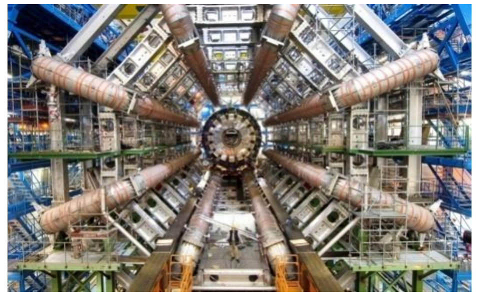
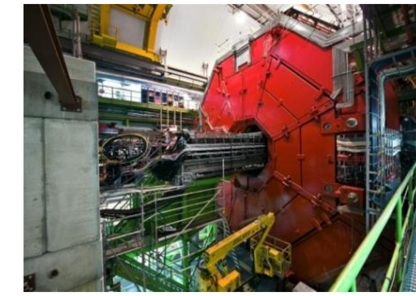



COMMISSIONING OF THE LHC WITH BEAM

V. Kain, LHC Operations

On behalf of the LHC Commissioning Team

V. Kain, HB2010, Morschach, 28th of September '10

Outline

LHC nominal parameters

Goals for current run

Commissioning strategy and steps achieved

Performance

Some puzzling effects

LHC Nominal Parameters

The LHC surpasses existing accelerators in two aspects

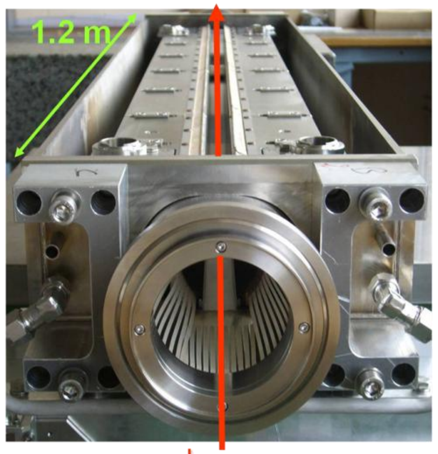
- 7 TeV beams in the former LEP tunnel
  - LHC dipole field 8.3 T

A factor **2** in field
A factor **4** in size above other accelerators

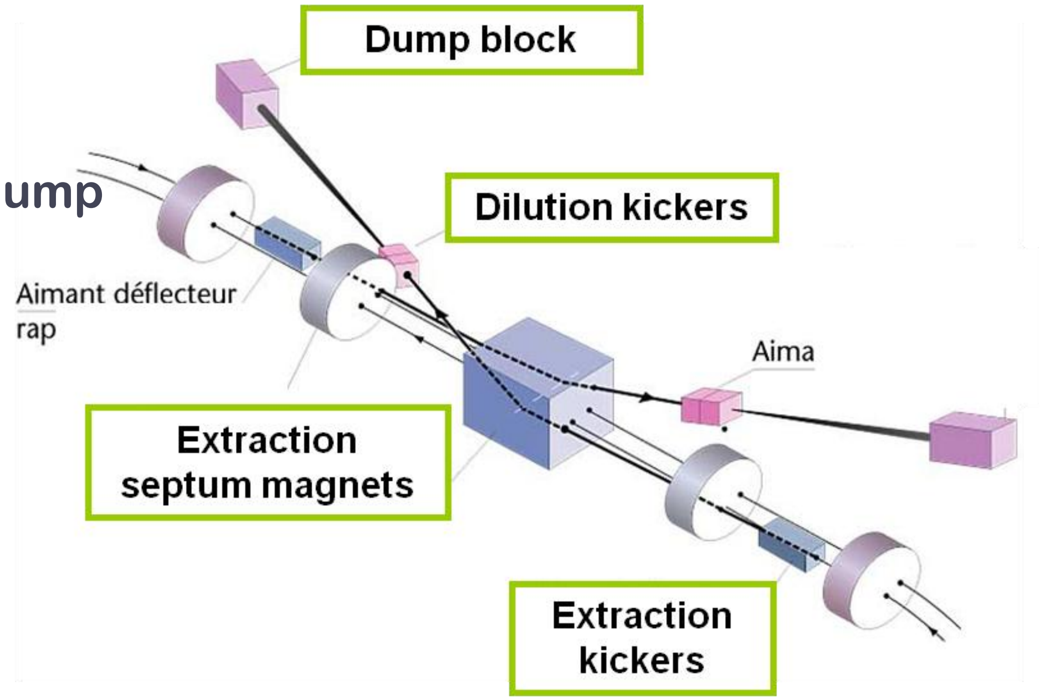
- Design luminosity: pp 10^{34} $cm^{-2}s^{-1}$
  - Intensity: 3×10^{14} p^+: stored energy 360 MJ
  - β^*: 0.55 m

A factor **30** in luminosity above other accelerators

- To cohabitate 360 MJ in superconducting environment:
  - ~ 100 collimators
  - 4000 Beam Loss Monitors
  - Absorbers at critical locations: injection and beam dump
  - 20'000 signals connected to beam abort system

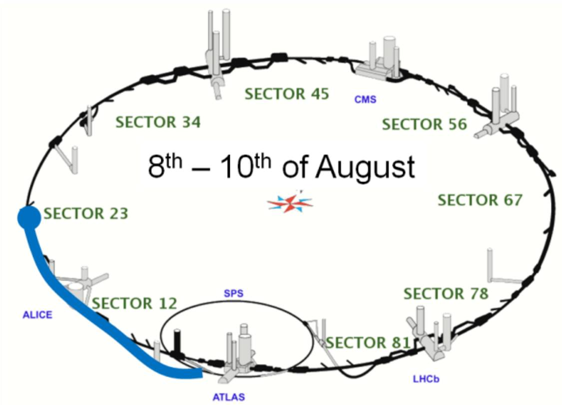


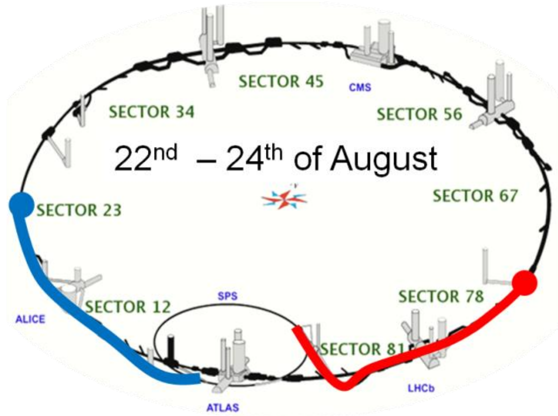
LHC collimator

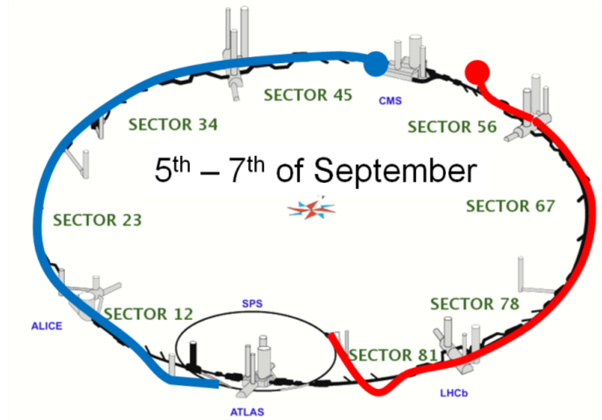


Commissioning in steps…

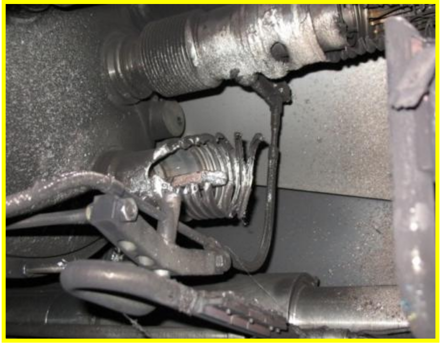
- 2008: injection tests, start-up and shutdown







LHC Start-up September 10, 2008



LHC shutdown September 19, 2008

- 2009: repair, re-start-up

20th Nov	Day 0	Both beams circulating after 6 hours
23rd Nov	Day 3	First pilot collisions at 450 GeV
29th Nov	Day 9	Beams ramped to 1.18 TeV
6th Dec	Day 16	Stable collisions @ 450 GeV for the experiments
8th Dec	Day 18	Both beams ramped to 1.18 TeV – first collisions

Our most optimistic plan had come true…

Goals for 2010-2011

2009			2010			2011		
Repair of Sector 34	1.18 TeV	nQPS 6kA	3.5 TeV $I_{safe} < I < 0.2\ I_{nom}$ β* ~ 3.5 m	Ions		3.5 TeV ~ $0.2\ I_{nom}$ β* ~ 3.5 m	Ions	
No Beam	B		Beam			Beam		

GOAL for 2010/11 running:

Collect 1 fmb^{-1} of data/experiment at 3.5 TeV/beam

- → Goal of LHC operation in 2011 **: $L \sim 10^{32}\ cm^{-2}s^{-1}$** ... Tevatron luminosity
  - ~ 700 bunches with 10^{11} protons/bunch: ~ 7 x 10^{13} protons\beam
  - Stored energy: **~ 30 MJ** (8 % of nominal)
- → Strict, clean and reproducible machine setup
- → Machine protection systems at near nominal performance

Commissioning phases

- Phase 1: low intensity commissioning of the LHC
  - Low intensity single bunches. Very limited risk of damage
  - Machine protection commissioning
- Phase 2: operation without crossing angle
  - Bunches with large spacing (> 1 – 2.5 μs)
  - Up to around kb = 50 bunches per ring
  - Machine protection running in

⇨ **Until end of August 2010**

- Phase 3: operation with crossing angle
  - Bunches with close spacing (< 150 ns)
  - Aim for ~ 400 bunches 2010

⇨ **Machine protection tests have finished**

Currently running with 104 x 104 bunches

Commissioning phases

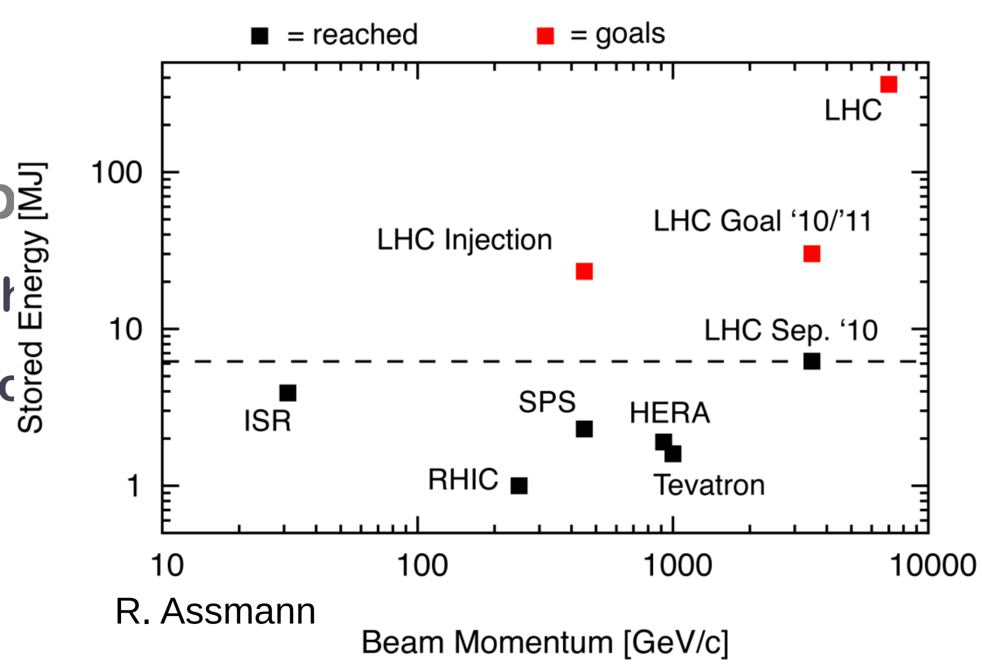
LHC

- Phase 1: low intensity commissioning of the LHC
  - Low intensity single bunches. Very limited risk of damage
  - Machine protection commissioning

- Phase 2: operation without crossing angle
  - Bunches with large spacing (> 1 – 2.5 μs)
  - Up to around kb = 50 bunches per ring
  - Machine protection running in

⇨ **Until end of August 2010**

- Phase 3: op
  - Bunch
  - Aim fo



R. Assmann

⇨ **Machine protection tests have finished**

Currently running with 104 x 104 bunches

LHC Commissioning Philosophy

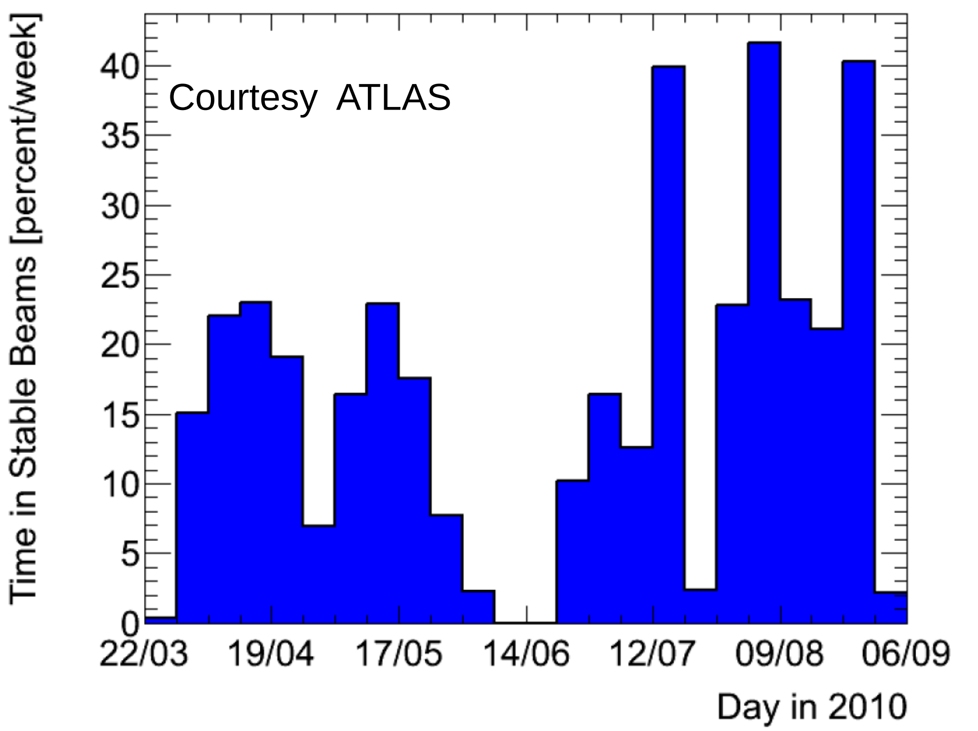
- Start operation with very LOW intensity
  - 100'000th of the nominal intensity
- Machine protection "light"
  - Machine protection is NEVER disabled, but flexibility is built into the system: MASKING with low intensity
- Before each change of configuration/intensity:
  - Measure and correct parameters with low intensity; establish references
    - Orbit, beta beating, aperture
  - Set up protection devices
    - Collimators, absorbers, interlocked BPMs,...
  - Qualify protection system
    - Loss maps: collimation hierarchy
    - Asynchronous dumps
  - Increase intensity
  - Gain experience: 3 fills with about 20 h in physics in total
- Continuous monitoring:
  - Post mortem analysis
  - Automatic post operational checks of beam dump and injection

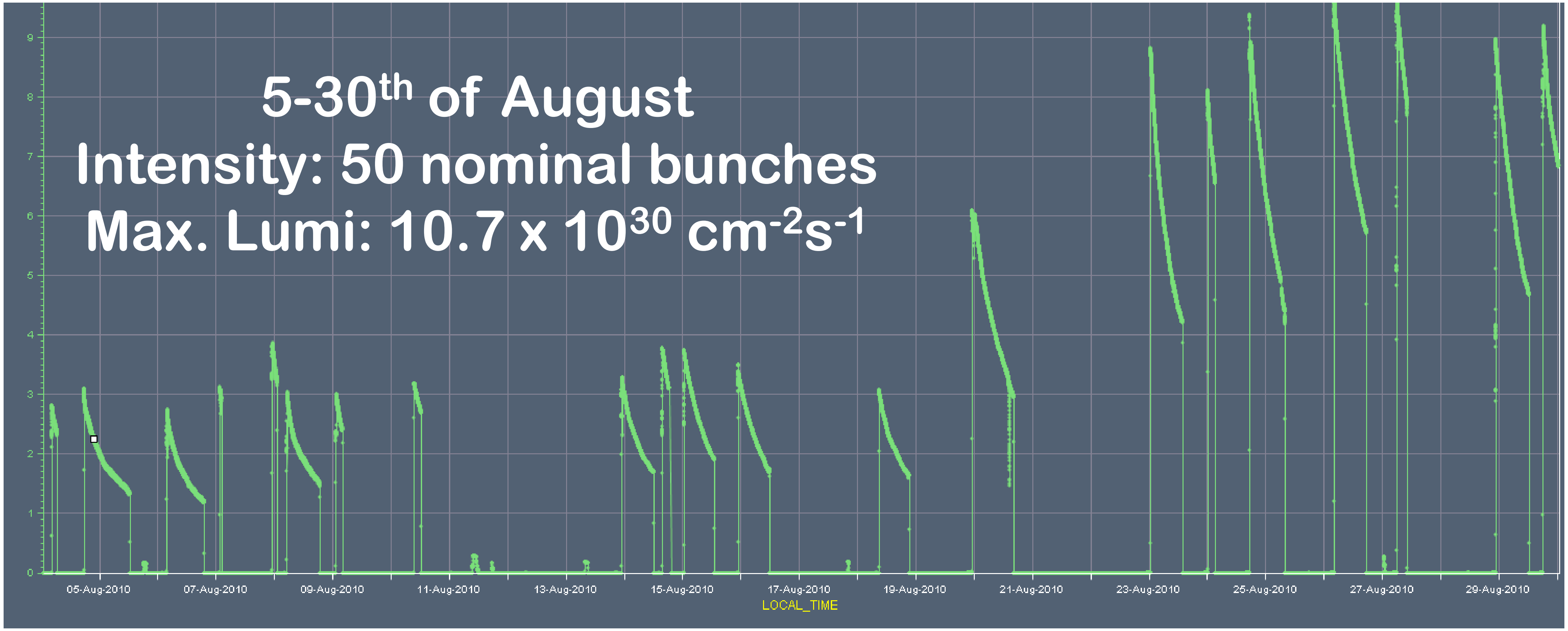
Commissioning steps 2010

- **Restart** with beam — **28th of Feb**
- Commissioning to **3.5 TeV** — March
  - Low intensity beams
- **First collisions at 3.5 TeV** — **30th of March**
- **Squeeze** commissioning — Mid April
  - Squeeze from β^* = 10/11 m to 2 m
- Increase number of bunches to 13 per beam — Mid April – Mid May
  - Bunch population N = 3 x10^{10} (30 % of nominal)
- Switch to **nominal bunch intensity** (10^{11}/bunch) — **June**
  - Single bunch instabilities: octupoles on, longitudinal blow-up, transverse damper
  - Luminosity gain factor ~ 10
  - Go to 3.5 m β^*: lose factor 3.5
- **Increase number of bunches up to 50** per beam — **July – August**
  - Bunch population ~ 9 x 10^{10}
  - Luminosity of 10^{31} $cm^{-2}s^{-1}$
- Commissioning of **crossing angle** and 10 A/s ramp — **September**
  - Switch to injection of bunch trains (spacing 150 ns)

Performance

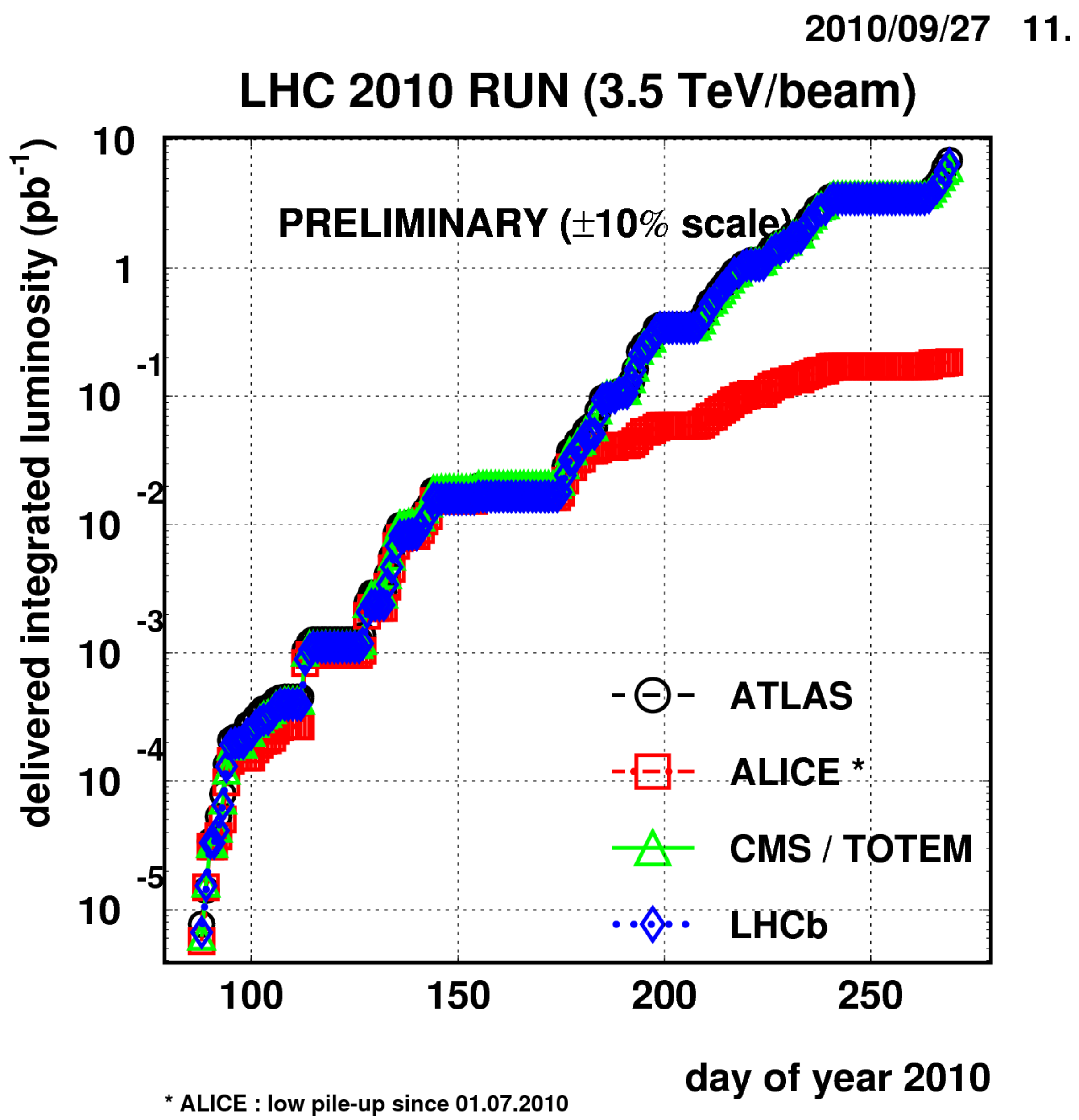
- A lot of commissioning still ongoing, but excellent performance of **ALL equipment**
  - ~ 40 % of time in physics → 10^6 collisions per month
  - Minimum turn around time ~ 4 h
- Another 5 weeks to go with protons: goal ~ 400 bunches by November.

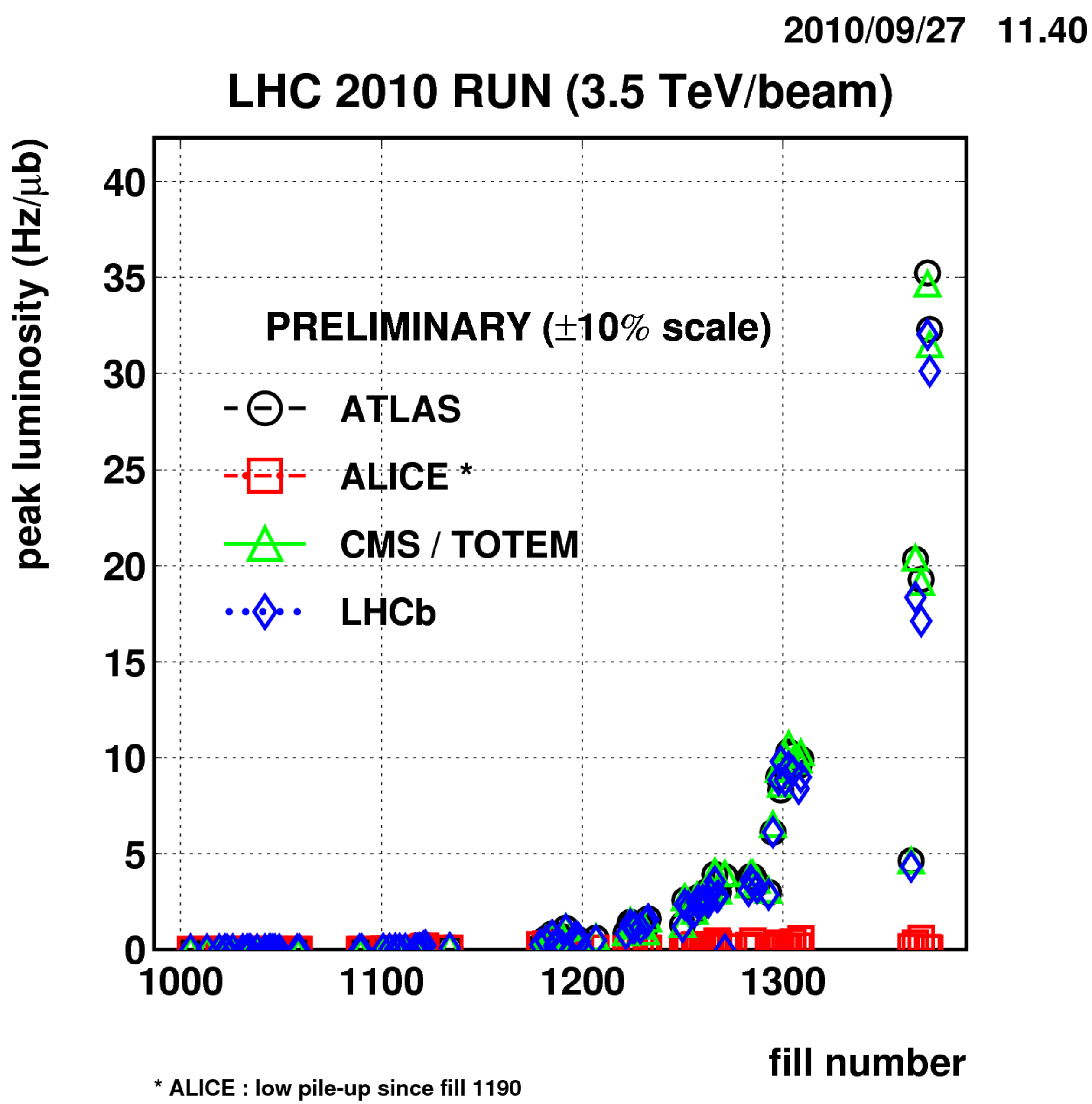




Performance

- Integrated luminosity until yesterday morning:
  - 7 pb^{-1}
- Maximum availability per week:
  - 85 %





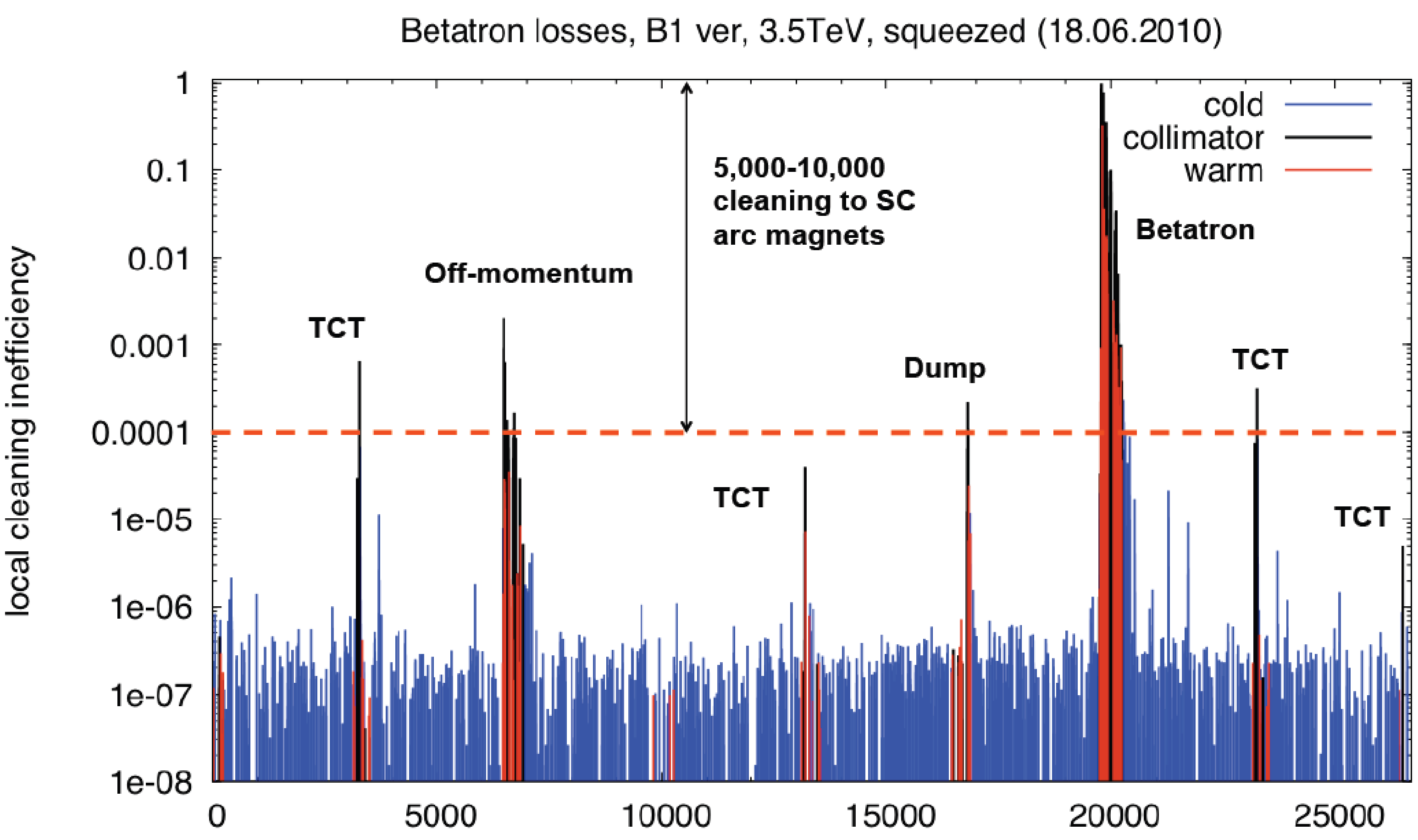
Protection System Performance

- Only about **14 %** of the beams above injection energy are dumped by the operations crew.

- Quenches: a local loss of ~ 10^7 p/s at 3.5 TeV can lead to quench
  - **So far, no quenches at 3.5 TeV**
    - → **excellent performance of collimation system**
    - → **fast reaction of Beam Loss Monitor System**

- Hierarchy of collimators must be preserved at all phases for cleaning and protection

- Beam cleaning efficiencies **≥ 99.98 %** : ~ as expected.

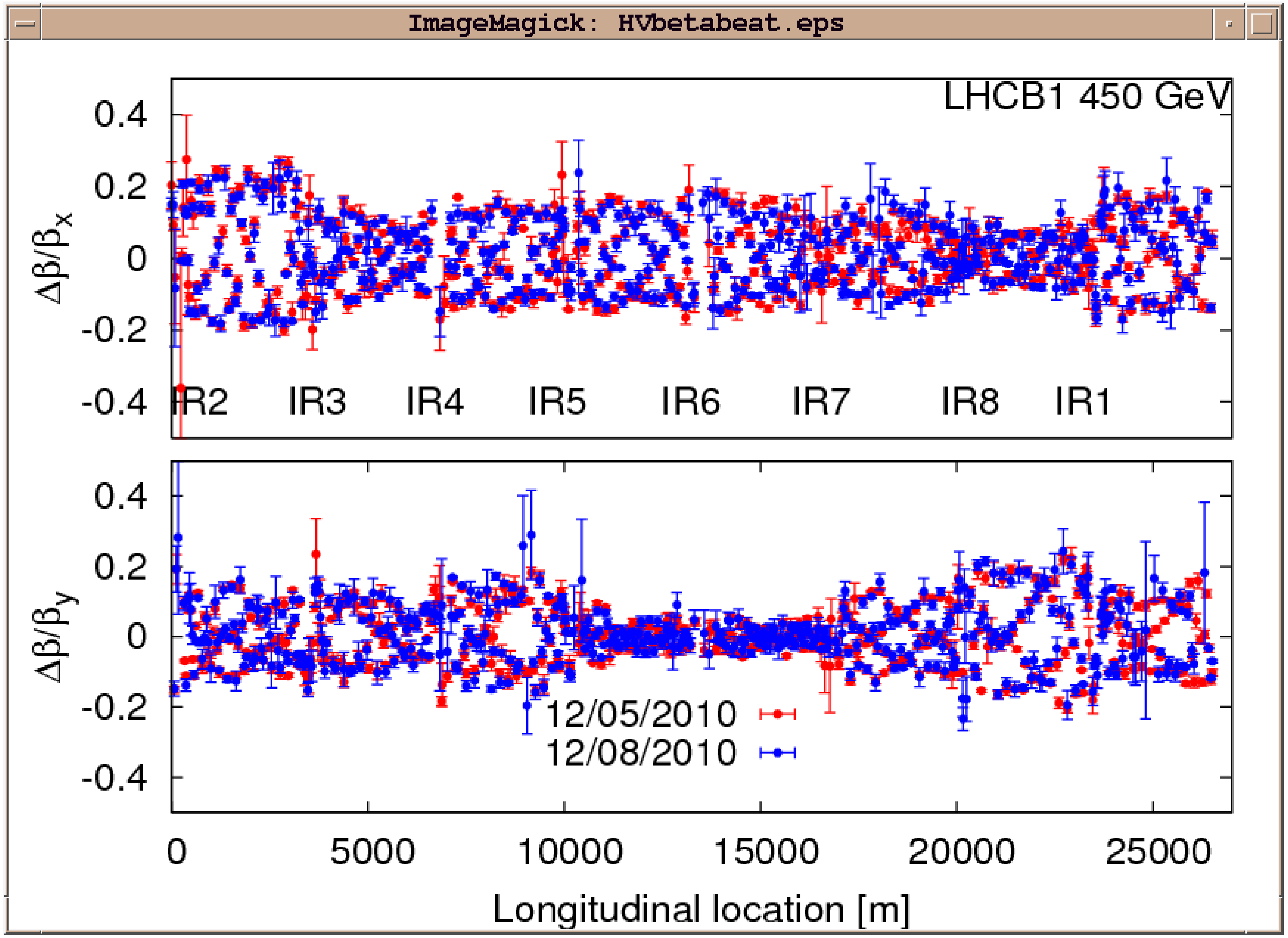


R. Assmann et al.

Beam optics

- Beta and dispersion beating within tolerances throughout all phases

- ...and **extremely reproducible**



R. Tomas Garcia et al.

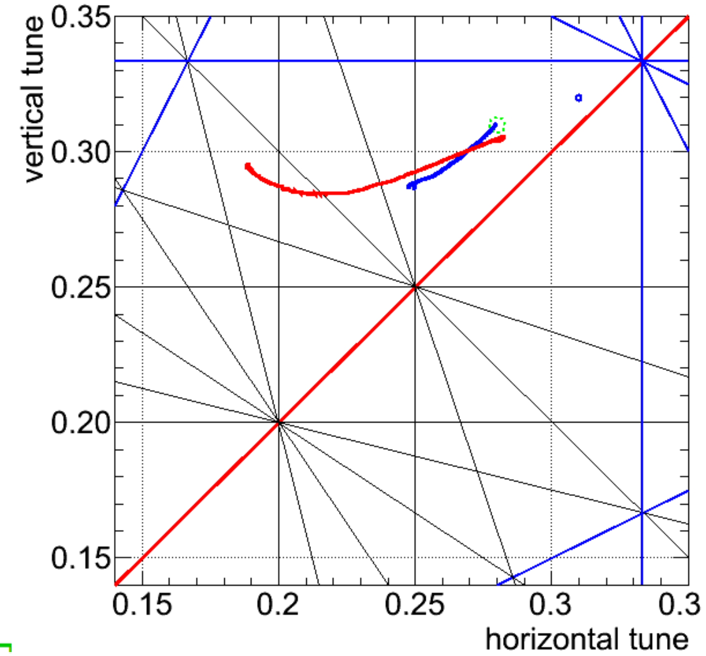
Reproducible optics is essential for increasing intensity, particularly for collimators.

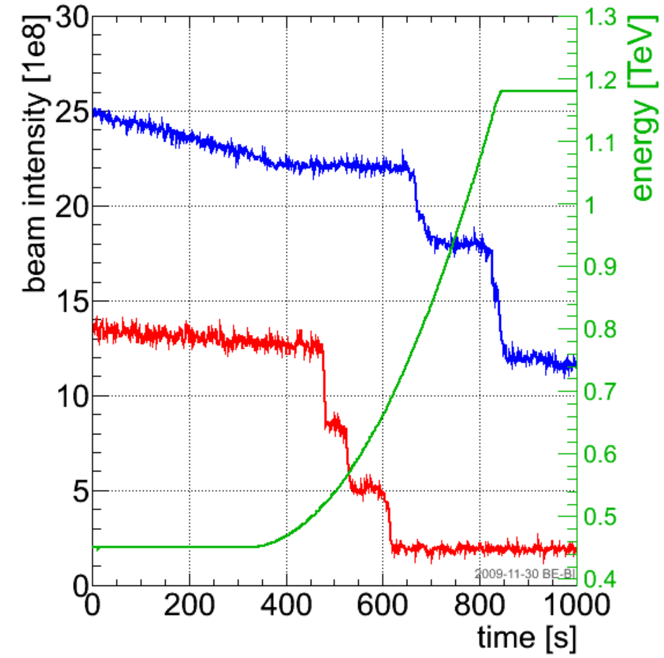
Beta beating measured with AC dipole in tolerance of 20 %.

Feedbacks

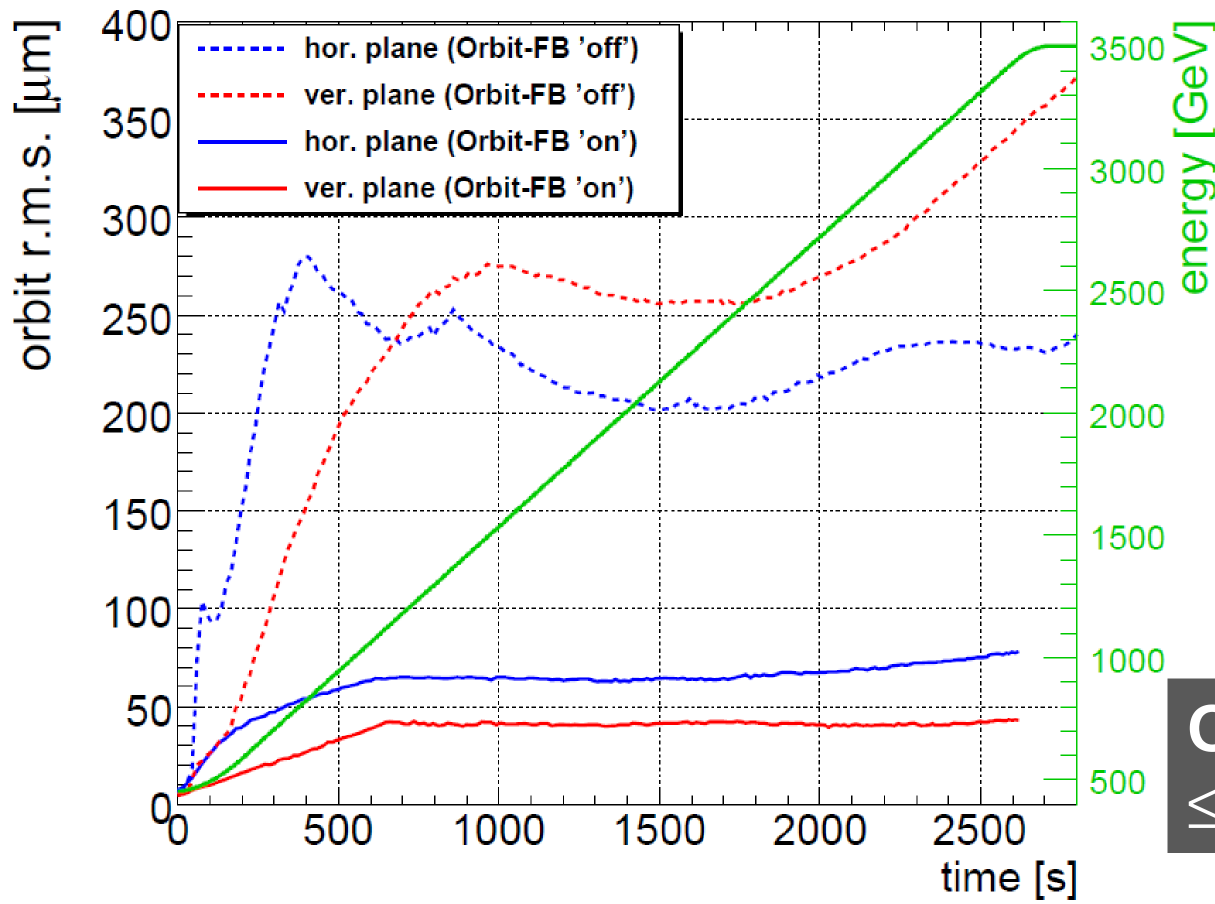
- Excellent performance of LHC also due to **feedbacks**
- Tune feedback, orbit feedback, transverse damper and radial loop

One of our first ramps: Losses due to resonance crossing →





R. Steinhagen



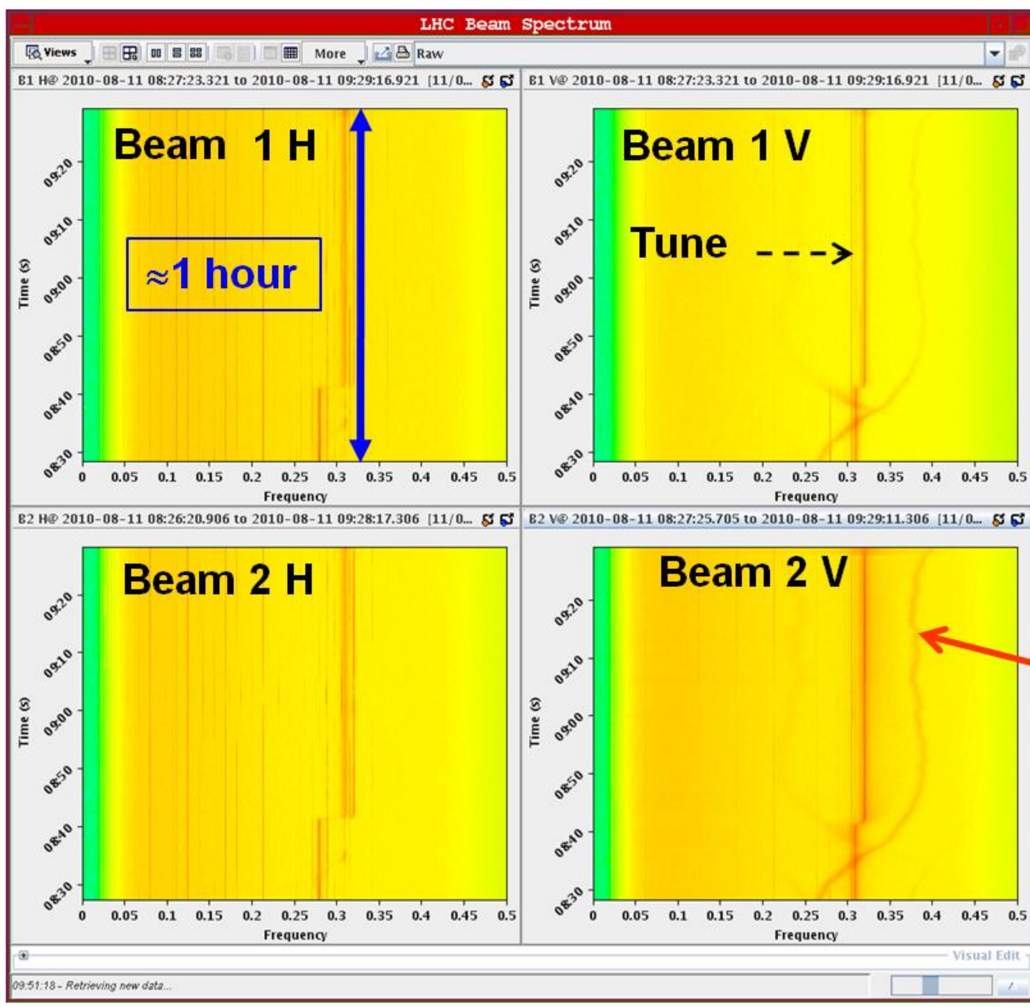
Running with:
tune feedback since ~ 3rd ramp trial
orbit feedback since May
transverse damper since June

Orbit stability during ramp: ≤ 80 μm with feedbacks

Emittances

- Good news for luminosity: injecting regularly nominal bunches with emittances below nominal (about 2 μm).
  - Nominal emittance 3.5 μm.

- However, emittance blow-up due to “hump” especially in B2V



Noise hump

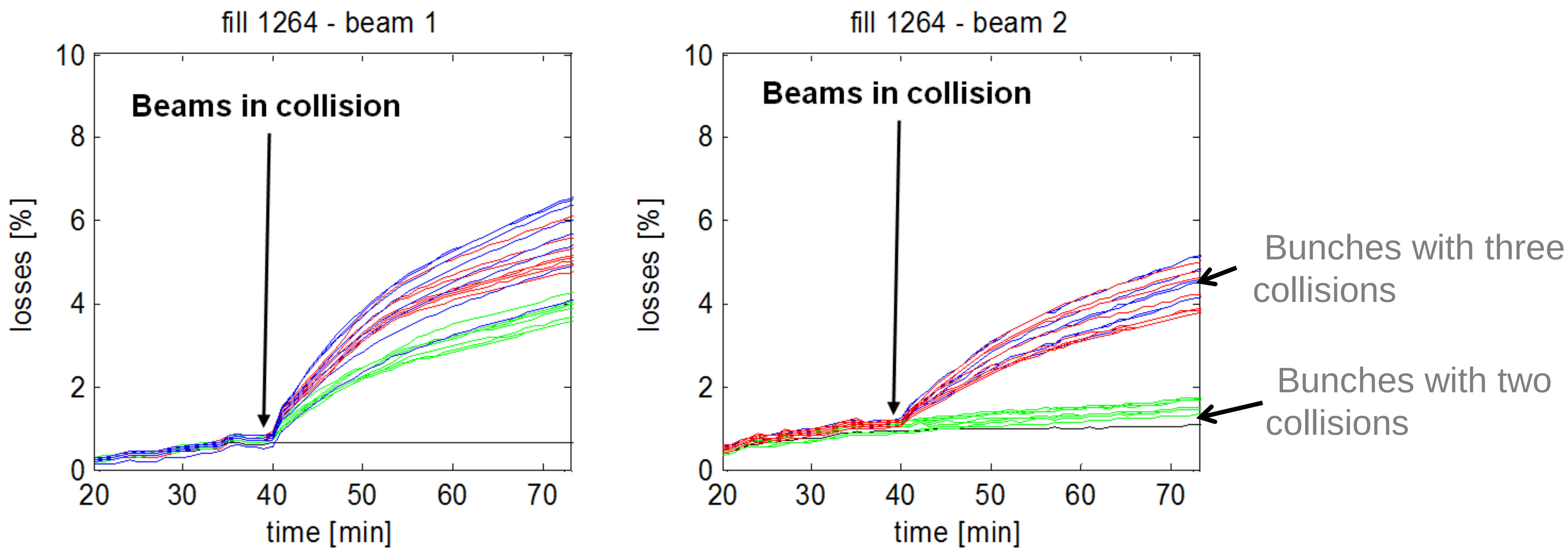
The beams are periodically excited by <u>UNKOWN</u> source (‘hump’) of varying frequency – affects mostly beam 2 V

Leads to emittance blow up

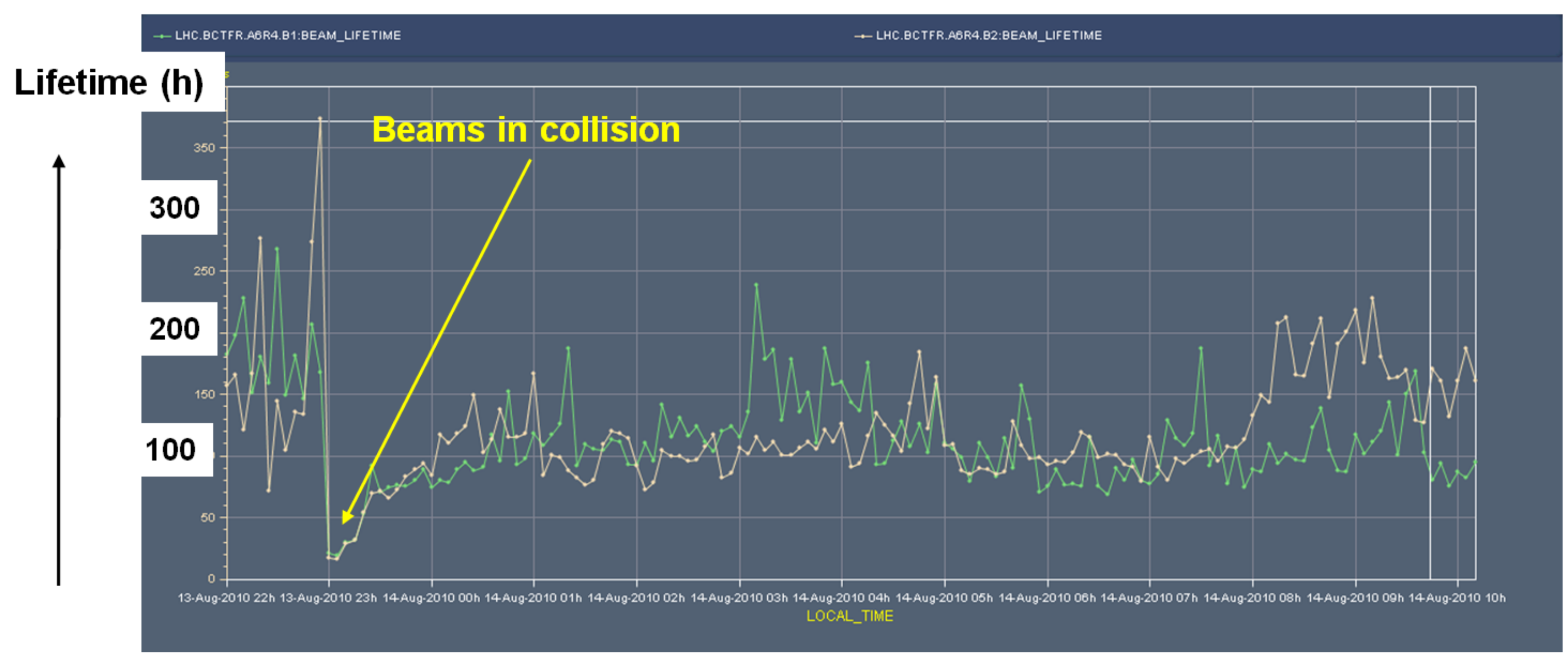
After tests: excluded sources:
Experimental magnets, transfer lines, LHC correctors, damper, AC dipole, RF cavities, injection kickers, GSM or fire brigade radio network, triplet beam screen cooling

Beam-beam

- Losses per bunch different for different bunches – as expected. Still studies needed to understand differences in detail.

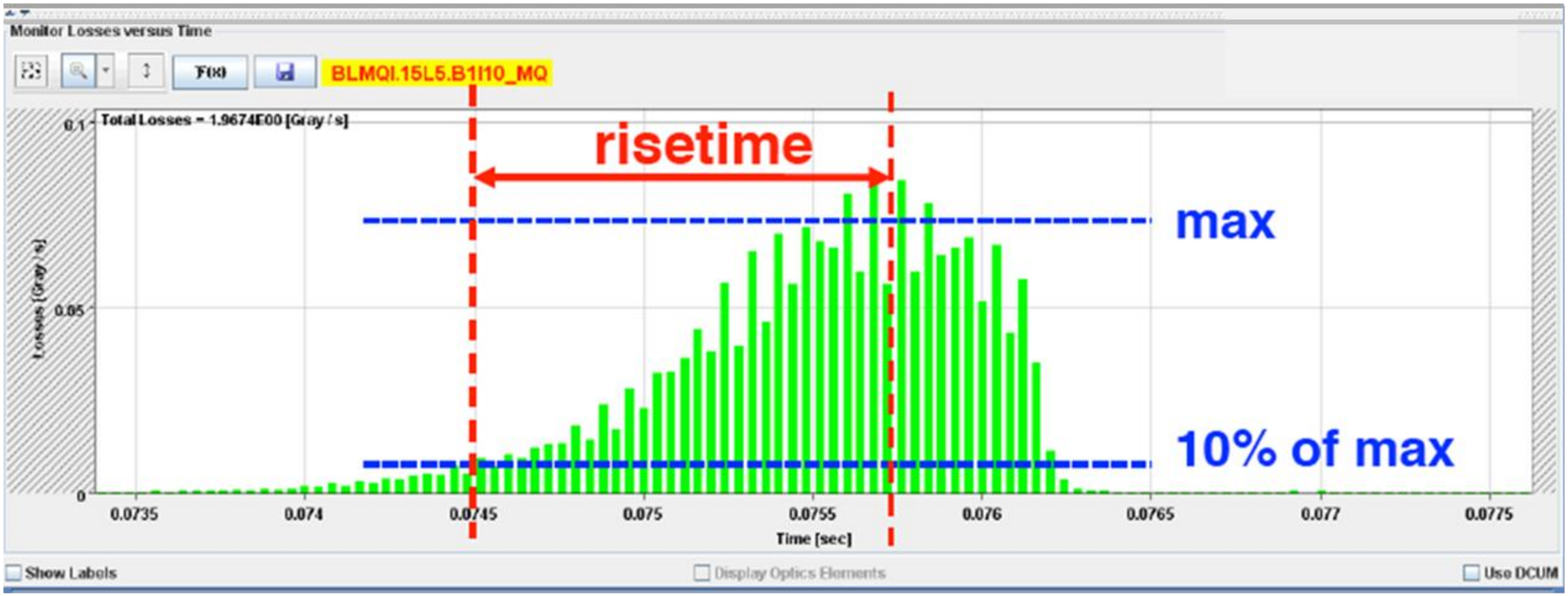


- Since July **transverse damper on during collisions**: stabilising coherent beam-beam instabilities
- ~ 20- 30 h luminosity lifetime due to emittance growth



Sudden local losses

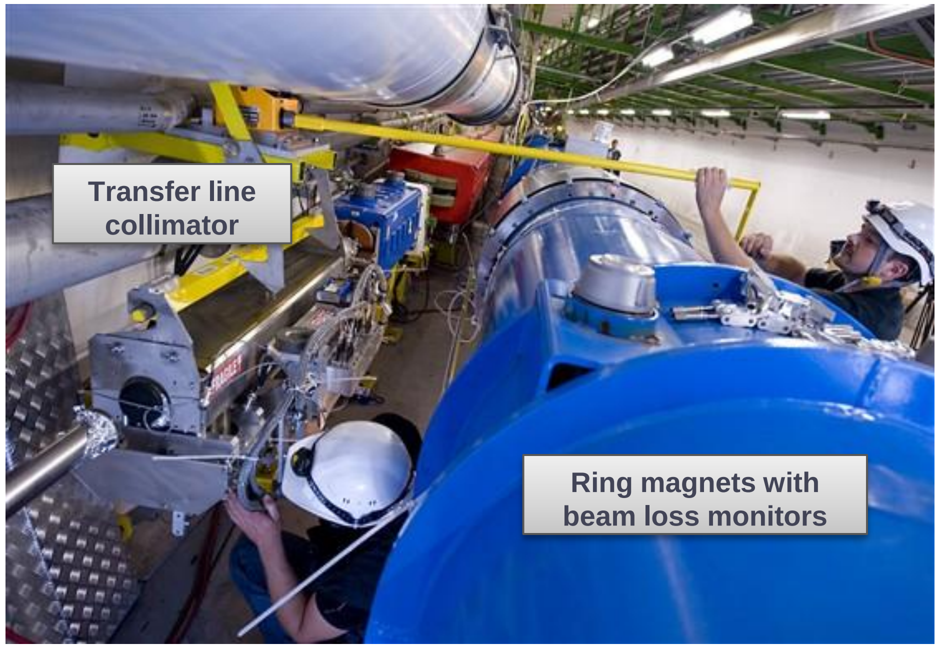
- **8 events** of sudden local losses (some in the middle of the arc) have been recorded. No quench, but preventive dumps
- Rise time partly < 1 ms.
- Potential explanation: dust particles falling into beam creating scatter losses and showers propagating downstream

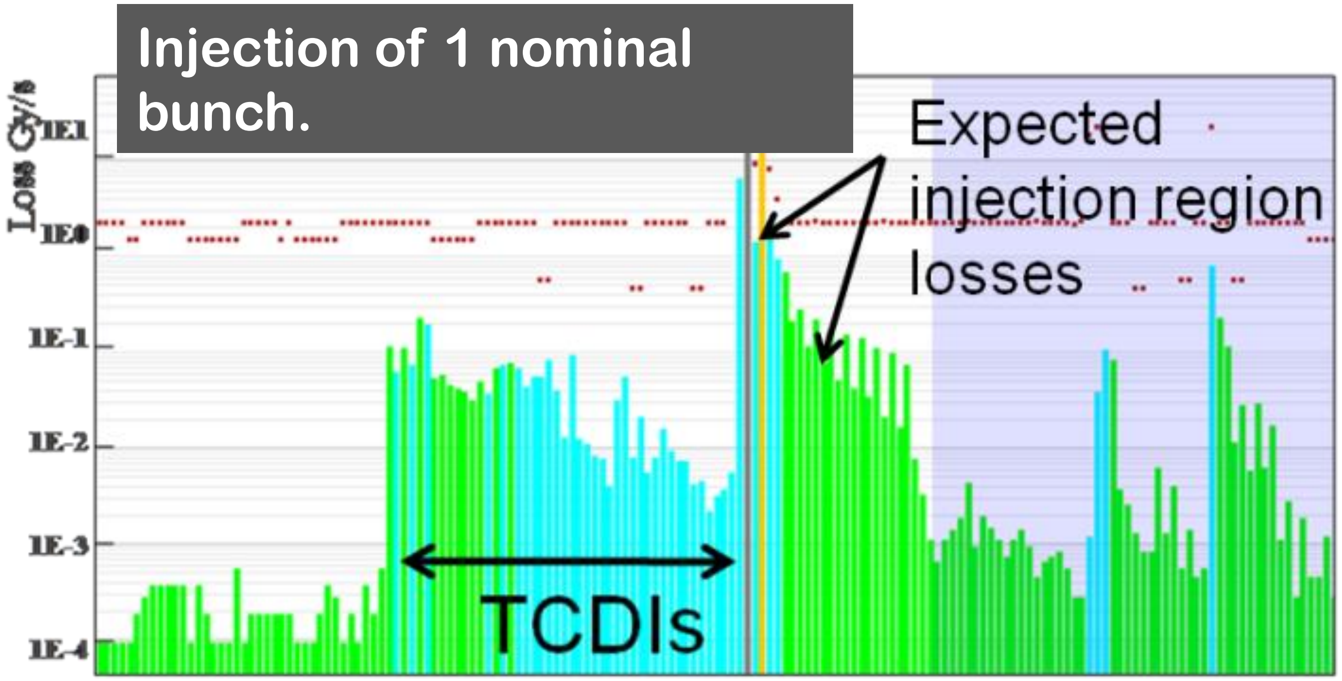


V. Kain, HB2010, Morschach, 28th of September '10

Next Big Step – "unsafe" injections

- Injections above "setup beam intensity" from this week (16 bunches per injection)
- Injection protection system commissioned
- Have to control transverse and longitudinal parameters from injectors extremely well not to lose beam immediately due to losses on transfer line collimators (TCDI)





Summary

- The LHC is being commissioned in steps of energy and intensity

- Machine protection is taken seriously. Qualification tests have to be performed before each change of configuration.

- Despite the machine complexity and immaturity, still manage 40 % of time in physics.

- Higher intensities might bring new challenges
  - Single event upsets, more frequent “sudden local losses”,…

- Due to an excellent performance of ALL equipment the ambitious goal of the 2010/2011 run seems to be doable
  - 30 MJ beams
  - Luminosity 10^{32} $cm^{-2}s^{-1}$

Luminosity steps