Status of the LHC Machine

Steve Myers

(on behalf of the LHC team)

RRB 19th April, 2010

Topics

1. 2010 Technical Stop
2. Beam Operation March-April 2010
3. First Collisions at 7TeV cm March 30, 2010
4. Where we are “today”
5. Strategy for Performance Evolution 2010-2011

Technical Stop and Hardware Commissioning in January-February 2010

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)

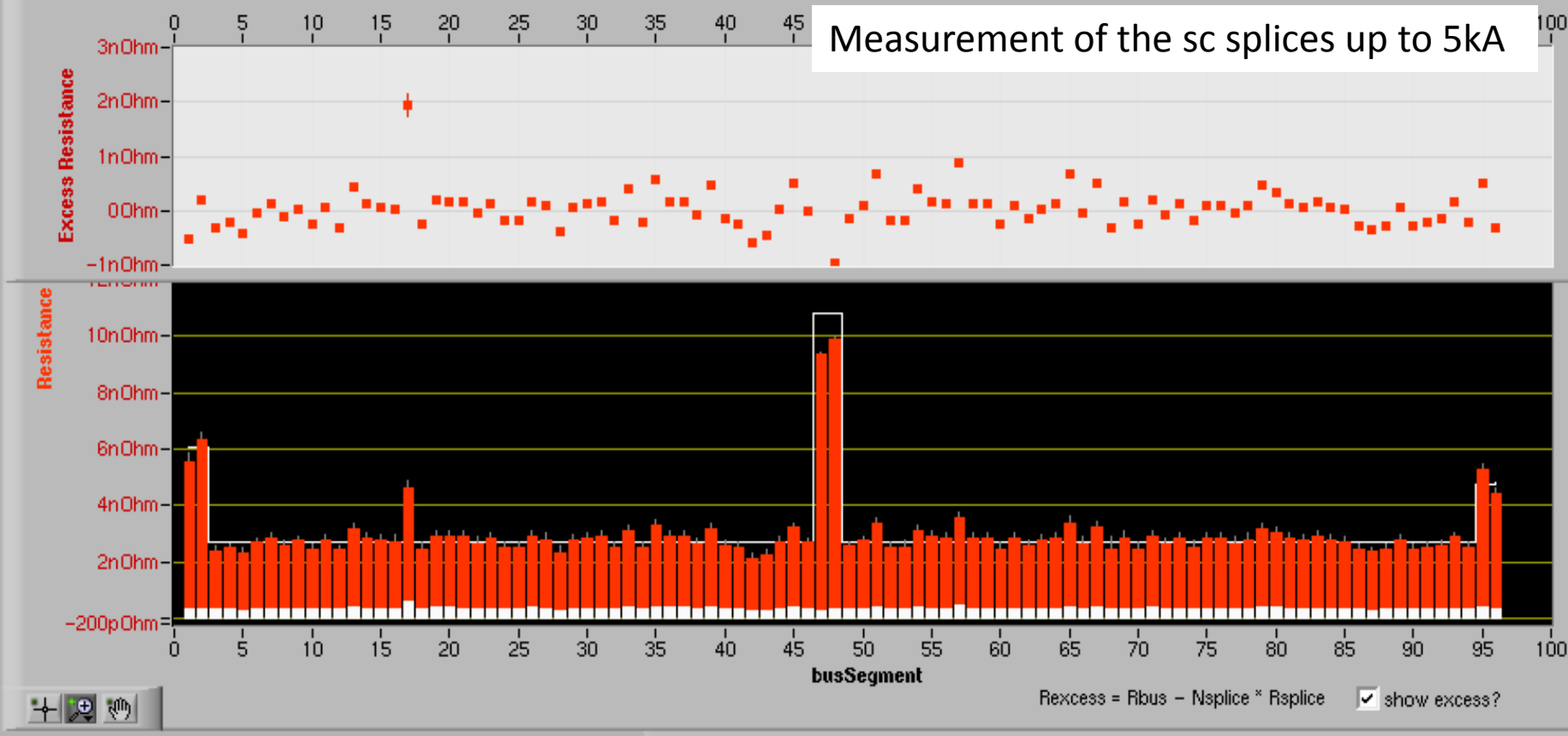
S12: RQF and RQD pyramids to 2kA and 5kA

A12_RQDRQF_20100206_130000-185959.data

Bus Splices

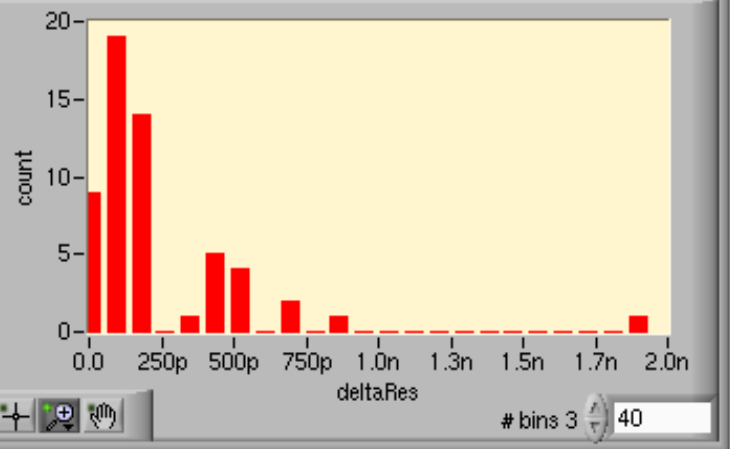
CLOSE

Measurement of the sc splices up to 5kA



busSegmentResistanceSorted

	signalName	spliceNum	resistance	deltaRes
1	DCQDQ.12L2.R	18	5.57E-9	2.76E-10
2	DCQFQ.12L2.L	18	6.31E-9	2.81E-10
3	DCQDQ.14L2.R	8	2.38E-9	1.76E-10
4	DCQFQ.14L2.L	8	2.49E-9	1.80E-10
5	DCQDQ.16L2.R	8	2.30E-9	1.79E-10
6	DCQFQ.16L2.L	8	2.68E-9	1.89E-10
7	DCQDQ.18L2.R	8	2.84E-9	1.89E-10
8	DCQFQ.18L2.L	8	2.60E-9	1.80E-10

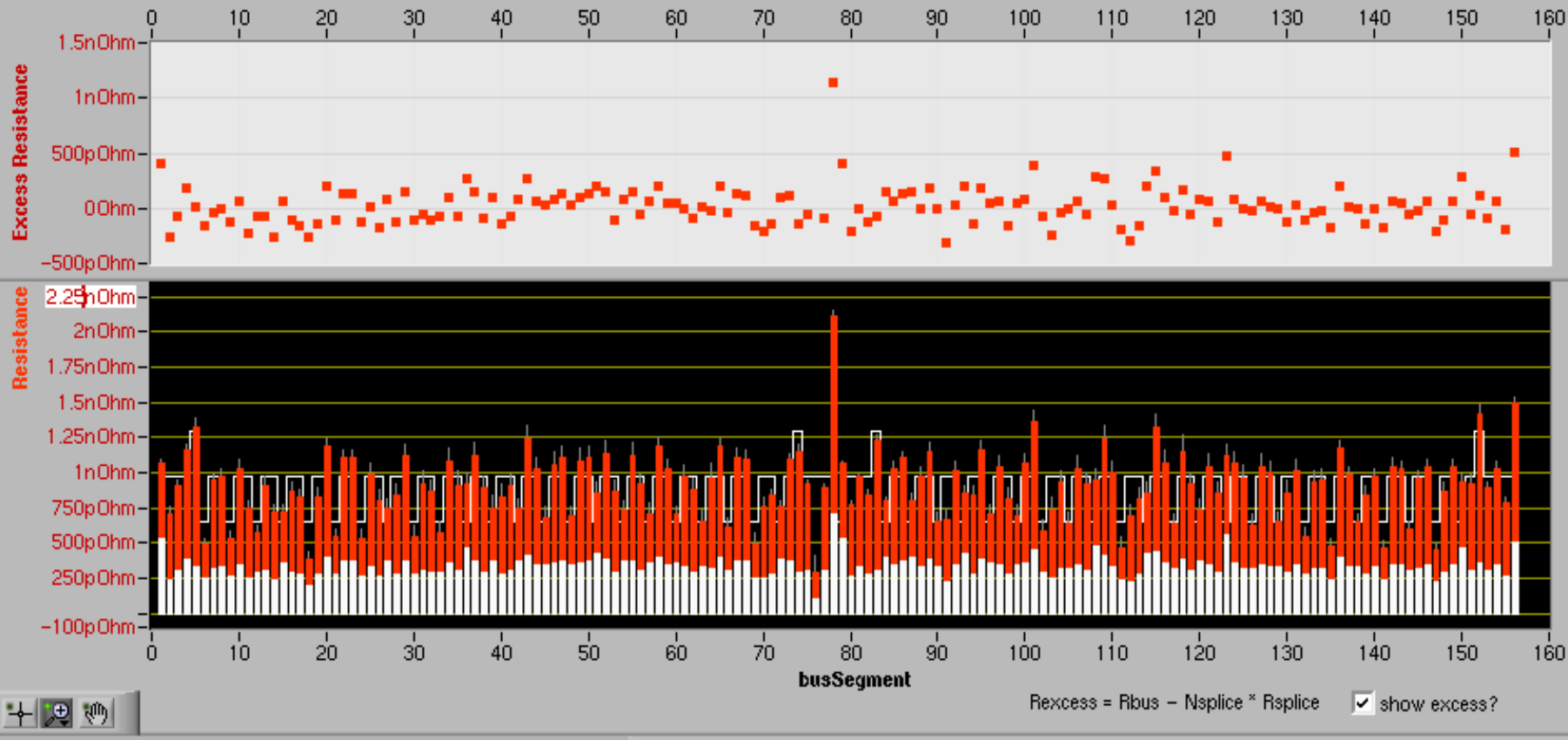


excess

A12_RB_20100205_100000-155959.data

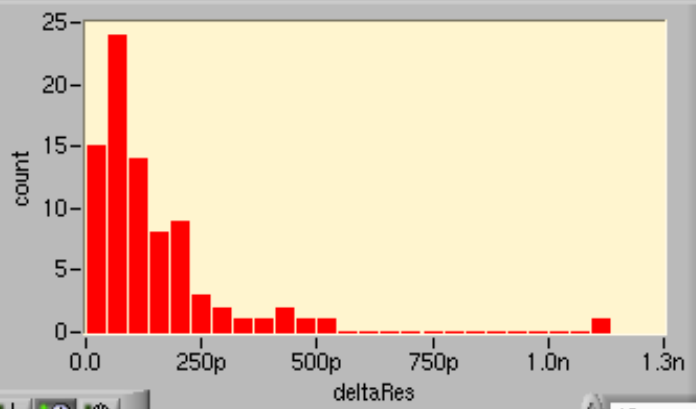
Bus Splices

CLOSE



busSegmentResistanceSorted

	signalName	spliceNum	resistance	deltaRes
1	DCBB.8L2.R	2	1.06E-9	2.89E-11
2	DCBB.9L2.R	3	7.10E-10	4.50E-11
3	DCBB.10L2.R	3	9.01E-10	4.57E-11
4	DCBB.11L2.R	3	1.16E-9	4.62E-11
5	DCBB.A12L2.R	4	1.32E-9	6.36E-11
6	DCBB.B12L2.R	2	4.86E-10	4.67E-11
7	DCBB.13L2.R	3	9.42E-10	5.62E-11
8	DCBB.A14L2.R	3	9.69E-10	5.61E-11



excess

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
  - di/dt of MB limited to 2 A/s in the meantime – system tested in this configuration

Beam Operation early in 2010

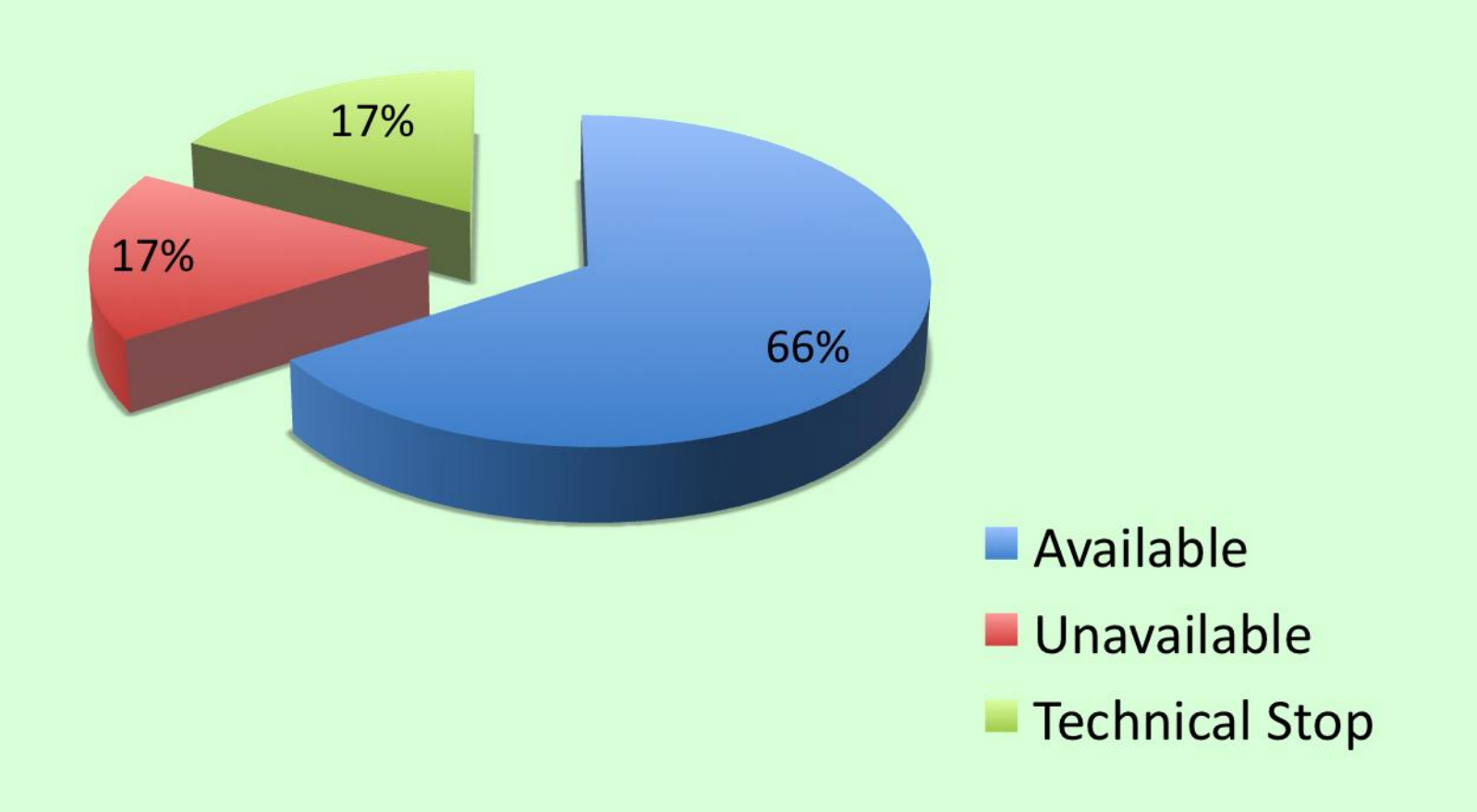
Beam milestones 2010

27th Feb	First injection
28th Feb	Both beams circulating
5th March	Canonical two beam operation
8th March	Collimation setup at 450 GeV
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 (1)

- 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.

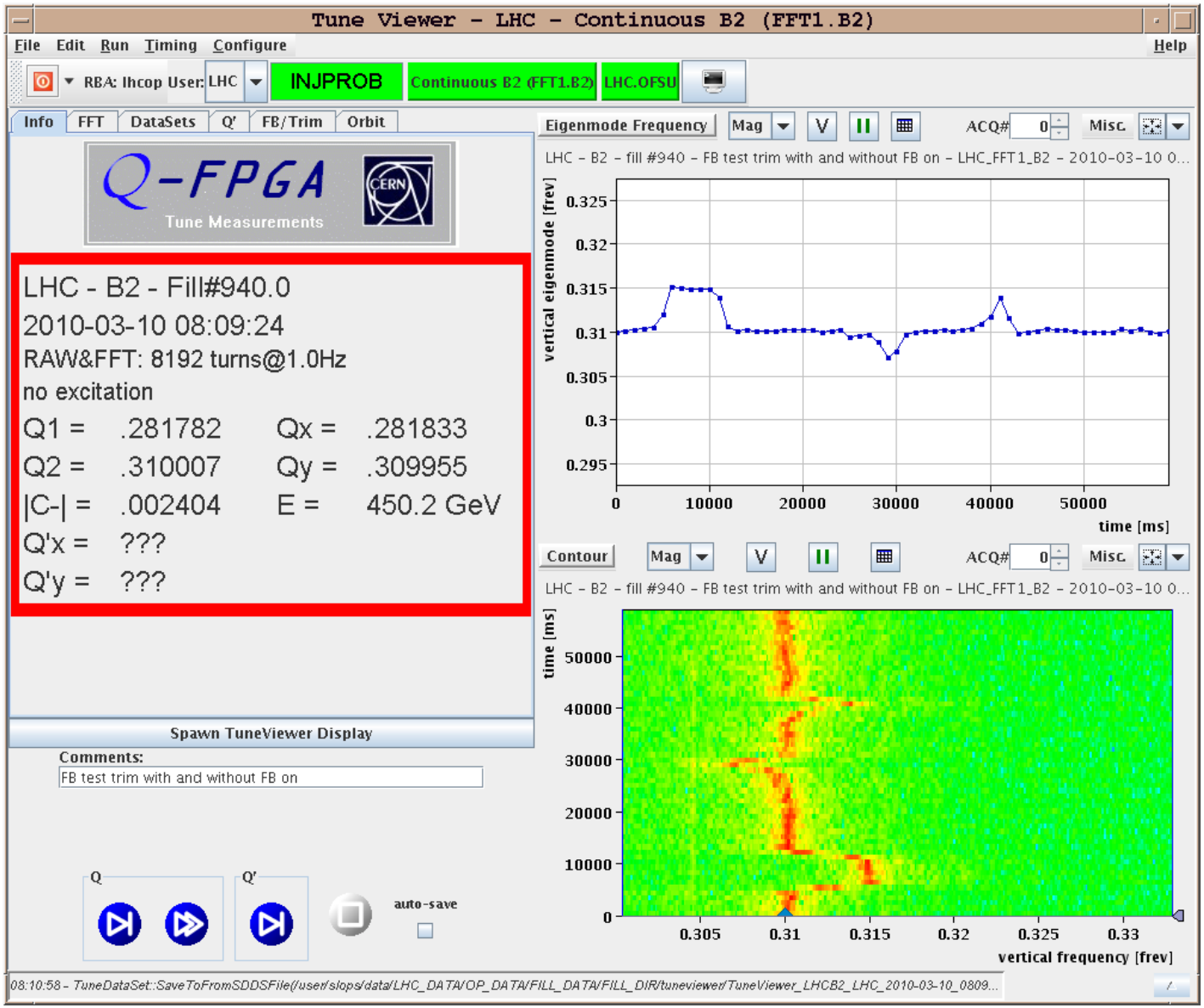
LHC Availability (Week 10)



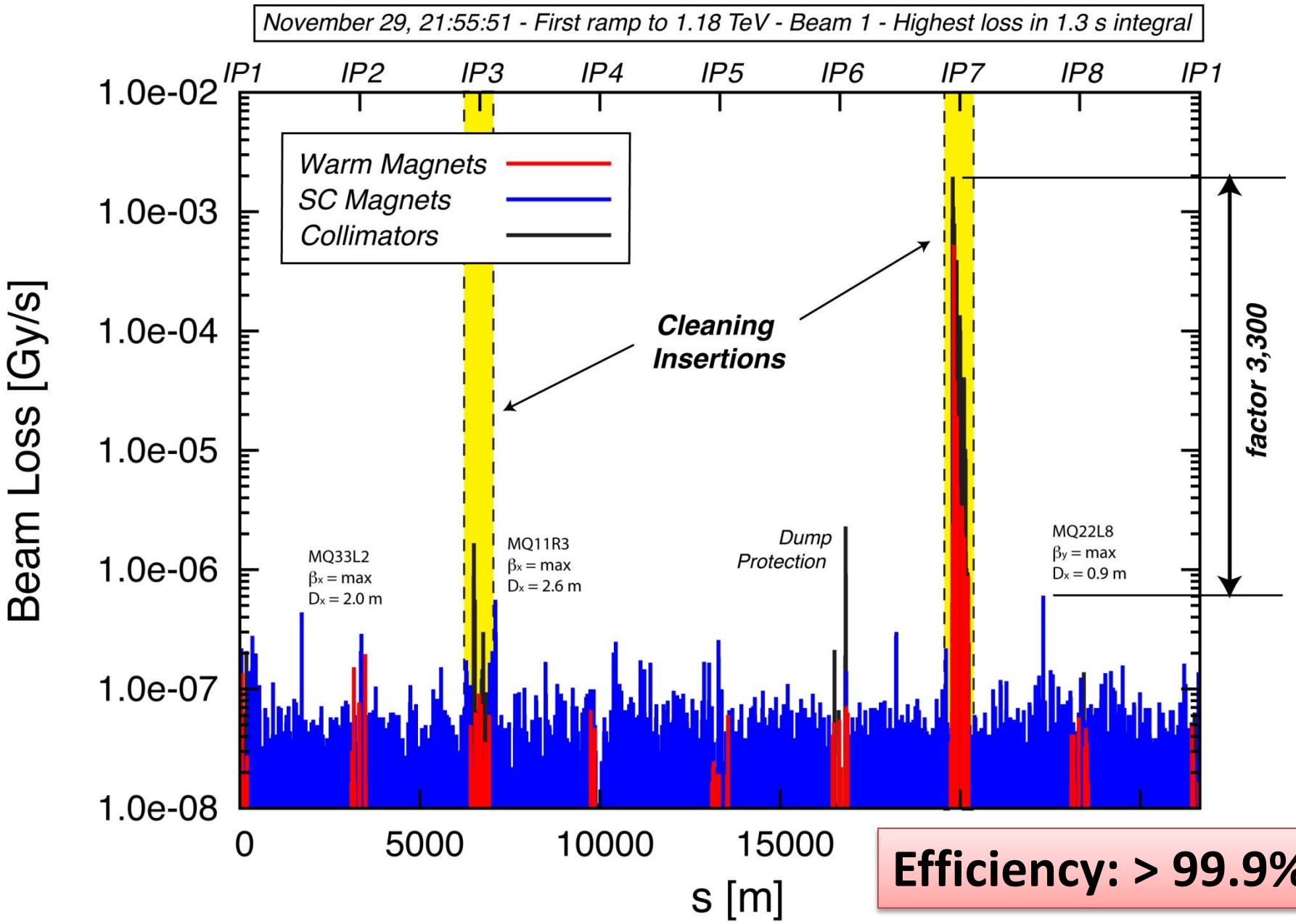
All technical systems contribute to very promising LHC availability!

One golden period for availability: Saturday-Sunday 13/14 March 24h00. 100% availability

Tune feedback



Collimation after beam based set up



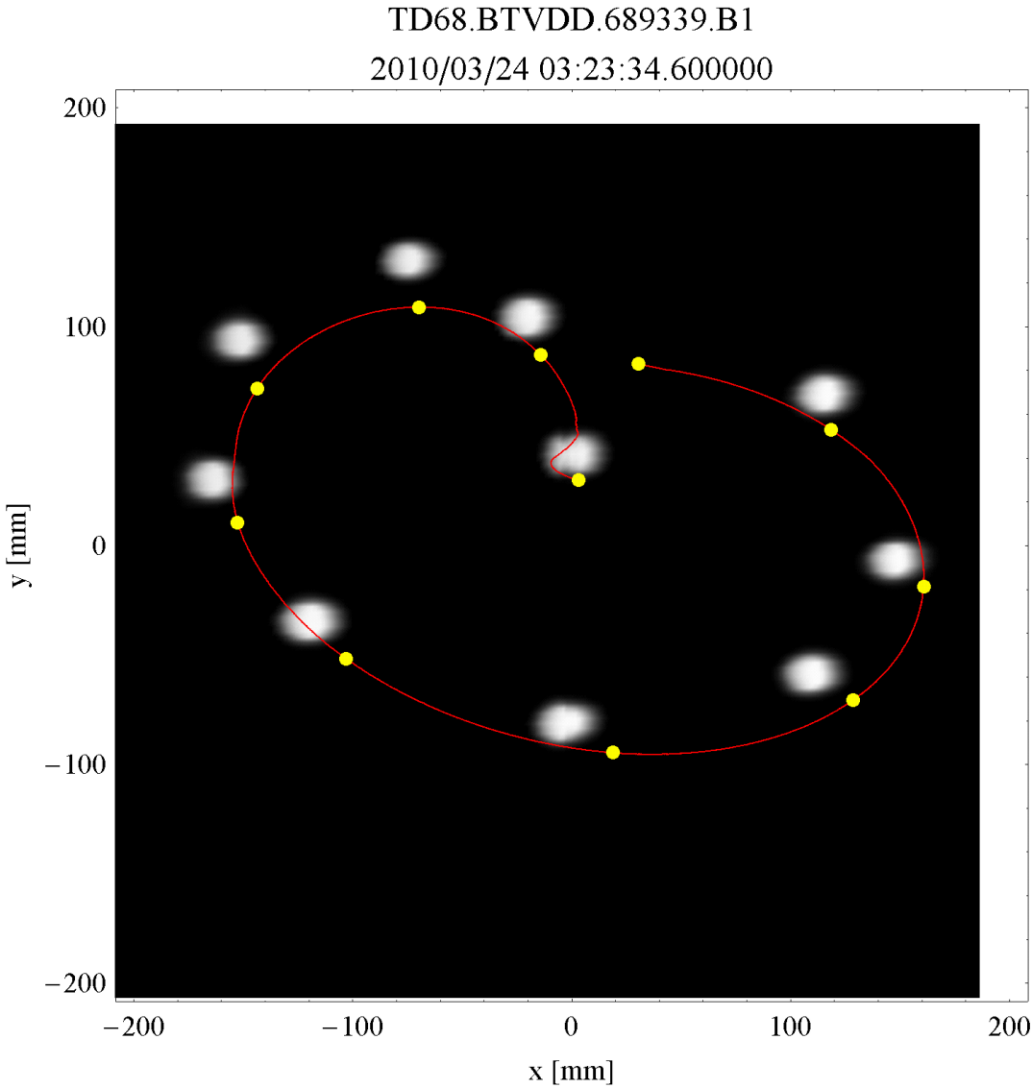
Efficiency: > 99.9%

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
- Huge parameter space, mistakes made, lessons learnt etc but…
- Tunes, energy matching, optics remarkably close to the model already
- Bodes very well for the future.

Beam dump

Beam dumping systems working very well
Systematic and very thorough testing and set-up in progress

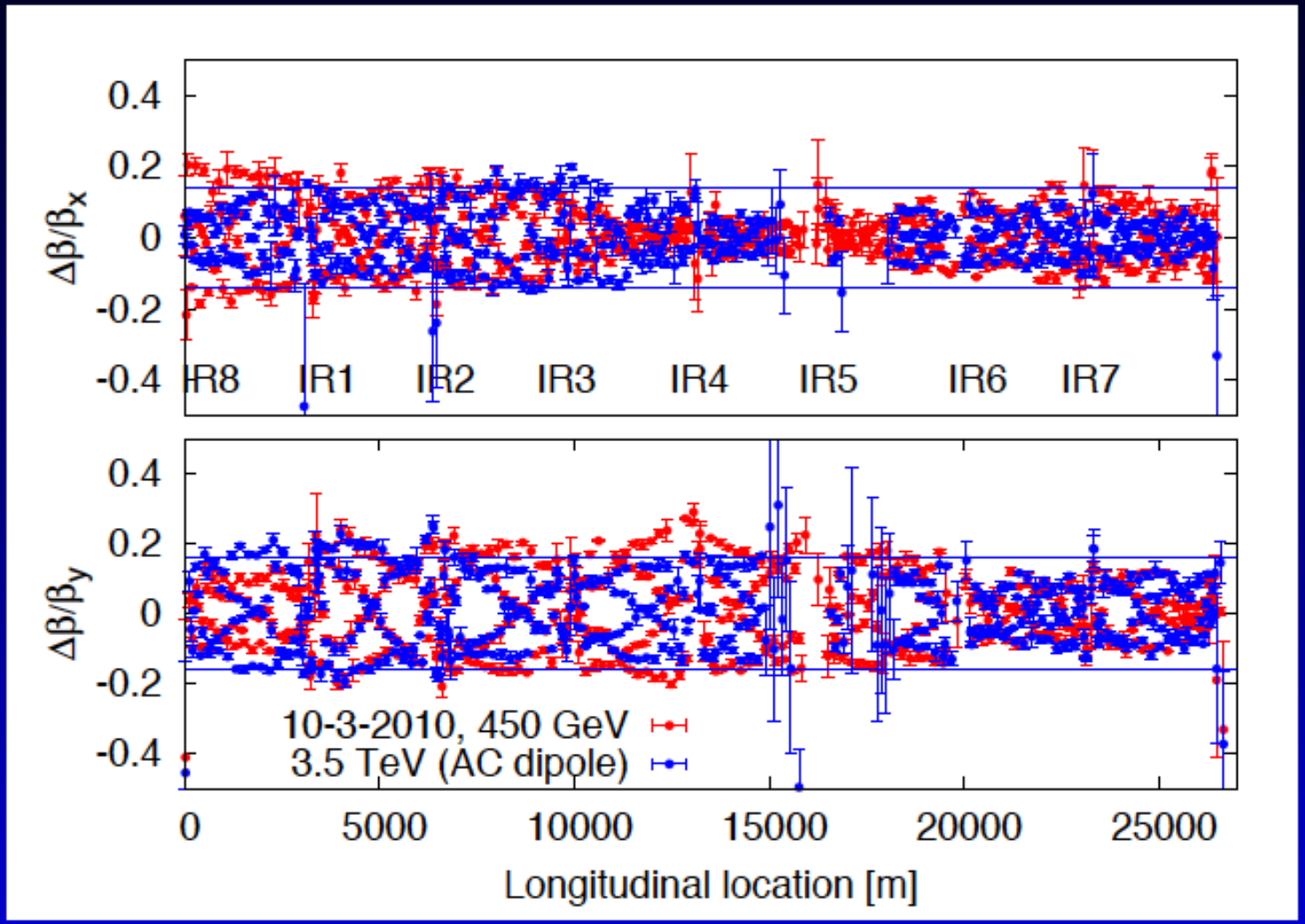


Collimation

Excellent initial beam based commissioning following careful preparation and tests

- Full program of beam based positioning
- System works as designed.
  - Expected cleaning and leakage processes seen.
- Possible to verify passive protection: losses at primary collimators.
- Hierarchy established and respected in tests
- Collimation setup remained valid over days, relying on orbit reproducibility and optics stability

Beam 2, 3.5 TeV beta-beating

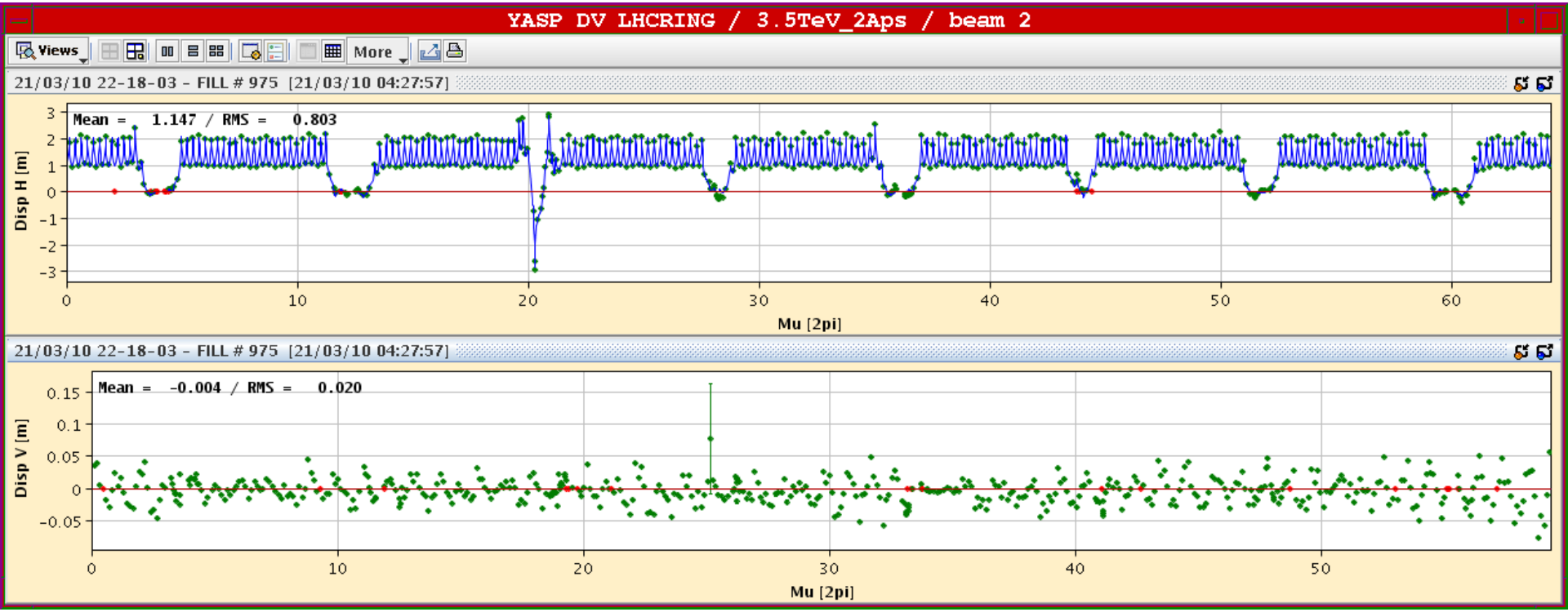


20% beating!

M. Aiba, R. Calaga, A. Franchi, R. Miyamoto, R. Tomás, G. Vanbavinckhove

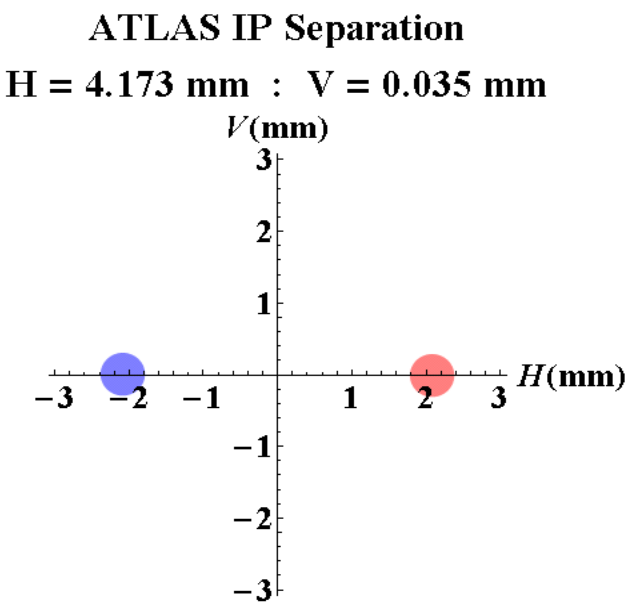
Dispersion

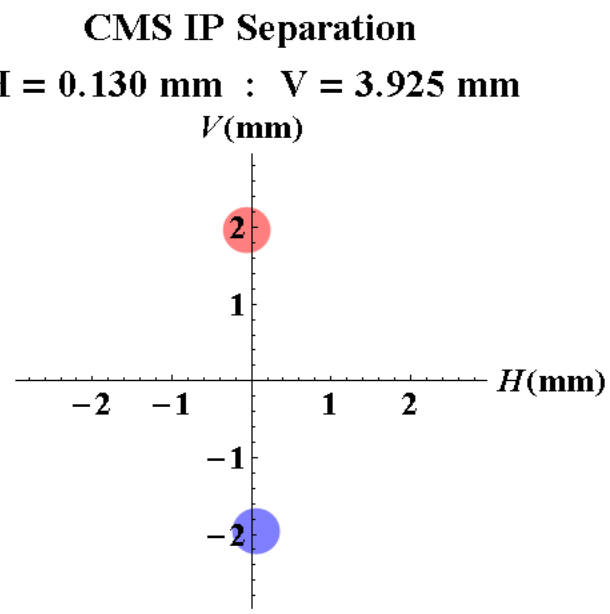
Dispersion B2 at 3.5 TeV

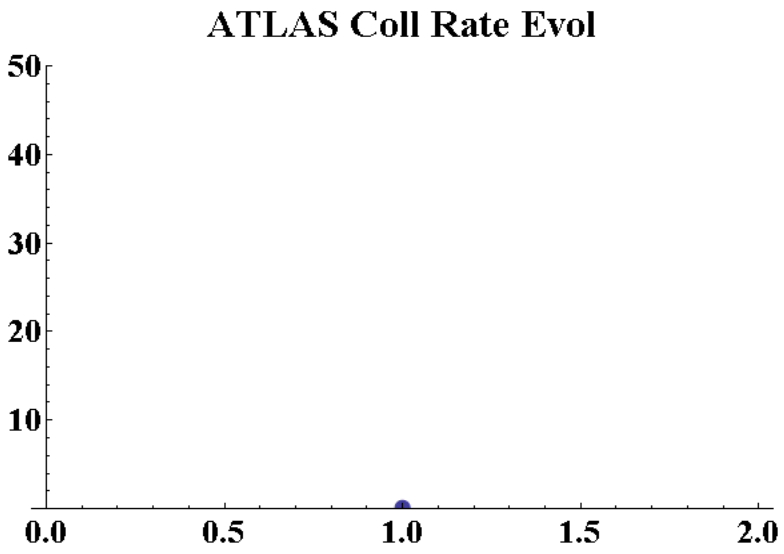


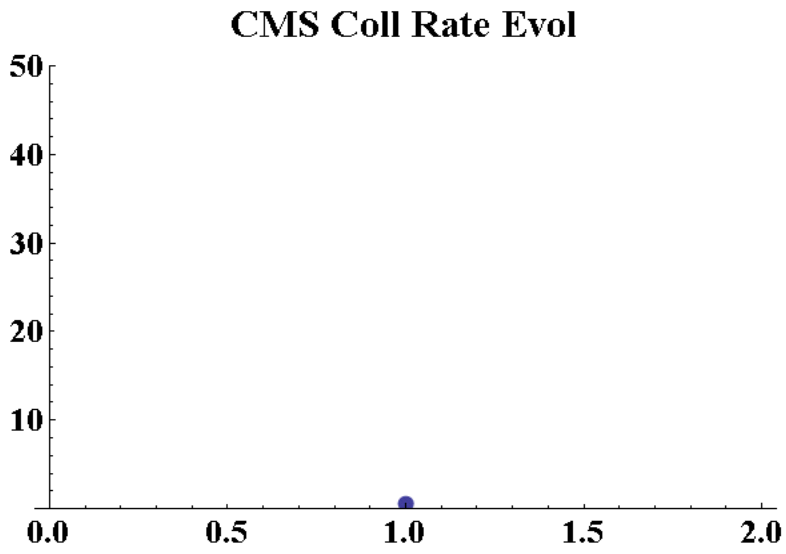
First Collisions at 7TeV cm
March 30, 2010

March 30 2010



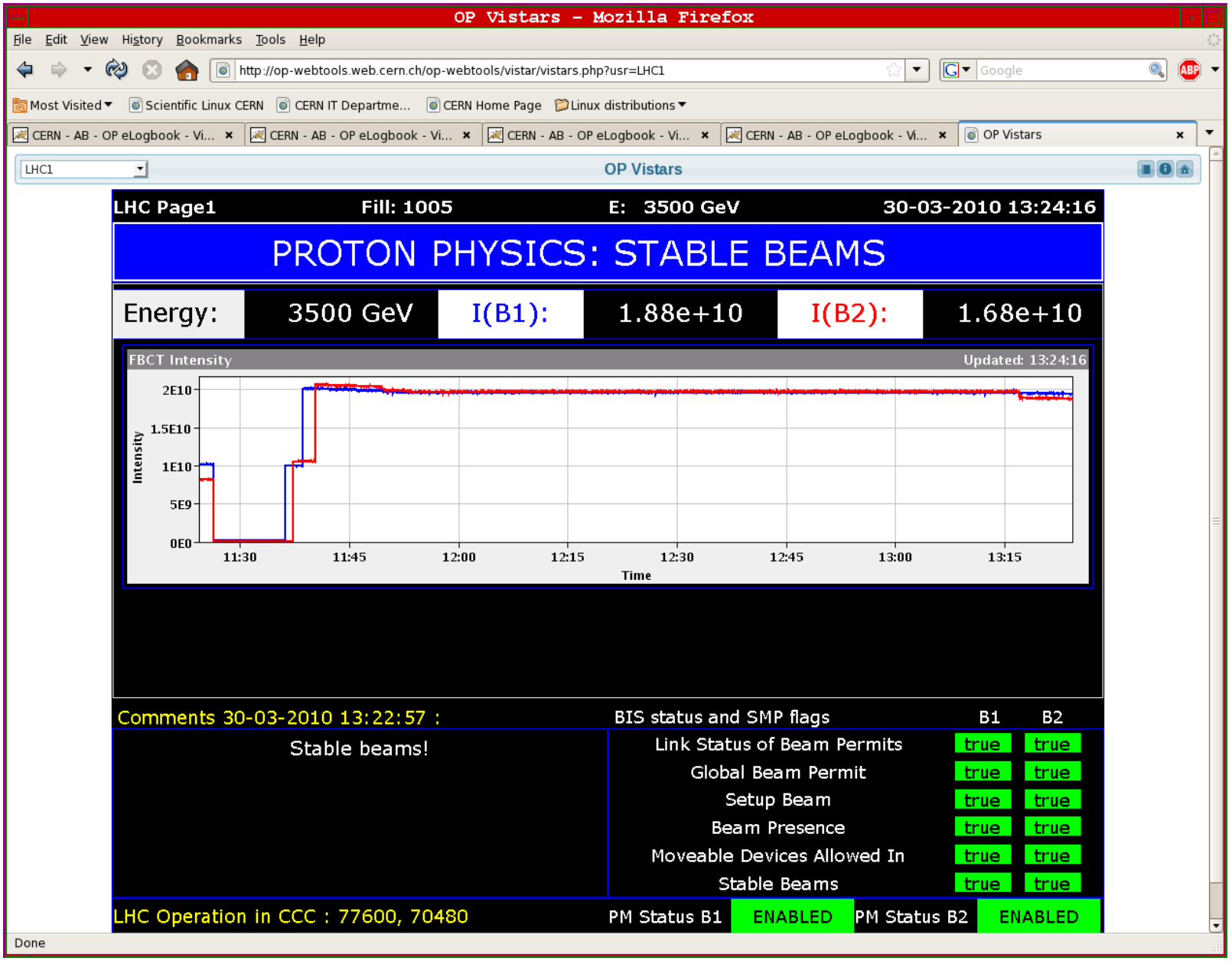






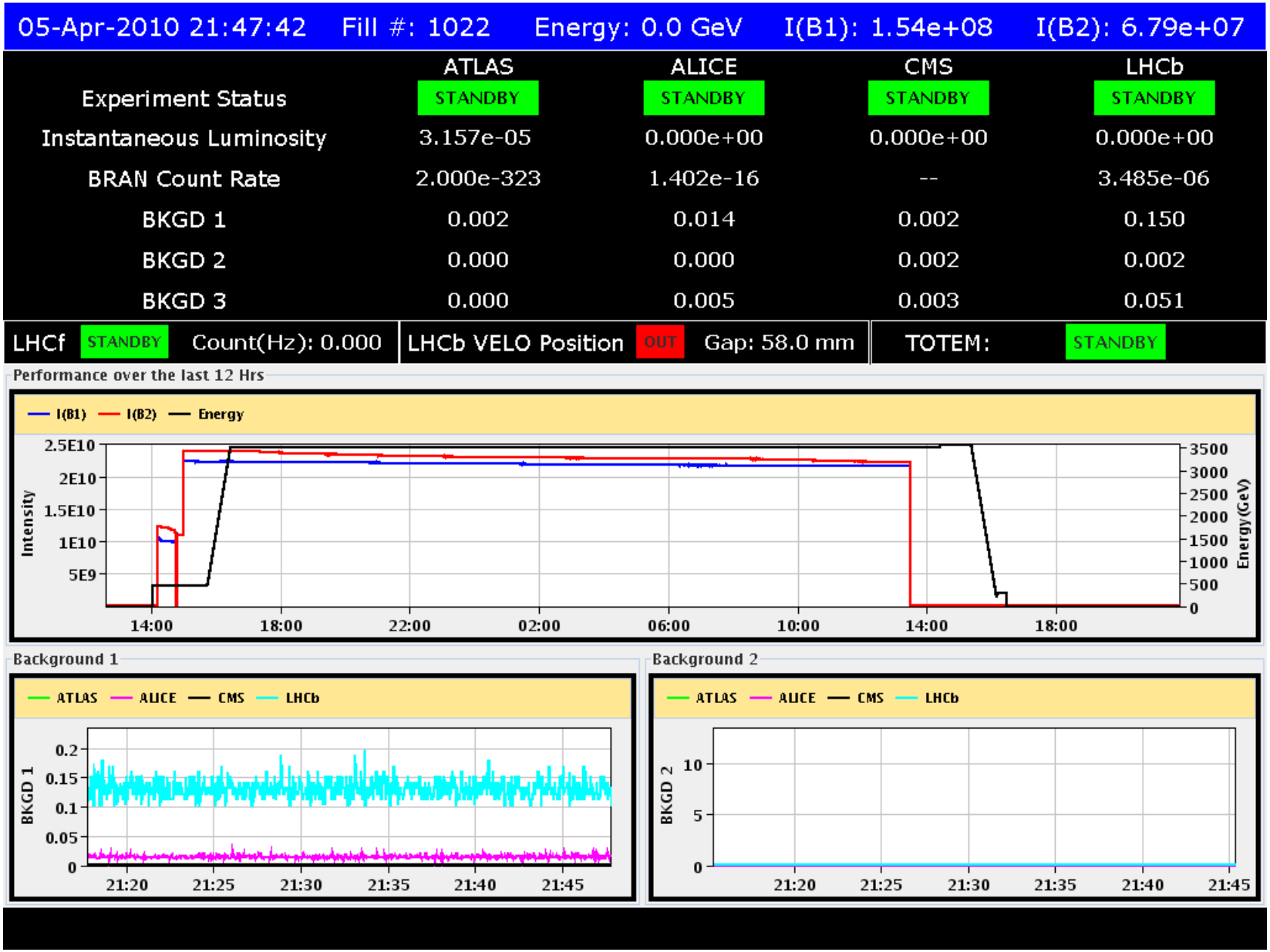
30/3/2010

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



Where we are “today”

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)

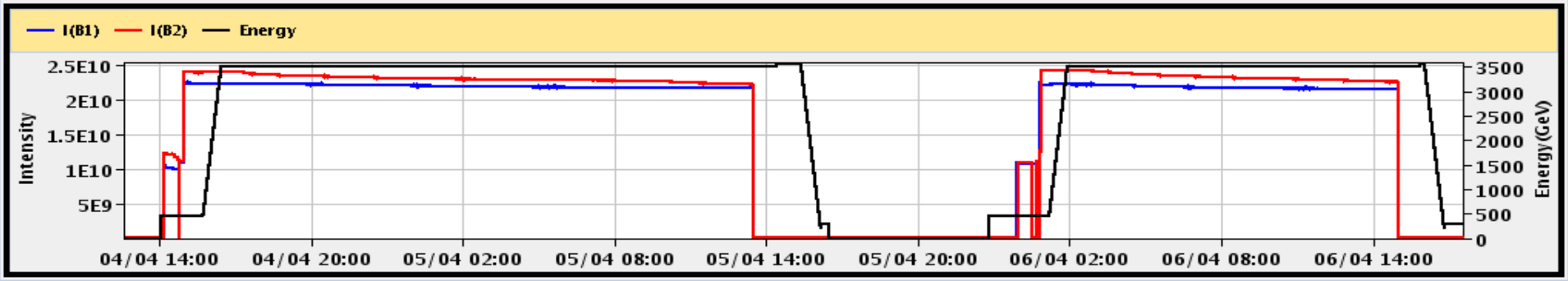
A very good 48 hour period!

06-Apr-2010 17:27:13 Fill #: 1023 Energy: 297.4 GeV I(B1): 1.55e+08 I(B2): 7.01e+07

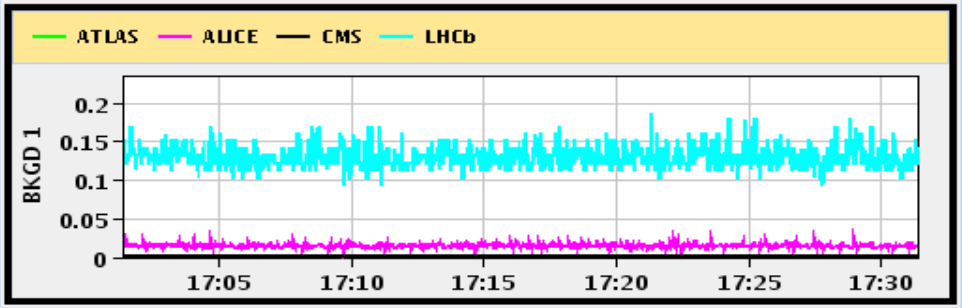
	ATLAS	ALICE	CMS	LHCb
Experiment Status	STANDBY	NOT READY	STANDBY	STANDBY
Instantaneous Luminosity	0.000e+00	0.000e+00	0.000e+00	8.989e-04
BRAN Count Rate	3.229e-07	4.059e-32	2.086e-11	1.635e-32
BKGD 1	0.002	0.014	0.002	0.131
BKGD 2	0.000	0.000	0.002	0.002
BKGD 3	0.000	0.005	0.003	0.037

LHCf STANDBY Count(Hz): 0.000 | LHCb VELO Position OUT Gap: 58.0 mm | TOTEM: CALIBRATION

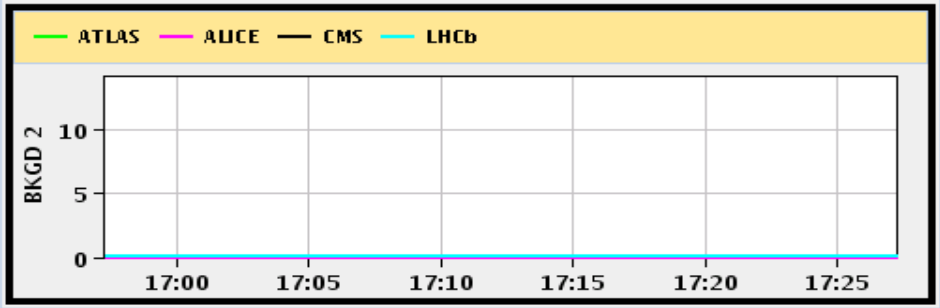
Performance over the last 12 Hrs



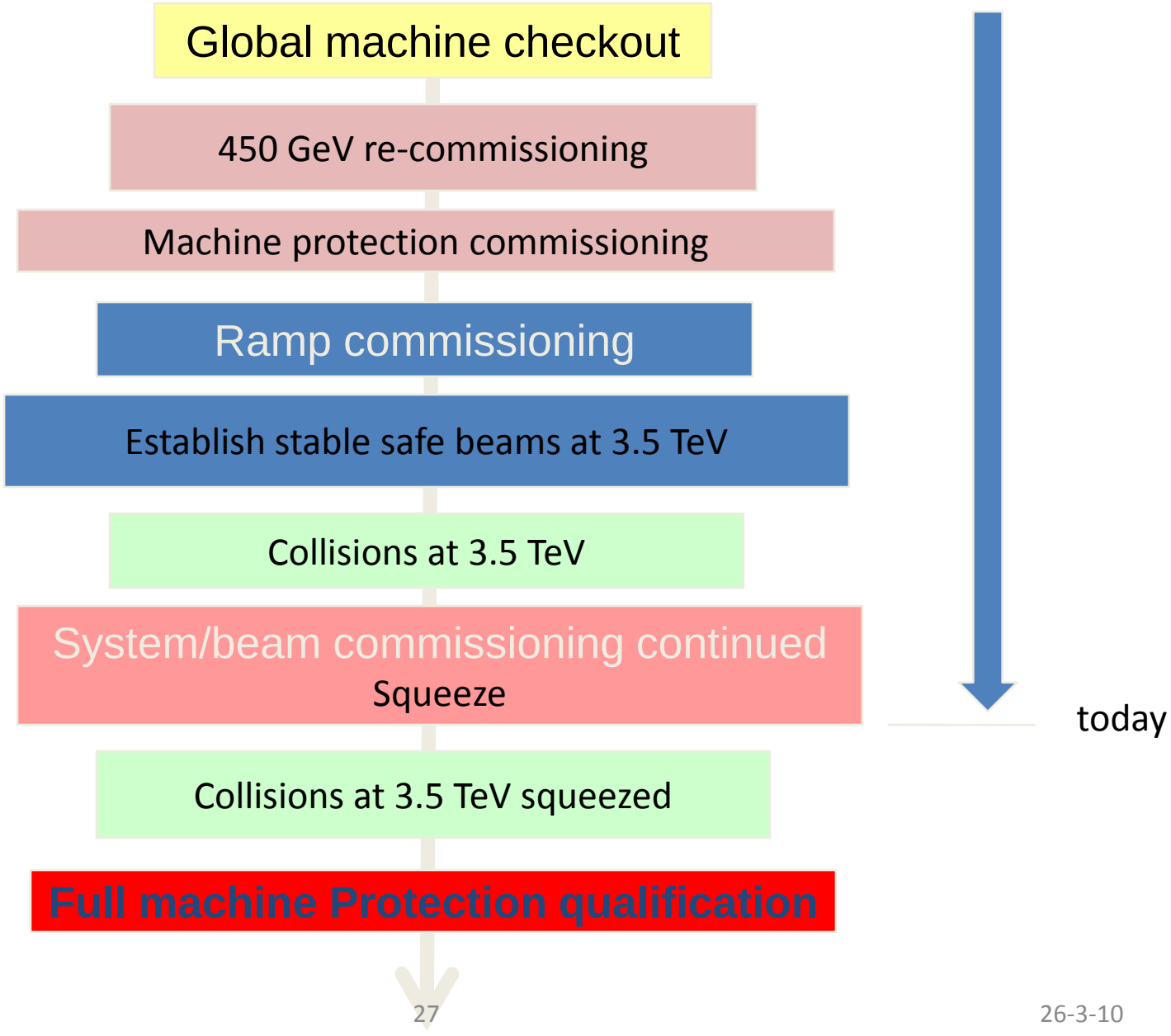
Background 1



Background 2

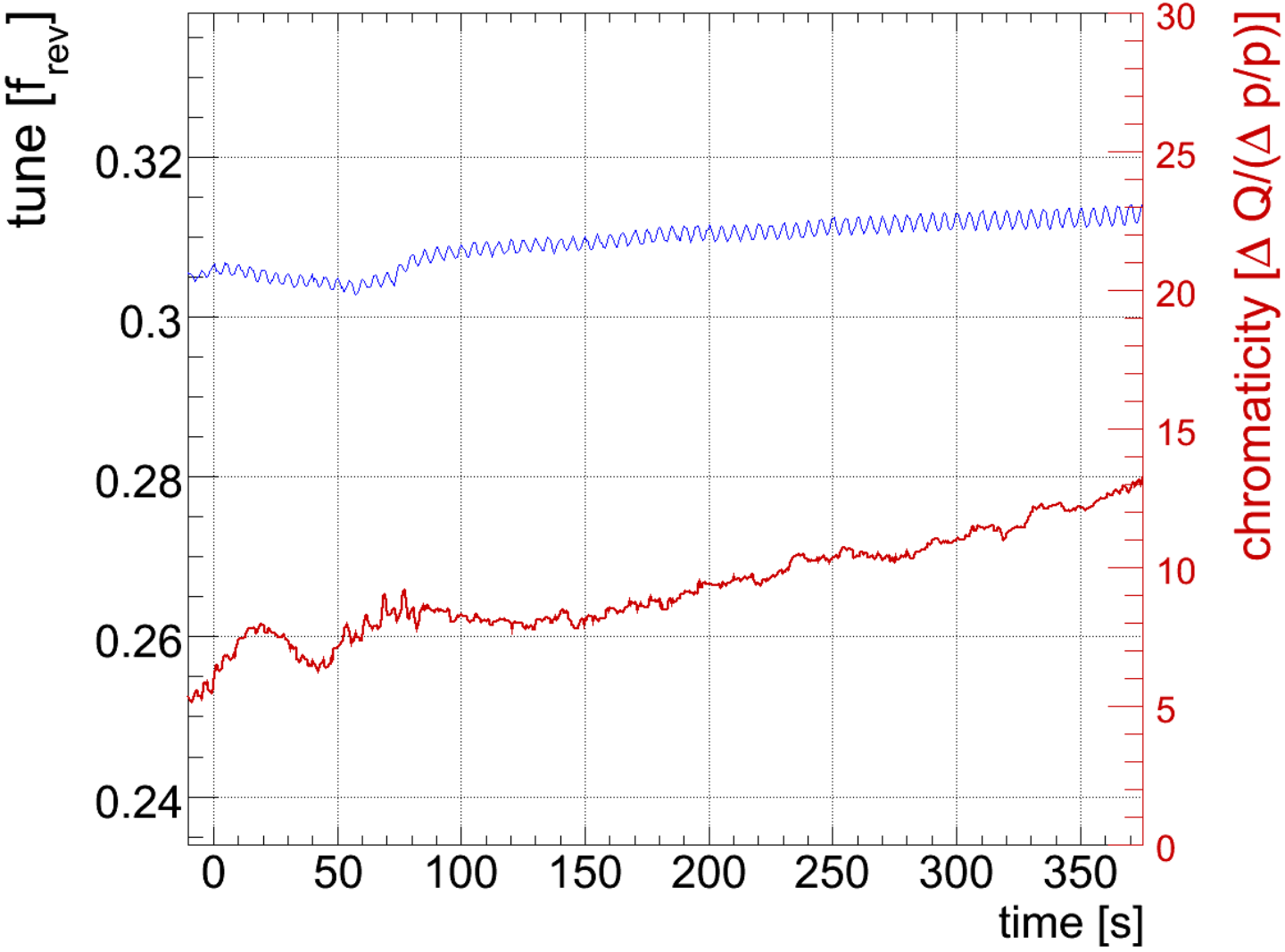


Beam commissioning strategy 2010



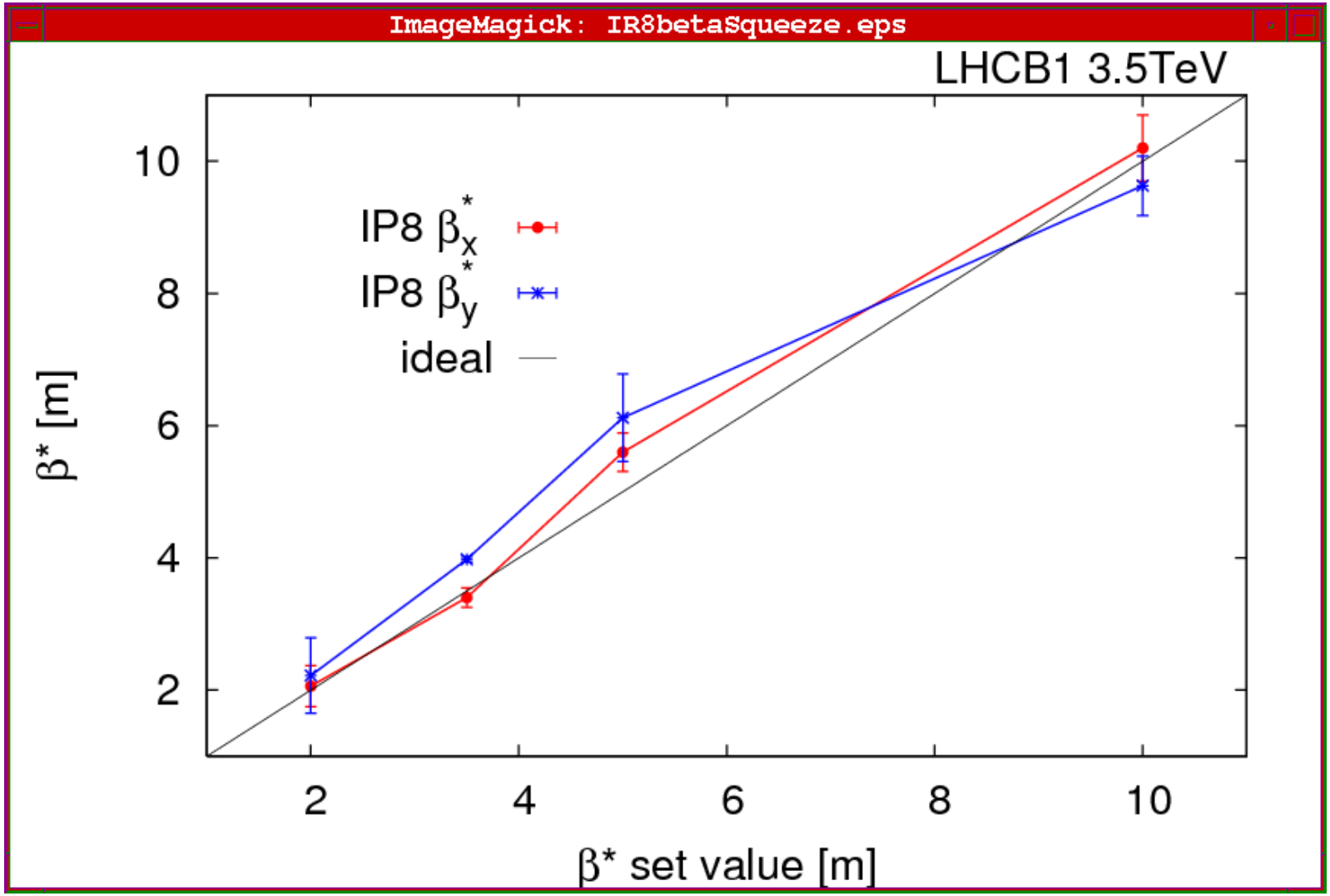
Tuesday 13.4.

- Q’ measurement during 800 GeV ramp: Beam2 Vertical



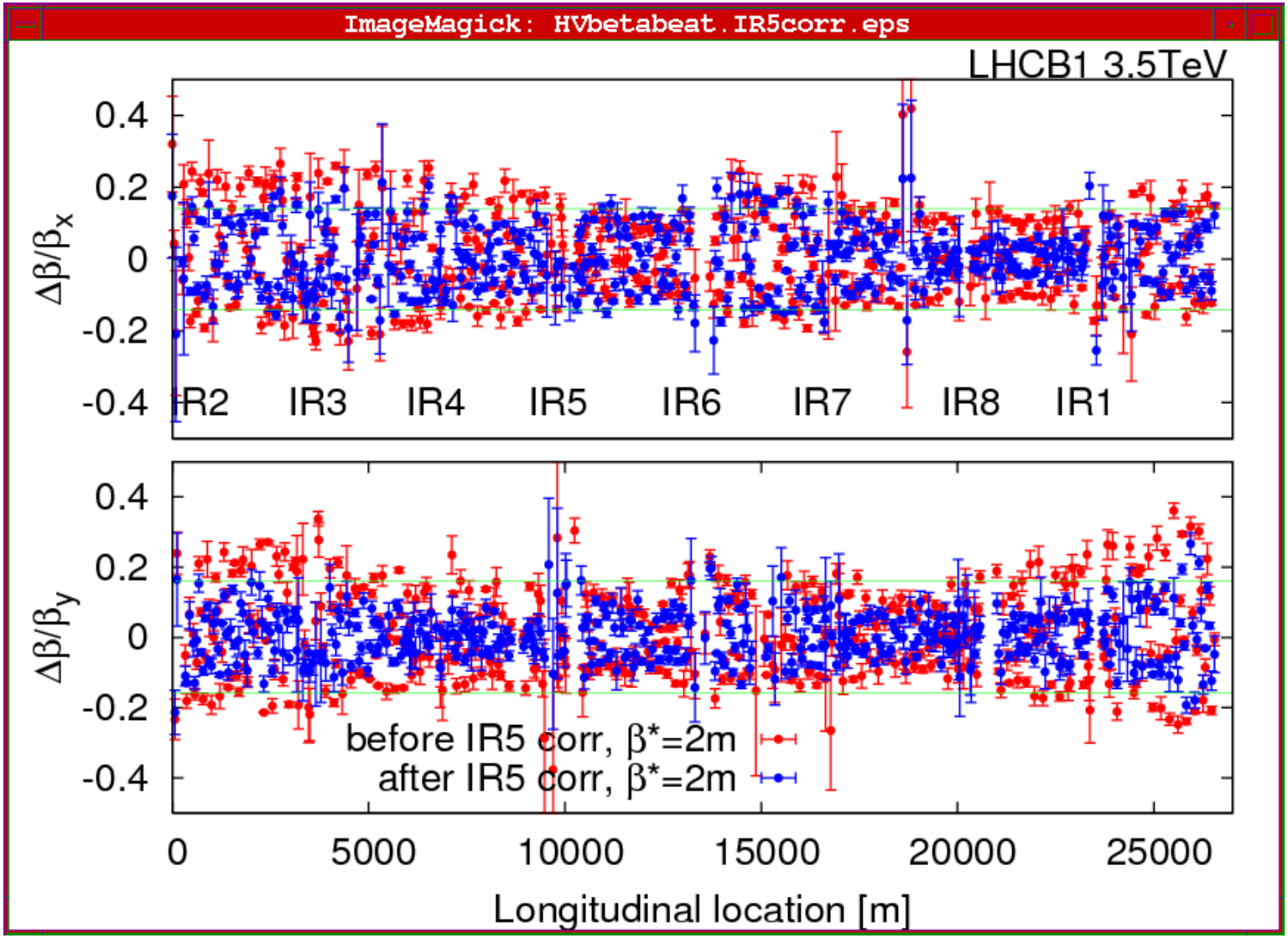
Tuesday 13.4.

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



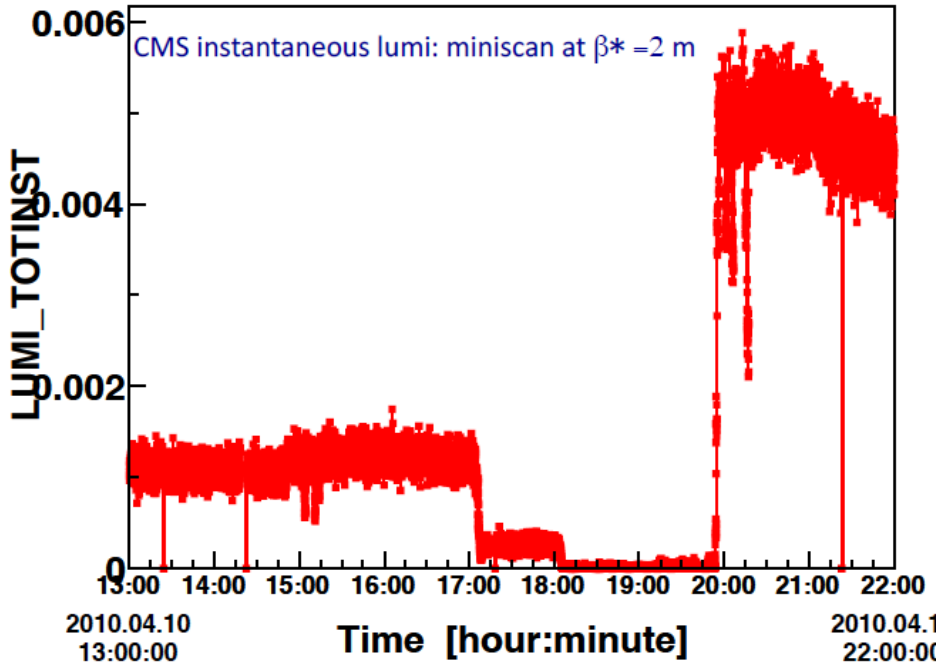
Tuesday 13.4.

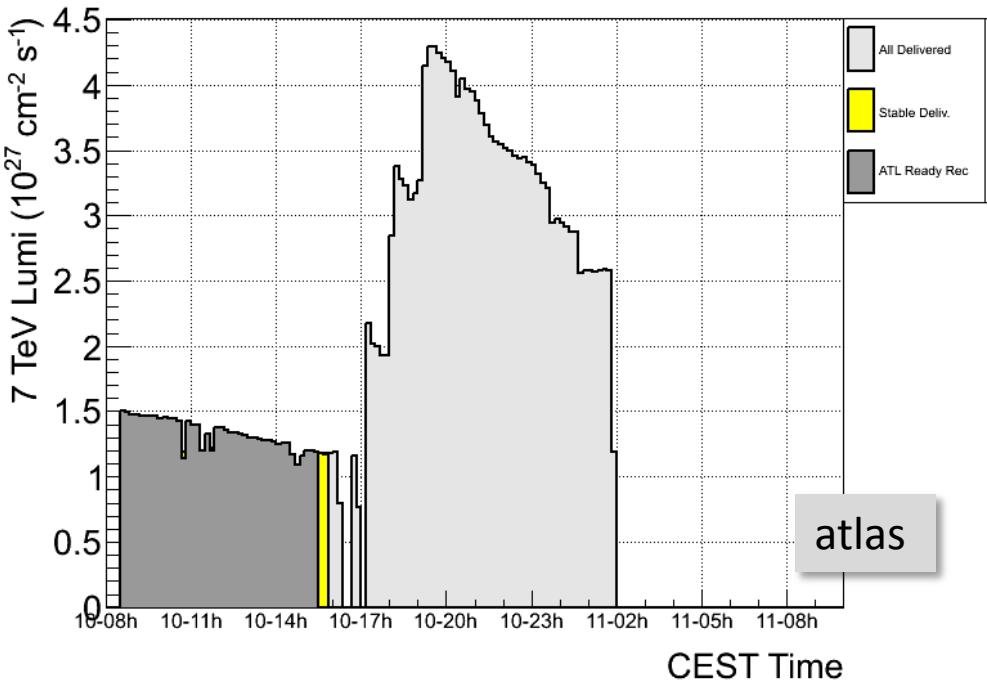
- β-beat for Beam1 @ β^* = 2m after correction using IR5 Q2:



IP1&5 luminosity vs squeeze

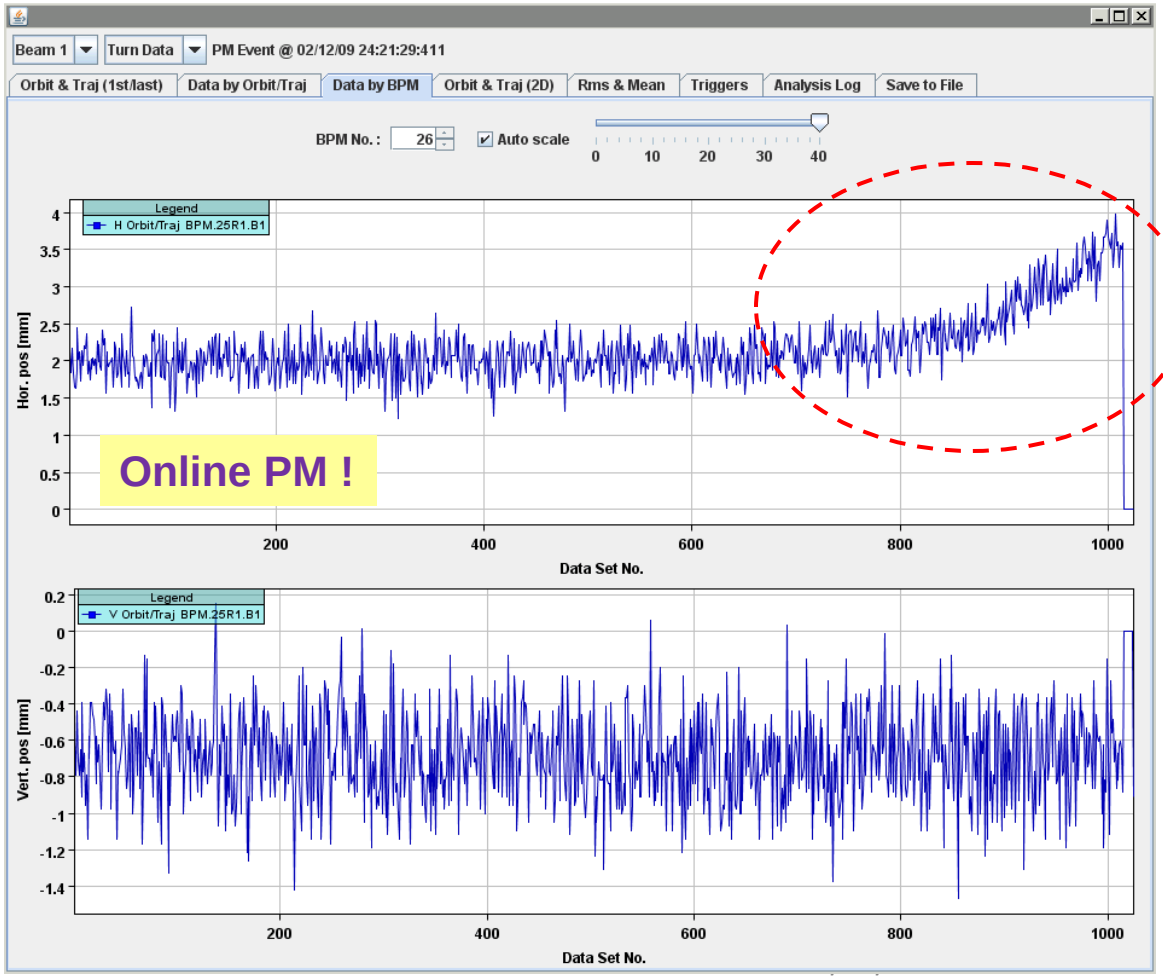
- Raw (online) lumi plots on 10 apr 2010, during the squeeze to 2m in IP1 and IP5
- Factor gained (raw numbers):
  - ~4.5 in Pt5 (after min scan)
  - ~4 in Pt1
- Not corrected for lumi decay over the ~5h of squeeze and mini scans





FMCM Beam Tests for D1 IR1/5

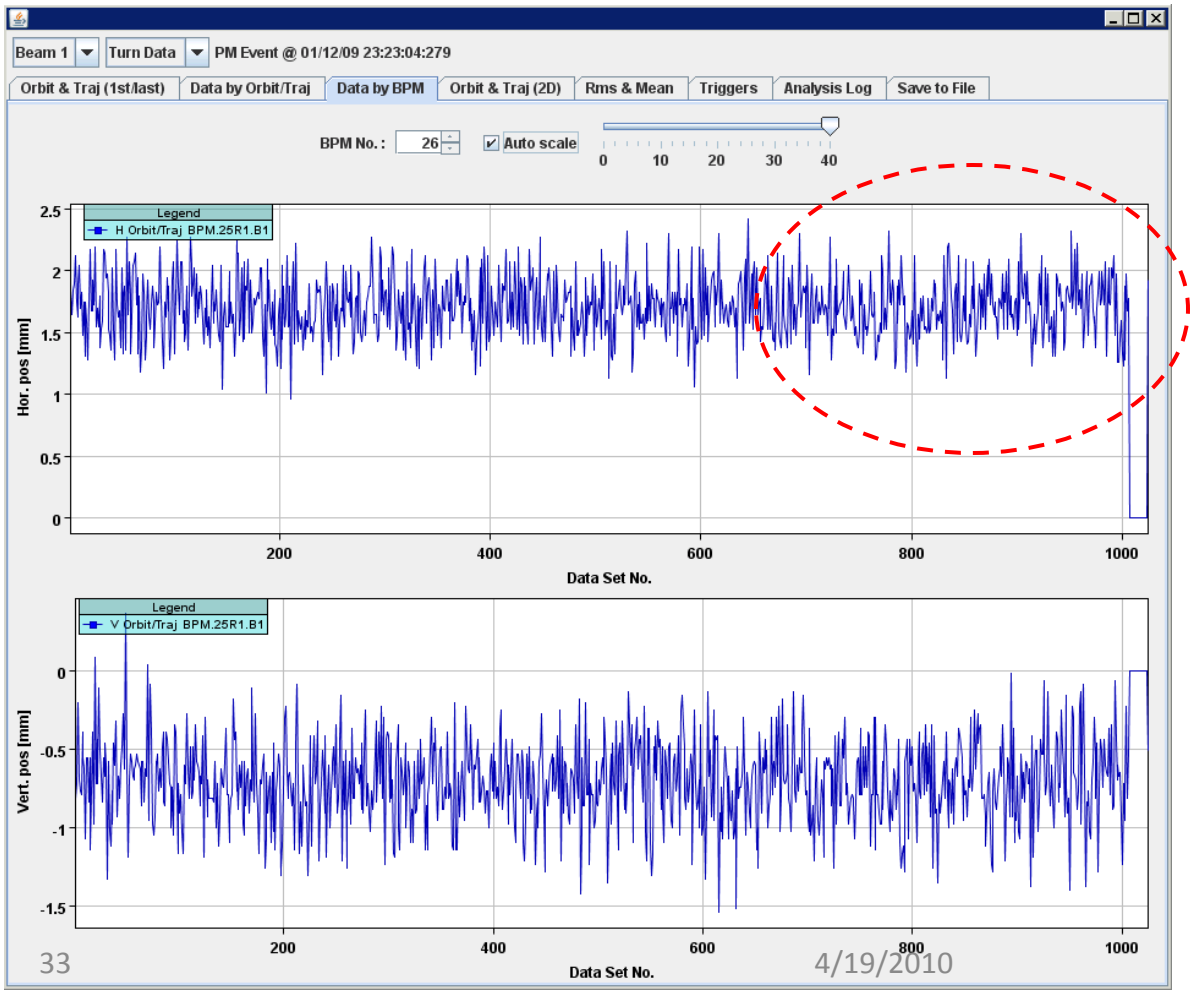
- Low intensity beam test.
- Trajectory evolution after OFF send to RD1.LR1, with FMCM masked.
- Beam dumped by BLMs in IR7.



- 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.

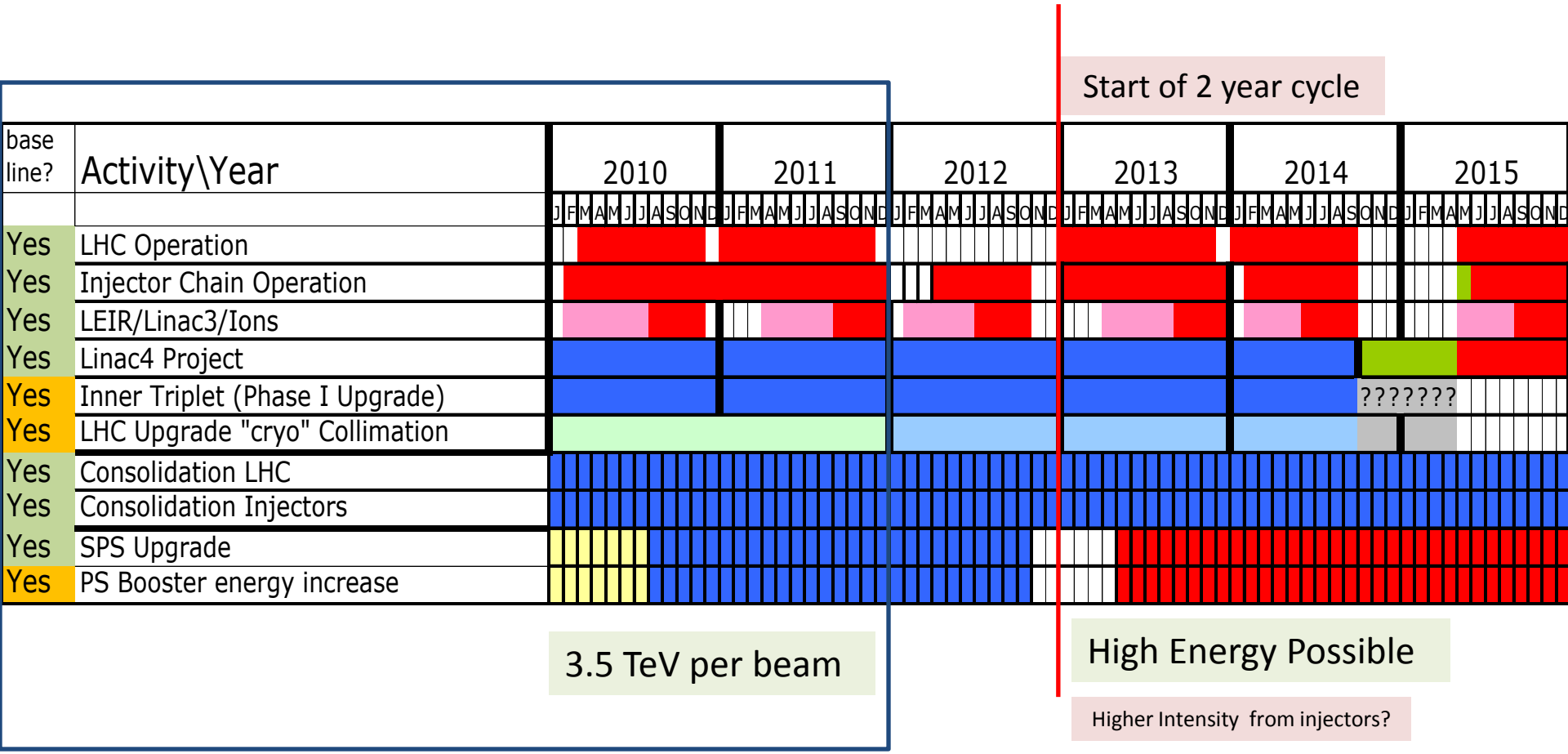
>> The redundant protection is working

Thursday 15.4.

- Higher intensity
  - Switching between PROBE and INDIV in the SPS is now working smoothly: adjusted some settings for the SPS rephasing.
  - Over-injection working well in IR2 (only one dump from pilot send to TDI).
  - Over-injected 1.1E11, collimators at nominal 4.5 sigma settings.
  - Emittance at 1E11: 2.5 um H, 2,3 um V.
  - The losses in the injection region do not scale with intensity: above 5E10, the losses go down (in absolute!).

Strategy for Performance Evolution 2010-2011

Time lines (Preliminary)



Instantaneous Luminosity

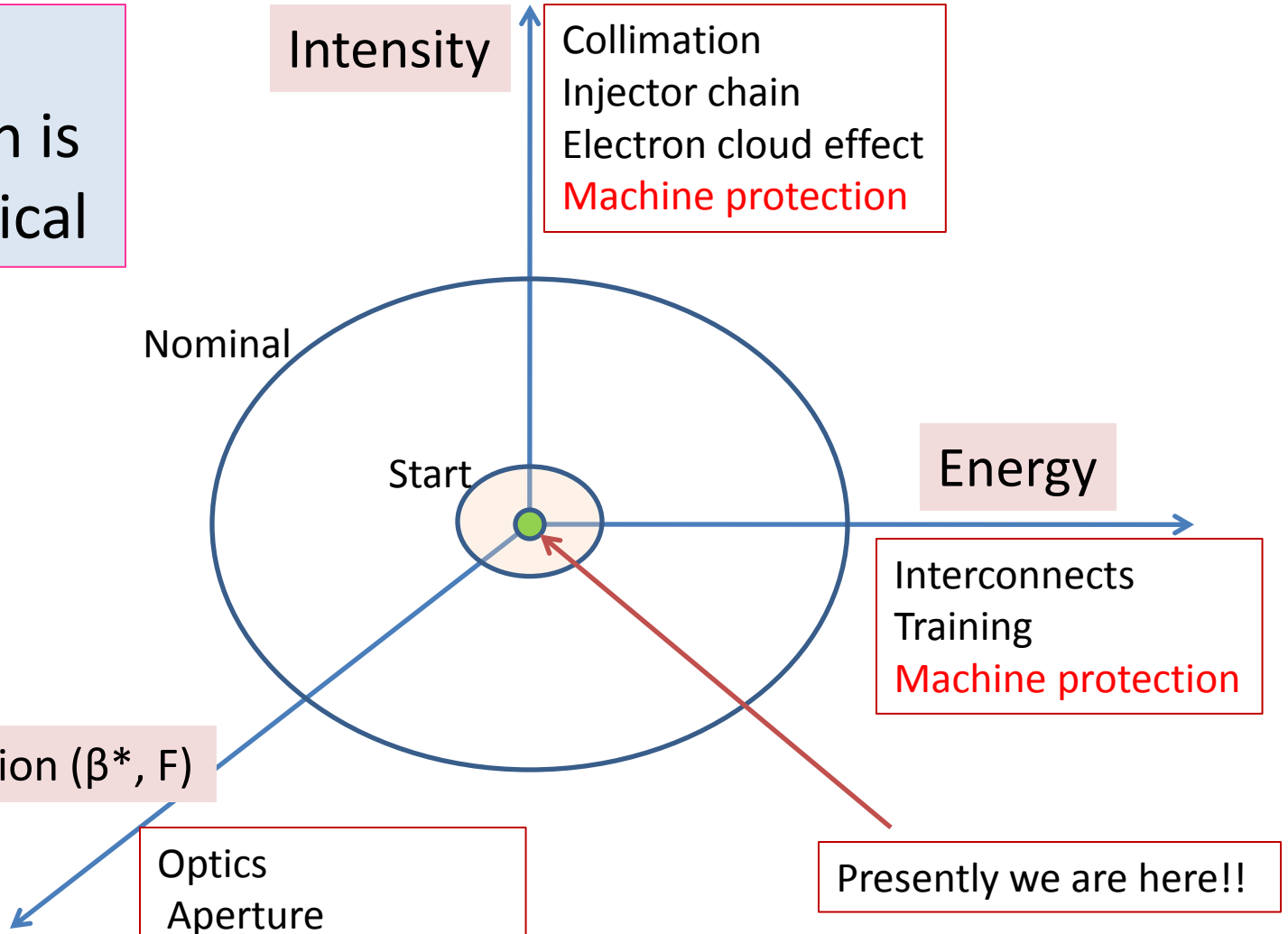
$$L = \frac{N^2 k_b f}{4\pi\sigma_x\sigma_y} F = \frac{N^2 k_b f\gamma}{4\pi\varepsilon_n\beta^*} F$$

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

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

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
  - Less aperture margin
  - Higher β* (lower β^{peak})

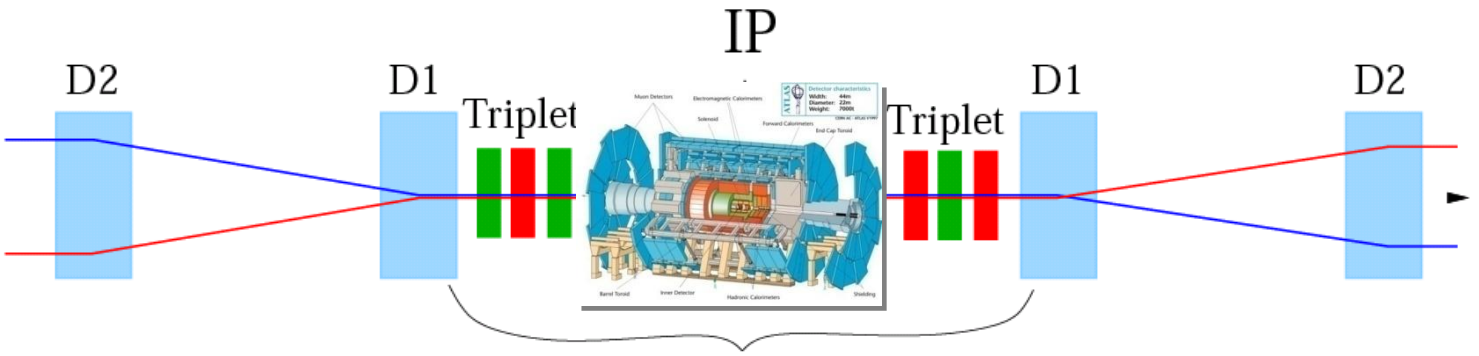
$$\varepsilon_n = \varepsilon\gamma \qquad \sigma = \sqrt{\varepsilon\beta}$$

At max

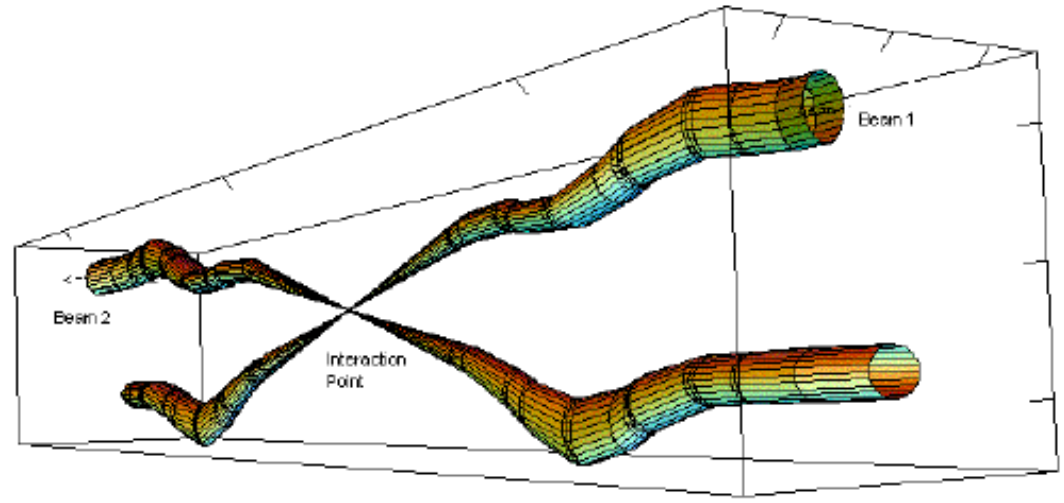
- > 150 bunches requires crossing angle (beam-beam)
  - Requires more aperture
  - Higher β*

- Targets for 3.5TeV
  - 2/2.5 m without/with crossing angle in 2010
  - 2m with crossing angle in 2011

Interaction Region - F



L = 116 meter



Relative beam sizes around IP1 (Atlas) in collision

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

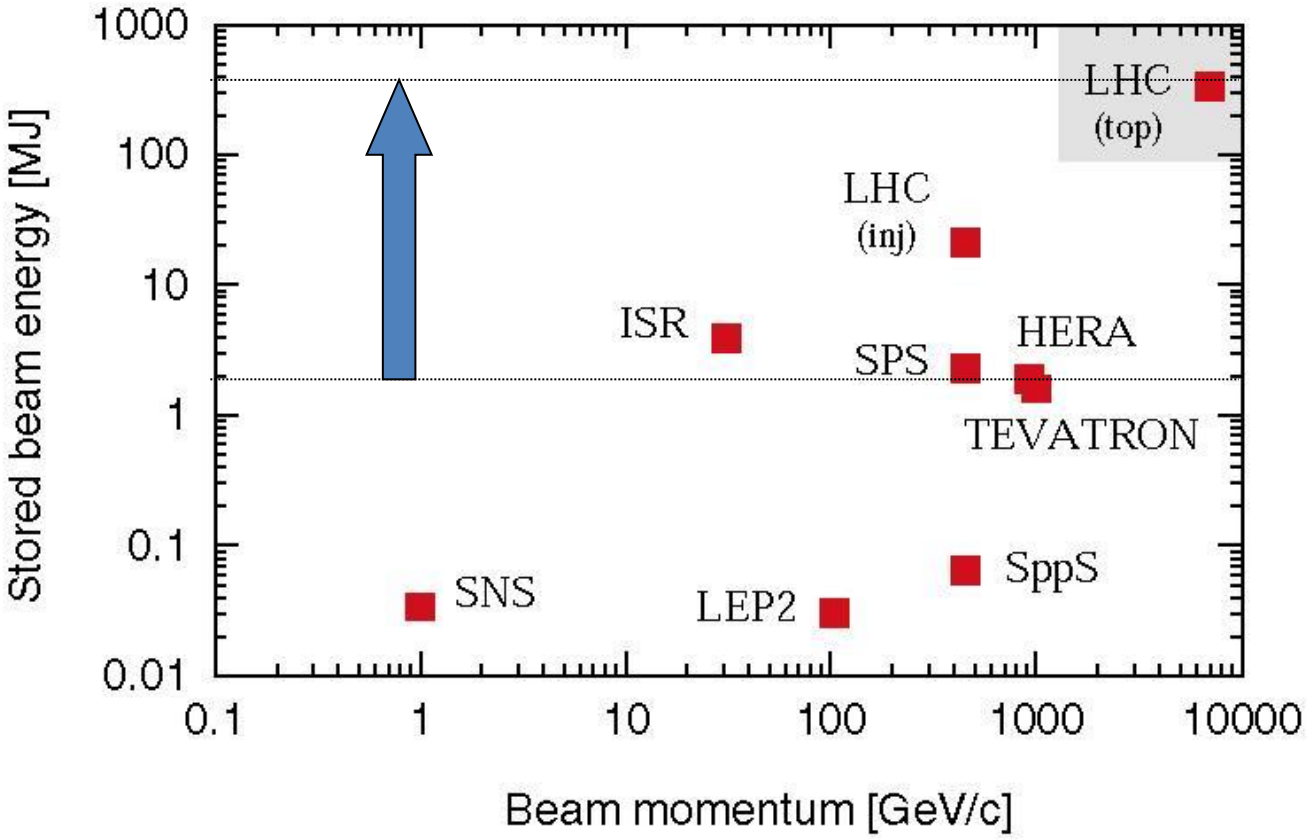
Machine Protection Strategy for intensity increase

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

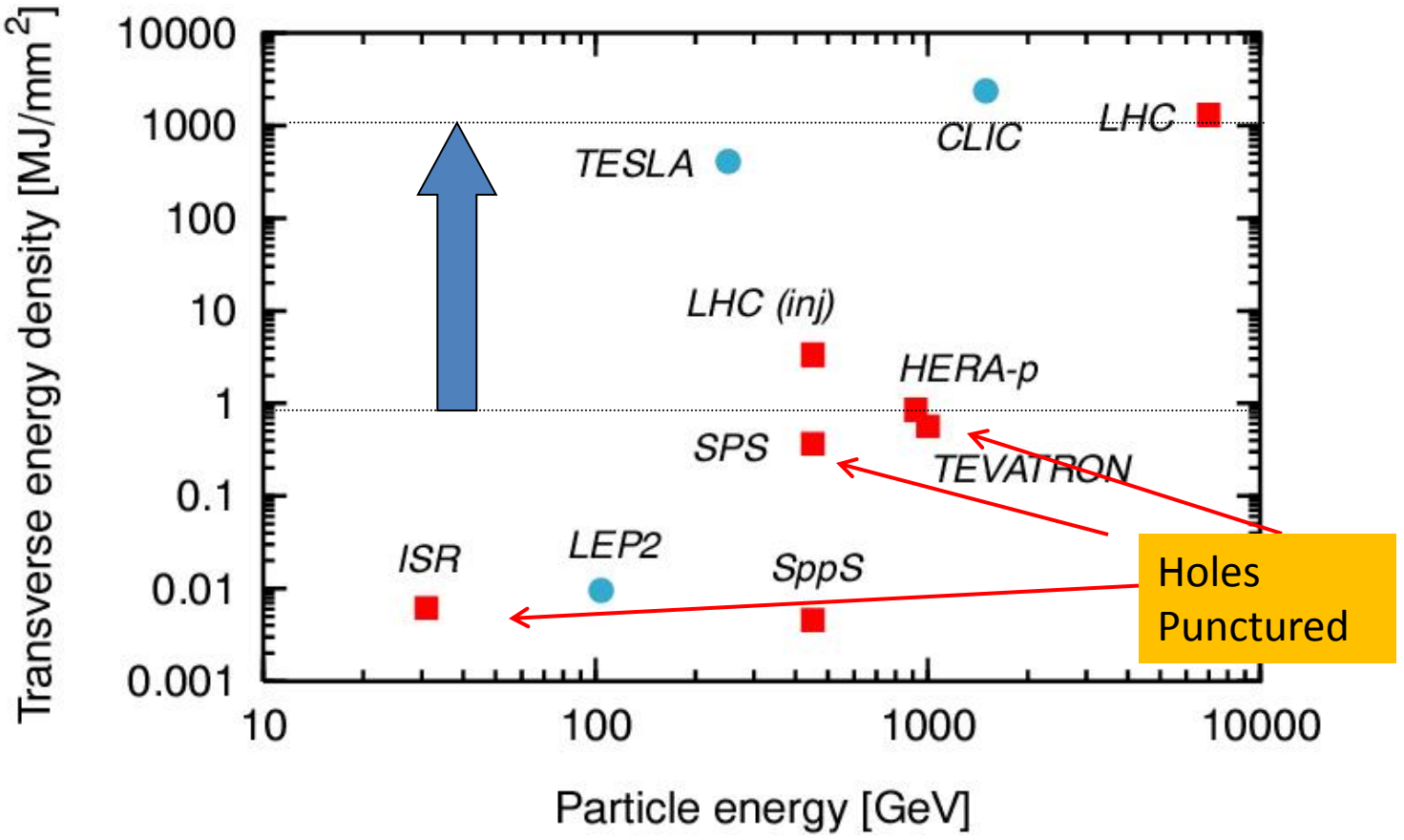


At less than 1% of nominal intensity LHC enters new territory. Collimators must survive expected beam loss…

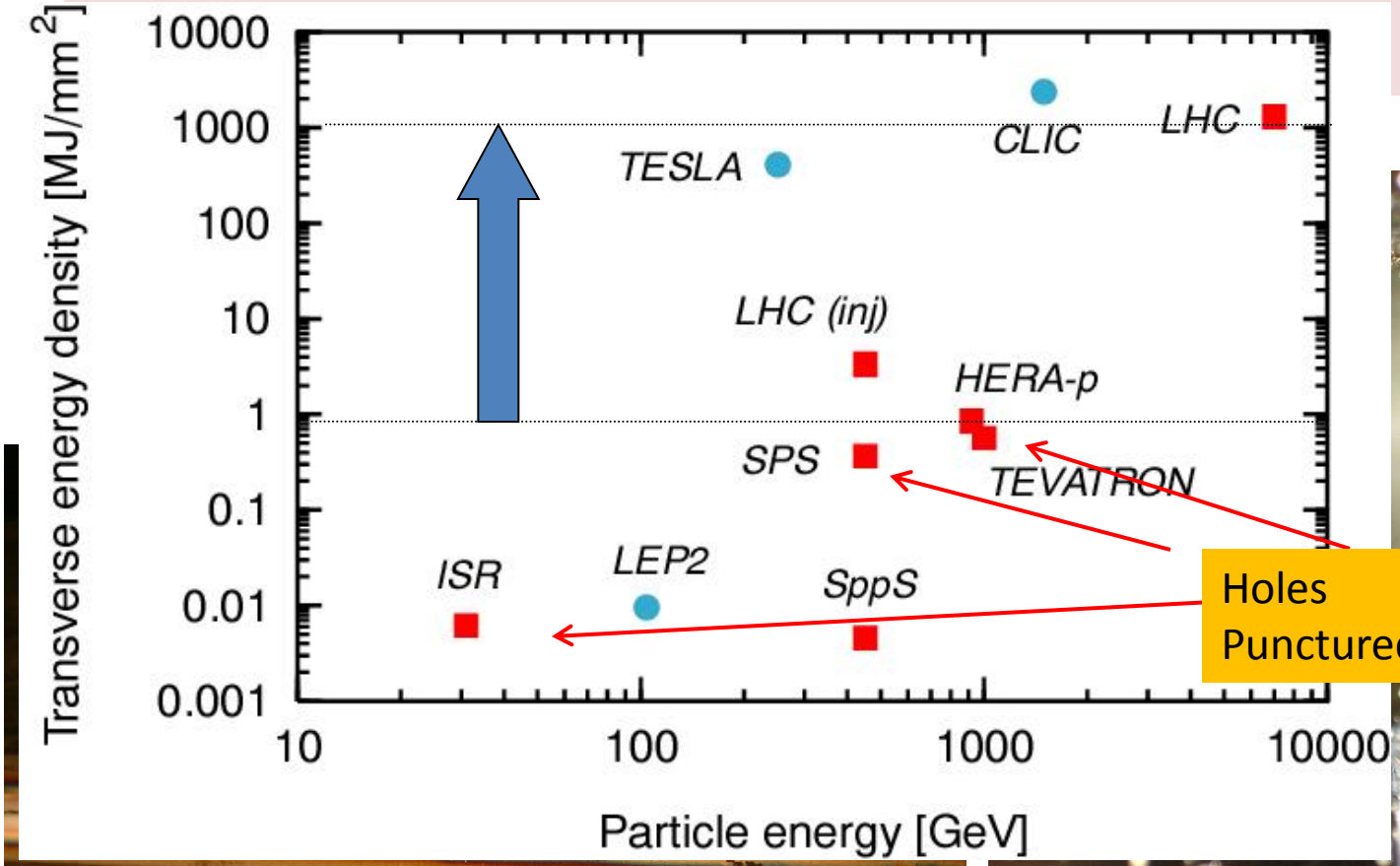
The Energy Density of the LHC beams

Transverse energy density is a measure of damage potential …

… AND proportional to luminosity!

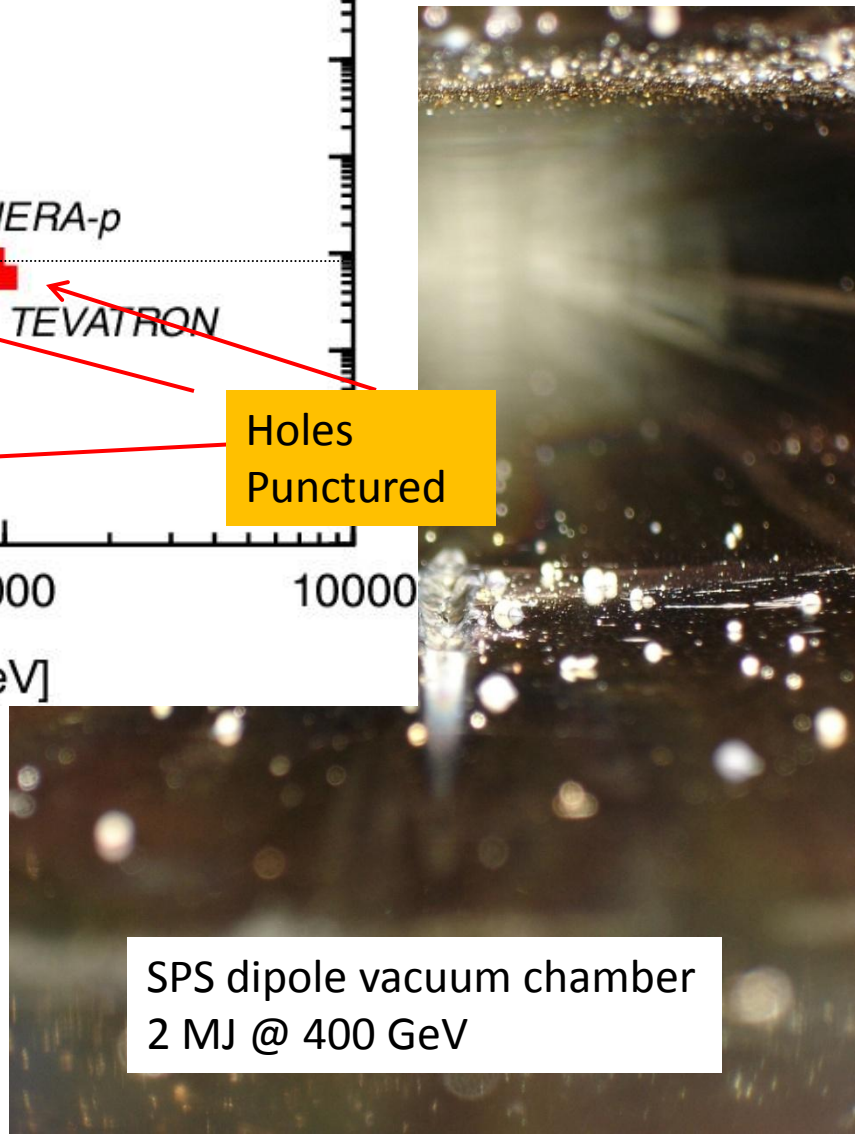


In terms of damage potential, LHC advances the state of the art by 3 orders of magnitude!



Holes Punctured

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 – Summary

- 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

Summary

- To reach a peak of luminosity of $2x10^{32}cm^{-2}s^{-1}$ in 2010 there must be a rapid progression in stored beam energy in parallel to a lot of commissioning activities.
  - Much faster than in previous machines, with the potential to cause damage !
  - Coupled to an excellent machine uptime.
- Progress will depend on confidence in MPS.
  - Tests … + operational experience.

2010

Step	E [TeV]	Fill scheme	N	β* [m] IP1 / 2 / 5 / 8	Run time (indicative)
1	0.45	2x2	$5x10^{10}$	11 / 10 / 11 / 10	Weeks
2	3.5	2x2	$2 - 5x10^{10}$	11 / 10 / 11 / 10	
3	3.5	2x2*	$2 - 5x10^{10}$	2 / 10 / 2 / 2	
4	3.5	43x43	$5x10^{10}$	2 / 10 / 2 / 2	Weeks/Months
5	3.5	156x156	$5x10^{10}$	2 / 10 / 2 / 2	
6	3.5	156x156	$9x10^{10}$	2 / 10 / 2 / 2	Months
7	3.5	50 ns - 144**	$7x10^{10}$	2.5 / 3 / 2.5 / 3	
8	3.5	50 ns - 288	$7x10^{10}$	2.5 / 3 / 2.5 / 3	
9	3.5	50 ns - 720	$7x10^{10}$	2.5 / 3 / 2.5 / 3	Months

* 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

2011

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

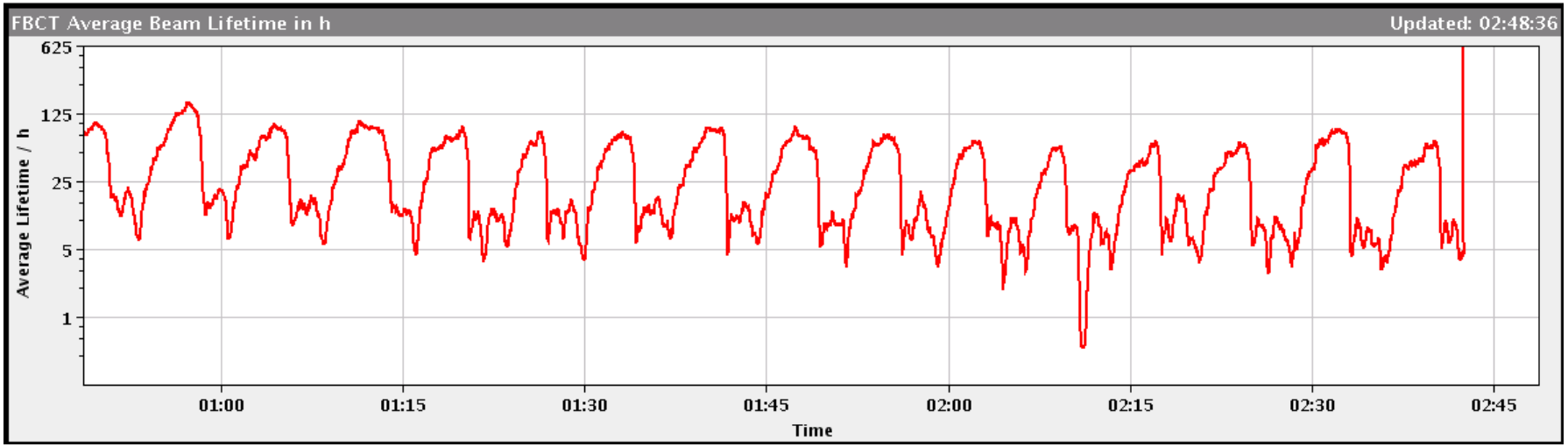
	No. bunches	ppb	Total Intensity	Beam Stored Energy (MJ)	beta*	Peak Lumi	Int Lumi per month [pb^{-1}]
50 ns	432	7 e10	3 e13	17	2	1.3 e32	~85
Pushing intensity limit	720	7 e10	5.1 e13	28.2	2	2.2 e32	~140
Pushing bunch current limit	432	11 e10	4.8 e13	26.6	2	3.3 e32	~209

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

Thank you for your attention

Hump

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



Hump

- Our friend the hump on the lifetime, tune amplitude and size