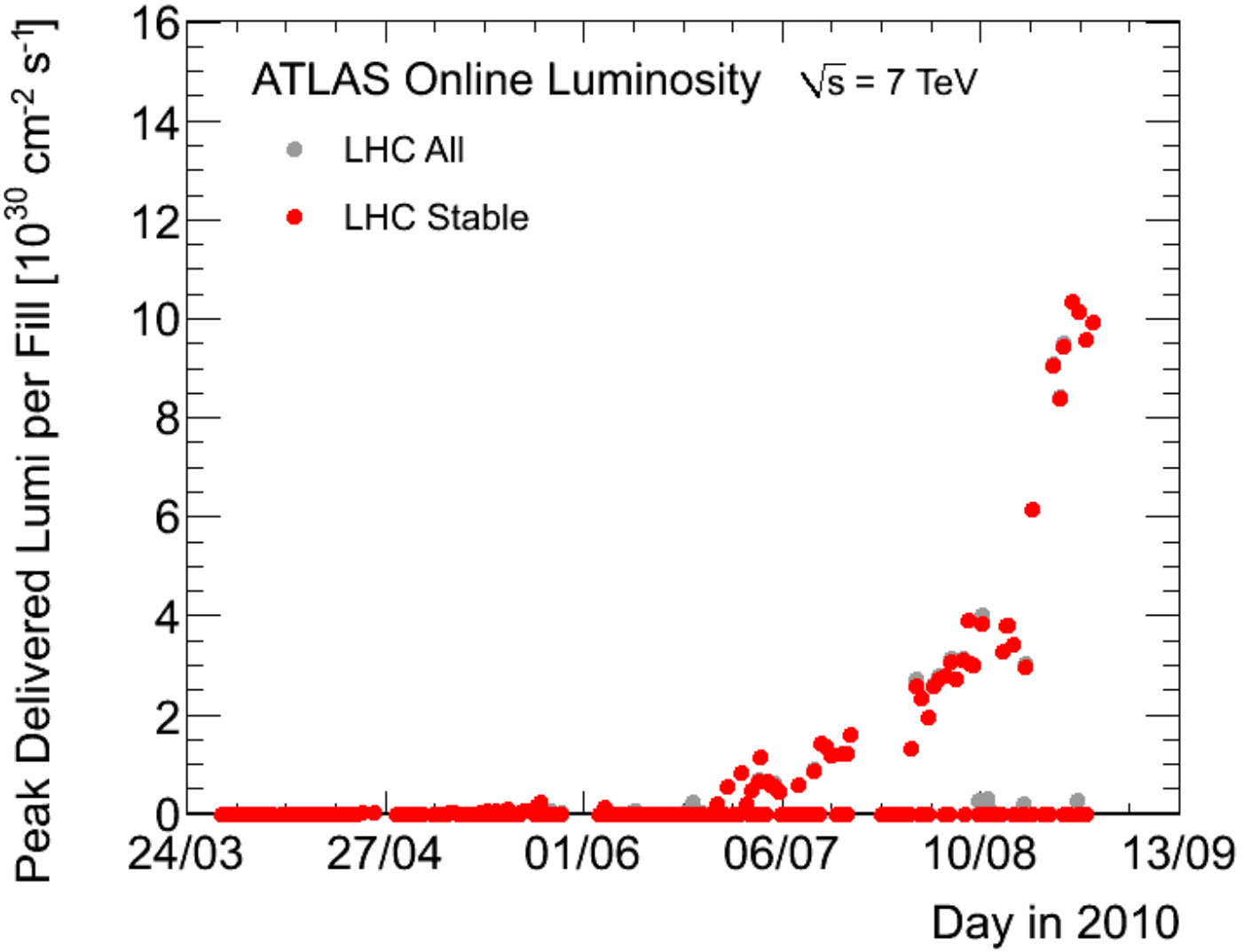
Maximum reached is $10.7 \times 10^{30}$ cm$^{-2}$s$^{-1}$

# Peak Luminosity 31/8/2010



# Plan for getting to $10^{32}$ before ion run

LMC 18th August.

- Parameters and Conditions
  - Nominal bunch intensity 1.1E11
  - Stick to β* = 3.5 m in all IPs
  - Commission bunch trains
    - Complete re-do of the whole machine protection set-up
  - Go to 150 ns bunch spacing
  - Commission faster ramp (10 A/s)

# Additional work for bunch trains

- Completely new set up of all phases of LHC under the new conditions needed for safe operation with high intensity bunch trains
  - Beam transfer (collimation)
  - Emittance control in injectors and during ramp in LHC
  - Transverse damper set up with lower noise
  - Injection with crossing angles (collimators and unsafe beam),
  - Accumulation with crossing angle; long discussions about magnitude of crossing angle
  - Ramp with 10A/s
  - Squeeze (changing crossing angles to collision values)
  - Collisions with crossing angles (collimation)

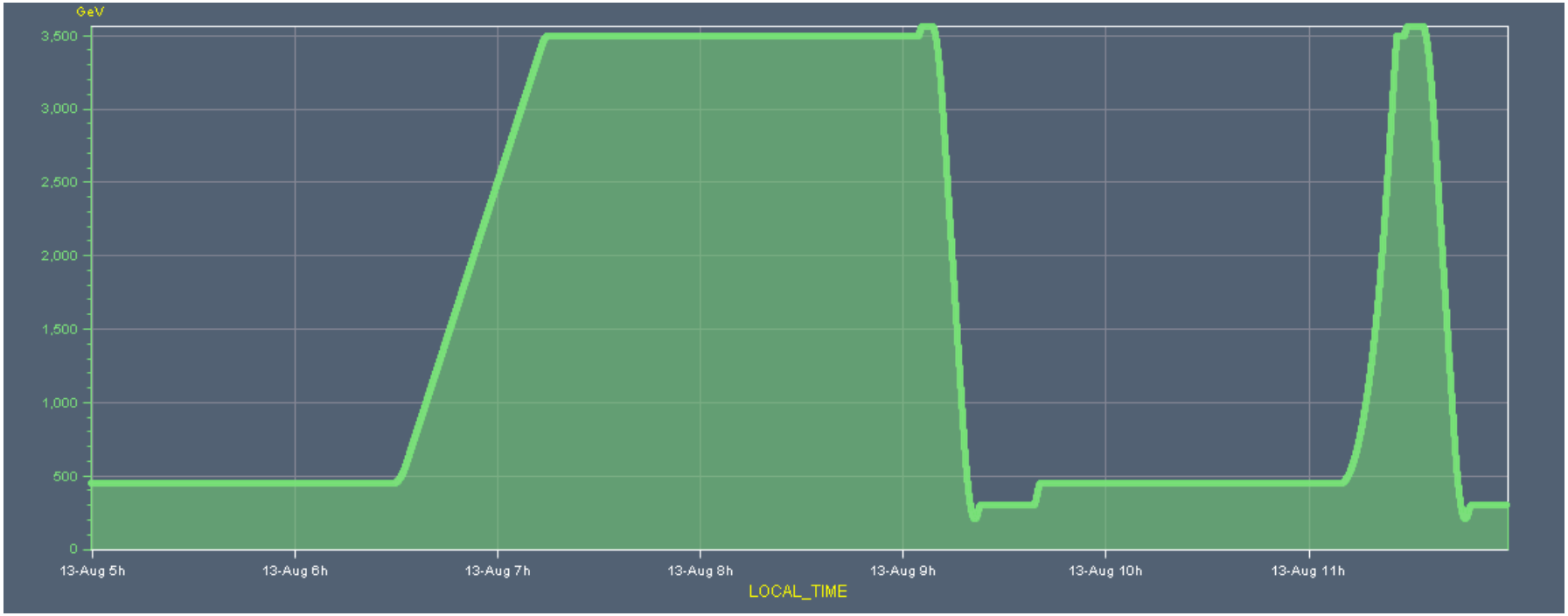
# Crossing angles

- External crossing angles
  - IR1: -170 μrad at inj./ramp and -100 μrad in squeeze/collision
  - IR2: +170 μrad at inj./ramp and +110 μrad squeeze+collision
  - IR5: +170 μrad at inj./ramp and +100 μrad in squeeze/collision
  - IR8: -170 μrad at inj./ramp and -100 μrad in squeeze/collision

- Good for beam-beam (do we need it for 150ns ?)
- Bad for aperture and MP (are we ready to do this ?)

- Strategy
  - Start with nominal angles at injection
  - Measure IR apertures
  - Test parasitic beam-beam with lower angles
  - Decide based on this

# Test ramp 10 A/s

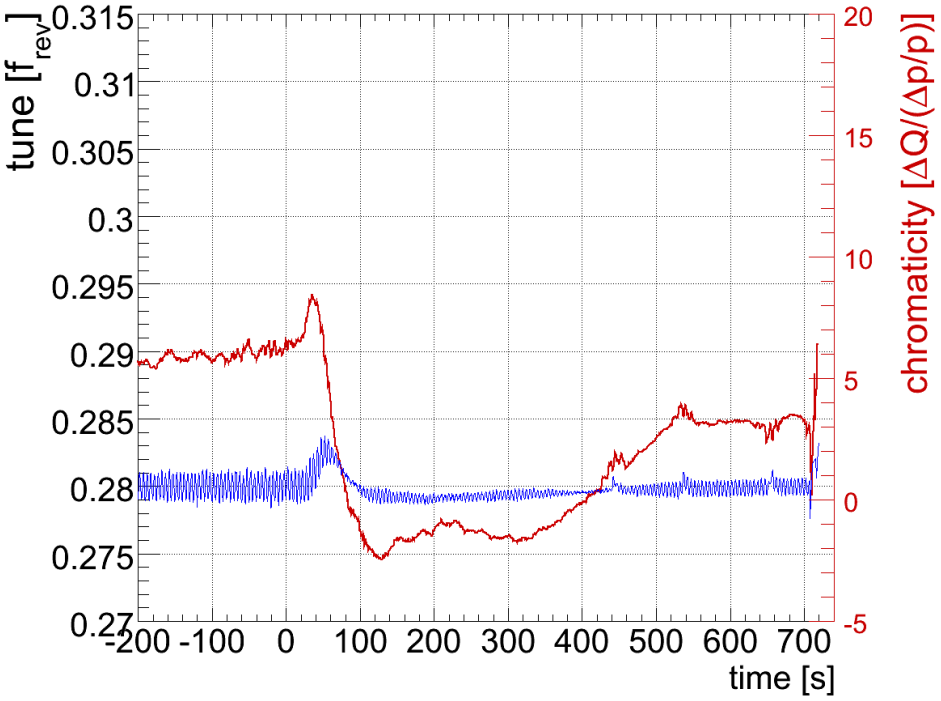



1st attempt reached 1.7TeV
2nd attempt perfect ramp up to 3.5TeV

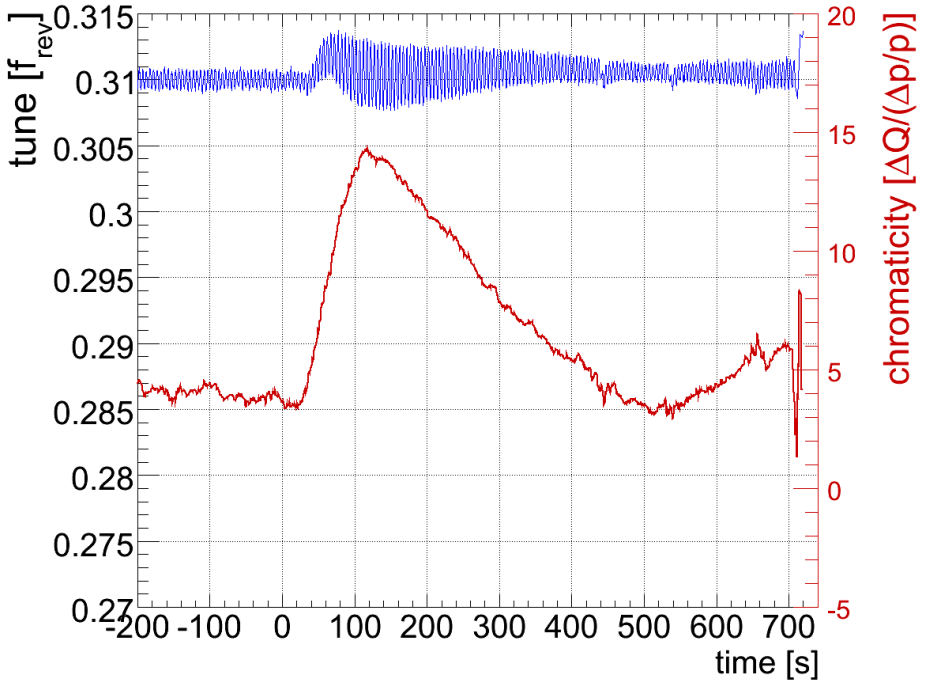
Ramp duration reduced from 46 to 16 minutes

# Test ramp at 10 A/s

Orbits, Tunes and Chromaticities measured and automatically corrected during the ramp and stored and fed forward for next ramp



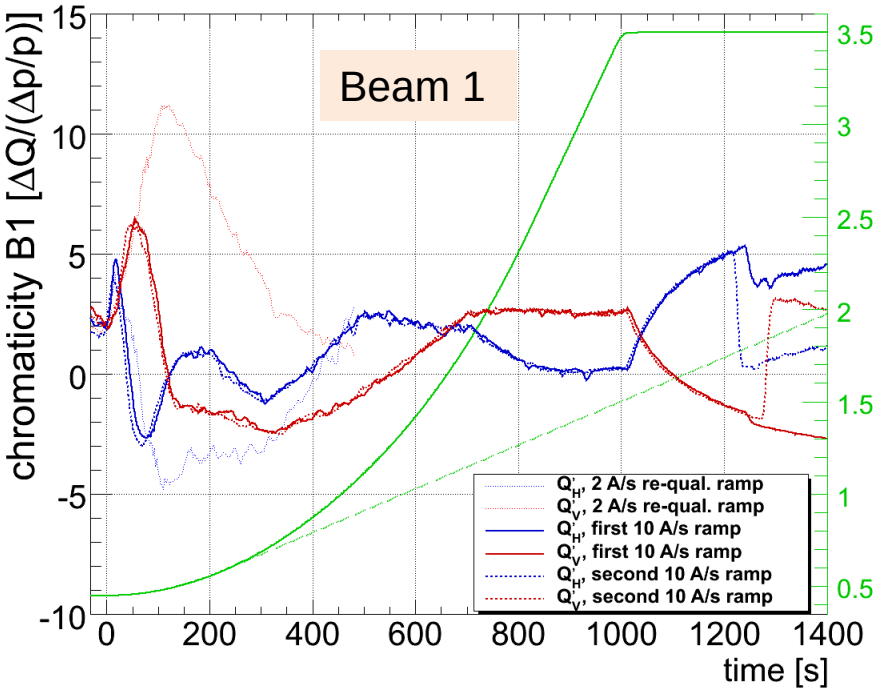

B1 horizontal

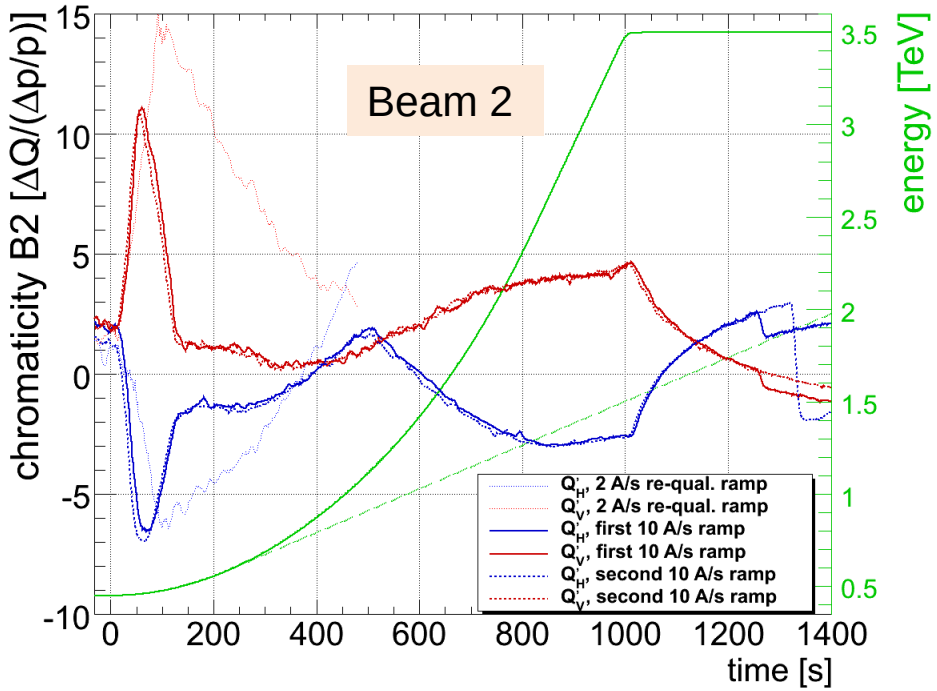



B1 vertical

# Ramp with 10 A/s

- Chromaticity during the ramp reproducible

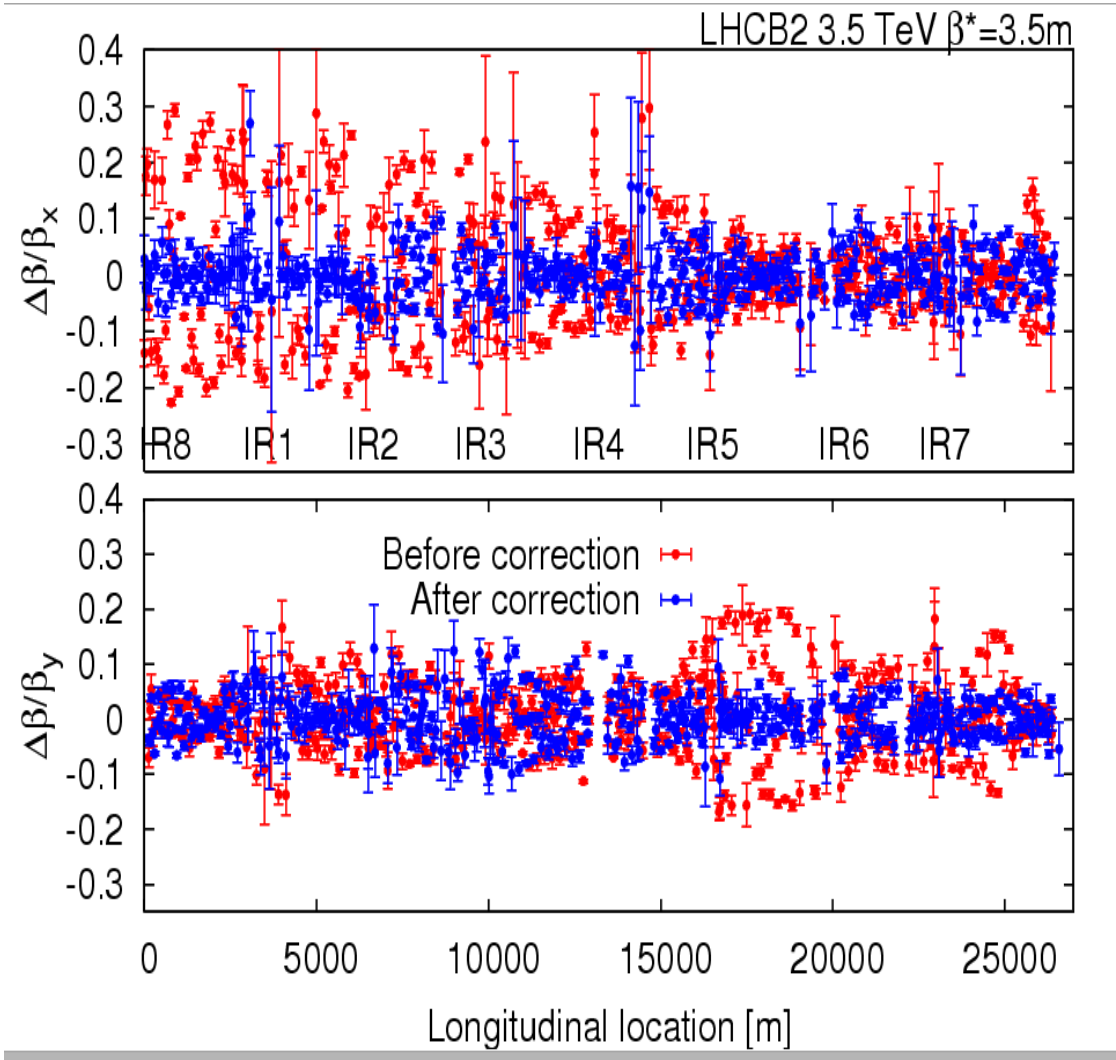


# Correction of Beta beating (Wednesday 8th Sep)

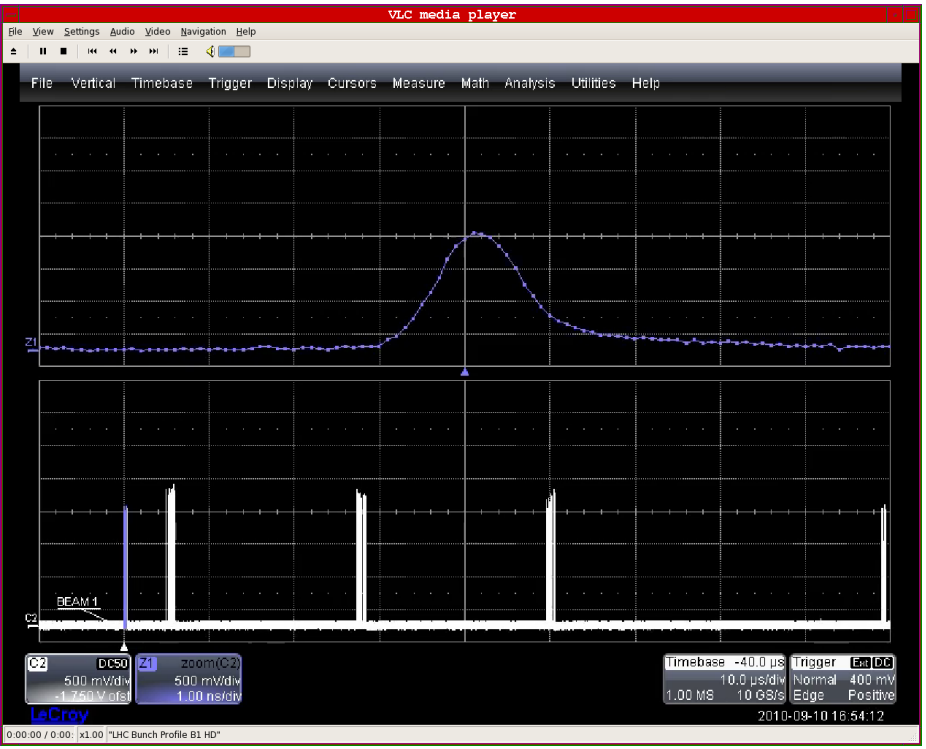
- Squeeze B2
- Brief optics studies on B2
  - Global correction
  - 100 quads !
  - Impressive results !

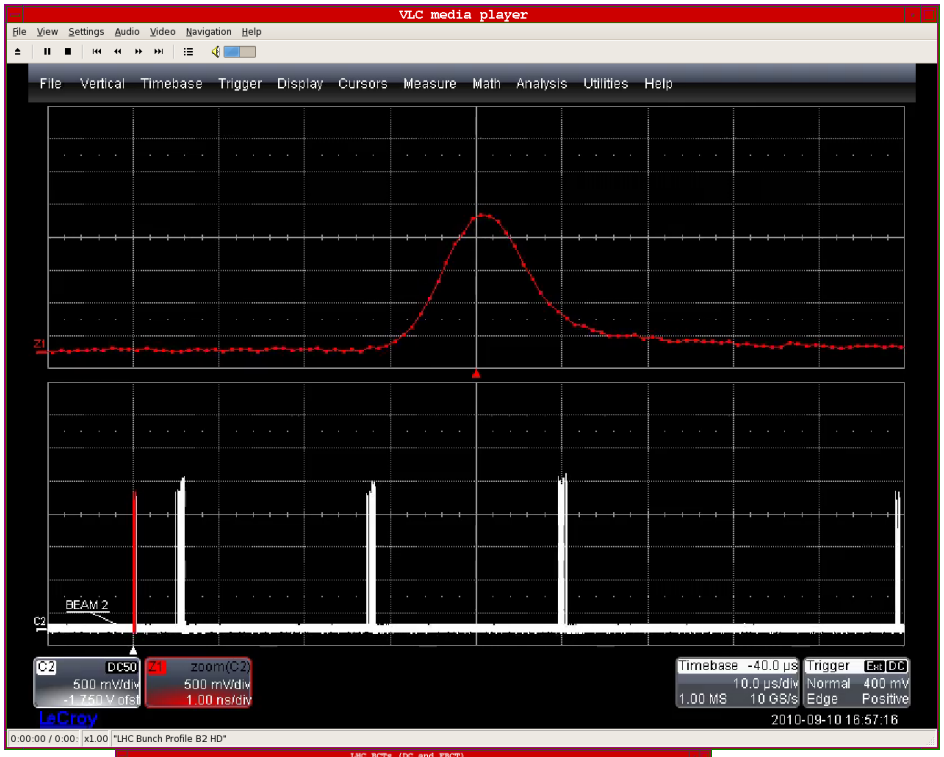
| | | |
|---|---|---|
| **IP1** | **3.22 0.22** | **3.62 0.40** |
| **IP2** | **3.83 0.61** | **3.43 0.26** |
| **IP5** | **3.67 0.07** | **3.28 0.25** |
| **IP8** | **3.26 0.10** | **3.51 0.09** |

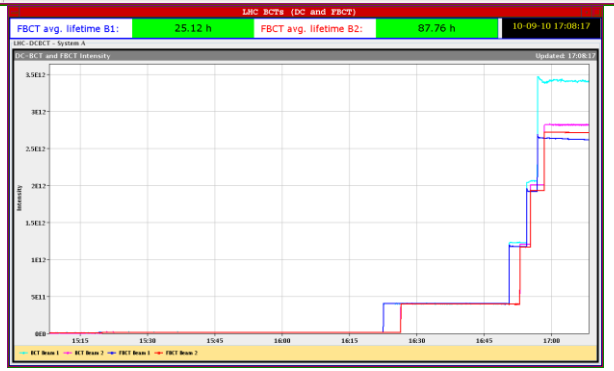


# Friday 10.9

- 17.00 Inject 1 train of 4, then 3 trains of 8, both beams

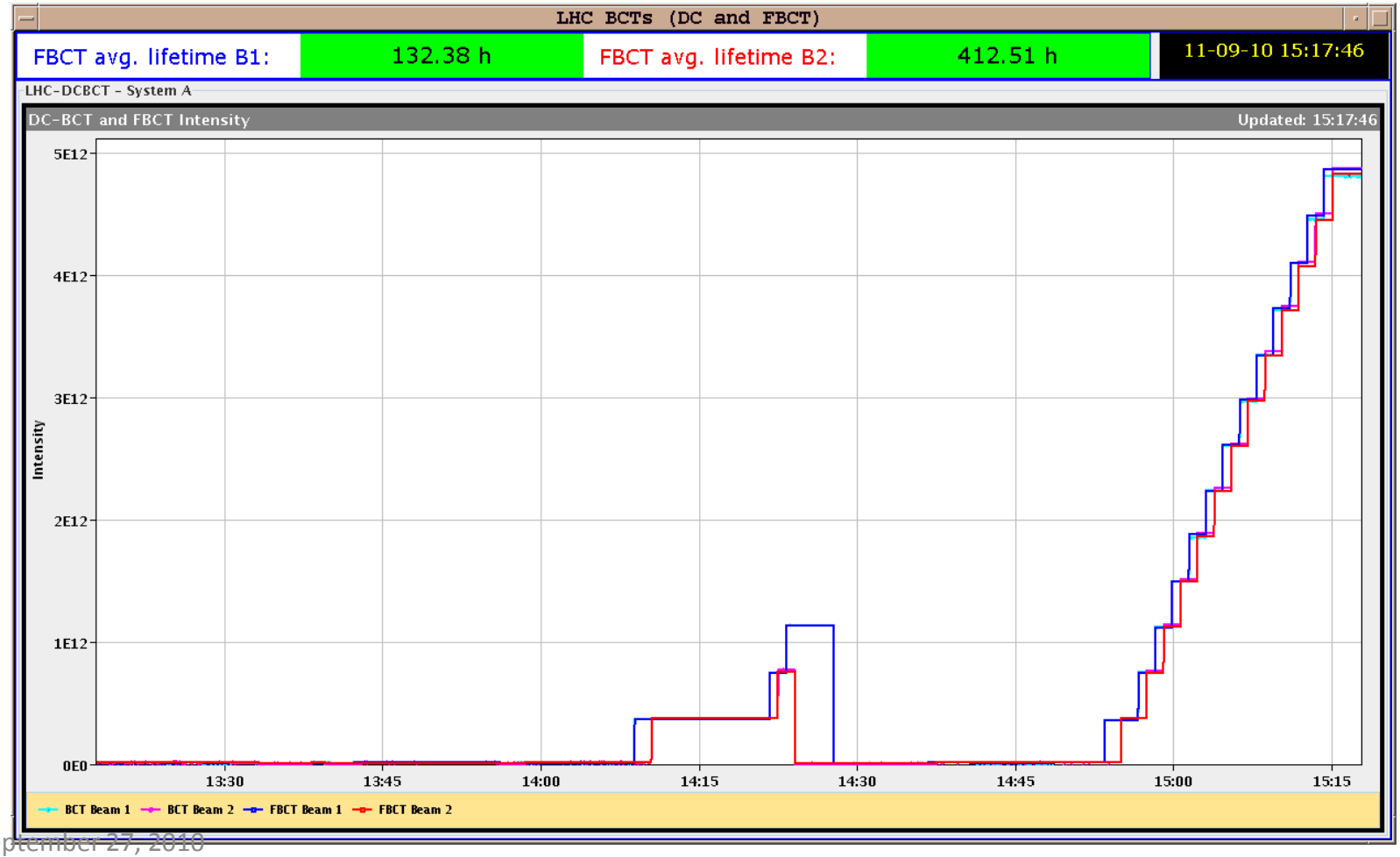


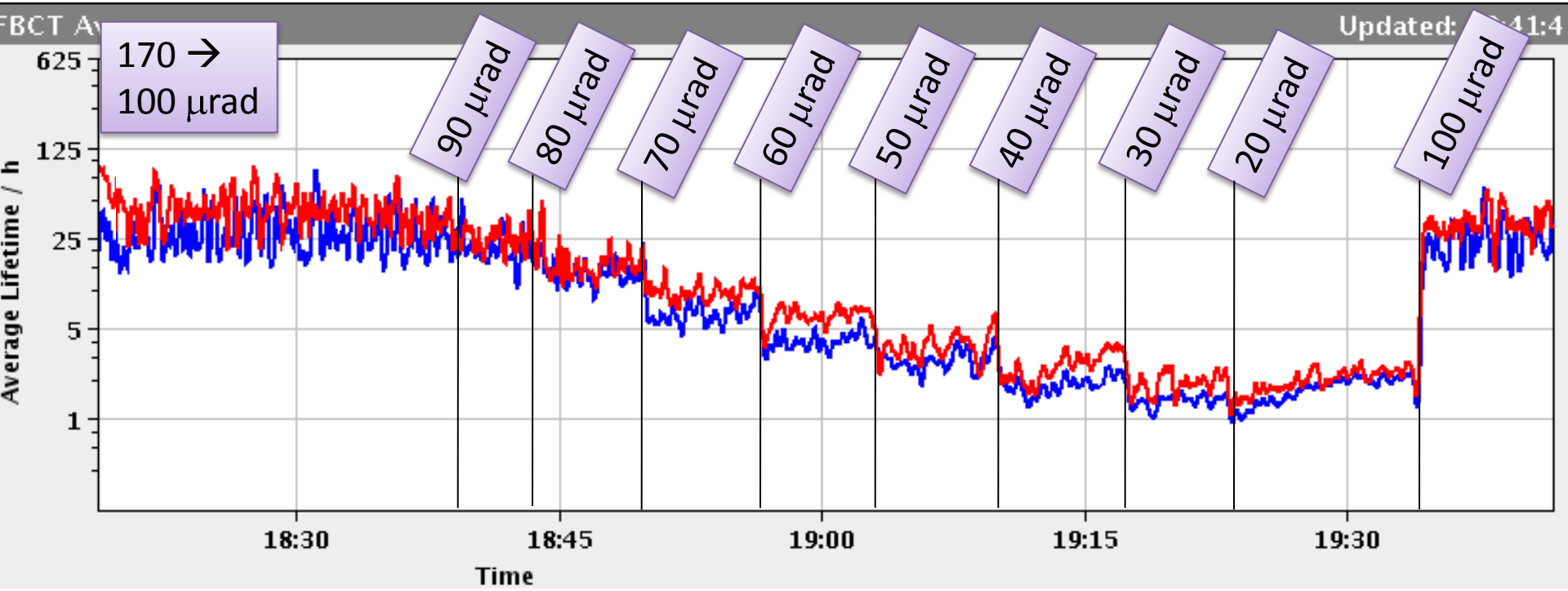
# Saturday 11.9

- RF setting up
  - Finally the complete injection sequence of 13x4 bunches per beam was executed and went smoothly with very little uncaptured beam



# Lifetime when Reducing Crossing Angle

3 batches of 8 bunches each, spacing 150 ns → up to 6 LR interactions per bunch




Conclusion: **Minimum required crossing angle is 100 μrad in 2010.**

(Werner Herr et al)

# Measured 450 GeV Aperture

| Beam / plane | Limiting element | Aperture [σ] |
|---|---|---|
| Beam 1 H | Q6.R2 | 12.5 |
| Beam 1 V | Q4.L6 | 13.5 |
| Beam 2 H | Q5.R6 | 14.0 |
| Beam 2 V | Q4.R6 | 13.0 |

- Predicted aperture bottlenecks in triplets (n1=7) do not exist.
- "Measured" n1 = 10 – 12 (on-momentum) instead design n1 = 7
- "We discover the aperture gold mine for performance"

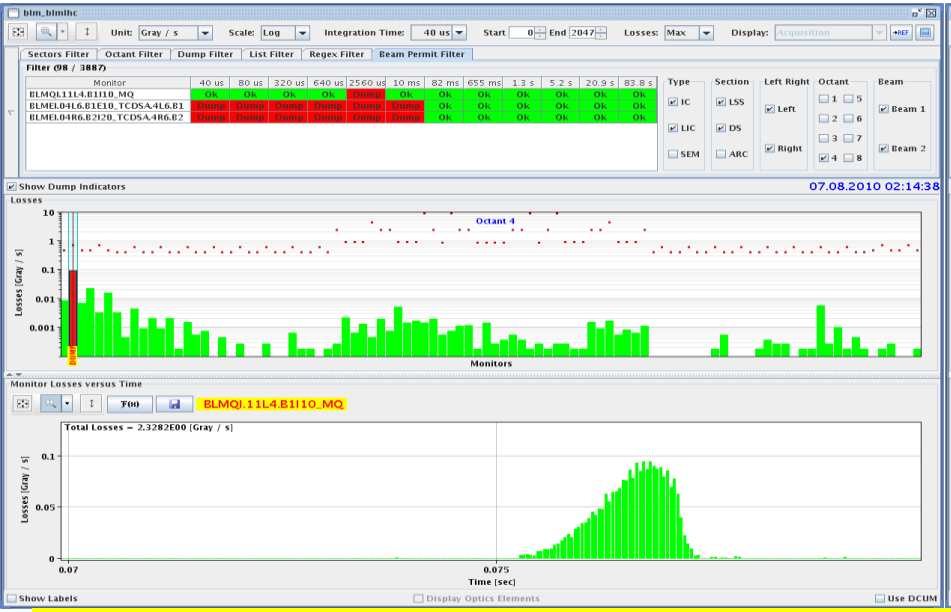
# Conclusion from Aperture

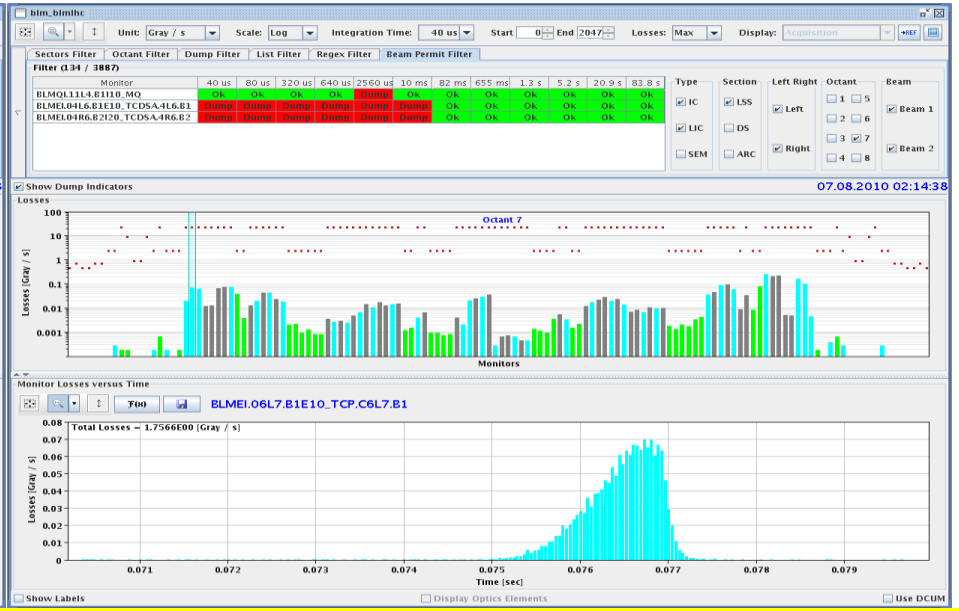
- **Plenty of aperture at triplets: > 13 σ (n1 > 10)**
- Can open tertiary collimators, e.g. to 13 σ at injection.
- **Can stay with 170 μrad crossing angle at injection.**
- Can also review settings for injection protection → Relax?
- We will measure aperture also at top energy with 3.5 m beta*. If (when) similar margins found , this will open the door for smaller beta* with same risk level.

# Unexplained Beam Losses

Losses with almost identical loss characteristics

- 5 unexplained beam losses (dump provoked by the Beam loss monitoring system)
- 1 unexplained beam loss while moving Roman Pots
- 1 beam loss provoked by a wire scan




- Suspicion is that debris if falling into the beam provoking a small beam loss seen by the BLM which triggers the beam dump (machine protection works well)

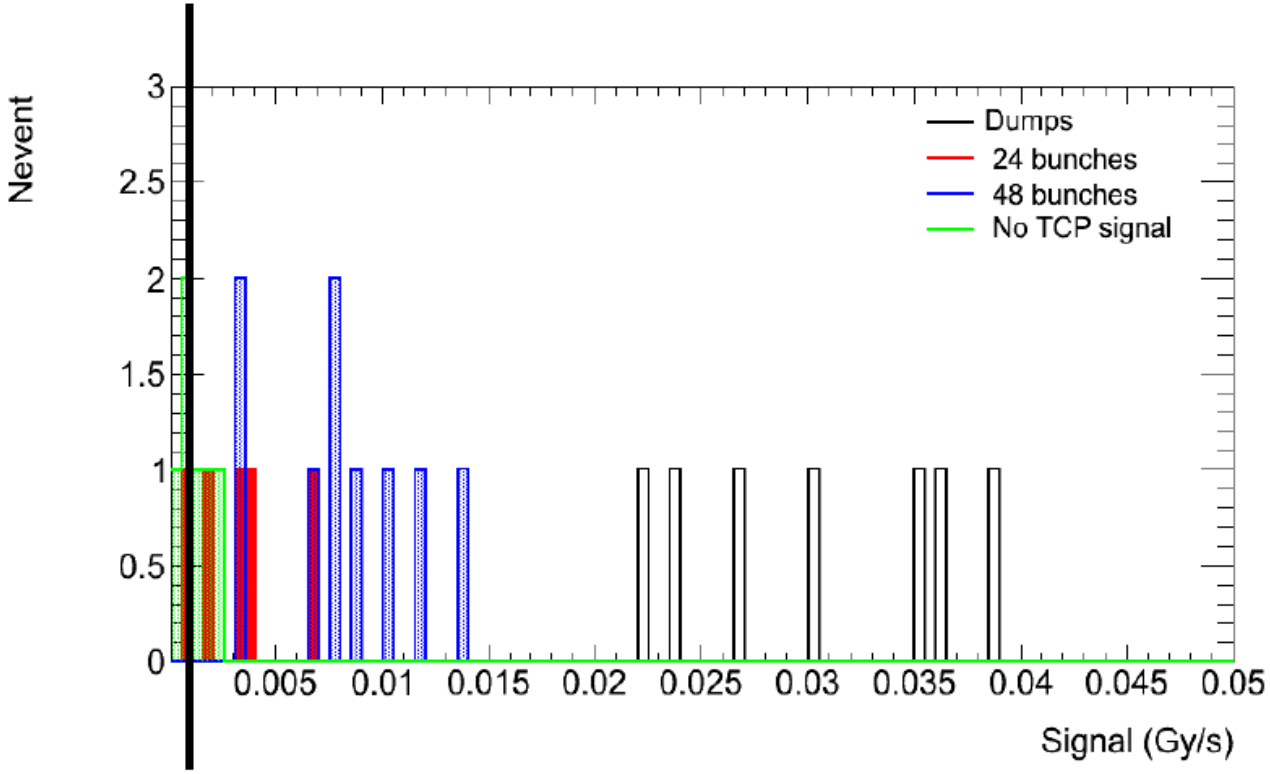
Proposal to verify the thresholds of the BLMs by doing a “quench” test.

# Update on UFOs (fast BLM event in SC regions)

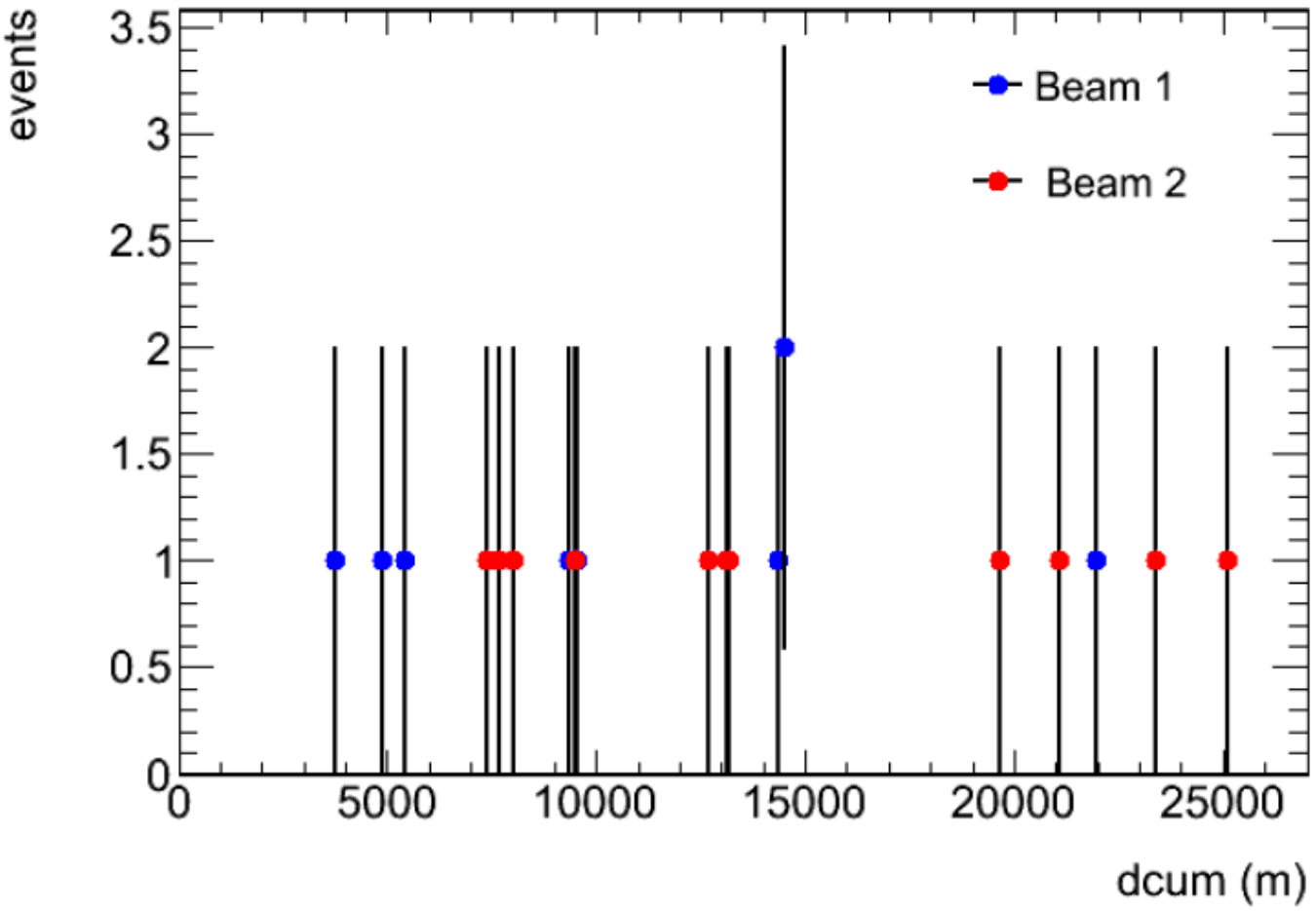
- 7 beam dumps due to fast (~ ms scale) losses in SC regions, triggered by the BLMs
- Search for similar events, but that did not trigger a beam dump, using the data logged in TIMBER.
  - The analysis was concentrated on the period with 24 and 48 bunches.

# Sub-threshold UFOs

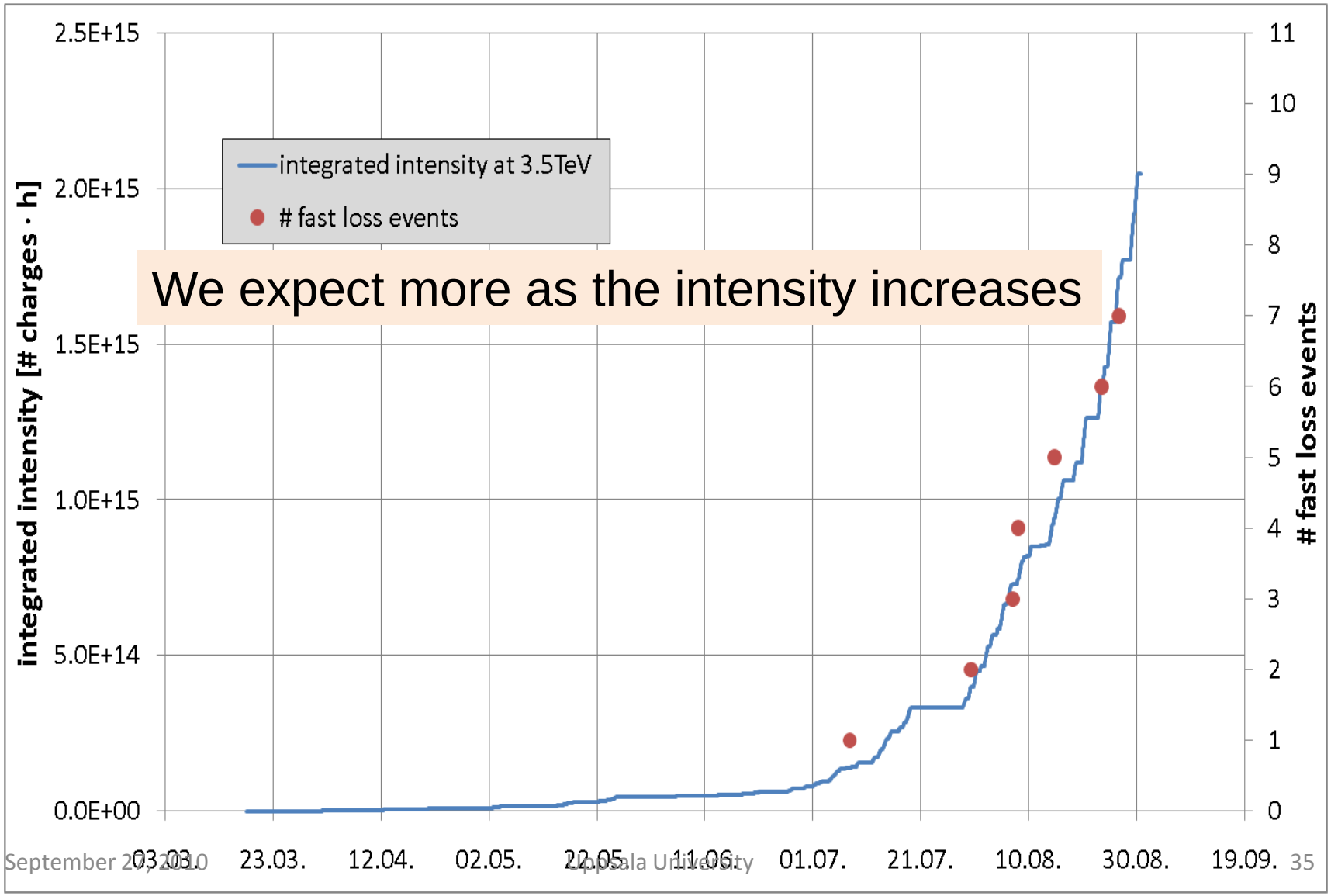
- Total of 228.6 hours of stable beam have been analyzed:
  - 141.3 hours (24 bunches) ==> 0.0566 evts/hour
  - 87.3 hours (48 bunches) ==> 0.1260 evts/hour



# Distribution along the ring



# Correlation of Number of fast Losses with beam Intensity



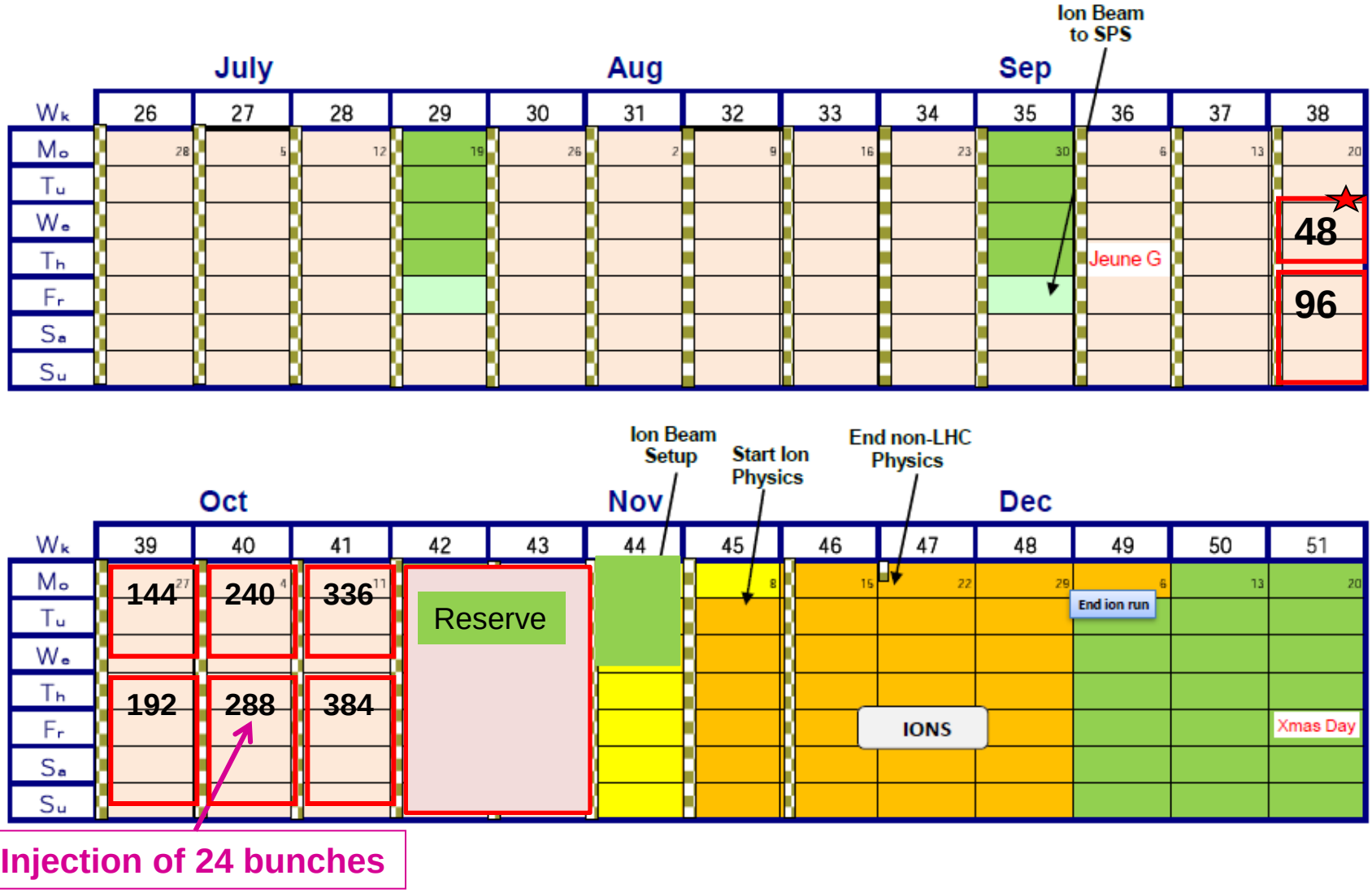
# Reconsidering rate of MJ increase

- Following the external review of the machine protection system
  - Considering speeding up the increase of MJ per week to 2 instead of 1
  - Could allow some time before the ion run for slight reduction of the beta* or increase in the number of bunches
- Bunch trains (with stable beams) since Wednesday 22nd September

# Intensity increase

- Intensity increase roadmap
  - Start train operation with 3x8 (or equivalent) – 2 fills, stabilize the sequence. Then move on to 6x8 (or equivalent).
  - 3 fills at a given intensity. Integrated physics time of ~20 hours.
  - Intensity step 48 bunches (+- 10%).
  - A checklist will be defined with the requirements for increasing the intensity.
  - Follow up on review items – as appropriate/possible.
  - Injection: significant change as we are now injecting unsafe beam.
    - Very careful monitoring of abnormal injections.

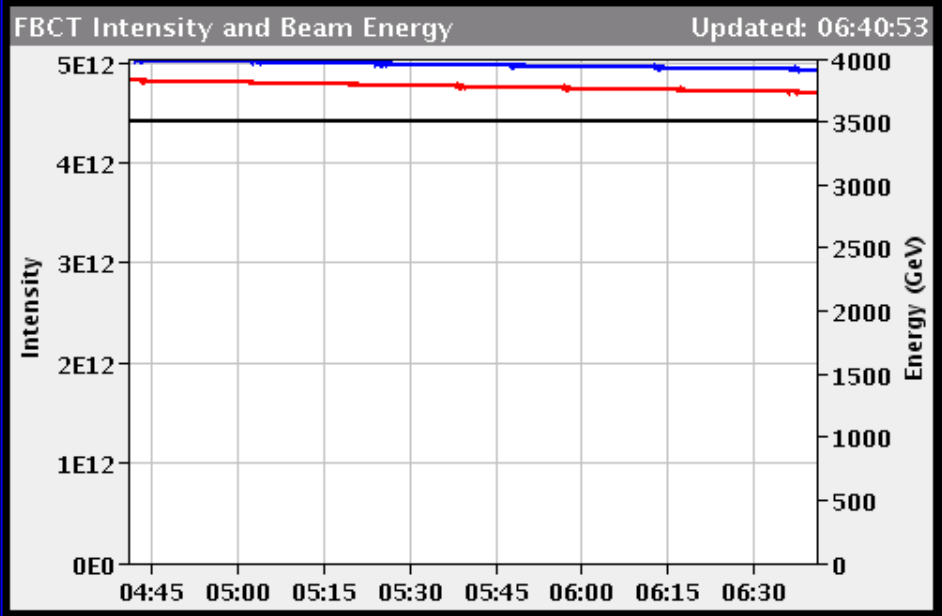
# Aggressive Schedule (short term)

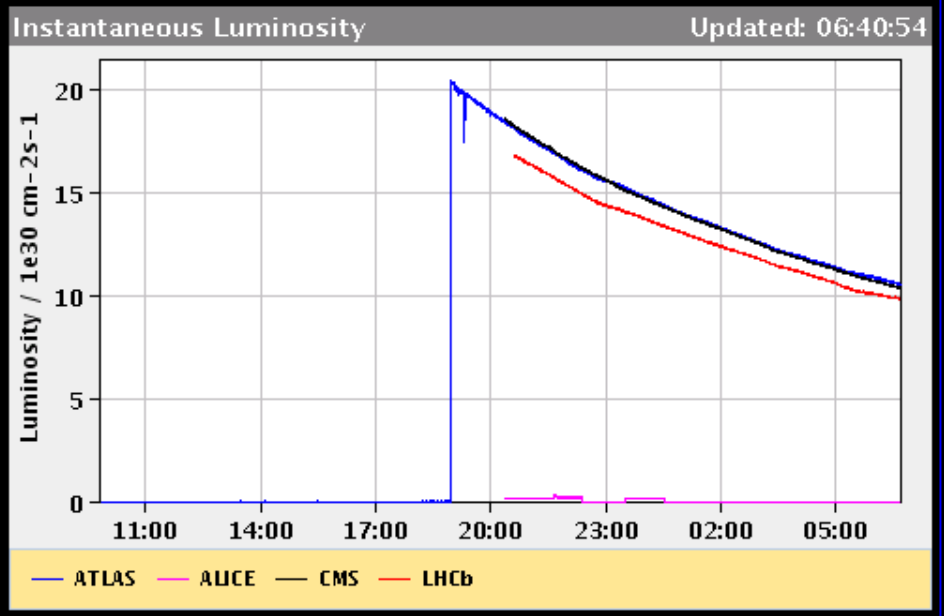


LHC Page1 | Fill: 1366 | E: 3500 GeV | 24-09-2010 06:40:53

# PROTON PHYSICS: STABLE BEAMS

| Energy: | 3500 GeV | I(B1): | 5.01e+12 | I(B2): | 4.73e+12 |
|---|---|---|---|---|---|




Comments 23-09-2010 22:16:30 :

Collisions with bunch trains; 22nd September 7x8 bunches;
Luminosity = $2 \times 10^{31}$

Fill. scheme: 150 ns_56b_47_16_47_8bpi

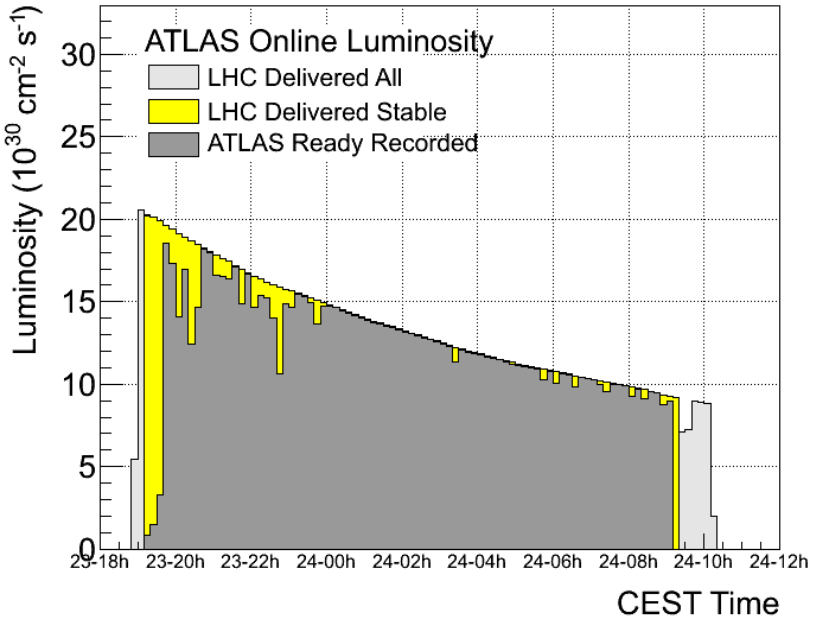
| BIS status and SMP flags | B1 | B2 |
|---|---|---|
| rmits | true | true |
| t | true | true |
| | false | false |
| Beam Presence | true | true |
| Moveable Devices Allowed In | true | true |
| Stable Beams | true | true |

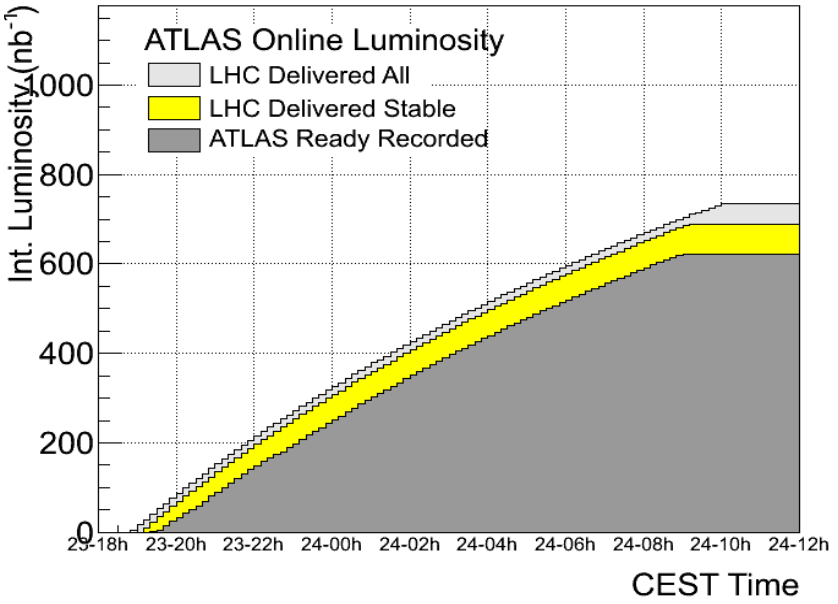
LHC Operation in CCC : 77600, 70480

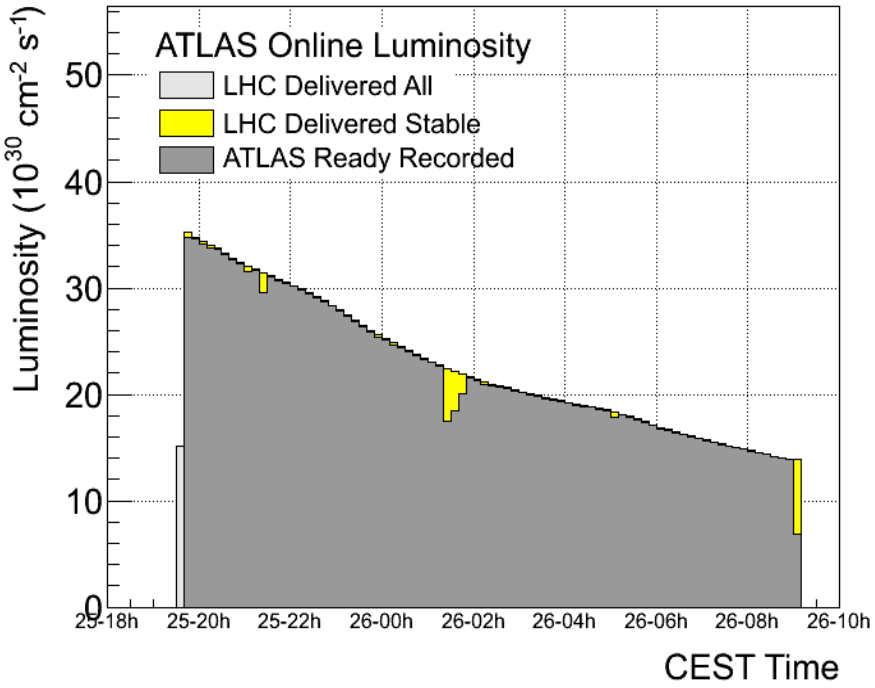
PM Status B1: ENABLED | PM Status B2: ENABLED

# September 23

- Best Fill so far (1366)

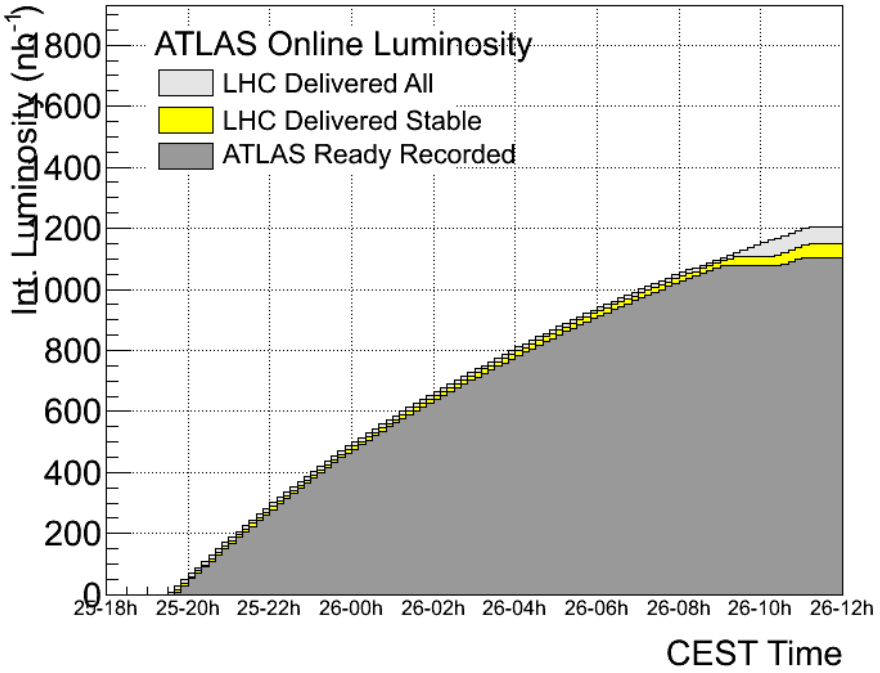


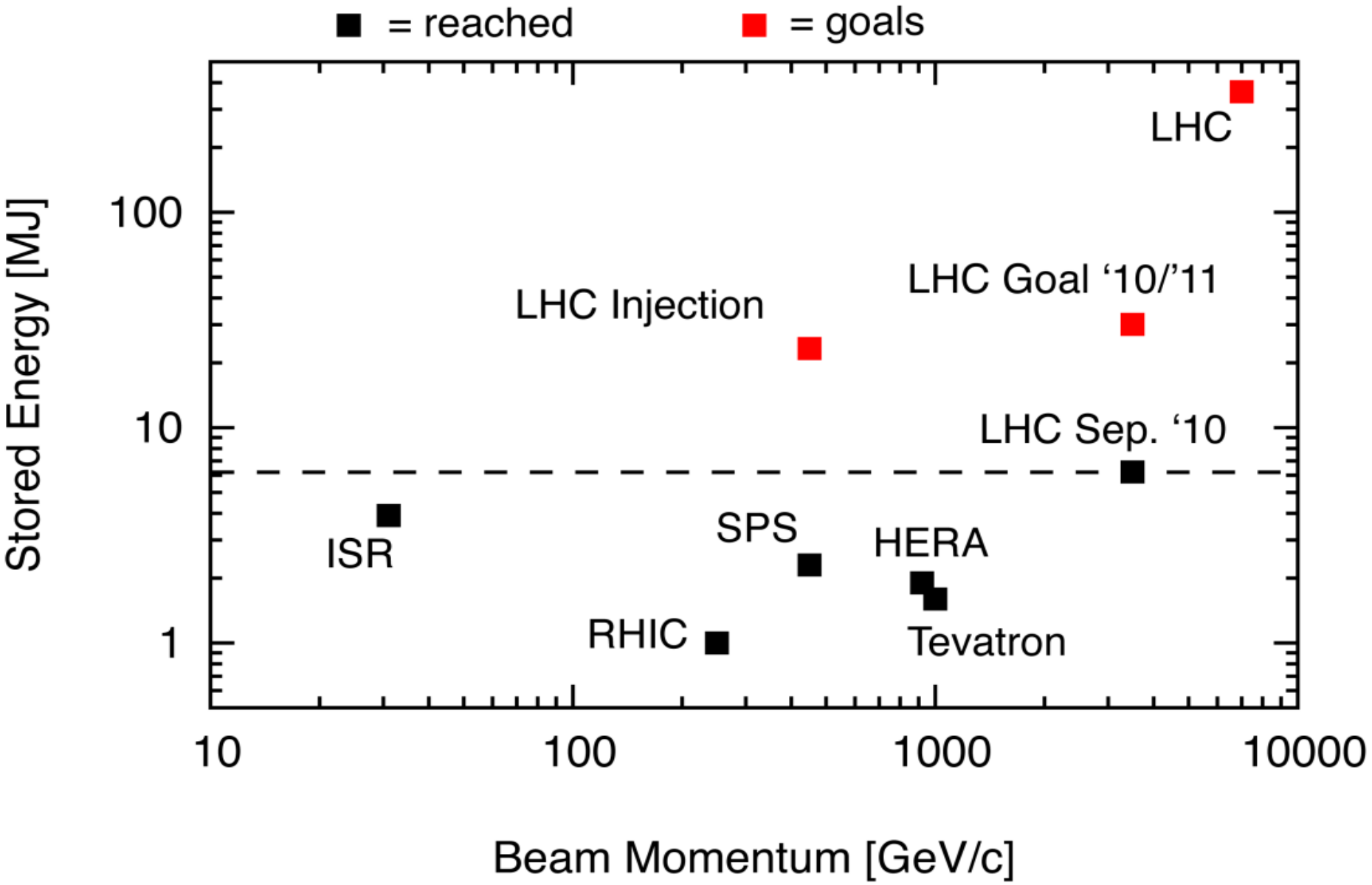



# September 25/26104 bunches per beam

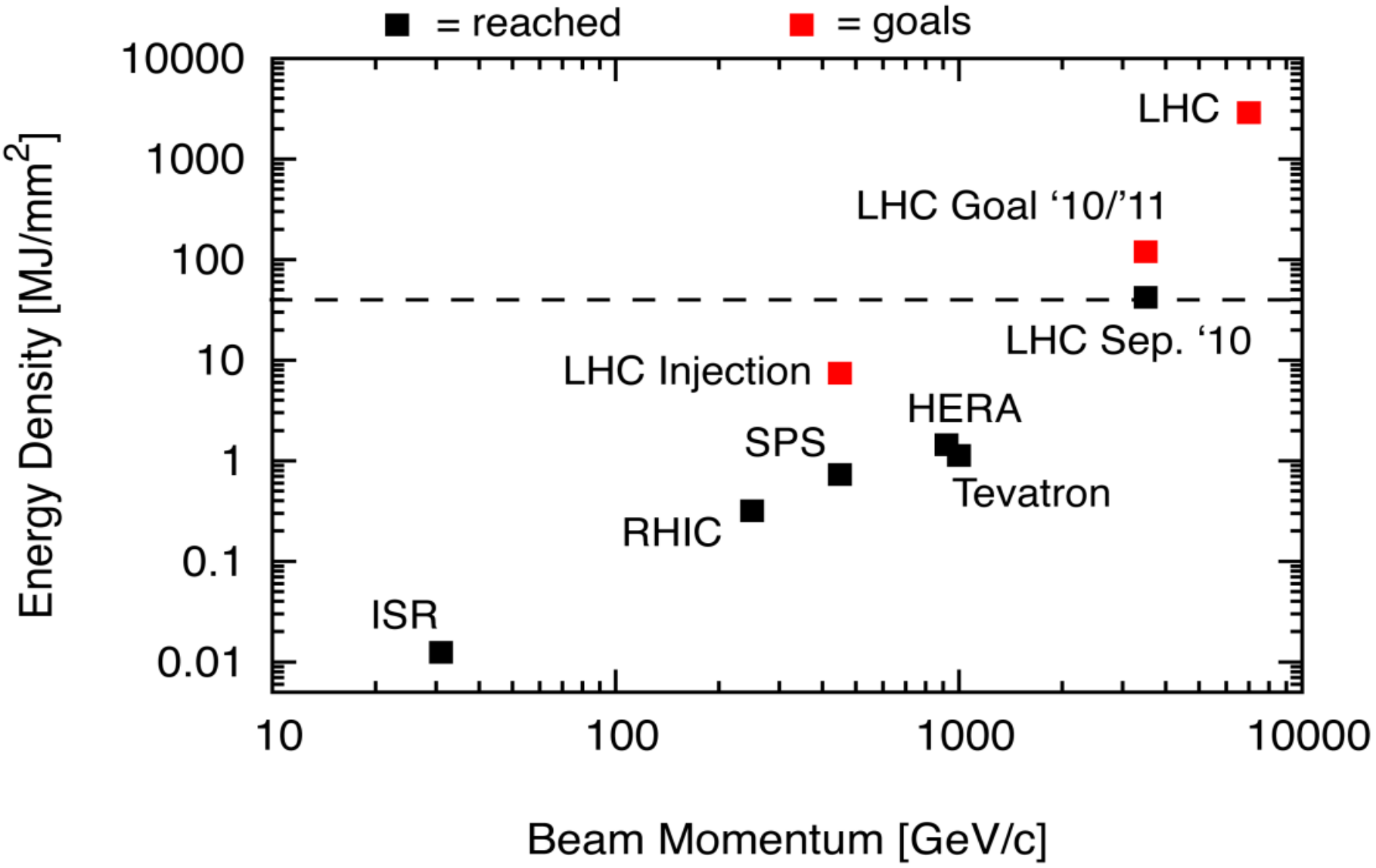
1pb-1 in a single fill
now done twice in the last 2 days



# Stored Beam Energy



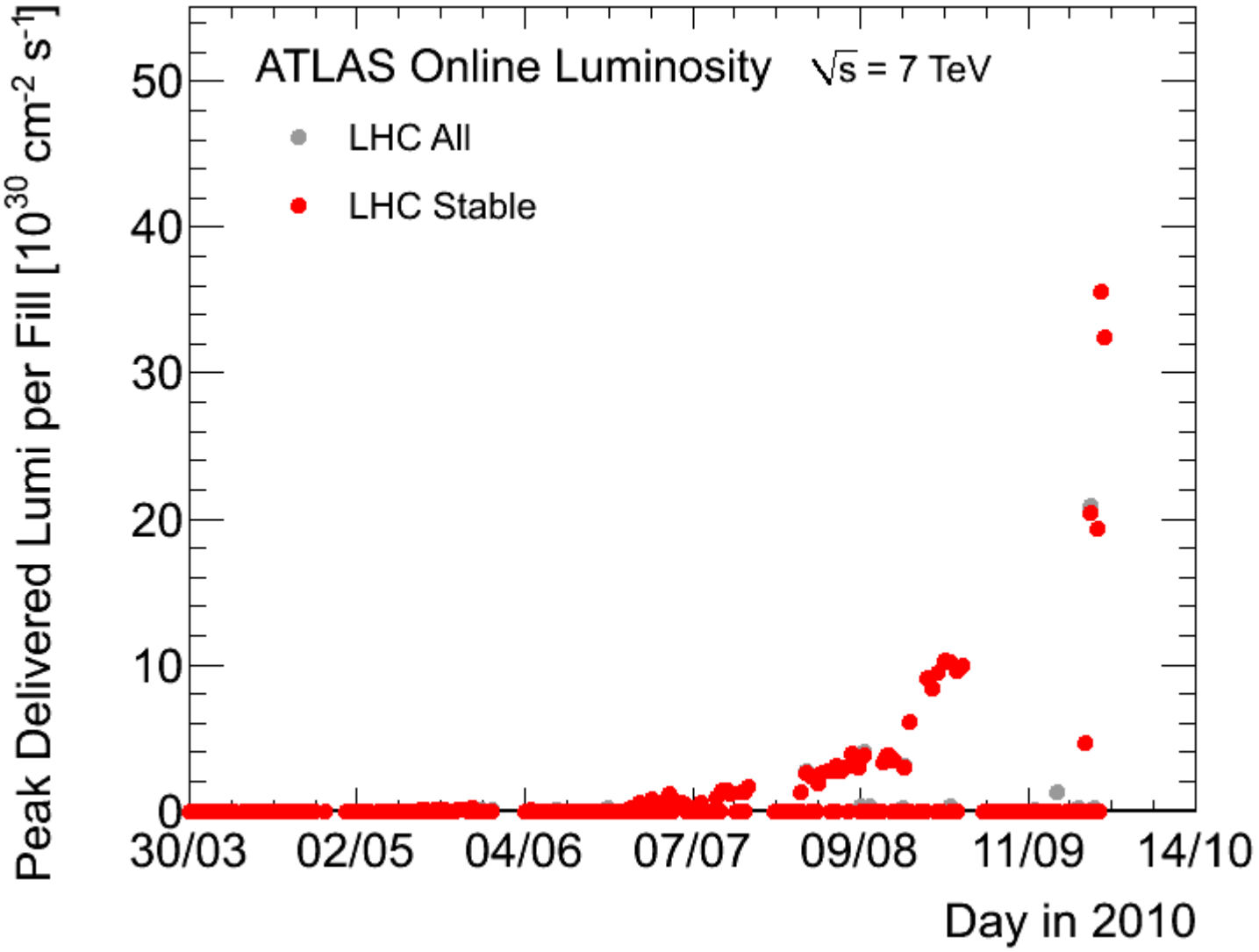
# Energy Density in Beams



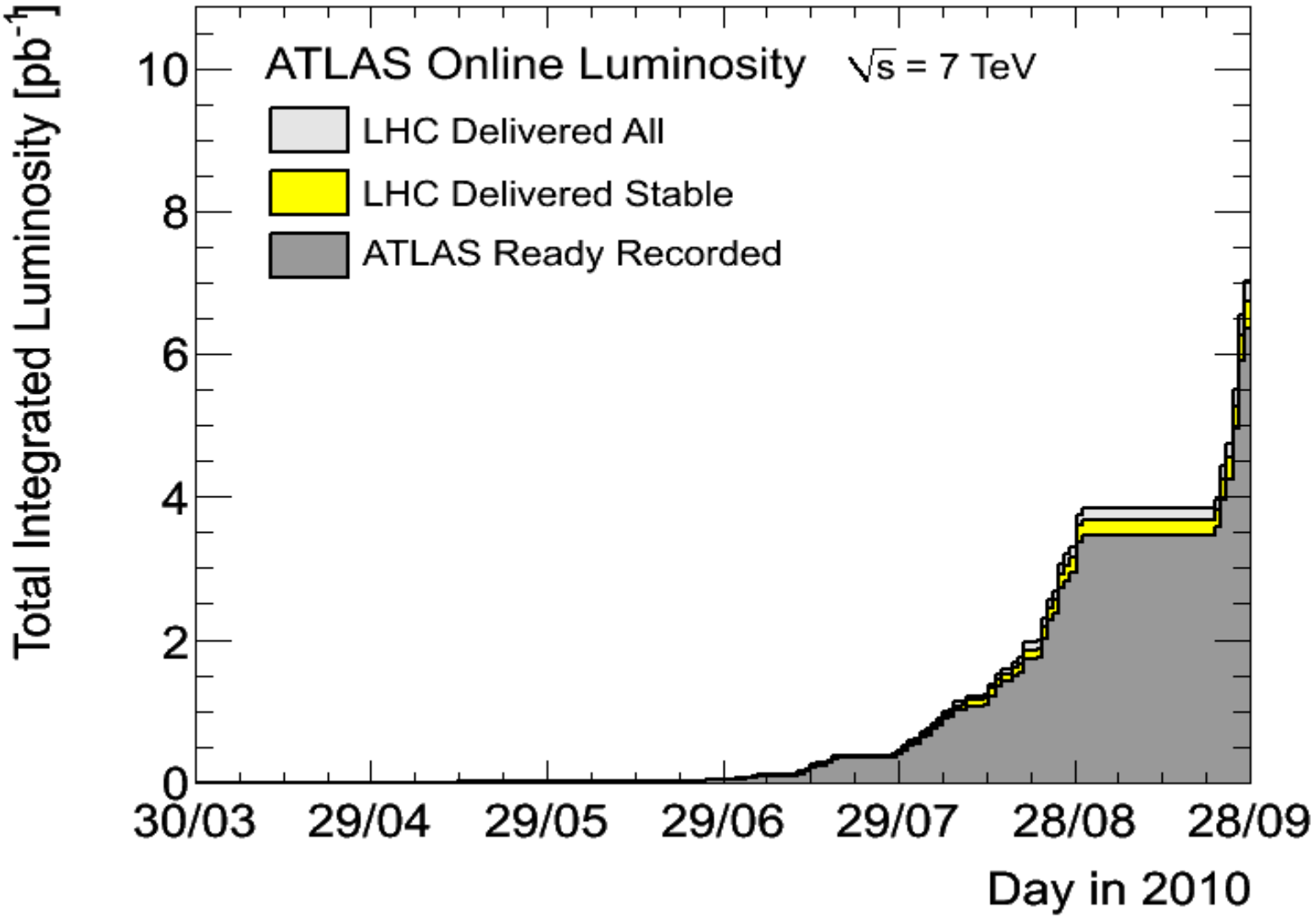
# PERFORMANCE AS OF THIS MORNING

Now operating with 104 bunches per beam

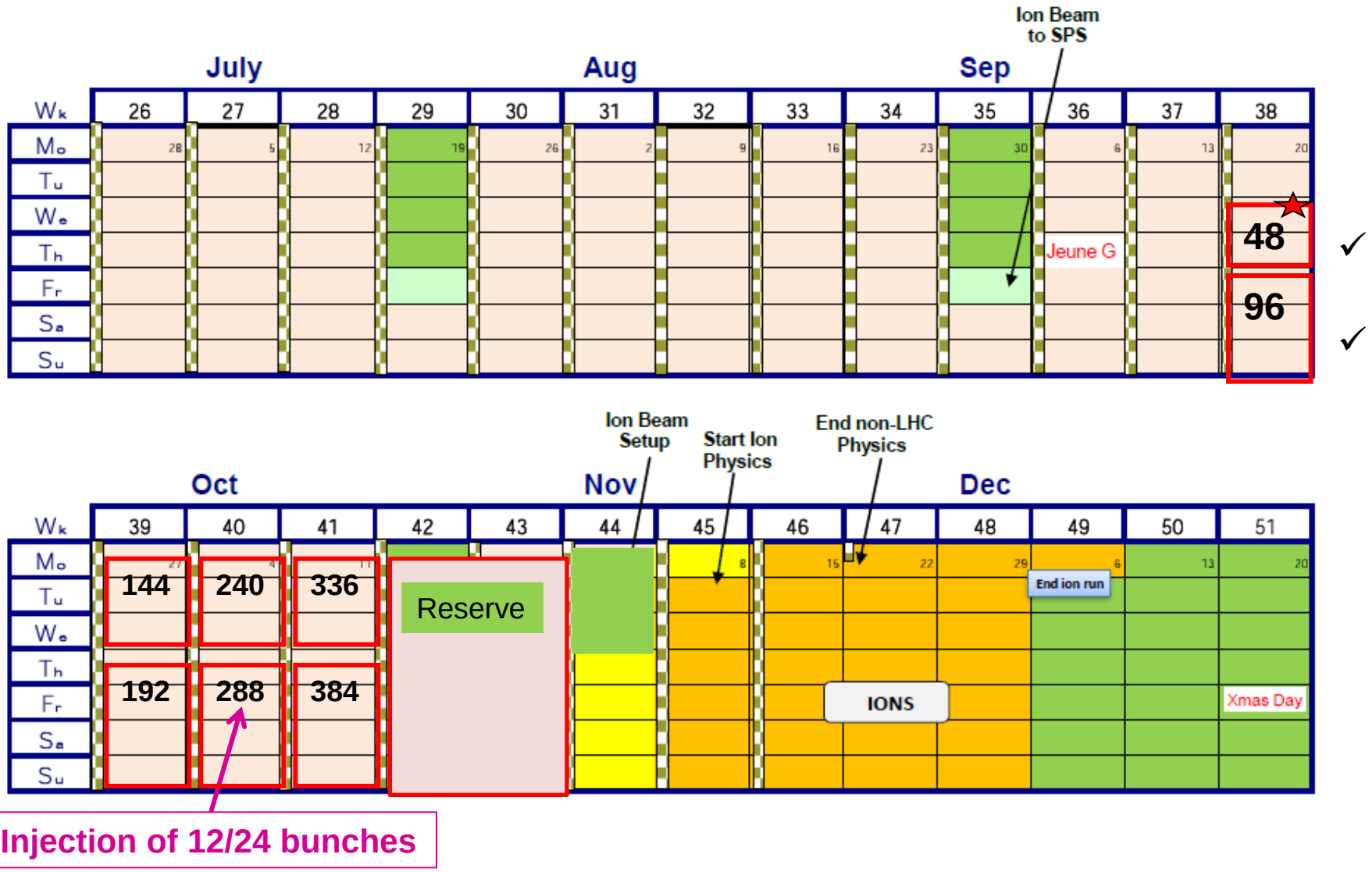
# Peak Luminosity Evolution



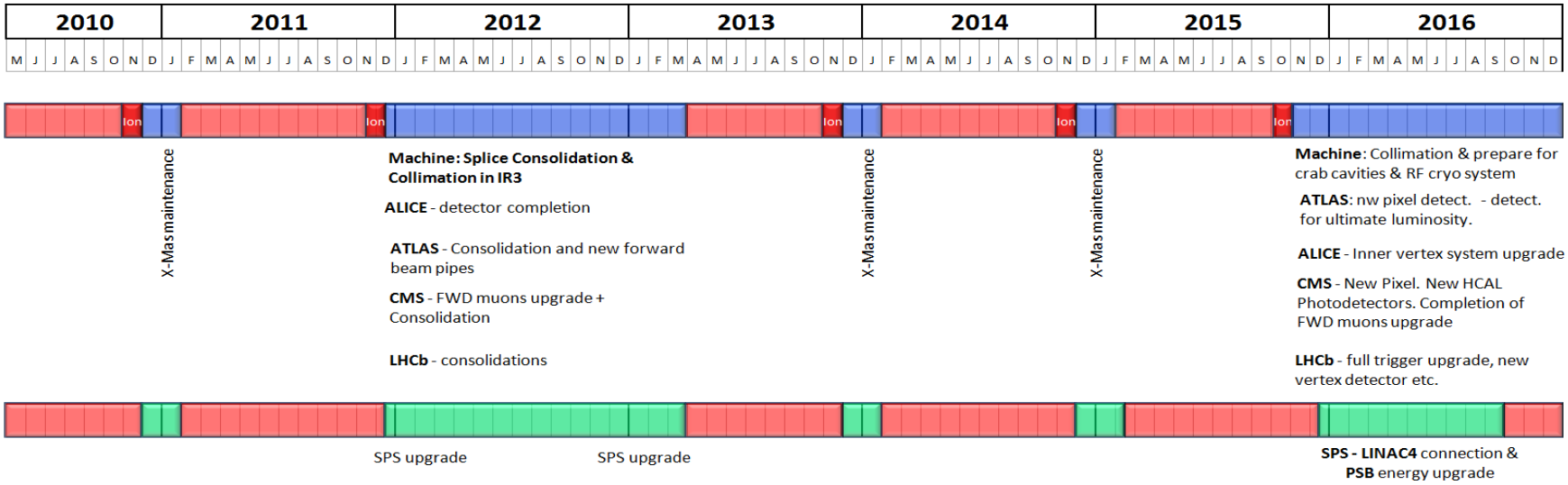
# Integrated 27/9 @08:15

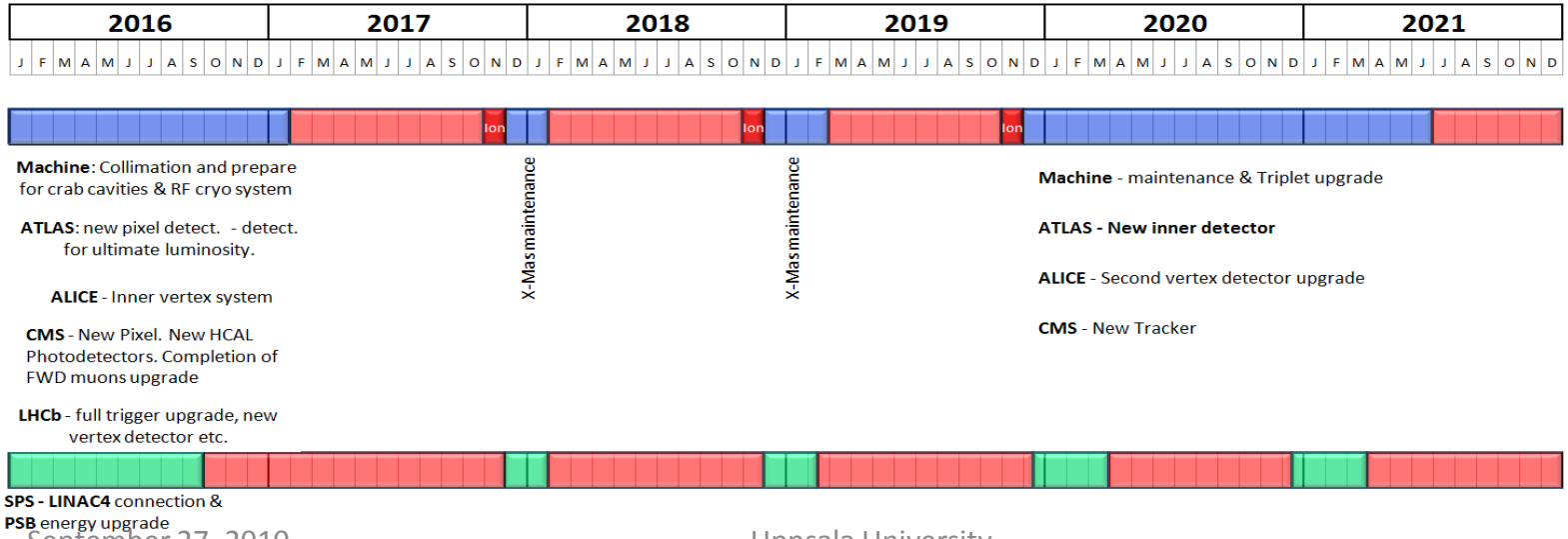


# Aggressive Schedule (short term)



# The 10 year technical Plan



# Acknowledgements

The superb progress and performance of the LHC machine and its injectors is due to the excellence, hard work and dedication of the CERN staff and our collaborators.

It is a great personal pleasure to acknowledge the success of this wonderful team.

# Thank You

# SPARES

# Preparations for $10^{32}$ ?

Which scenario is easier?

$\beta^* = 3.5$, Nb = 394, MJ =22.2

$\beta^* = 2.0$, Nb = 226, MJ = 12.8

Unanimous answer

$\beta^* = 3.5$, Nb = 394, MJ =22.2