LHC Status Report

(progress since 17th February 2010)

Steve Myers

(on behalf of the LHC team)

CERN LHCC 5th May 2010.

Topics

- LHC Status
  - Technical stop and Hardware Commissioning
  - **Beam Commissioning and Operation March→ now**
- Strategy for Performance Evolution 2010-2011

Technical Stop

- nQPS connectors completed as schedule
- CMS repair of water cooling finished on time
- BUT! A few scares
  - CMS vacuum chamber
  - PS Motor generator set
- Hardware Commissioning finished a few days late.
  - 2 sectors late (S78 and S81): oil leak on a transformer:
  - 50 magnet quench (perverse set of conditions for nQPS)
  - 11 magnet quench

Hardware Commissioning

- New QPS fully deployed and tested
  - Massive job, limited resources, very tight schedule
- All magnet circuits qualified for 3.5 TeV
  - Main bends and quads to 6000 A
- Outstanding problem – discovered in final stages of HWC
  - Multiple induced quenches during power off - related to power converter switch off at same time as a fast discharge
  - **new QPS** – problem solved by a change of thresholds
  - **old QPS** – problem still there
    - Solution involves delaying one of the transients – requires modification of cards in tunnel
    - Solution will be fully tested and deployed after initial beam operation
  - Temporary fix: di/dt of MB limited to 2 A/s (normally 10A/s)
    - This fix has been used for all beam operation so far

Last LHCC was on 17 February

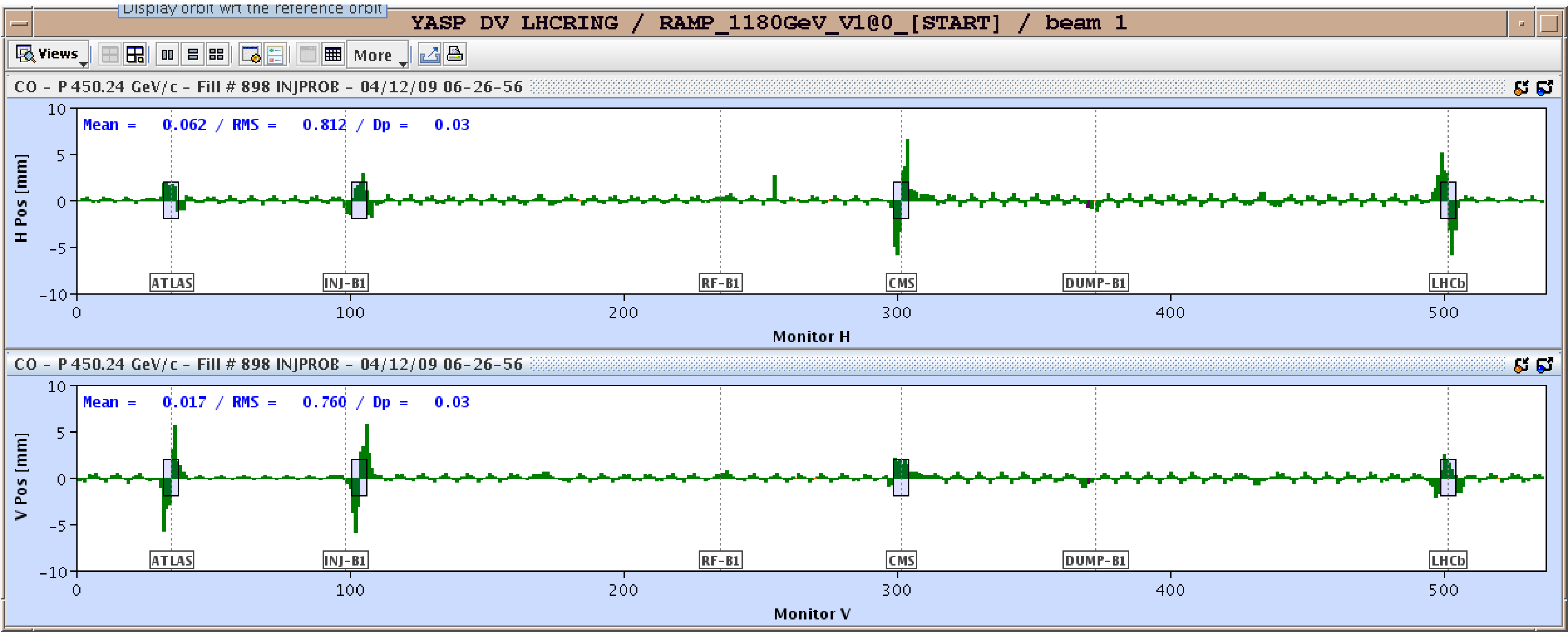
12th March	Ramp to 1.18 TeV
15th - 18th March	Technical stop – bends good for 6 kA
19th March	Ramp to 3.5 TeV
26th March	Set-up for 3.5 TeV collision under 'stable' beam conditions in progress

Overall Progress with Beam

- Successful ramps with beam to 1.18 TeV.
- Injection and capture of both beams & beam dump set up for safe beam.
- Machine tunes adjusted and controlled to nominal values routinely.
- Chromaticity measured and adjusted. Optics verified and corrected.
- Closed orbit adjusted to an **rms of ~0.45 mm** (about +-2 mm peak to peak) ➔ factor 2 better than design orbit.
- Dispersion measured and verified (in vertical plane: **3 cm rms**).
- Spectrometer and compensators set up and corrected with beam.
- Nominal separation bumps set up and included to corrected closed orbit.
- Golden reference orbit defined for collimation and machine protection.
- Collimation system (all ring collimators) set up. Efficiency: **> 99.9%**.
- Beam feedback commissioning partially completed, still ongoing.
- Luminosity separation knobs tested.
- Grazing events to ATLAS and CMS. Splash events to all experiments.

First Collisions at 7TeV cm
March 30, 2010

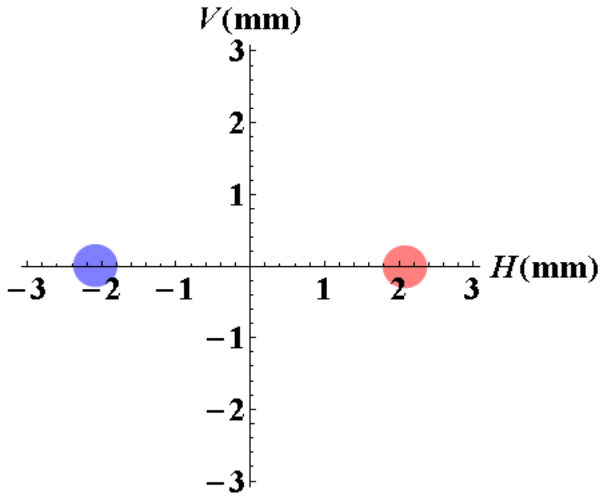
Separation bumps



March 30 2010

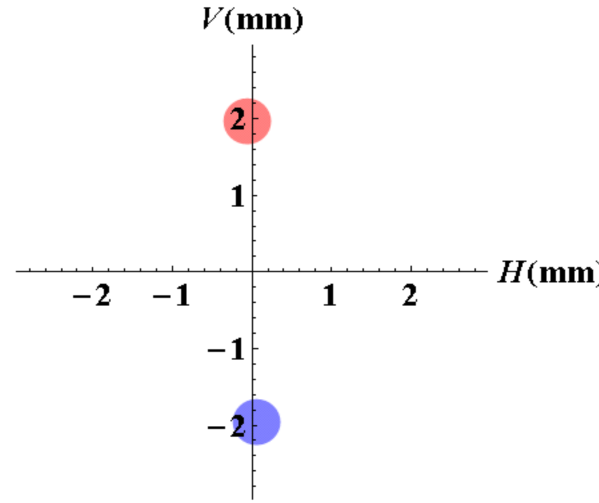
ATLAS IP Separation

H = 4.173 mm : V = 0.035 mm

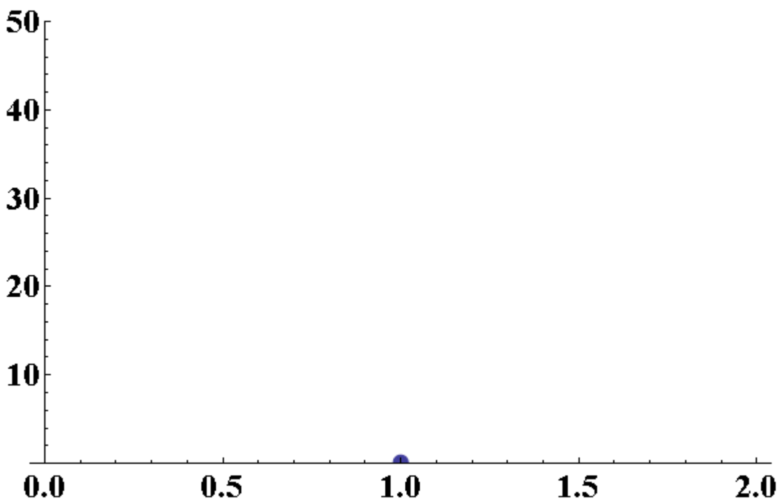


CMS IP Separation

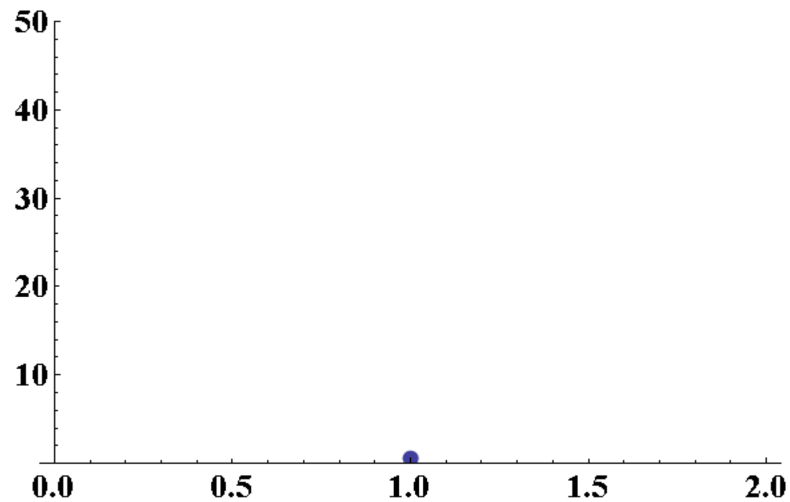
H = 0.130 mm : V = 3.925 mm



ATLAS Coll Rate Evol

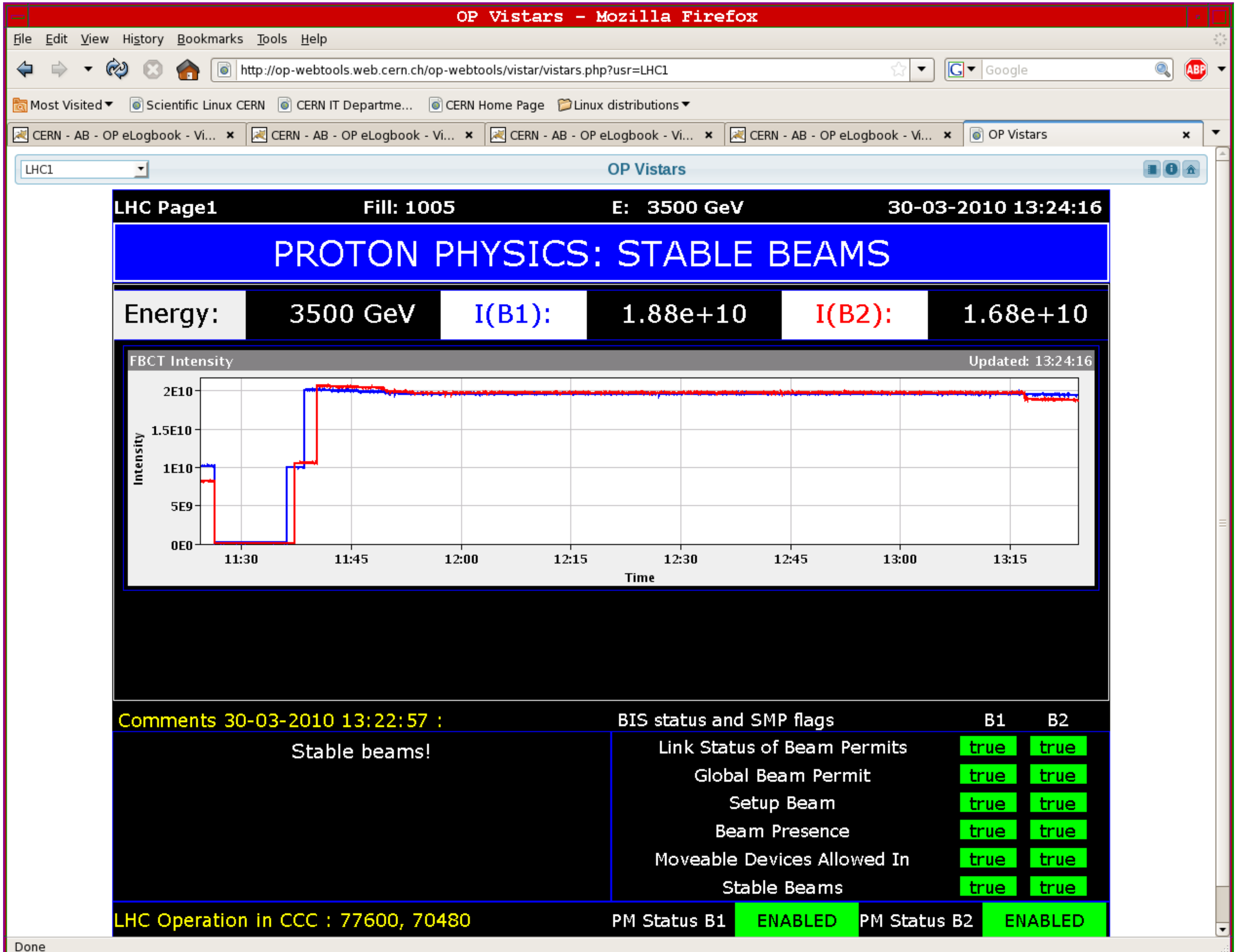


CMS Coll Rate Evol



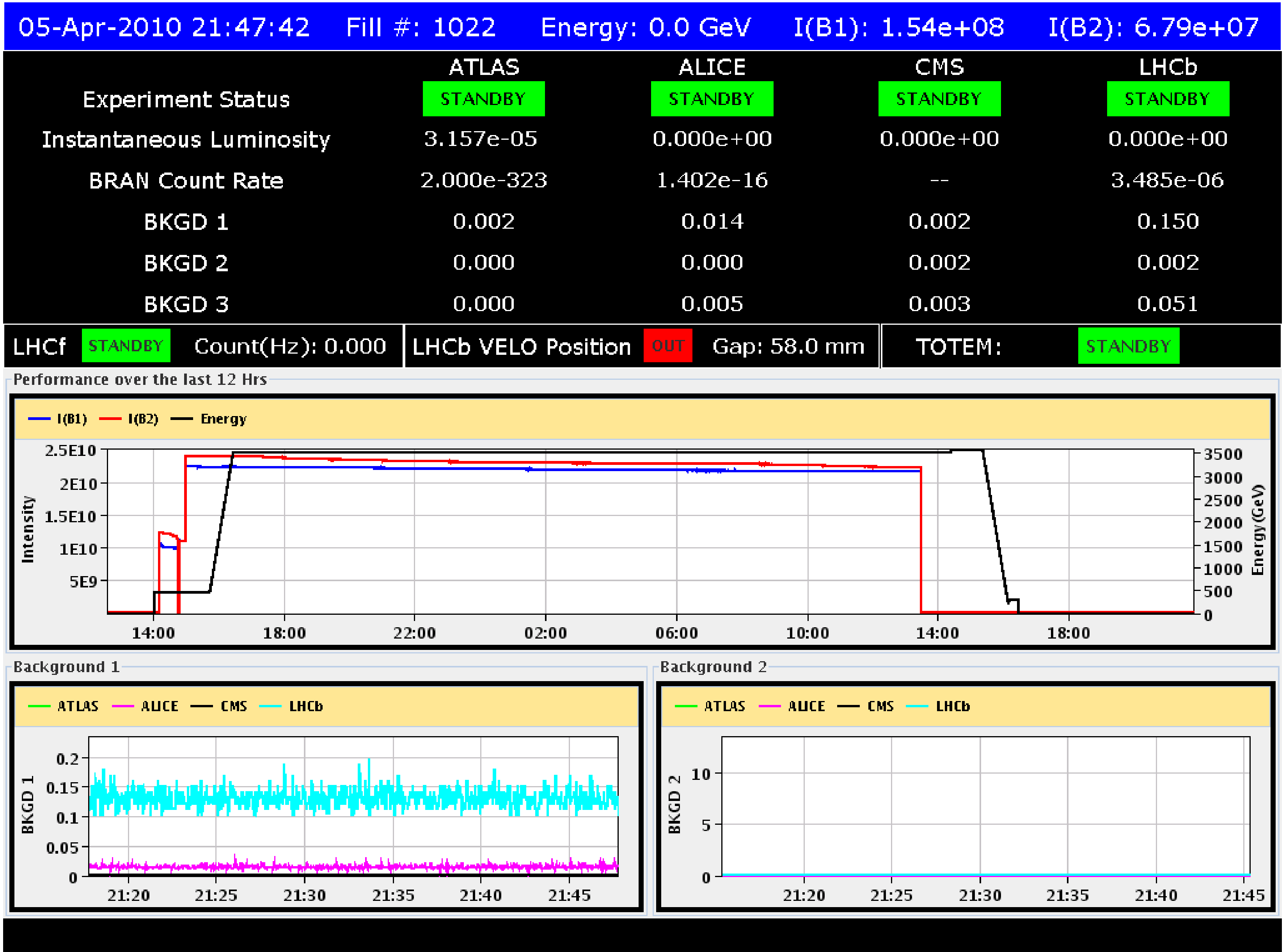
30/3/2010

11:15 injected again
12:38 : At 3.5 TeV



Since the first Collisions

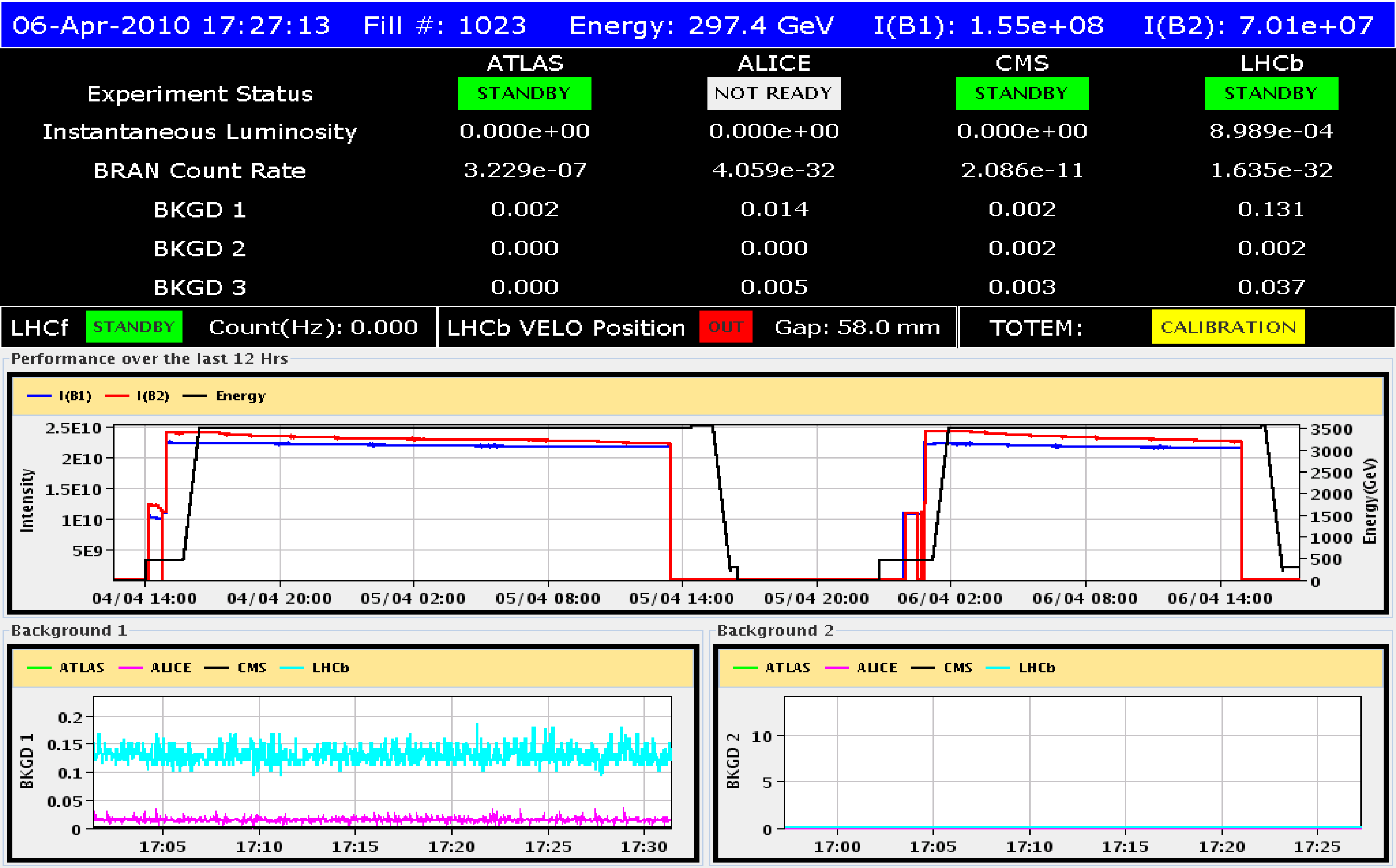
Easter Week-end; 21 hours colliding run at 7TeV cm



Fill 1022

- Single beam lifetimes:
  - Beam 1: 990 hours
  - Beam 2: 730 hours
  - Very good beam-gas, negligible luminosity burn, negligible diffusion
- Luminosity lifetime
  - 40 – 50 hours
  - Mainly from gentle beam blow-up (tau ~ 40 hours for B2V)
  - Beam tune shift ~ 0.0015 (one plane, 2 real collision points, reduced emittances)

A very good 48 hour period!

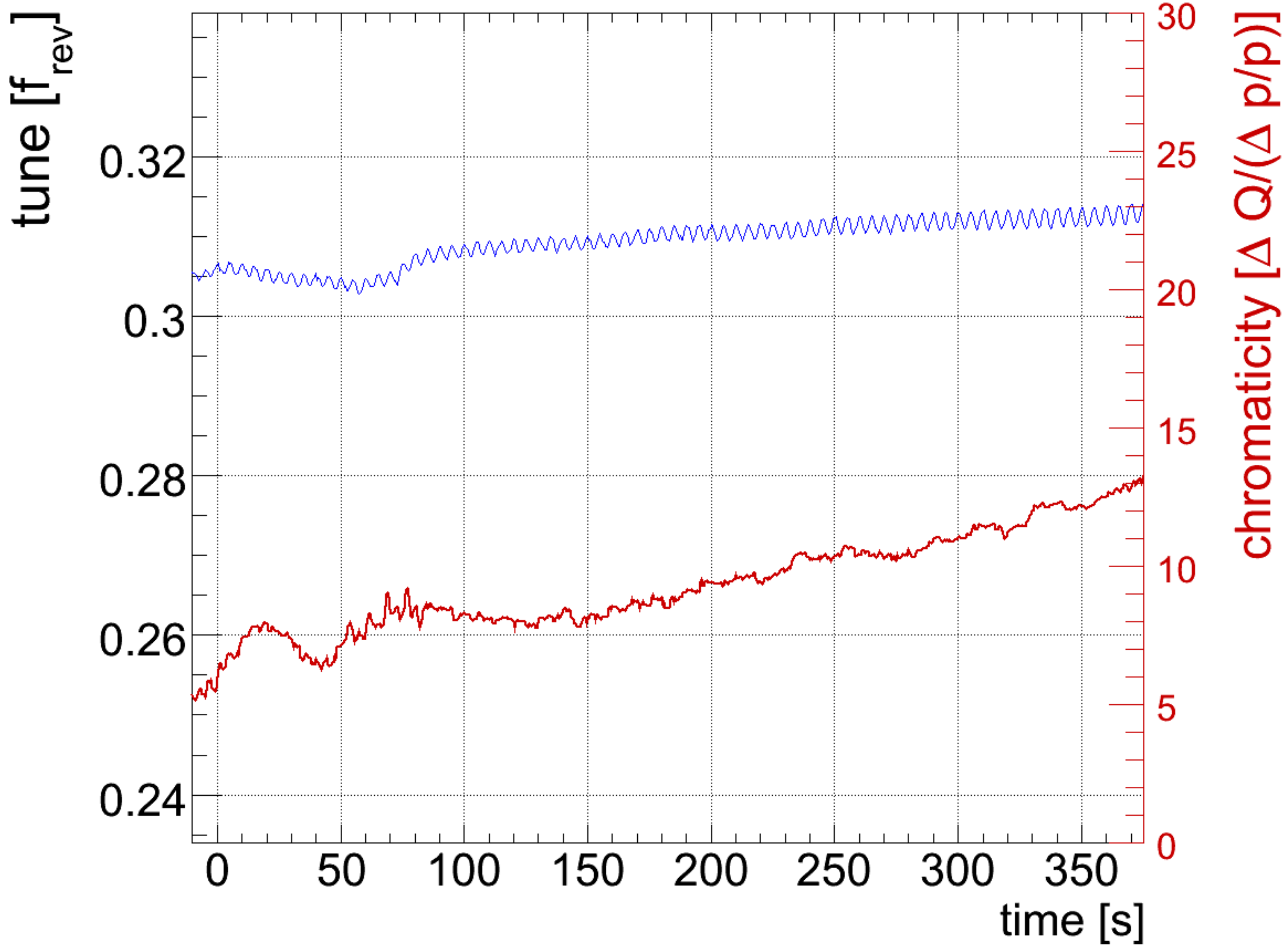


Magnet model

- The knowledge of the magnetic model of the LHC is remarkable and has been one of the key elements of a very smooth beam commissioning
- Tunes, energy matching, optics remarkably close to the model already
- Bodes very well for the future.

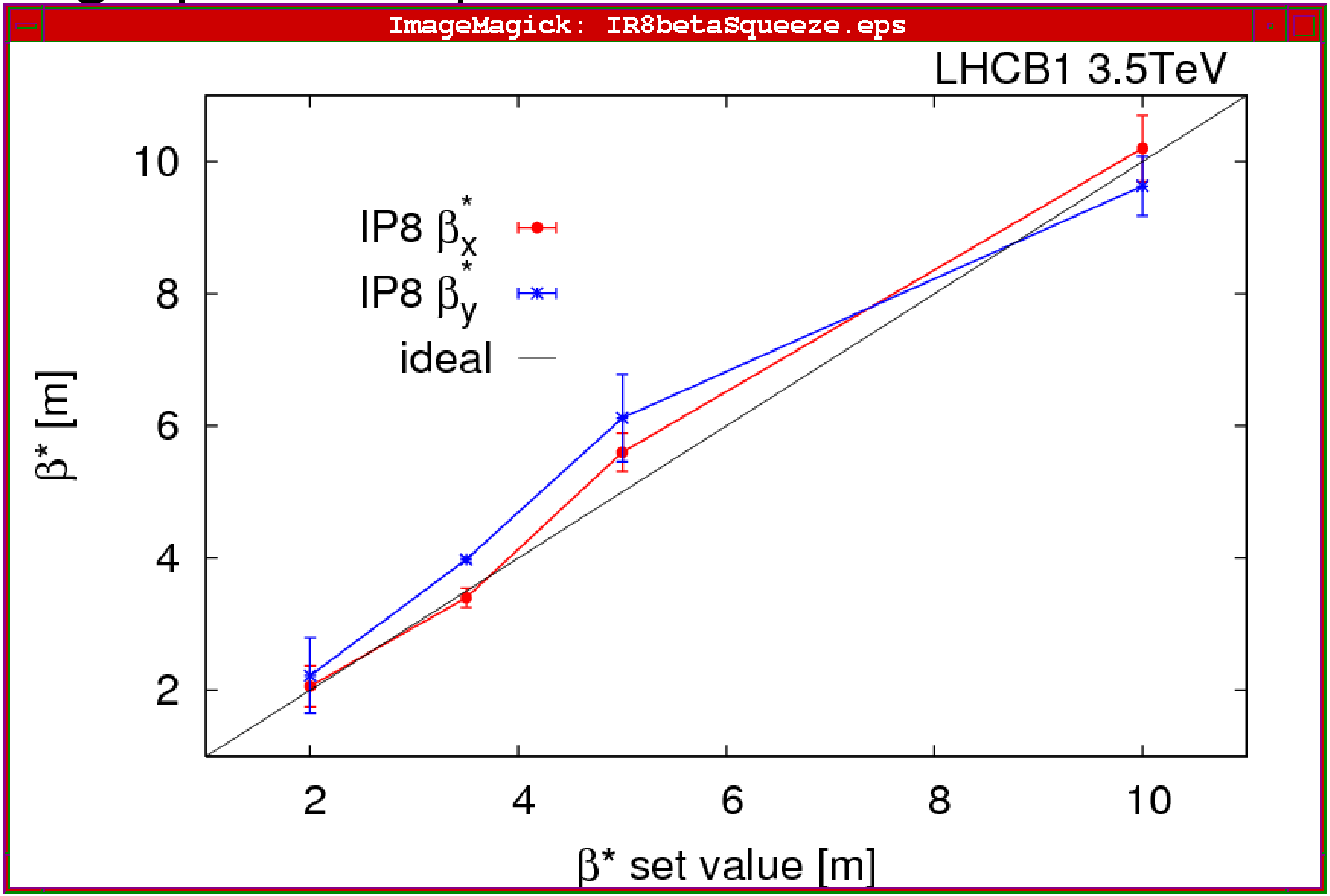
Tuesday 13.4.

- Q’ measurement during 800 GeV ramp: Beam2 Vertical



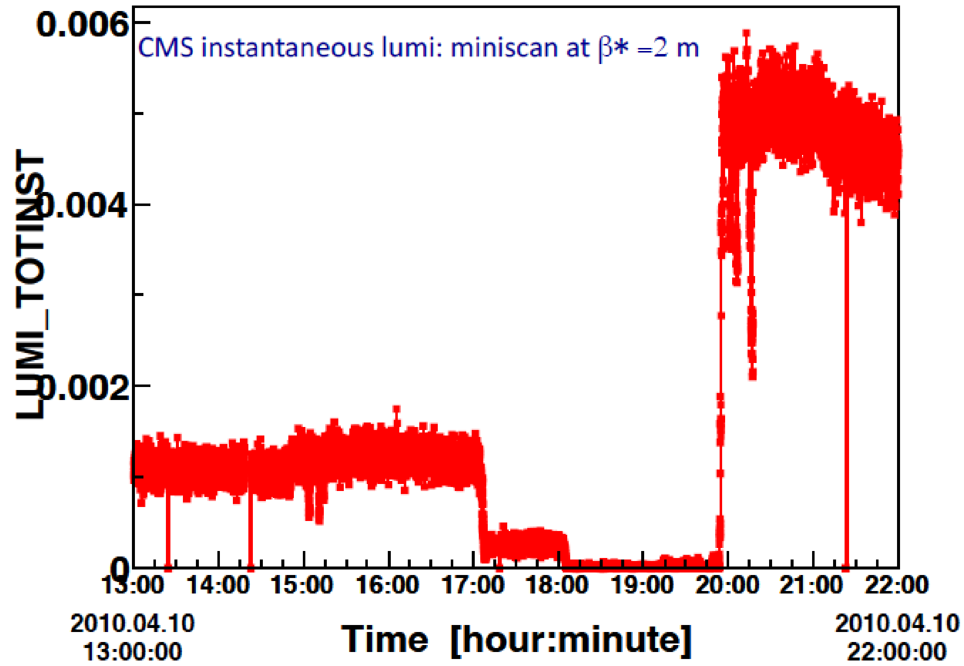
Tuesday 13.4.

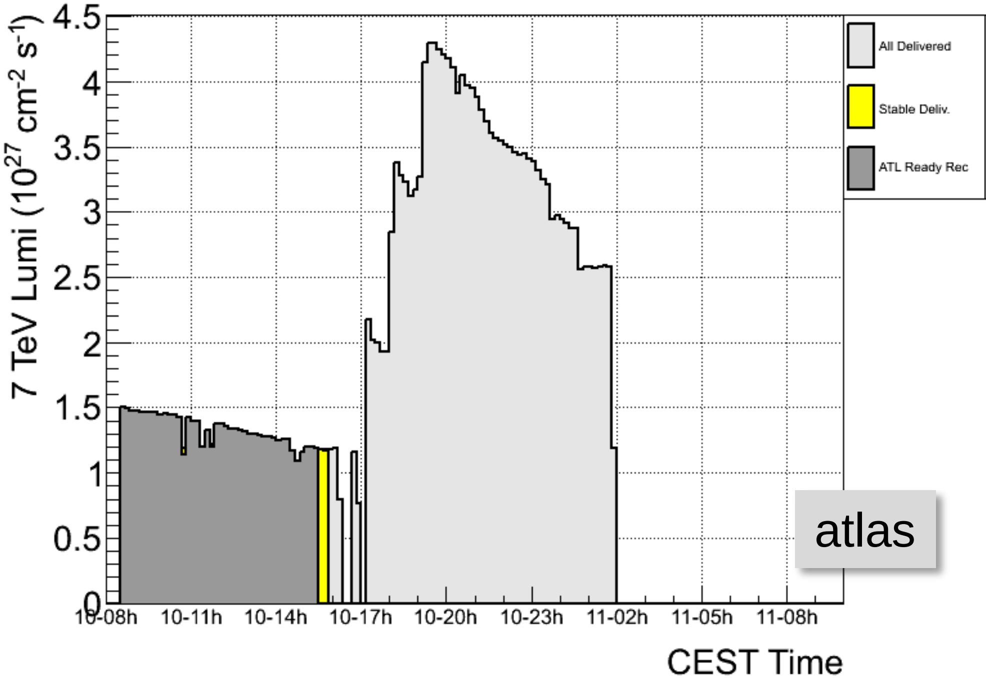
- β^* during squeeze to $\beta^* = 2$m in IR8:



IP1&5 lumi vs squeeze

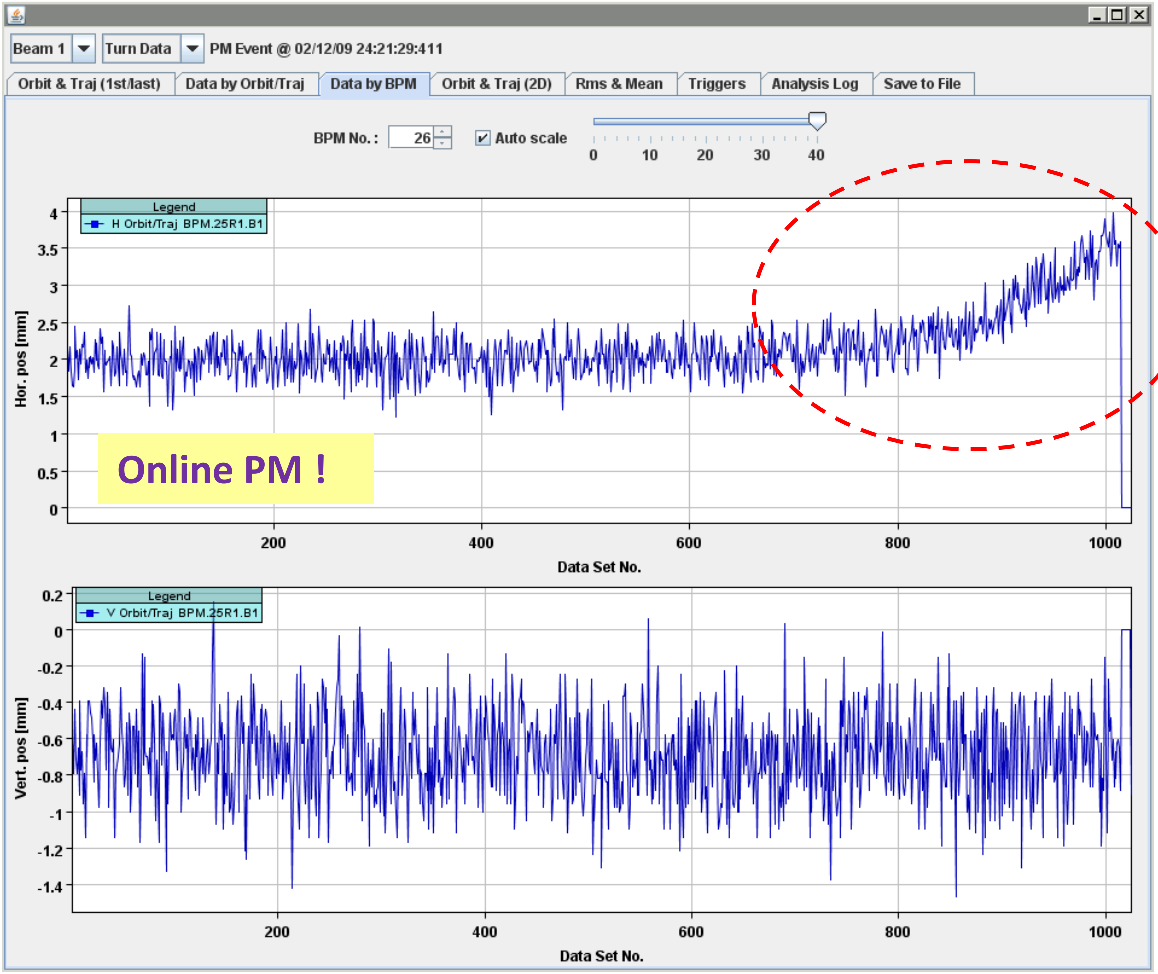
- Raw (online) lumi plots on 10 apr 2010, during the squeeze to 2m in IP1 and IP5
- Factor gained (raw numbers):
  - ~4.5 in Pt5 (after min scan)
  - ~4 in Pt1
- Not corrected for lumi decay over the ~5h of squeeze and mini scans





FMCM Beam Tests for D1 IR1/5

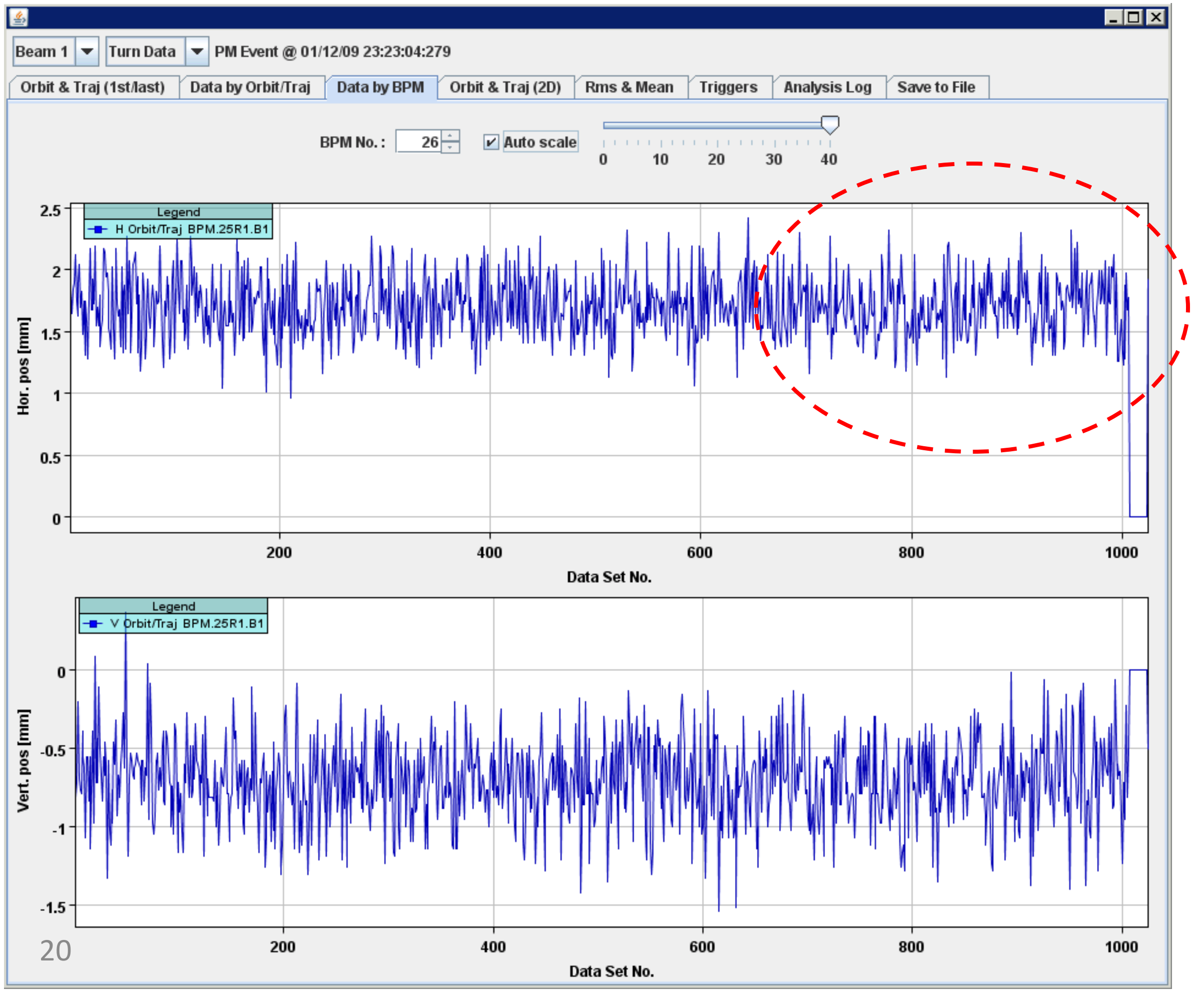
- Low intensity beam test.
- Trajectory evolution after OFF send to RD1.LR1, with FMCM masked.
- Beam dumped by BLMs in IR7.



- Trajectory over 1000 turns at a BPM.
- Position change of ~1.5 mm over last 250 turns.

FMCM beam tests

- Low intensity beam test.
- Trajectory evolution after OFF send to RD1.LR1, with FMCM active.
- Beam dumped by FMCM.



- Trajectory over 1000 turns at a the same BPM.
- No position change visible within resolution.

>> The redundant protection is working

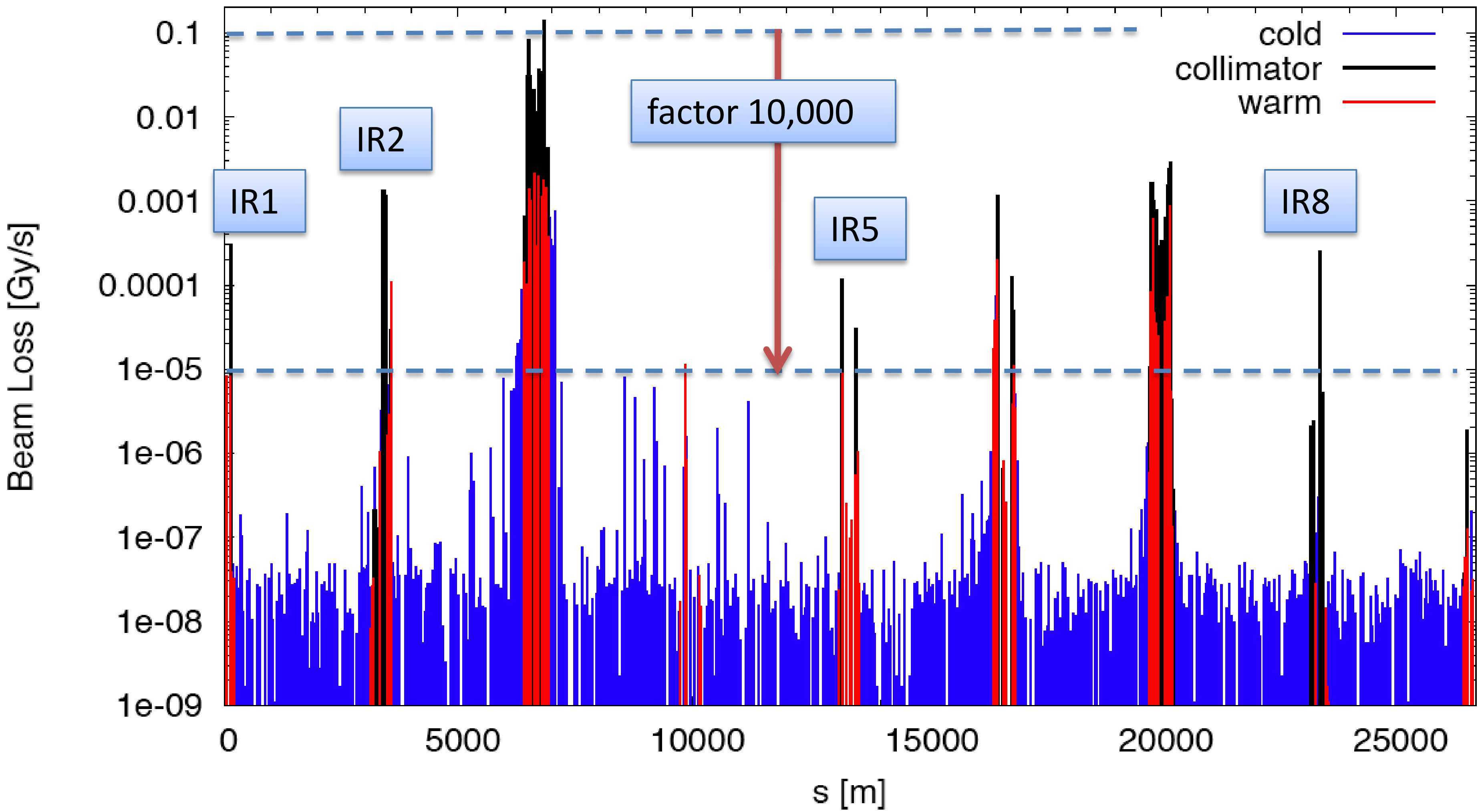
LHC Design Bunch Intensity:

Thursday 15.4.2010

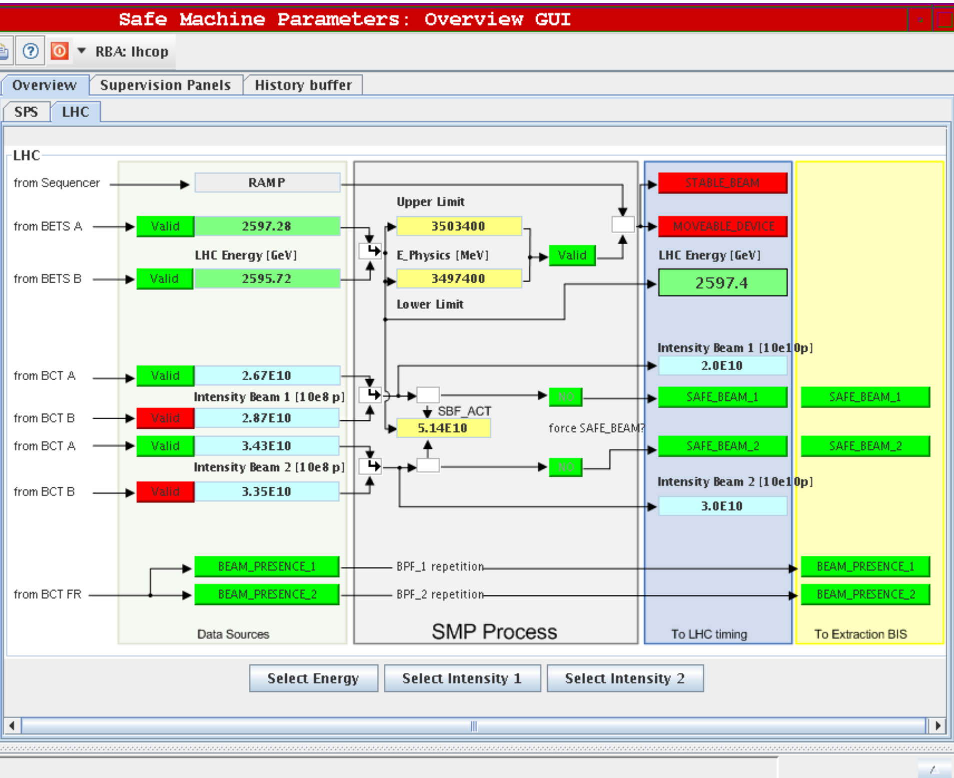
- Higher intensity
  - Over-injection working well
  - Over-injected 1.1E11, with collimators at nominal 4.5 sigma settings.
  - Emittance at 1E11: 2.5 um H, 2,3 um V.

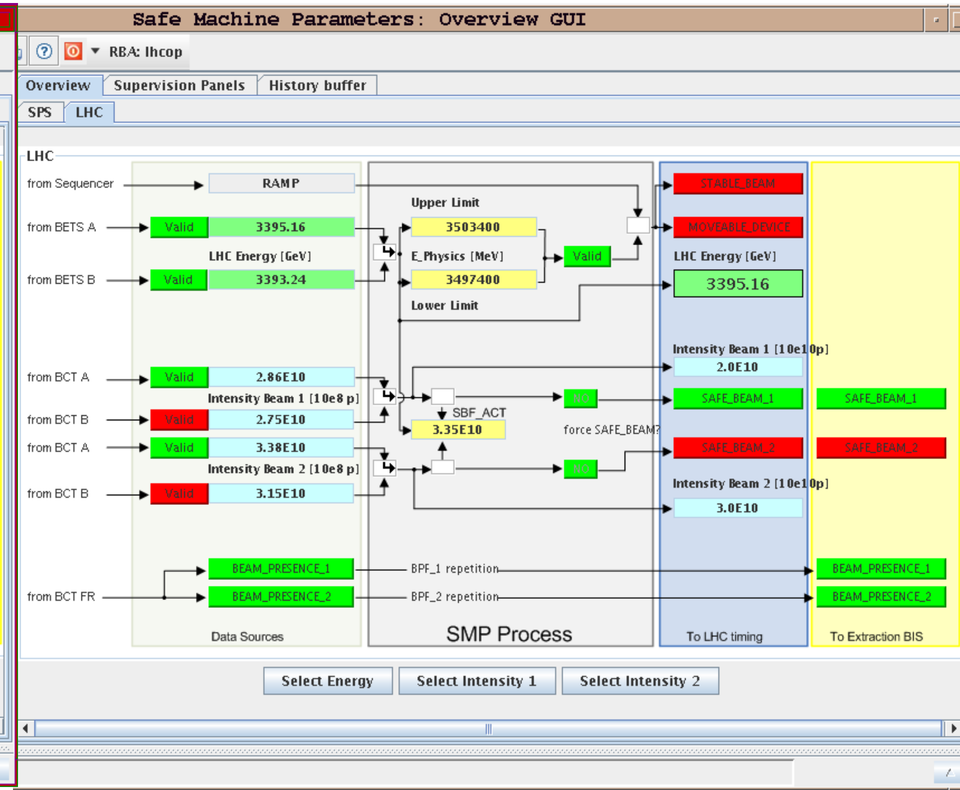
Qualification: Off-momentum collimation

Loss map for off-momentum error. All OK. See expected low leakage to experimental IR's. **OK for stable beams from coll.**



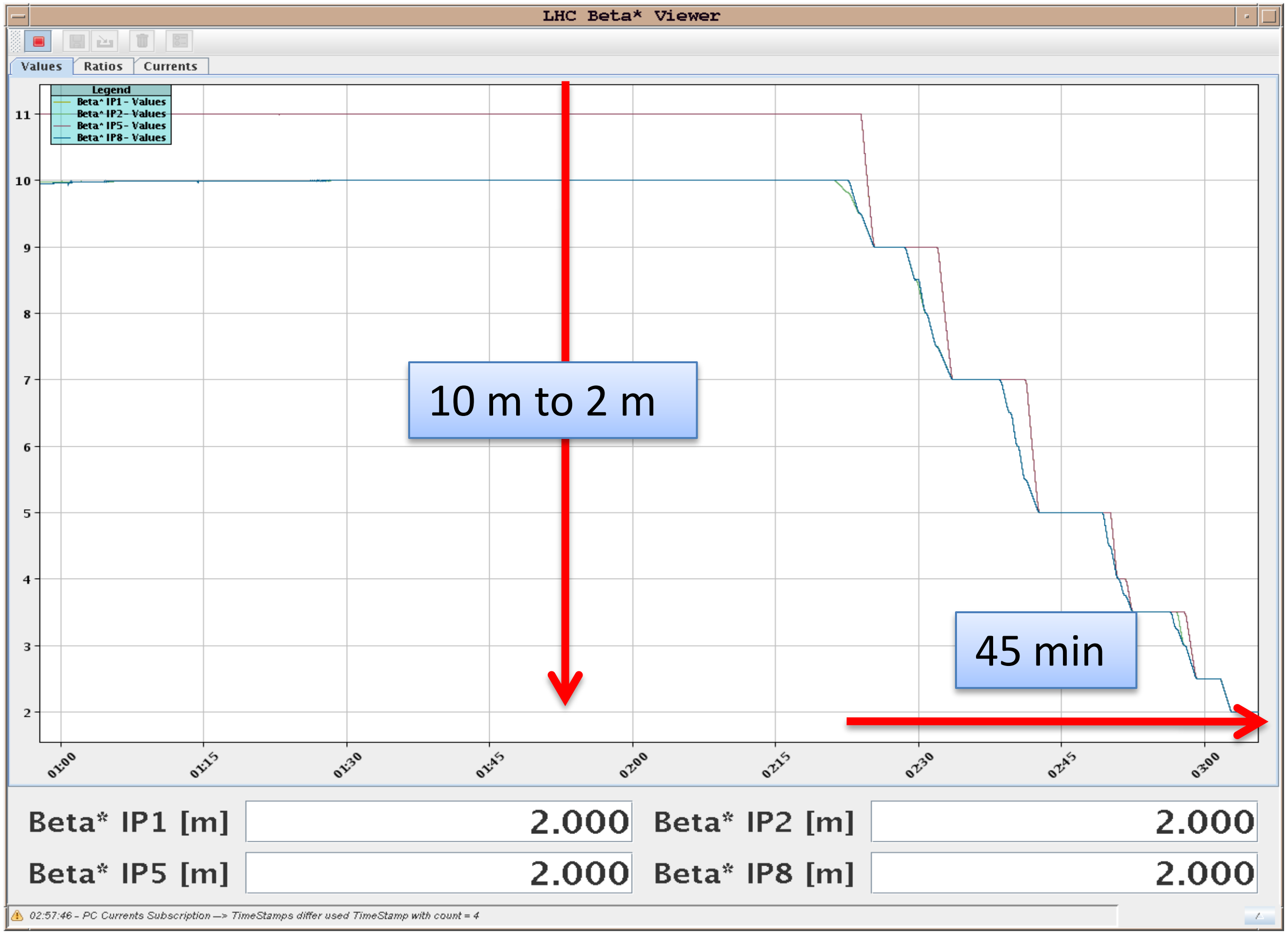
Saturday 24/4/2010



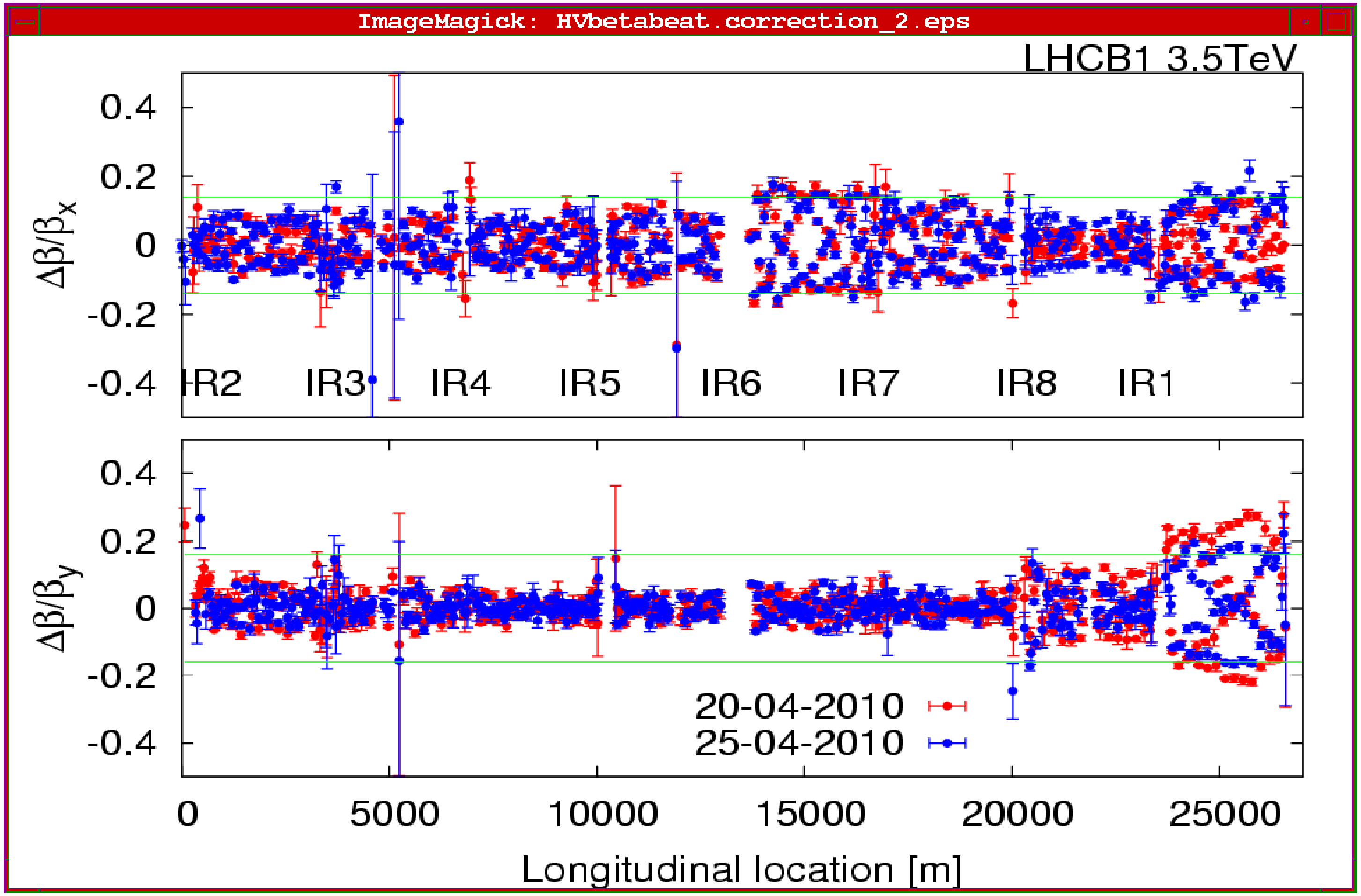


Setup Beam Flag : UNSAFE beam for the 1st time

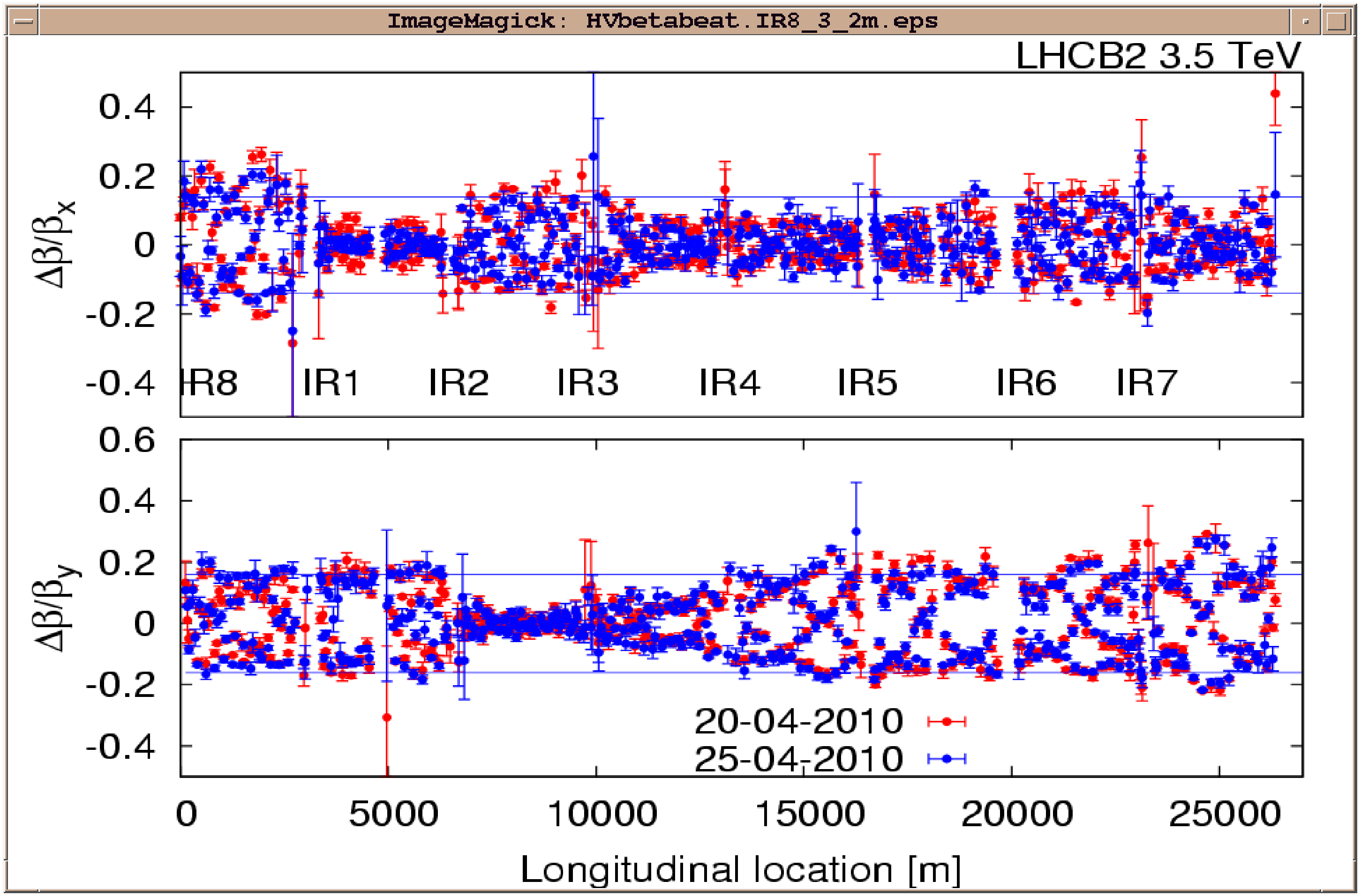
Squeeze to 2 m: Fast and Smooth



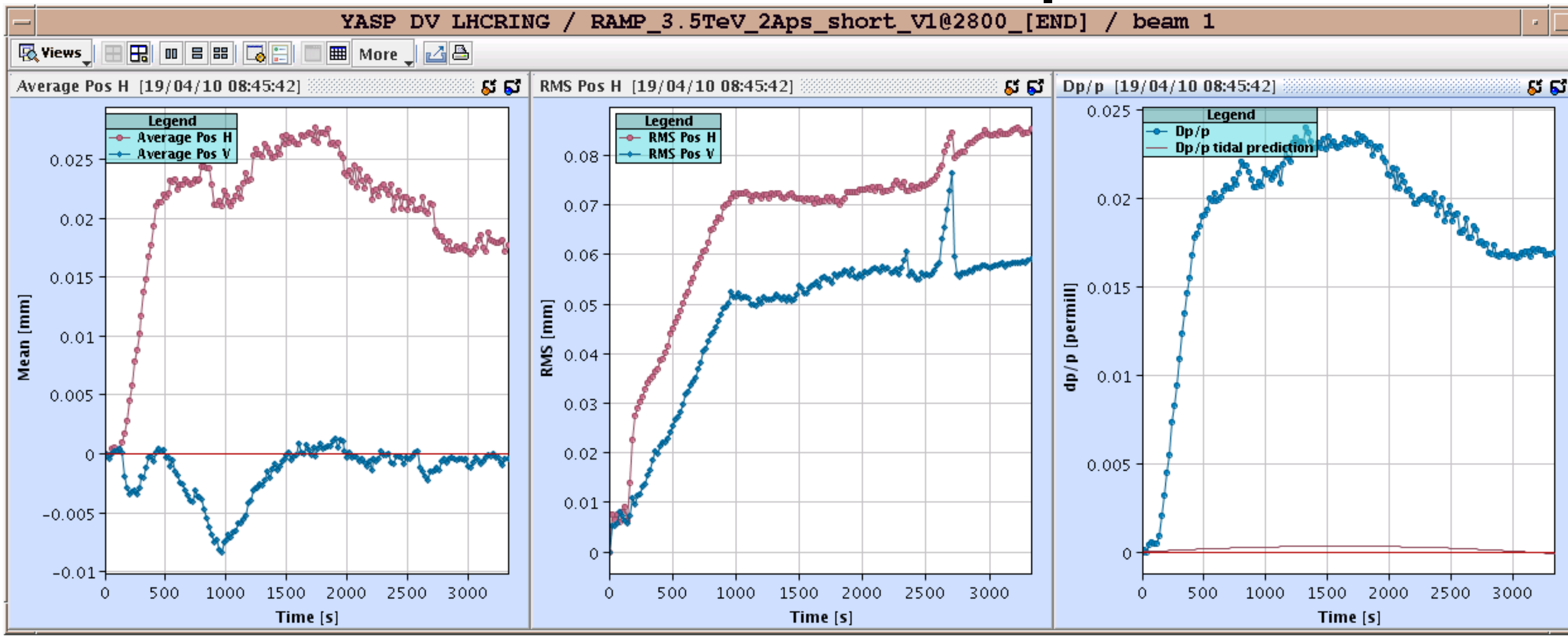
Beta Beat at 3.5 TeV – beam 1



Beta Beat: Beam 2



Orbit Feedback in Operation

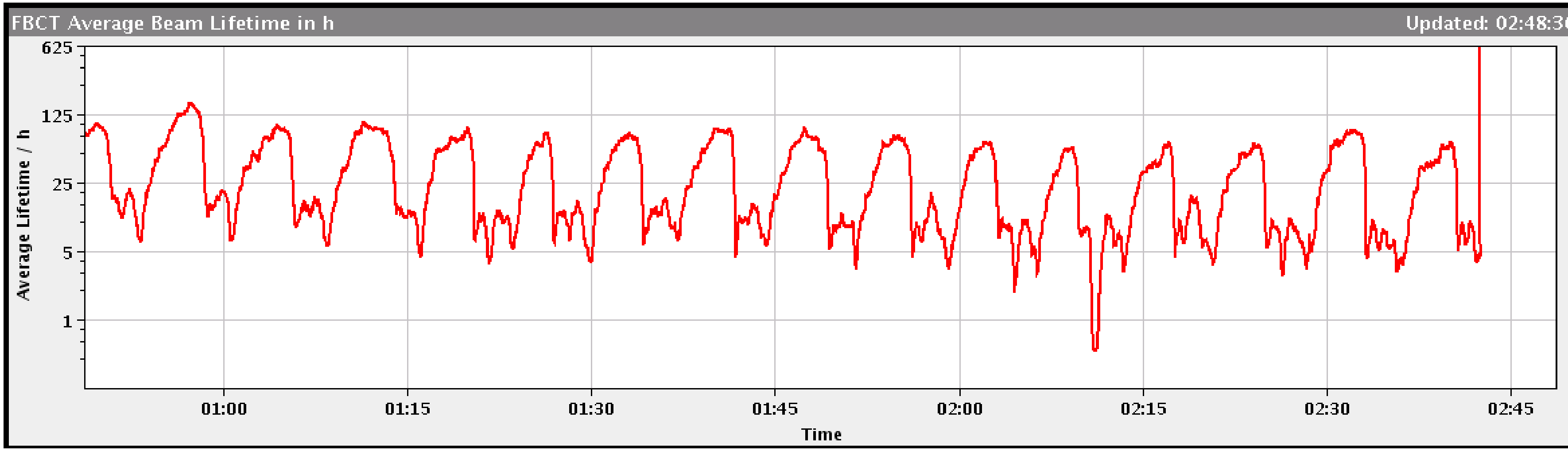


Maximum orbit change during energy ramp: **0.08 mm**

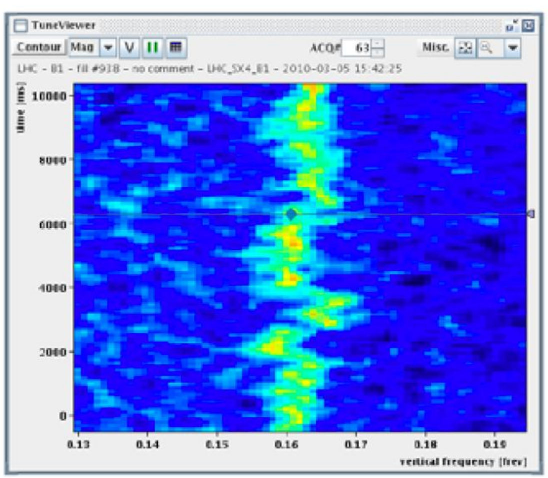
Ralph Steinhagen et al

Lifetime Drops with "Quiet" Beam

- Our friend the hump on the lifetime - ~ 7 minute period

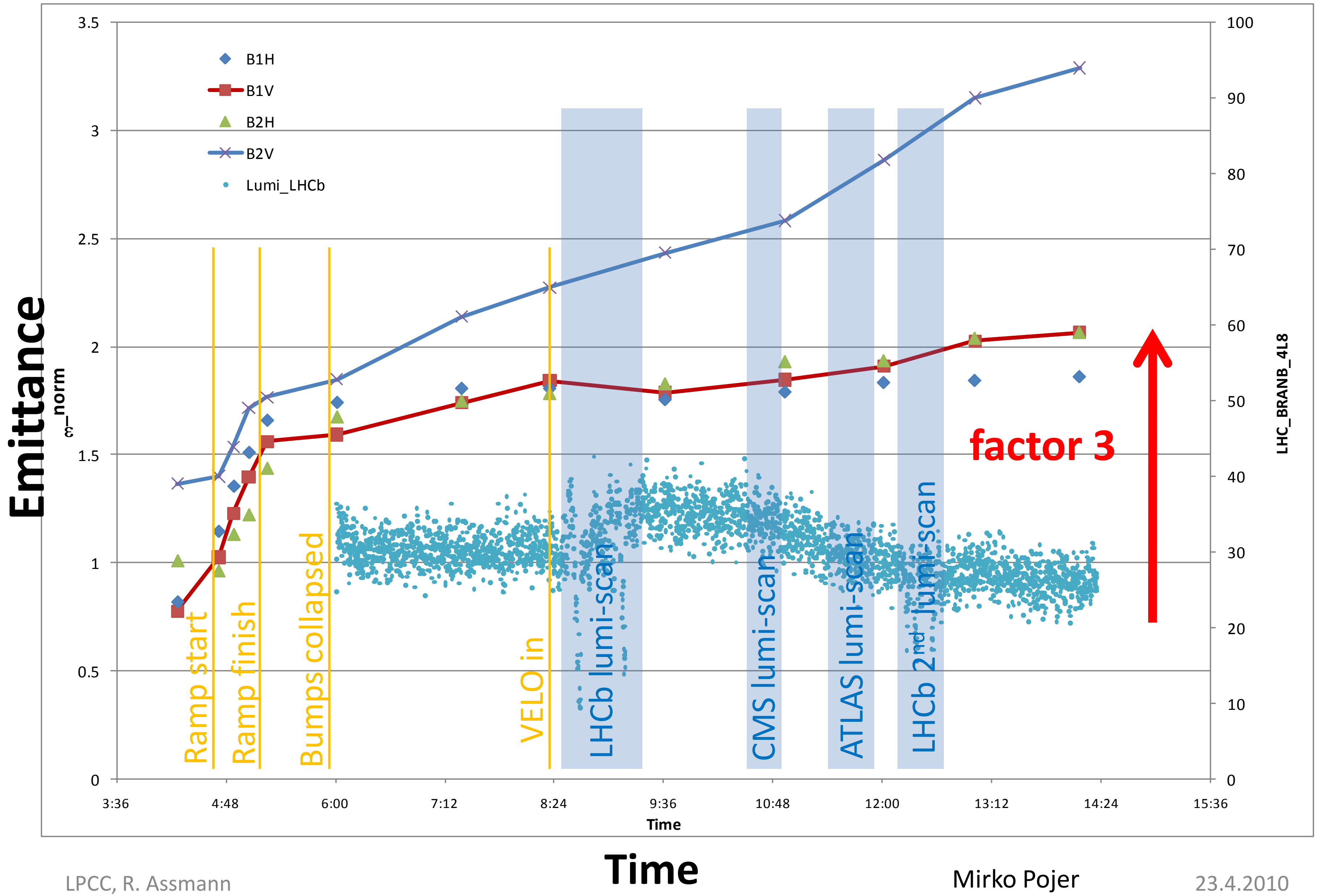


Hunting the Hump!



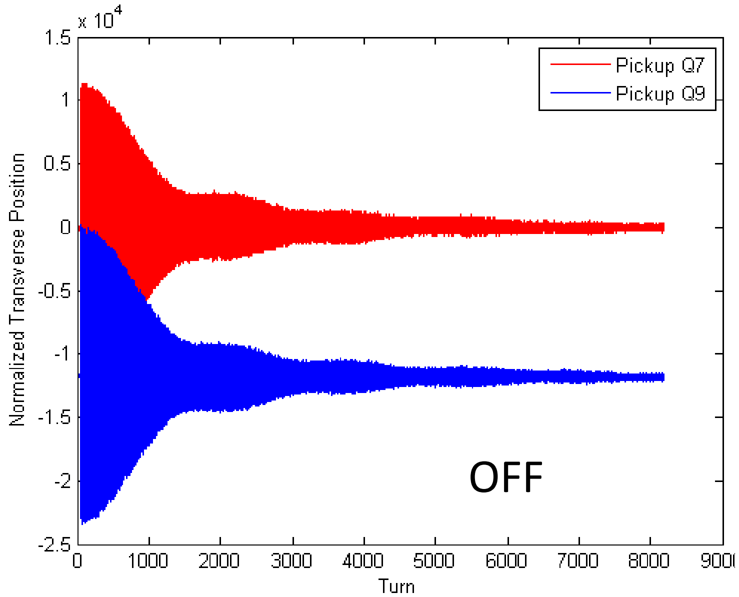
The hump is a vertical excitation on the beam that has a fast frequency component (therefore visible as "hump" in the tune spectrum and a slow moving frequency component (7 min).

Emittance Growth: Still a Problem



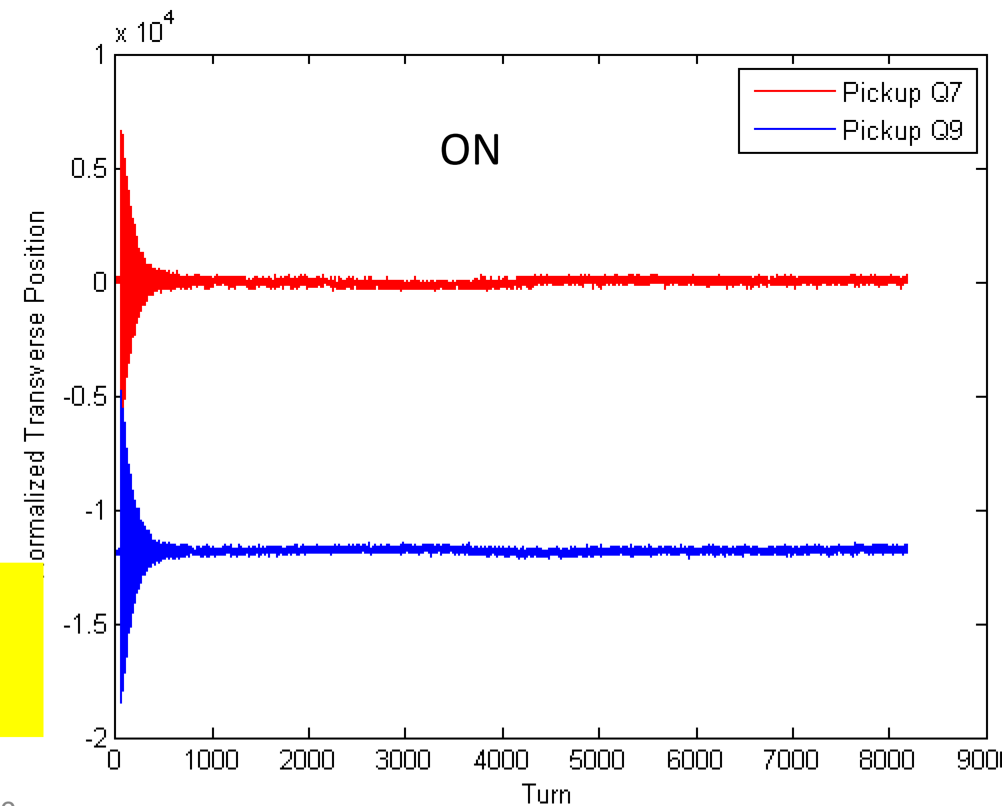
Mirko Pojer

Transverse Damper: Damping Beam Excitations



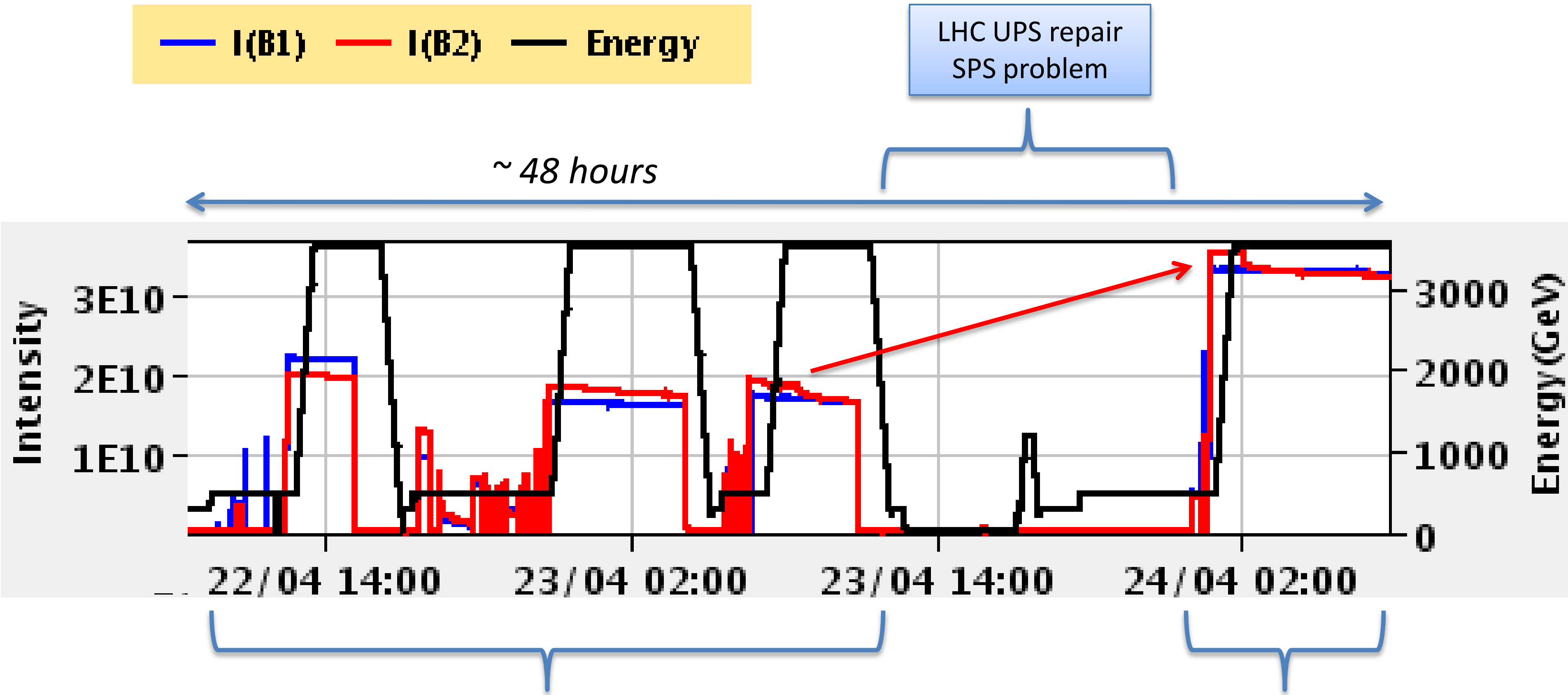
Crucial device to keep emittance growth under control!

Wolfgang Hoefle et al



Transverse Damper will stabilize against the Hump

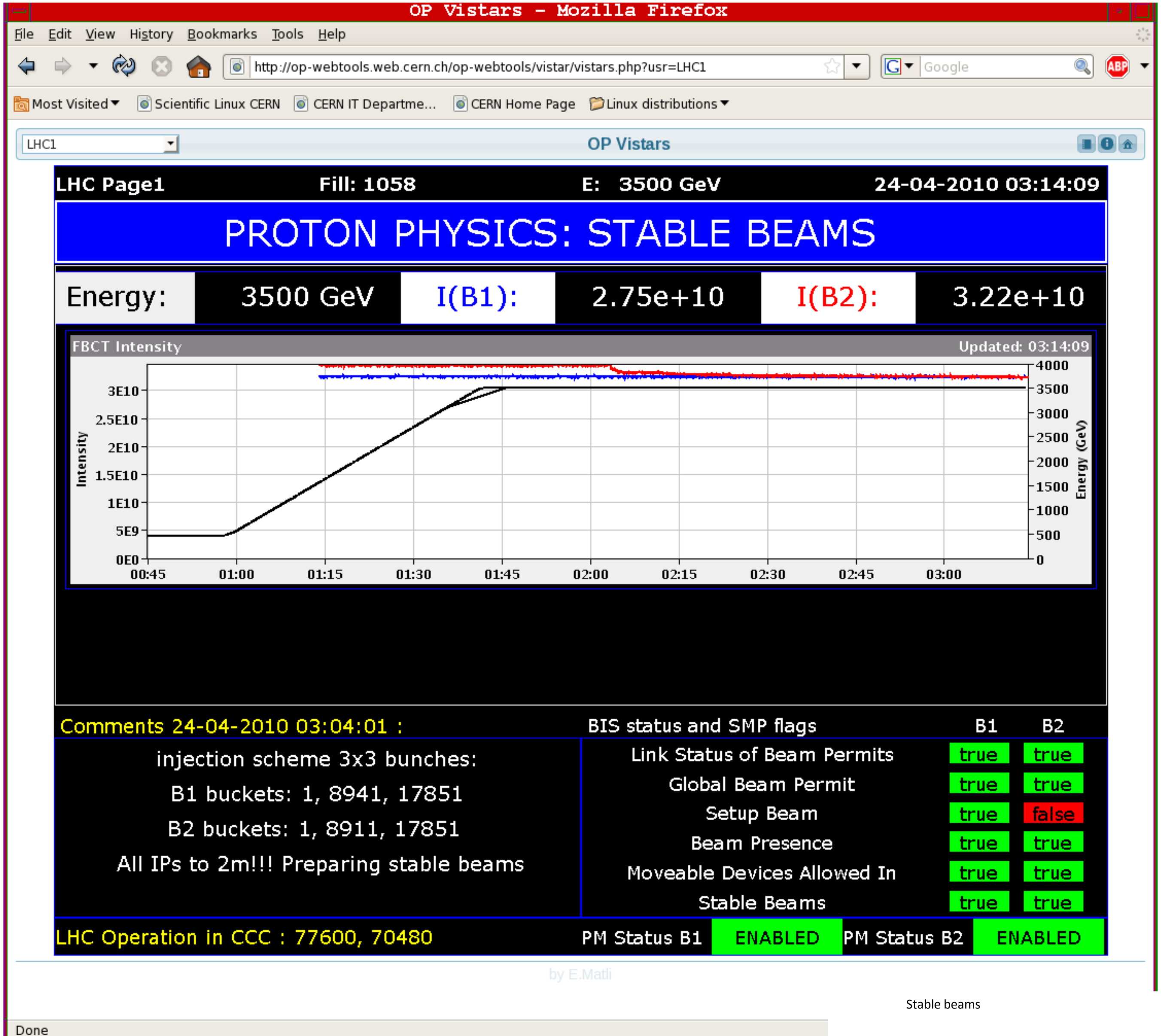
Ramp & Squeeze Start to Work Smoothly



Ramp & squeeze @ 3.5 TeV qualification:
...last 2 fills w/o problem, lost on purpose...
Transverse damper commissioning @ 450 GeV

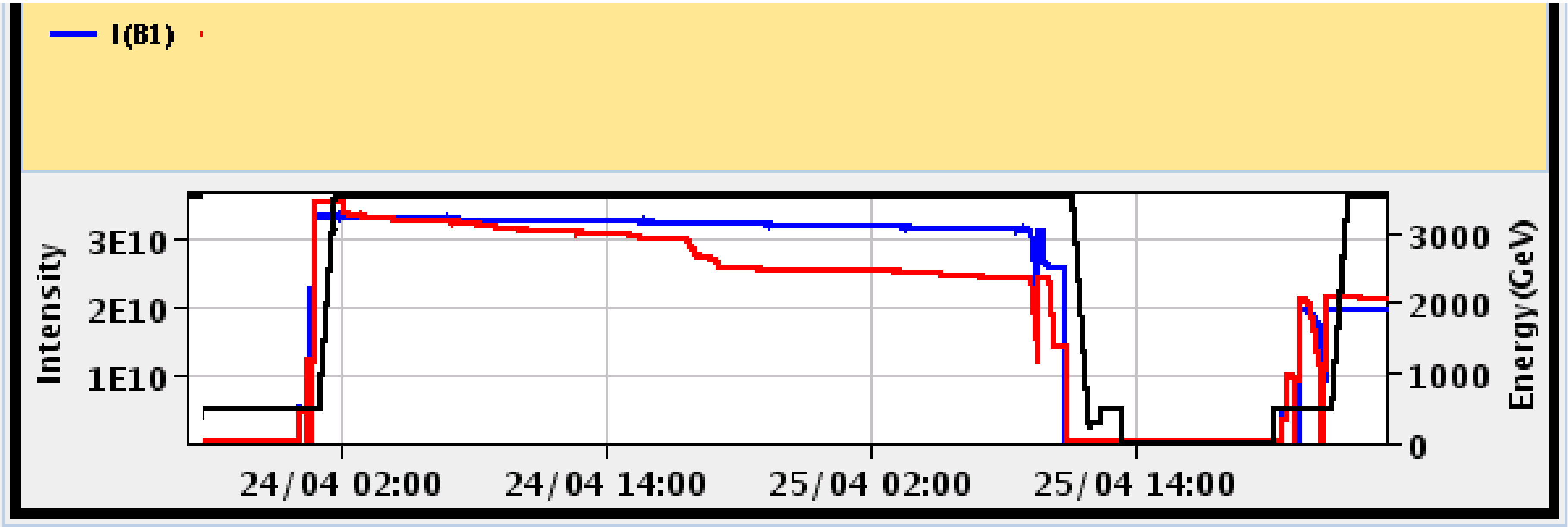
Ramp & squeeze for physics @ 3.5 TeV with higher intensity

Saturday 24/4/2010



Stable beams

New Record Fill



Fill length:	**30 h**
First time:	**with unsafe beam.**
Luminosity	**> 1.1e28 Hz/cm^2**
First time:	**3 bunch scheme**
First time:	**end of fill studies and dump.**

One order of magnitude increase in luminosity

Just 4 more to go before the long shutdown!!!

Performance 3.5 TeV

IP	Beta* (x, beam 1)	Beta* (y, beam 1)	Beta* (x, beam 2)	Beta* (y, beam 2)
1	2.28 m	2.02 m	1.92 m	2.10 m
2	2.07 m	1.85 m	2.09 m	2.12 m
5	2.05 m	2.02 m	1.92 m	2.58 m
8	2.07 m	1.86 m	2.24 m	1.72 m

24-Apr-2010 05:32:51 Fill #: 1058 Energy: 3500.3 GeV I(B1): 3.28e+10 I(B2): 3.25e+10

	ATLAS	ALICE	CMS	LHCb
Experiment Status	PHYSICS	PHYSICS	PHYSICS	PHYSICS
Instantaneous Luminosity	1.284e-02	1.147e-02	1.444e-02	1.497e-02
BRAN Count Rate	1.966e+02	1.159e+02	3.518e+02	3.810e+02
BKGD 1	0.048	0.014	0.040	0.141
BKGD 2	5.000	24.770	5.608	2.321
BKGD 3	0.000	0.005	0.003	0.045

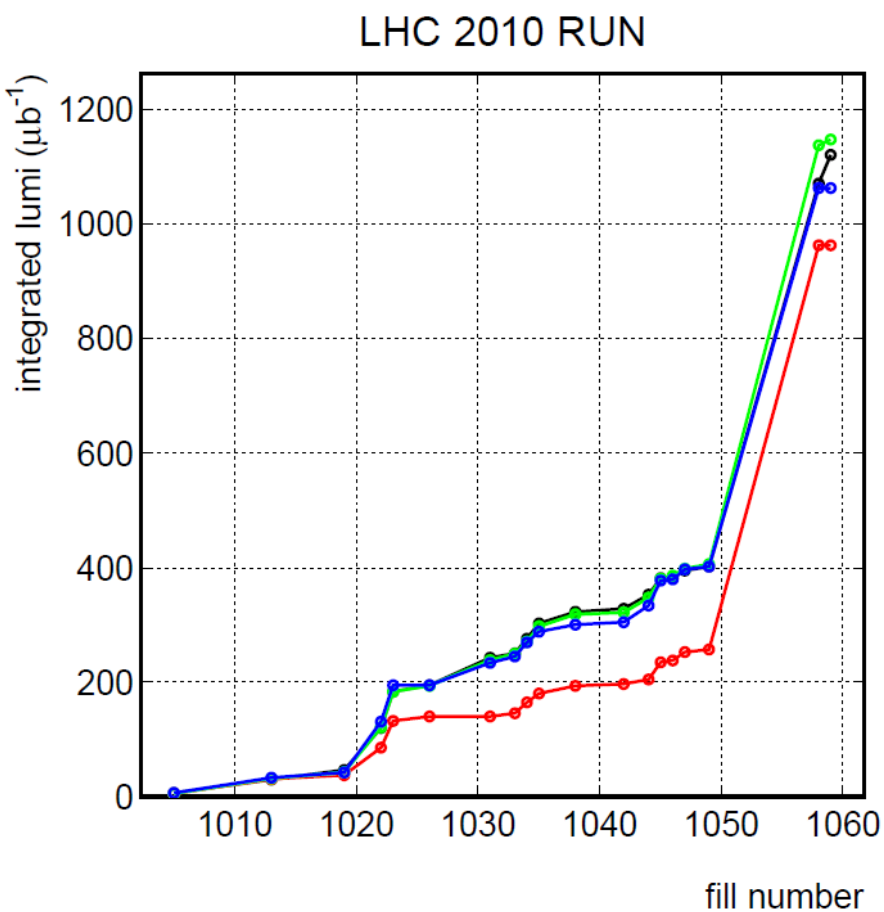
LHCf PHYSICS Count(Hz): 5.400 | LHCb VELO Position IN Gap: 0.0 mm | TOTEM: STANDBY

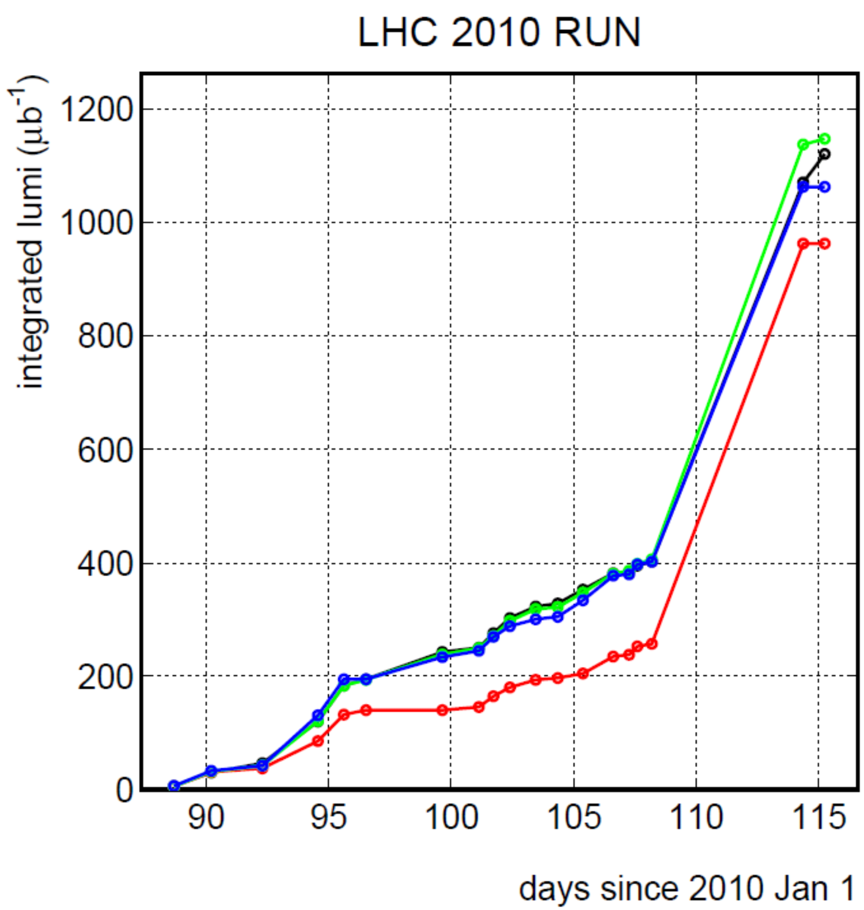
All experiments: $L > 1.1 \times 10^{28}\ cm^{-2}\ s^{-1}$

factor ~10 achieved, as predicted

Integrated lumi (delivered, in STABLE BEAMS)

(modulo some possible luminometers down time...)



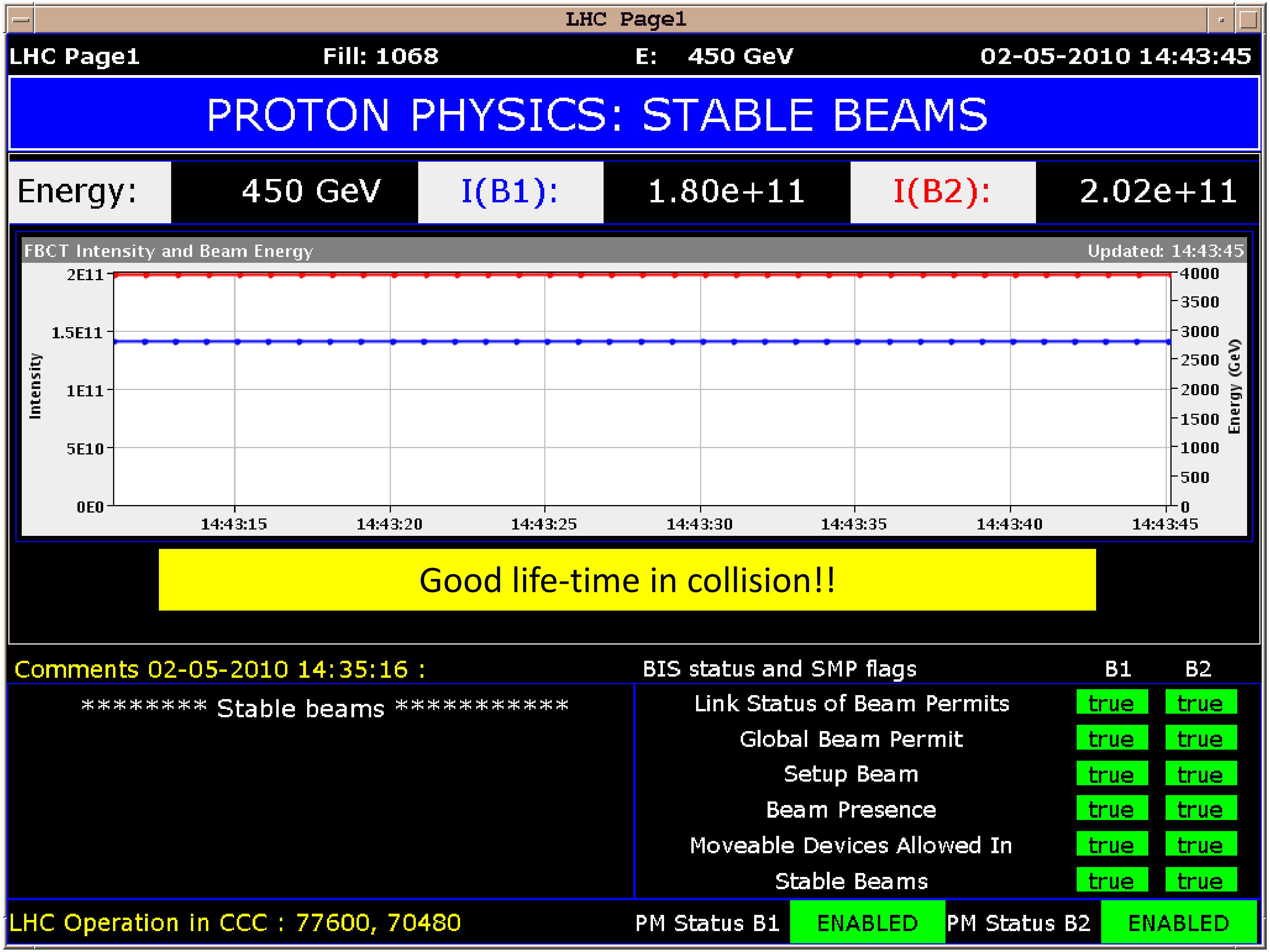


PRELIMINARY

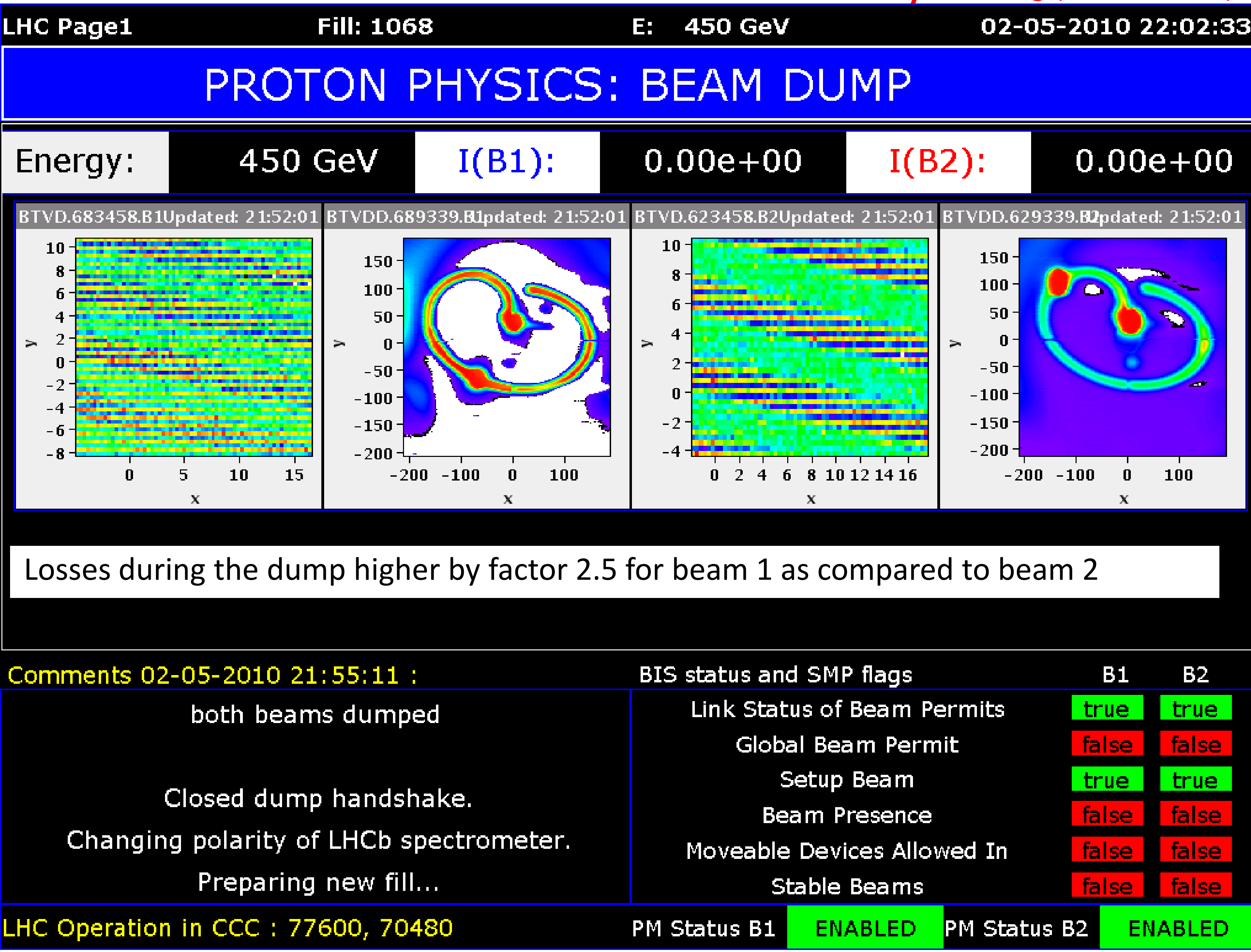
Sunday (02/05/2010)

- 9:05 : 1st fill for "test run" with injection of **2x2, $1x10^{11}$/bunch**
  - No lifetime problems during injection with separated beams
- 9:40 : Separation bump collapsed, **all IPs at once**, lifetime of about 5 h for both beams
- 13:44 : Filling again for Stable Beams, 1e11/ bunch, 2x2
- 14:10: Collapsing bumps, all at once
- 14:34 : STABLE BEAMS
- Luminosity scans "manually" performed for all IPs

Sunday afternoon (02/05/2010)

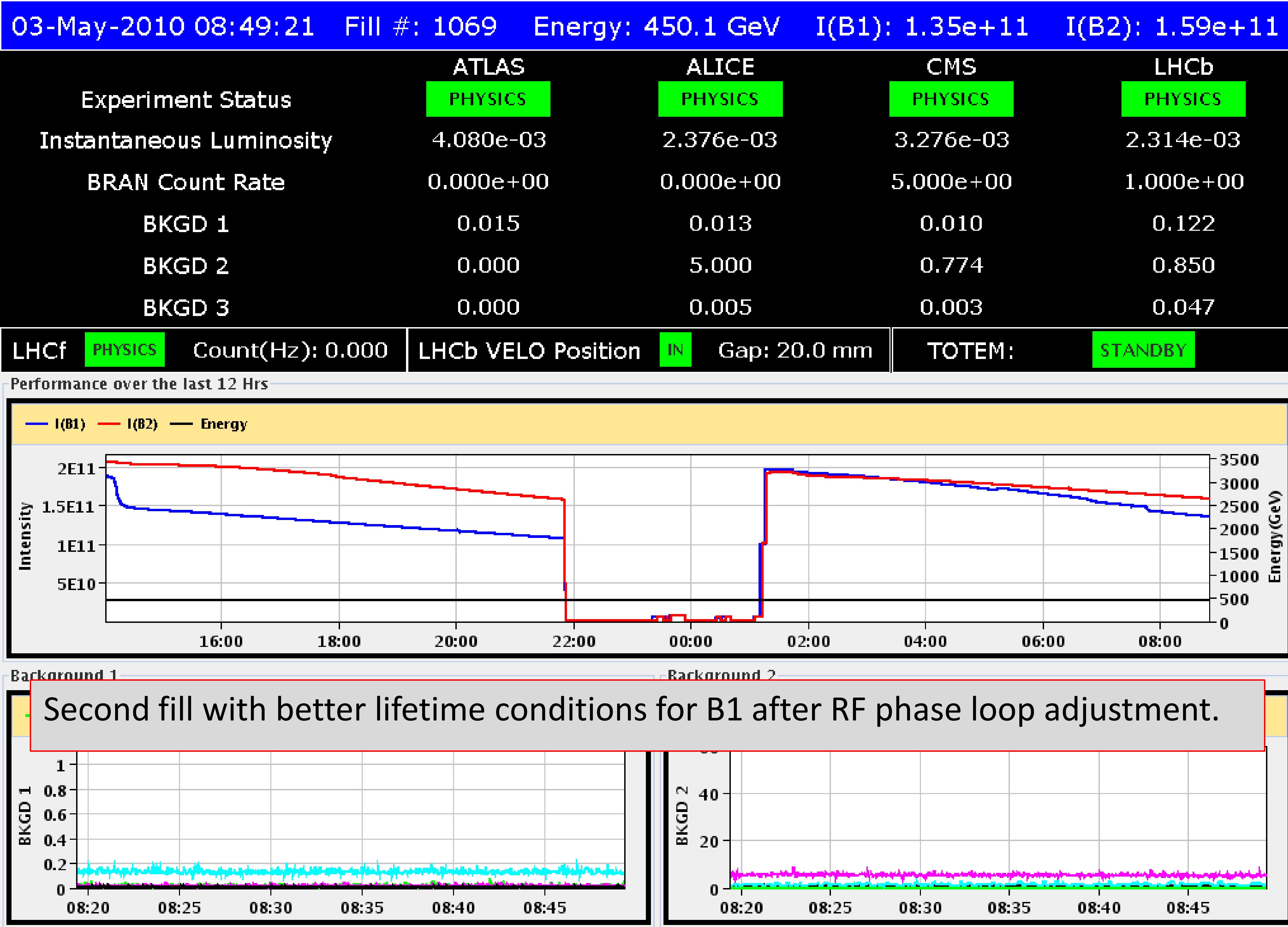


Sunday evening (02/05/2010)



Losses during the dump higher by factor 2.5 for beam 1 as compared to beam 2

ed

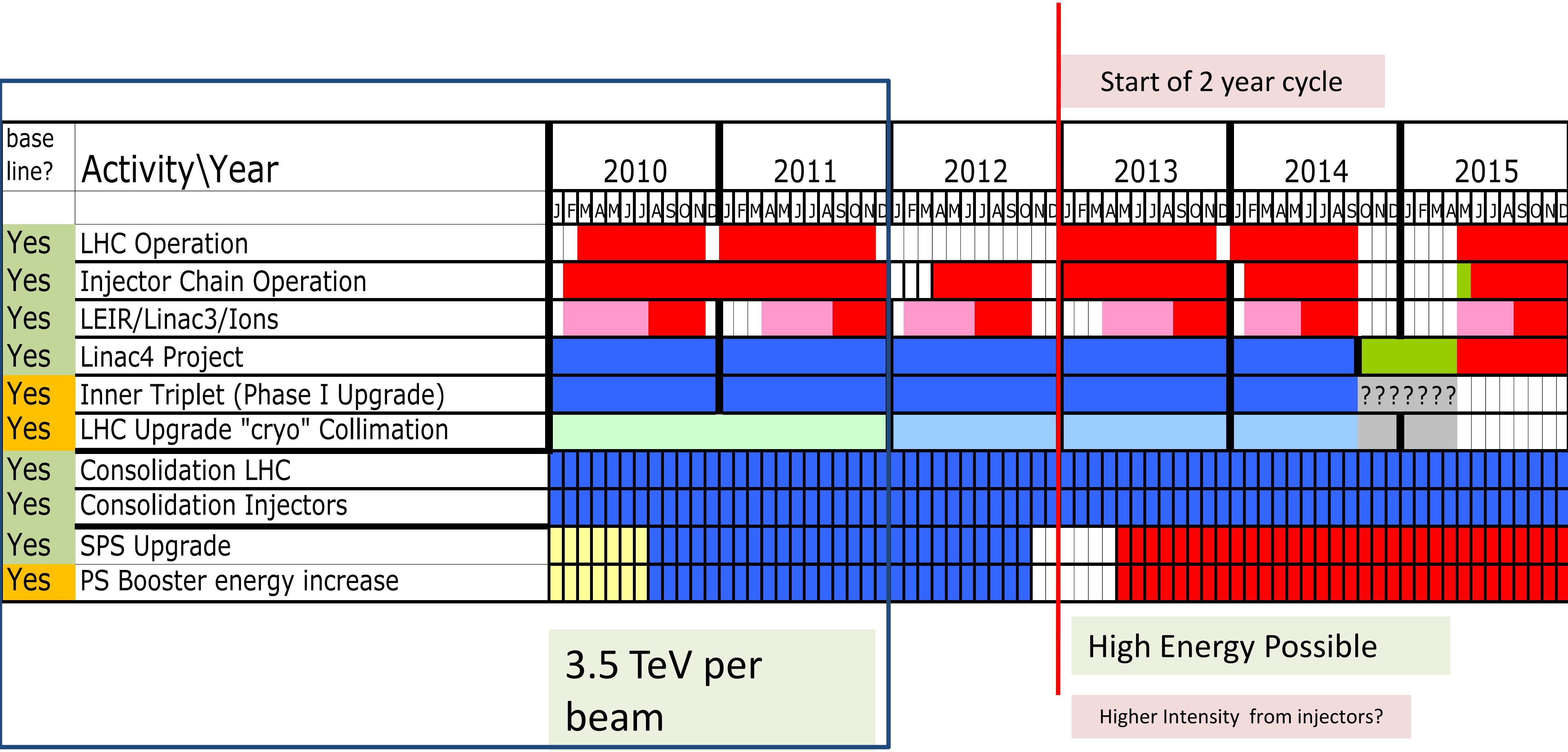


Second fill with better lifetime conditions for B1 after RF phase loop adjustment.

Topics

- LHC Status
  - Technical stop and Hardware Commissioning
  - **Beam Commissioning and Operation March→ now**
- Strategy for Performance Evolution 2010-2011

Time lines (Very Preliminary)



Beam commissioning strategy 2010

Global machine checkout

450 GeV re-commissioning

Machine protection commissioning

Ramp commissioning

Establish stable safe beams at 3.5 TeV

Collisions at 3.5 TeV

System/beam commissioning continued
Squeeze

Collisions at 3.5 TeV squeezed

Full machine Protection qualification

Finish This!!

today

Instantaneous Luminosity

$$L = \frac{N^2 k_b f}{4\pi\sigma_x \sigma_y} F = \frac{N^2 k_b f \gamma}{4\pi\varepsilon_n \beta^*} F$$

- Nearly all the parameters are variable (and not independent)
  - Number of particles per bunch N
  - Number of bunches per beam k_b
  - Relativistic factor (E/m_0) γ
  - Normalised emittance ε_n
  - Beta function at the IP β^*
  - Crossing angle factor F
    - Full crossing angle θ_c
    - Bunch length σ_z
    - Transverse beam size at the IP σ^*

Intensity (N, k_b)

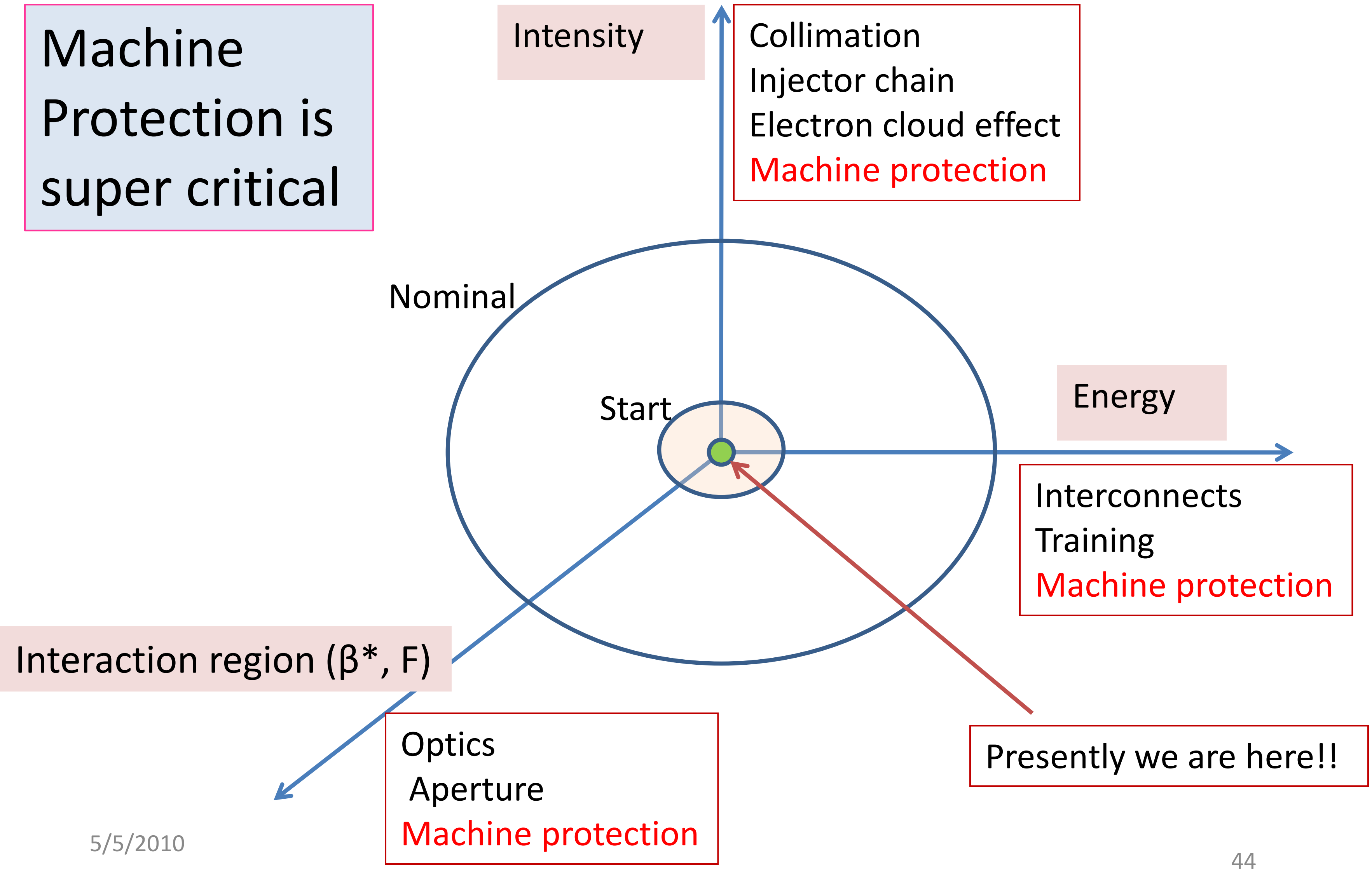
Energy (γ)

Interaction Region (β^*, F, θ_c)

$$F = 1 \Big/ \sqrt{1 + \left(\frac{\theta_c \sigma_z}{2\sigma^*}\right)^2}$$

LHC performance drivers/limiters

Machine Protection is super critical



Beam Energy; Chamonix

Decision from Management following Chamonix

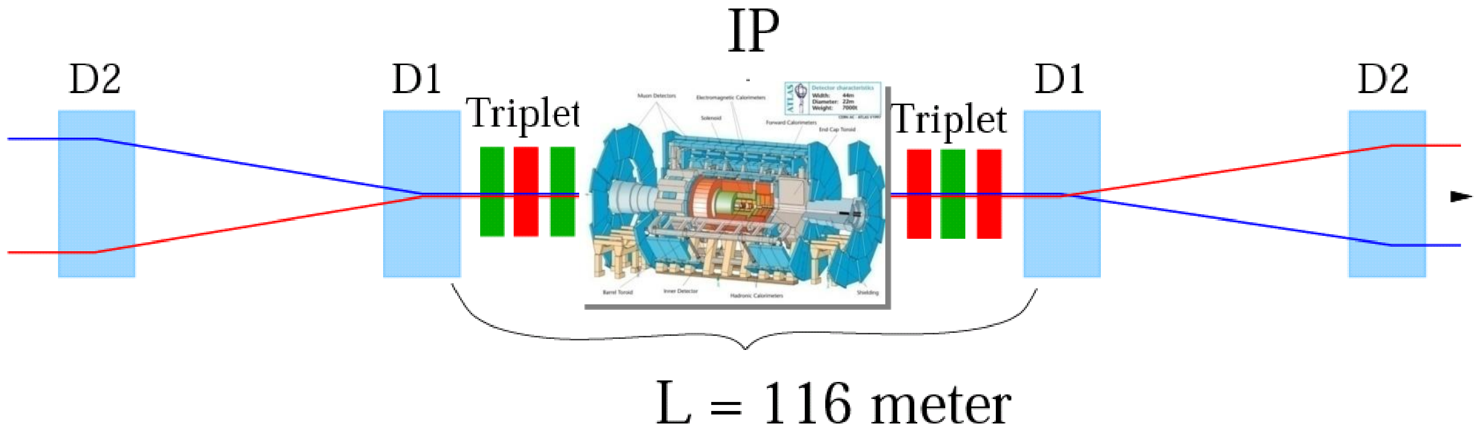
- Run at 3.5 TeV/beam (or slightly higher e.g. 4TeV) up to a predefined integrated luminosity ($1fb^{-1}$) with a date limit (end 2011).
- Then consolidate/repair the whole machine for 7TeV/beam.

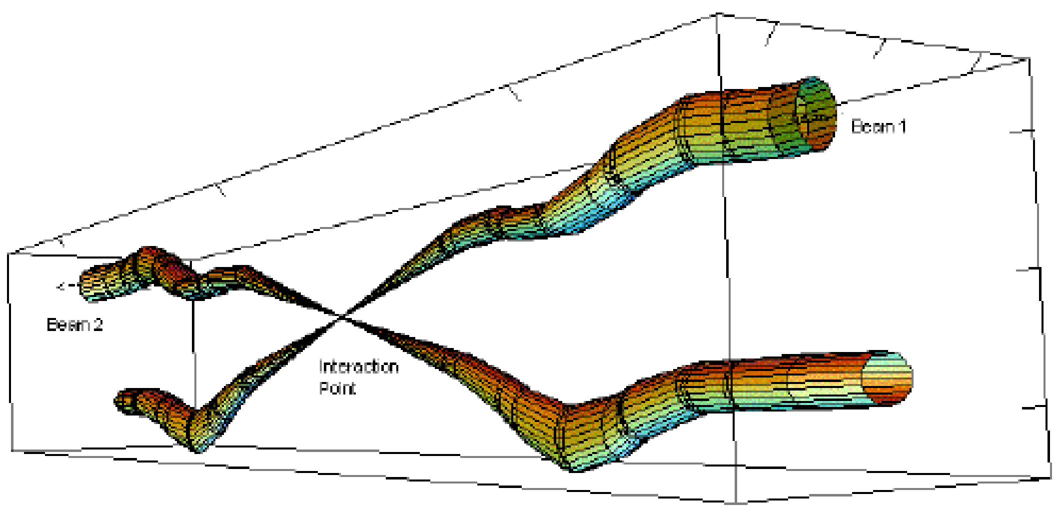
Interaction Regions β* and F in 2010

- Lower energy means bigger beams $\varepsilon_n = \varepsilon\gamma$ $\sigma = \sqrt{\varepsilon\beta}$
  - At max
  - Less aperture margin
  - Higher β* (lower β^{peak})
- > 150 bunches requires crossing angle (beam-beam)
  - Requires more aperture
  - Higher β*

- Targets for 3.5TeV
  - 2m without/with crossing angle in 2010
  - 2m with crossing angle in 2011

Interaction Region - F





Relative beam sizes around IP1 (Atlas) in collision

With > 150 bunches per beam, need a crossing angle to avoid parasitic collisions

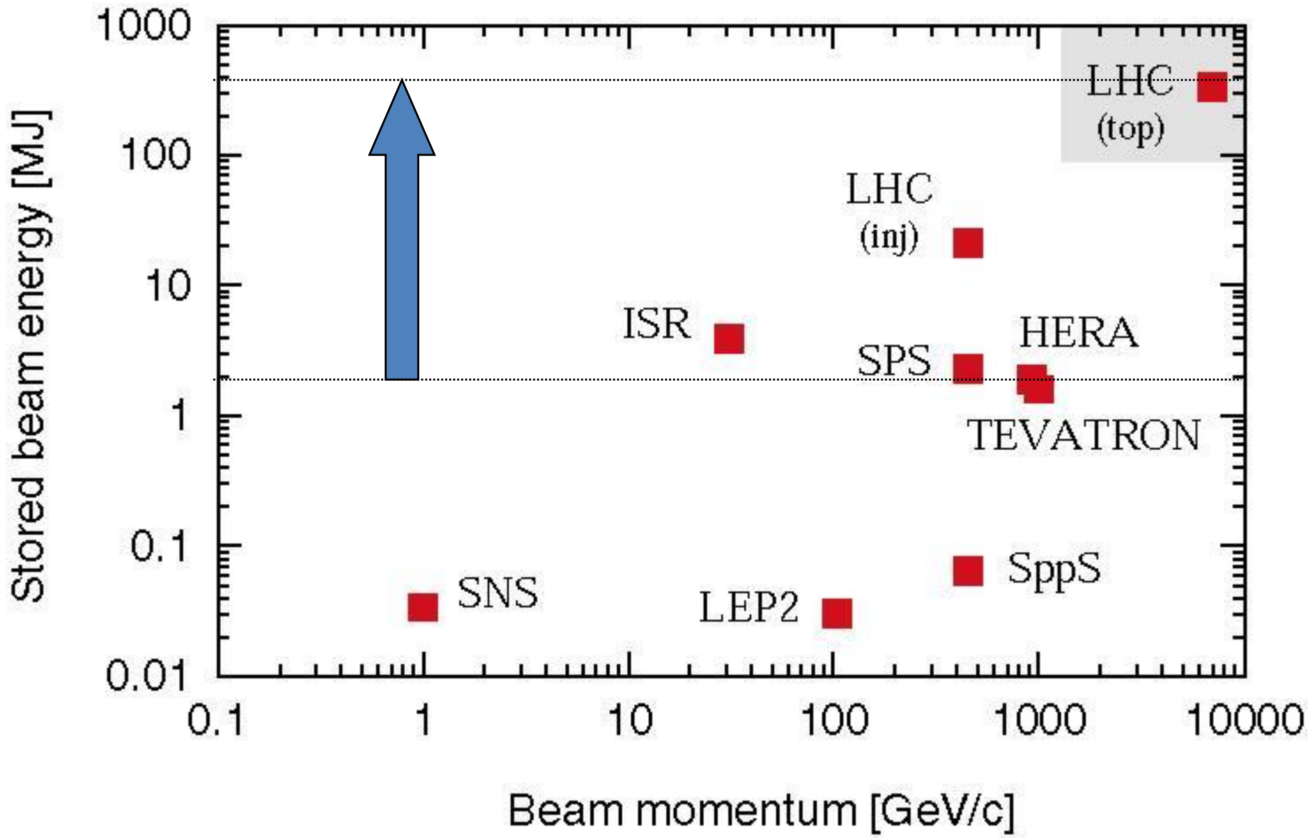
Machine Protection Strategy for intensity increase

Presentation (Jorg Wenninger) to LMC on 17 February

Or **Why are we so diligent about increasing the LHC intensity?**

The Energy of the LHC beams

Nominal LHC design: 3×10^{14} protons accelerated to 7 TeV/c circulating at 11 kHz in a SC ring

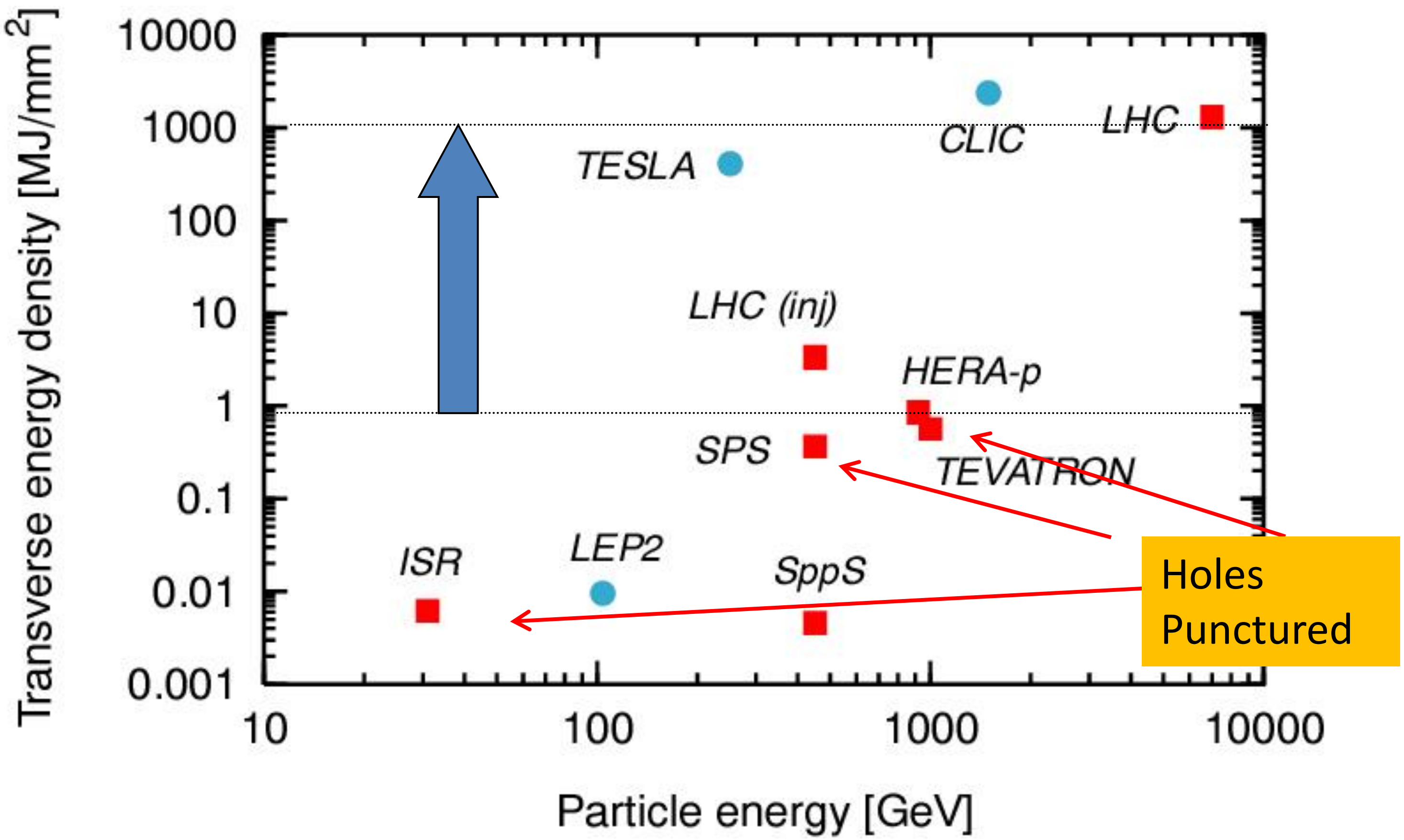


At less than 1% of nominal intensity LHC enters new territory. Collimators must survive expected beam loss…

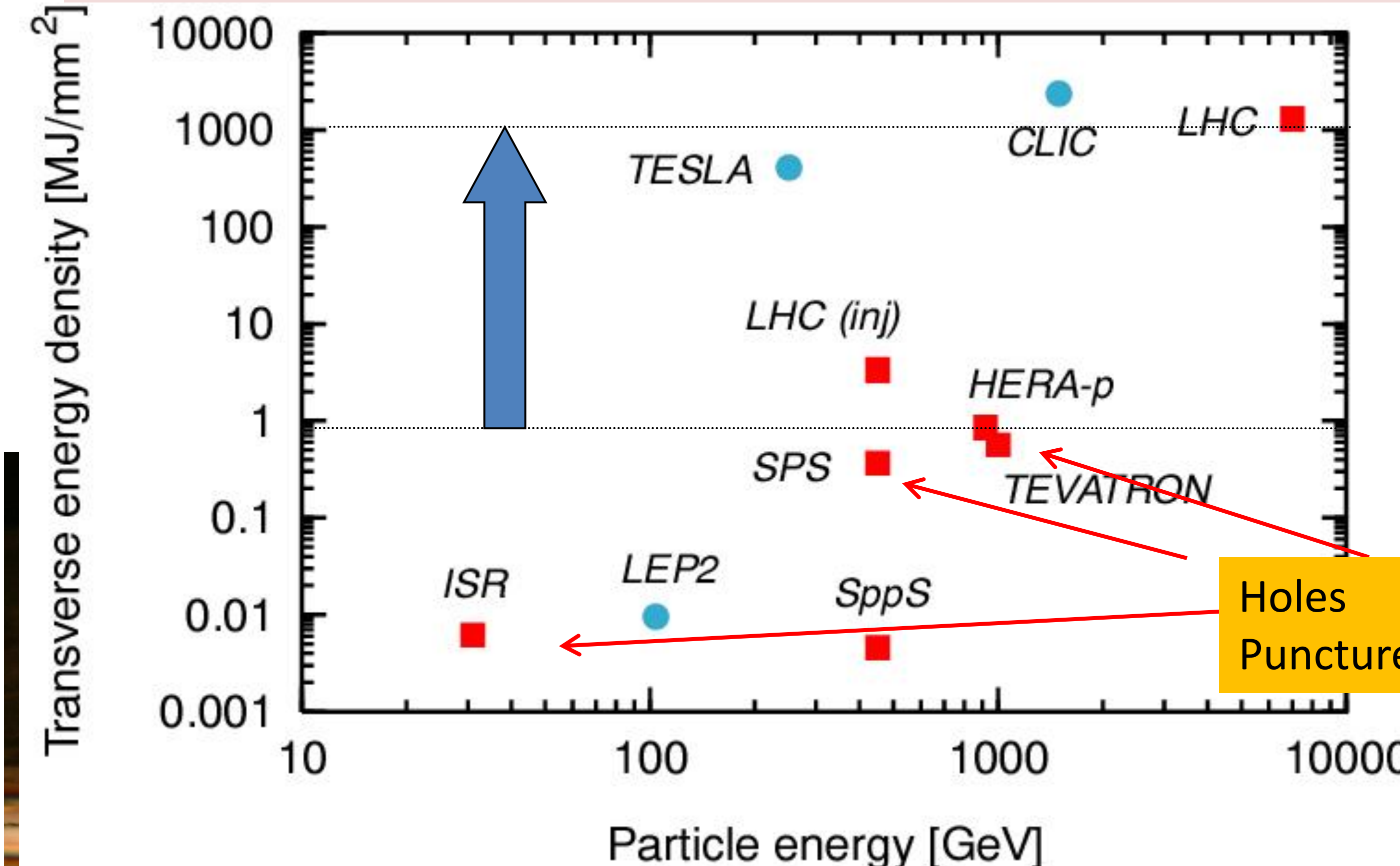
The Energy Density of the LHC beams

Transverse energy density is a measure of damage potential …

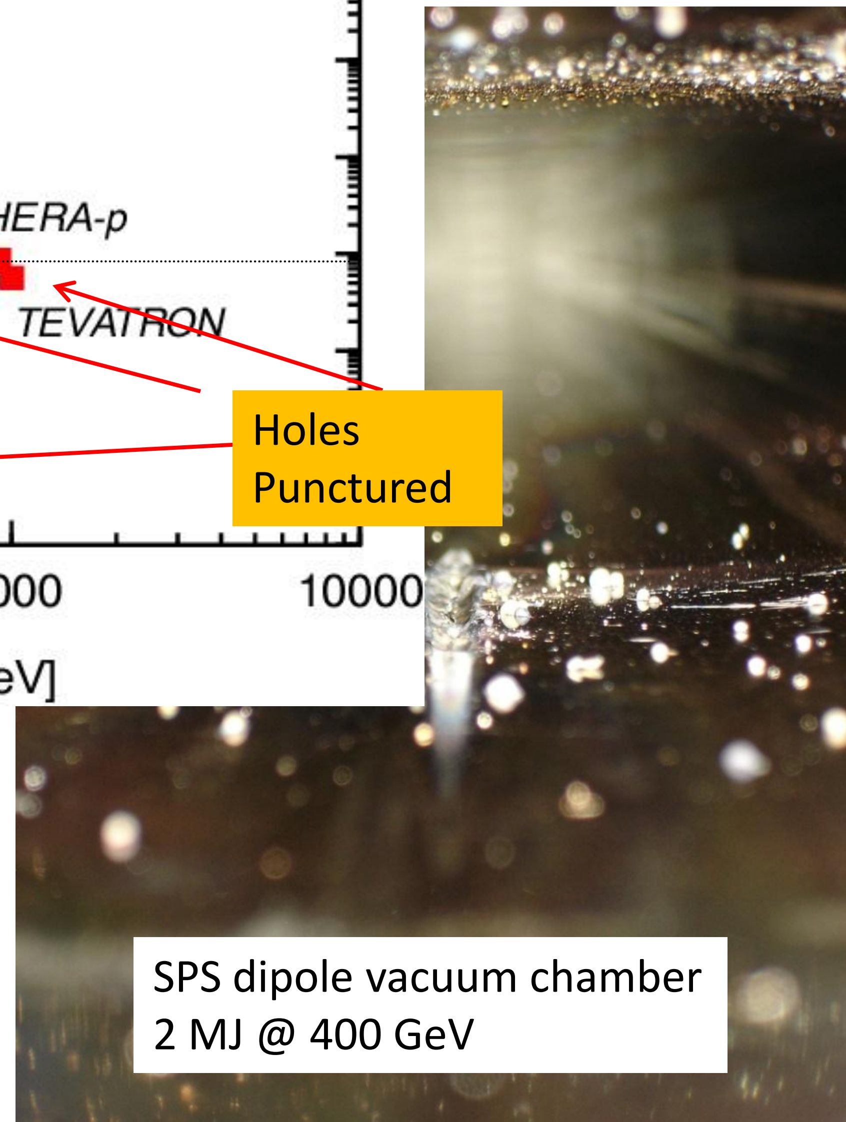
… AND proportional to luminosity!



In terms of damage potential, LHC advances the state of the art by 3 orders of magnitude!



TT40 transfer line quadrupole vac. chamber
2.2 MJ @ 450 GeV



SPS dipole vacuum chamber
2 MJ @ 400 GeV

Strategy for Increasing the Beam Intensity

- The magic **number for 2010/11 is 1 fb^{-1}**. To achieve this, the LHC must run flat out at 1-2x10^{32} $cm^{-2}s^{-1}$ in 2011,
  - Correspond to 8e10 ppb, 700 bunches, with a stored energy of 35 MJ (with β^*=2 m and nominal emittance).

Intensity increase – Strategy

- Maximum intensity increase versus stored energy:
  - Up to 0.25 MJ typical factor ~2, max 4
  - Up to 1-2 MJ max. factor ~2
  - Above 1-2 MJ ≤ ~2 MJ per step

"Old Predictions" 2010

Step	E [TeV]	Fill scheme	N	β* [m] IP1 / 2 / 5 / 8	Run time (indicative)
1	0.45	2x2	5×10^{10}	11 / 10 / 11 / 10	Weeks
2	3.5	2x2	$2 - 5 \times 10^{10}$	11 / 10 / 11 / 10	
3	3.5	2x2*	$2 - 5 \times 10^{10}$	2 / 10 / 2 / 2	
4	3.5	43x43	5×10^{10}	2 / 10 / 2 / 2	Weeks/Months
5	3.5	156x156	5×10^{10}	2 / 10 / 2 / 2	
6	3.5	156x156	9×10^{10}	2 / 10 / 2 / 2	Months
7	3.5	50 ns - 144**	7×10^{10}	2.5 / 3 / 2.5 / 3	
8	3.5	50 ns - 288	7×10^{10}	2.5 / 3 / 2.5 / 3	
9	3.5	50 ns - 720	7×10^{10}	2.5 / 3 / 2.5 / 3	Months

Now under revision since we collided 1e11

* Turn on crossing angle at IP1.

**Turn on crossing angle at all IPs.

One month: 720 bunches of 7 e10 at beta* = 2.5 m. gives a peak luminosity of 1.3 e32 $cm^{-2}s^{-1}$ and an integrated of about 85 pb^{-1} per month

"Old Predictions" 2011

3.5 TeV: run flat out at ~100 pb^{-1} per month

	No. bunches	ppb	Total Intensity	Beam Stored Energy (MJ)	beta*	Peak Lumi	Int Lumi per month [pb^{-1}]
50 ns	432	7 e10	3 e13	17	2	1.3 e32	~85
Pushing intensity limit	720	7 e10	5.1 e13	28.2	2	2.2 e32	~140
Pushing bunch current limit	432	11 e10	4.8 e13	26.6	2	3.3 e32	~209

Also being updated

With these parameters we should be able to deliver 1 fb^{-1}

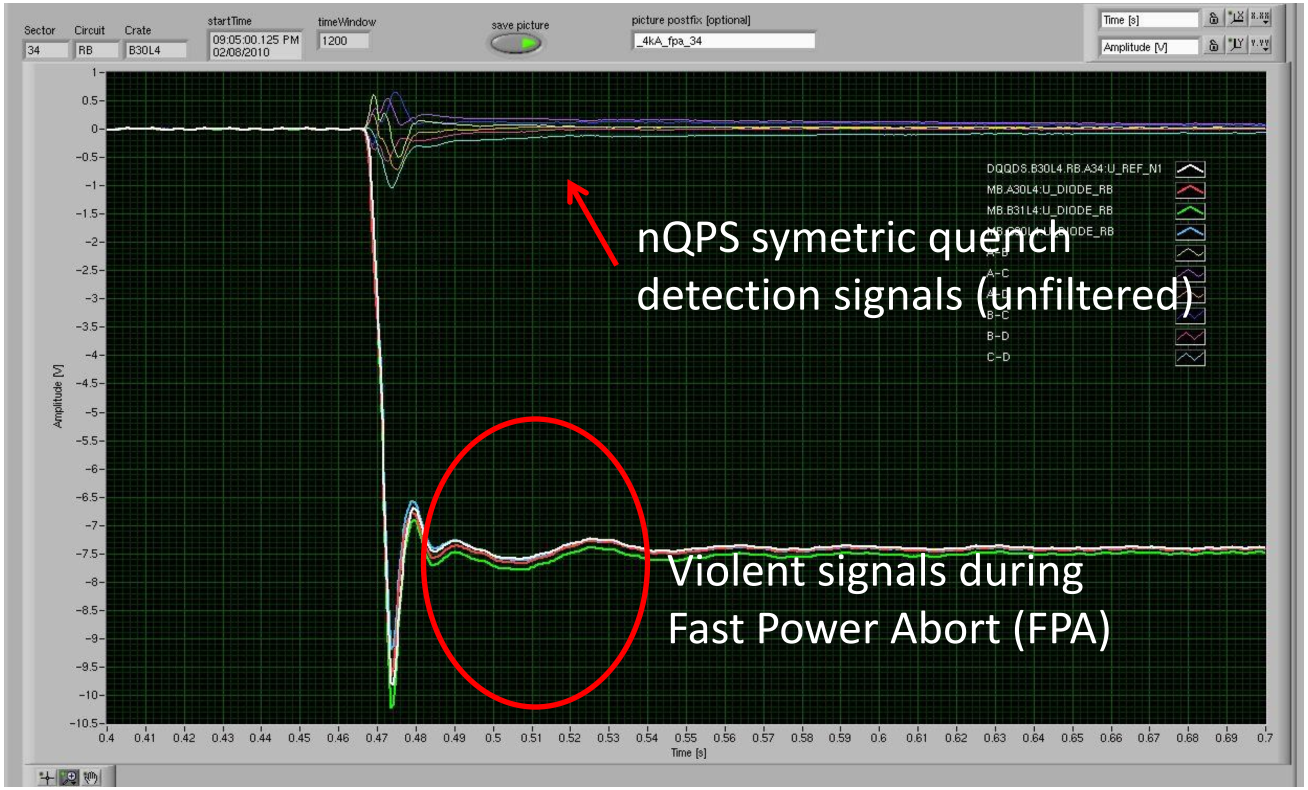
Thank You

Electromagnetic transient along the dipole magnet string

Problem A (50 magnet quench problem): when switching off the power converter for the main dipole magnets at full voltage and later opening the energy extraction switches, an electromagnetic transient along the magnet string triggers detectors of the new quench detection system. The voltage difference for adjacent magnets exceeds the threshold of 200mV and fires heaters. This led to the quench of 50 magnets on 24/2/2010.

Problem B (11 magnet quench problem): when switching off the power converter at full voltage and at the same time opening the energy extraction switches during a ramp down, an electromagnetic transient along the magnet string triggers detectors of the existing quench detection system. The voltage difference for the two apertures in one magnet exceeds the threshold of 100mV and fires the heaters. This led to the quench of 11 magnets on 4/3/2010.

Impact of EM Transients from Power Converters and Energy Extraction on Quench Detection

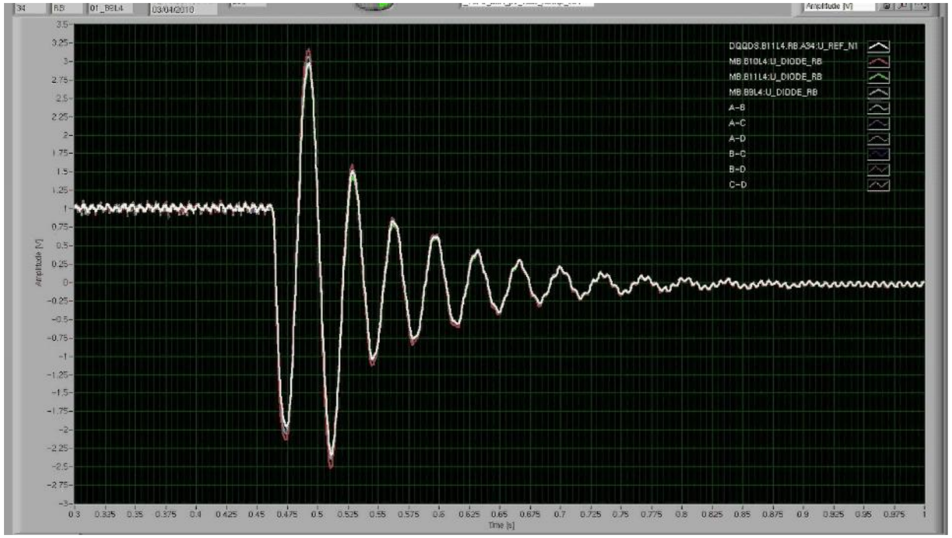


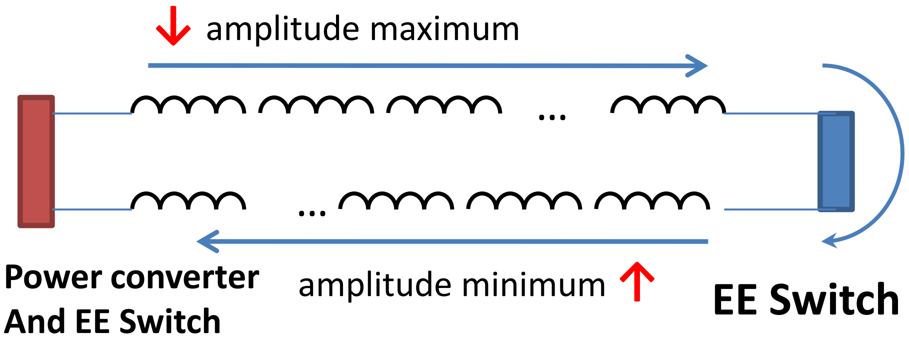
The adaptive filter was implemented in new QPS to cope with transient signals during Fast Power Abort, preventing spurious firing of quench heaters

➔Elevate threshold for 1300ms after fast power abort to ignore the spike

➔Rearm condition: all voltages of the detector > 0V i.e. during next powering cycle

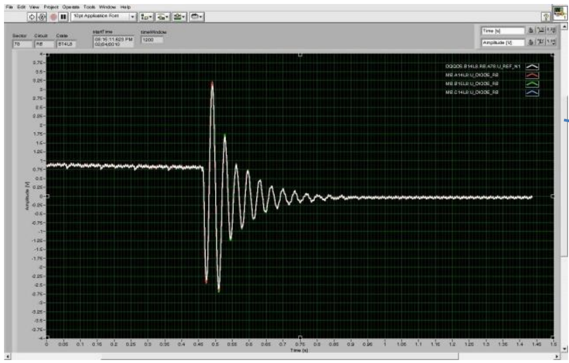
Oscillations along the magnet string due to Power Converter switch-off during ramping

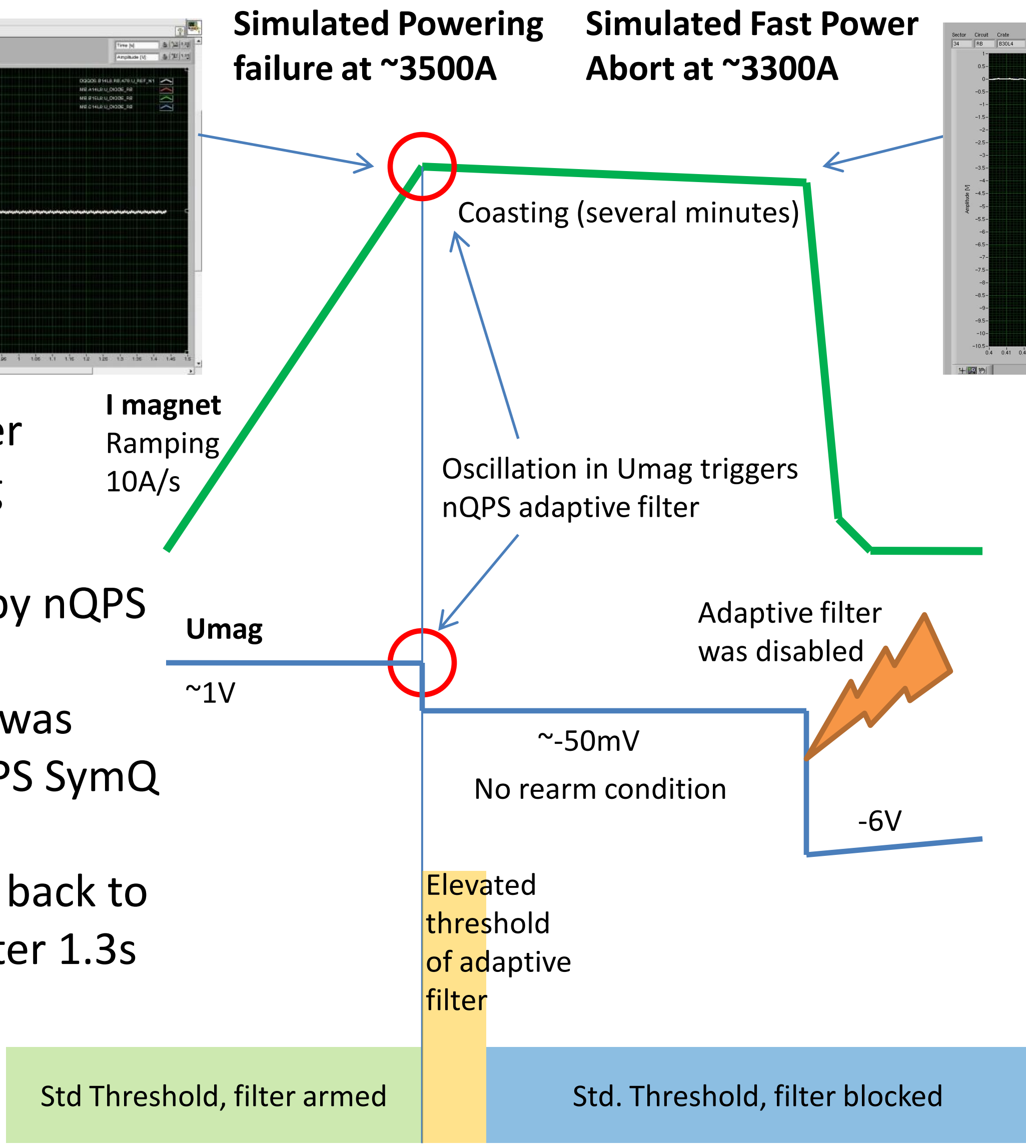




- The new QPS acquisition allowed for the first time to record and measure the waves created by a power converter during its emergency switch-off
- Amplitudes of the oscillations are particularly high if power converter is switched-off during ramping up or ramping down the current
- Oscillations influence the proper functionality of the new QPS symmetric quench detection adaptive filter
- Power Converter oscillations superposed with Fast Power Abort perturbations can trigger the old QPS as well

Event of Feb-24 at 3.5kA
Quench heaters of 50 dipoles fired after FPA





- Power converter switch-off during ramping causes oscillation seen by nQPS
- Adaptive filter was activated for nQPS SymQ of 50 dipoles
- Filter switched back to std. threshold after 1.3s and was blocked

- At Fast Power Abort filter was not available (threshold stayed low)

→ **nQPS SymQ triggered heaters in 50 dipoles**

Mitigation

- Both, power converter and energy extraction EM transients are now well investigated and understood
- Two “side effects” of the EM transients were observed:
  - Symmetric quench detector can fire heaters on multiple transients
  - Old QPS can fire heaters due to superposition of transients
- Symmetric quench detector vulnerability can be treated by raising the threshold (at 6 kA still well within the protection margins)
  - 436 controllers storing the device parameters need to be re-programmed
- Old QPS triggering can be mitigated by delaying the energy extraction switches