LHC Status Report

Steve Myers
(on behalf of the LHC team)

CERN MAC 26-28 April, 2010

Topics

- Chamonix and Outcome
- LHC Status
    - Beam commissioning end 2009
    - Technical Stop Jan-Feb 2010
    - Hardware Commissioning March 2010
    - Commissioning and Operation March→ now
- Strategy for Performance Evolution 2010-2011

Outcome of Chamonix 2010

- I will not give a summary of summaries but present selected. There are many more topics which are also very important but not as urgent. All will be followed up in the LMC

1. Running scenarios for 2010-2011
2. Upgrade of the Injector Chain
3. Upgrade of the insertions (IT "phase 1")
4. Future Upgrade Plans

5. Continue on 1. (after Chamonix)

Splices and Beam Energy: Statements

- Simulations for safe current used pessimistic input parameters (RRR......) but have no safety margins
- For 2010, 3.5 TeV is safe
    - **Measure the RRR (asap) to confirm the safety margin for 3.5TeV/beam**
- Without repairing the copper stabilizers, **5 TeV is risky**
- For confident operation at 5TeV we would need
    - Repairs to the "outlier" splices
    - Better knowledge of the input parameters (RRR...)
    - With present input parameters the "limit" splice resistances are **43 μΩ (RB)** and **41 μΩ (RQ)** **NOTE: these values are close to the limit of the resolution of our measurements made for the RBs at 300K**

Splices and Beam Energy: Statements

- For confident operation at 14TeV we need
  - To replace all splices with new clamped shunted ones!

► F. Bertinelli, A. Verweij, P. Fessia (unaminous)

For safe running around 7 TeV/beam, a shunt has to be added on all 13 kA joints, also on those with small R_{addit}. Joints with high R_{addit} or joints with large visual defects should be resoldered and shunted.

A Cu-shunt with high RRR and a cross-section of 16x2 mm^2 is sufficient, if soldered at short distance from the gap. Experimental confirmation by means of a test in FRESCA should be foreseen.

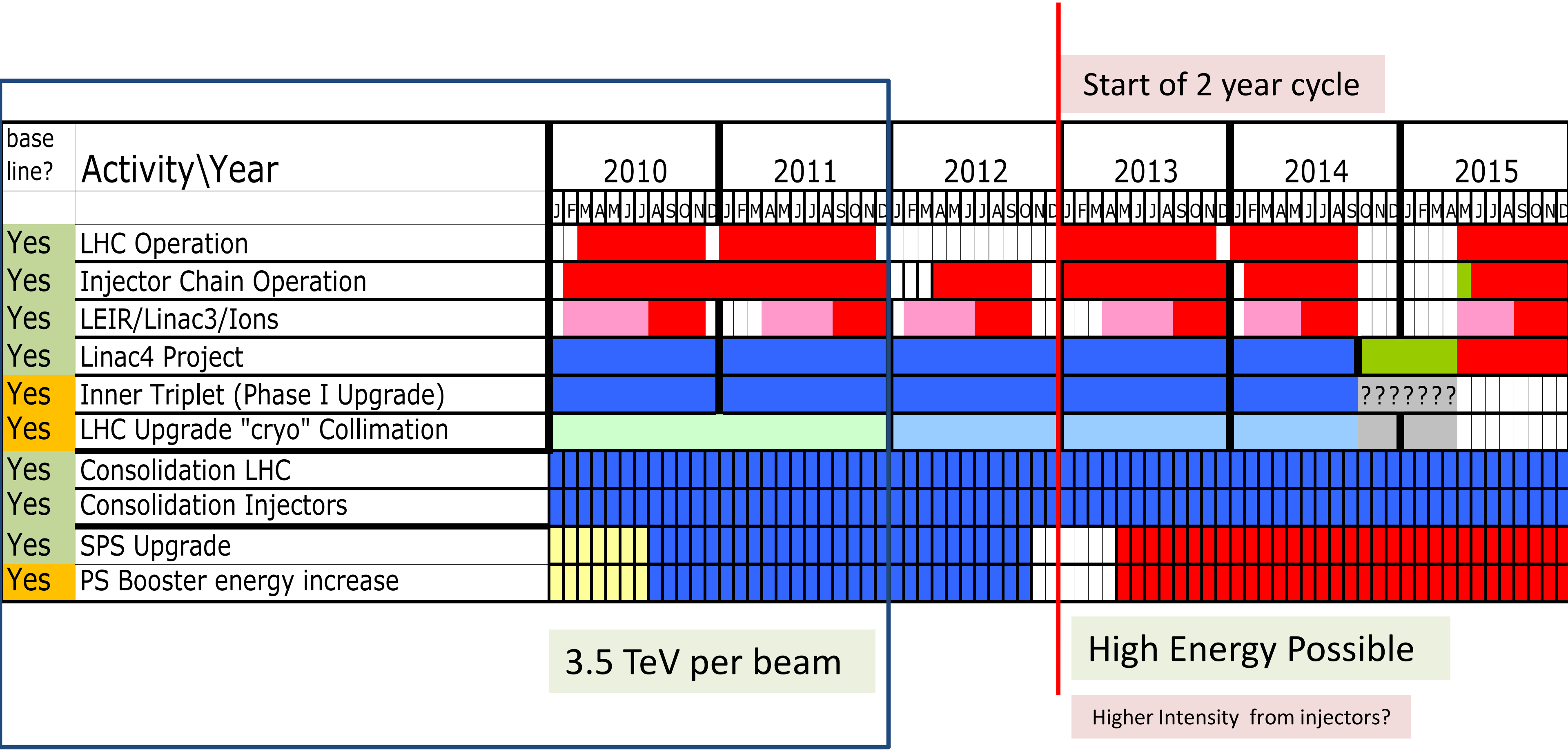
Two Possible Scenarios 2010-2011

1. Run at 3.5 TeV/beam up to a predefined integrated luminosity with a date limit. Then consolidate the whole machine for 7TeV/beam.
    - Need to determine the needs for the shutdown (resources, coactivity etc)

Decision from Management following Chamonix

Run at 3.5 TeV/beam up to a predefined integrated luminosity ($1fb^{-1}$) with a date limit (end 2011). Then consolidate the whole machine for 7TeV/beam. (Higher energies of around 4TeV/beam are not excluded.)

Time lines (Preliminary)



Upgrades: Foreword

New Studies have been launched about one year ago and are ongoing

- Performance Aim
  - To maximize the useful integrated luminosity over the lifetime of the LHC
- Targets set by the detectors are:
  $3000 fb^{-1}$ (on tape) by the end of the life of the LHC
  → $250\text{-}300 fb^{-1}$ per year in the second decade of running the LHC

- Goals
  - Check the coherence of the presently considered upgrades wrt
    - accelerator performance limitations,
    - Detector needs,
    - manpower resources and,
    - shutdown planning including detectors

Injector Upgrades

- Present Peak Performance Situation

Intensity Limitations (10^{11} protons per bunch)	
Reminder: design = 1.15 (for 10^{34}); Ultimate = 1.7 (for $2.3x10^{34}$)	
	Present
Linac2/LINAC4	4.0
PSB or SPL	3.6
PS or PS2	1.7
SPS	~1.2
LHC	1.7-2.3?

Conclusion 1: SPS is the bottleneck for Ultimate!

SPS Bottleneck

- Other injectors are limited by a fundamental limitation, the space charge effect ($\Delta Q_{sc} = 0.3$)
- In the SPS at injection: $\Delta Q_{sc} = 0.07$! (no fundamental limitation)
- Known Intensity Limitation in SPS (mitigation)
  - Electron cloud (vacuum chamber coating)
  - Transverse Mode Coupling Instability (Impedance reduction and/or transverse feedback)
  - RF effects such as beam loading etc (redesign of existing RF or build new system)

Immediately after Chamonix a task force has been set up to investigate the removal of the SPS bottleneck for ULTIMATE

Injectors Performance (Availability)

- From the LINAC2 to the SPS we have ageing machines
  - We need consolidation or replacement
- Proposed scenario (White Paper, 2006) was to replace LINAC2 by LINAC4 and to study replacement of PSB and PS by a LP-SPL and a new PS2 resp.
  - CDR to be presented to Council in 2011 (was delayed by one year in 2009: due to the accident)
- Recently these studies have shown that the time scale for operation of the PS2 is at earliest 2020.
  - Conclusion: We need to aggressively consolidate the existing injector chain to allow reliable operation of the LHC until at least 2022.
  - Consolidation Task force was set up late last year.
- BUT: Resources needed for the consolidation of the existing injectors are in direct competition with those needed for the construction of LP-SPL/PS2
- Question: What would be the implication on LHC performance of not constructing SPL/PS2??

Intensity Limits with LP-SPL and PS2

Intensity Limitations (10^{11} protons per bunch)

Reminder design = 1.15 (for 10^{34}); Ultimate = 1.7 (for 2.3×10^{34})

	Present	LP-SPL/PS2
Linac2/LINAC4	4.0	4.0
PSB or SPL	3.6	4.0
PS or PS2	1.7	4.0
SPS	1.2	>1.7?
LHC	1.7-2.3?	1.7-2.3?

It would be wonderful to be able to afford these additional margins and flexibility! (Also an asset to CERN for future high intensity proton project proposals)

Performance Limitations without LP-SPL/PS2

- Alternative scenario to LP-SPL/PS2
  - Consolidate existing injectors for the life of the LHC (2030)
  - During the same consolidation, improve the performance of PSB/PS as injectors for the LHC
- New "Idea"(Preliminary and needs to be verified)
  - Increase the extraction energy of the PSB which would allow an increase of the injection energy of the PS.
  - 2GeV injection energy in the PS allows ~3×10^{11} ppb with the same space charge tune shift (preliminary study presented in Chamonix)

"Project" set up immediately after Chamonix

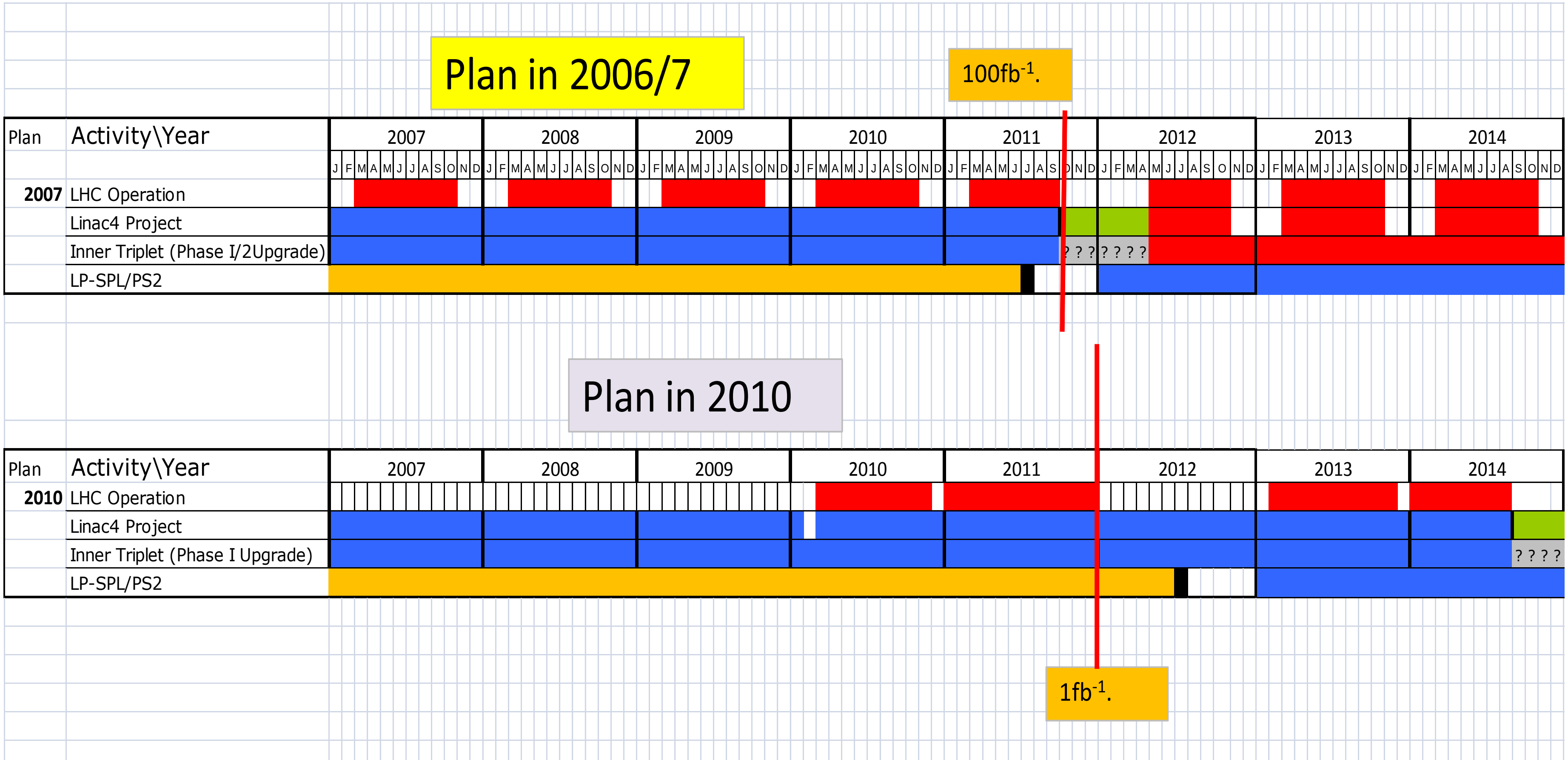
Intensity Limits

Intensity Limitations (10^{11} protons per bunch)			
Reminder design = 1.15 (for 10^{34}); Ultimate = 1.7 (for 2.3×10^{34})			
	Present	SPL-PS2	2GeV in PS
Linac2/LINAC4	4.0	4.0	4.0
PSB or SPL	3.6	4.0	3.6
PS or PS2	1.7	4.0	3.0
SPS	1.2	>1.7?	>1.7?
LHC	1.7-2.3?	1.7-2.3?	1.7-2.3?

Conclusion:
We continue (as planned) and terminate the study for LP-SPL/PS2 and study in parallel the PS Booster energy upgrade
Decision can be taken when we have the results of these studies and experience with the LHC operation

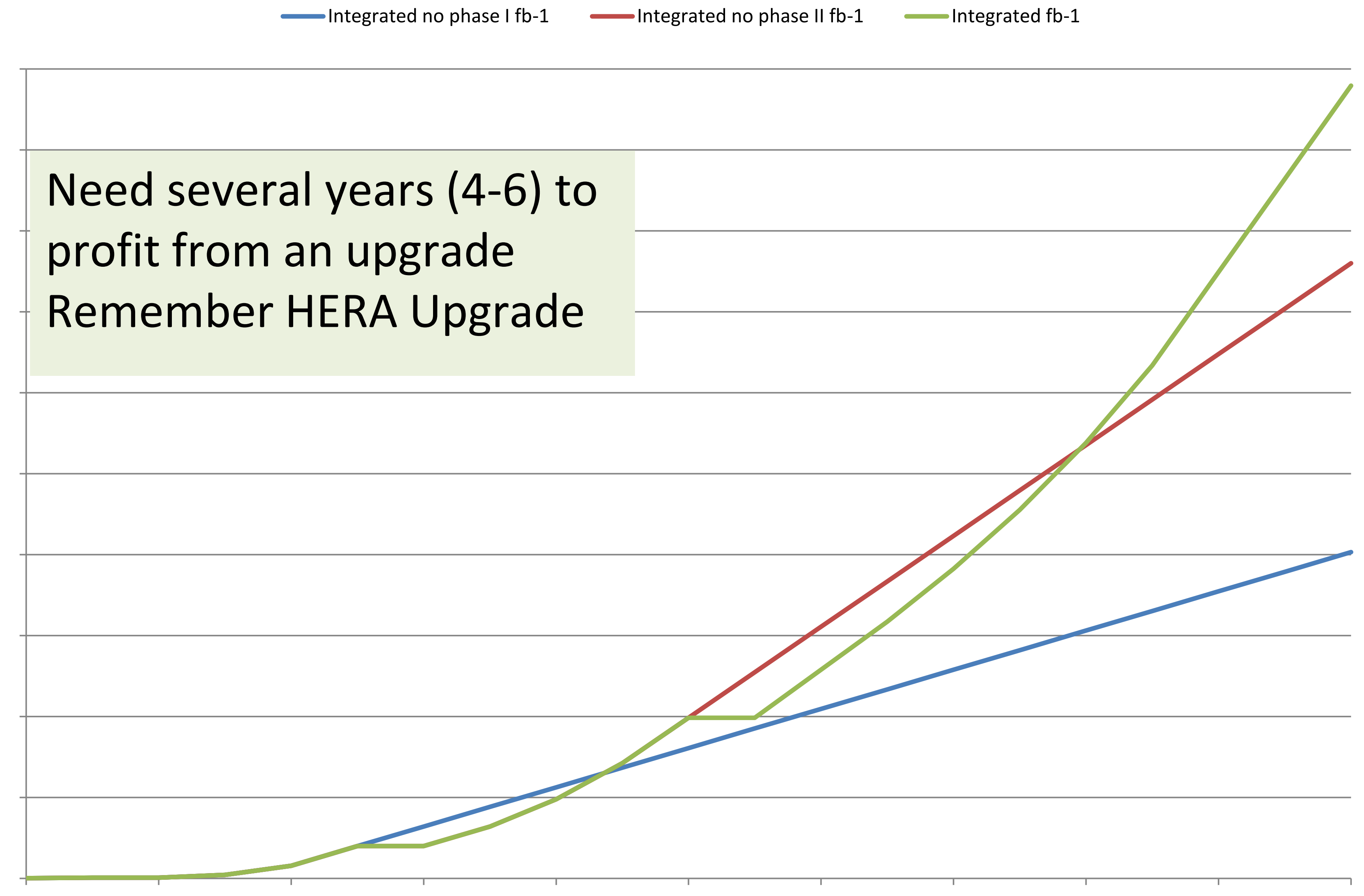
Upgrade of the “Inner Triplet Phase 1”

Inner Triplet Upgrade Plans 2007 and 2010



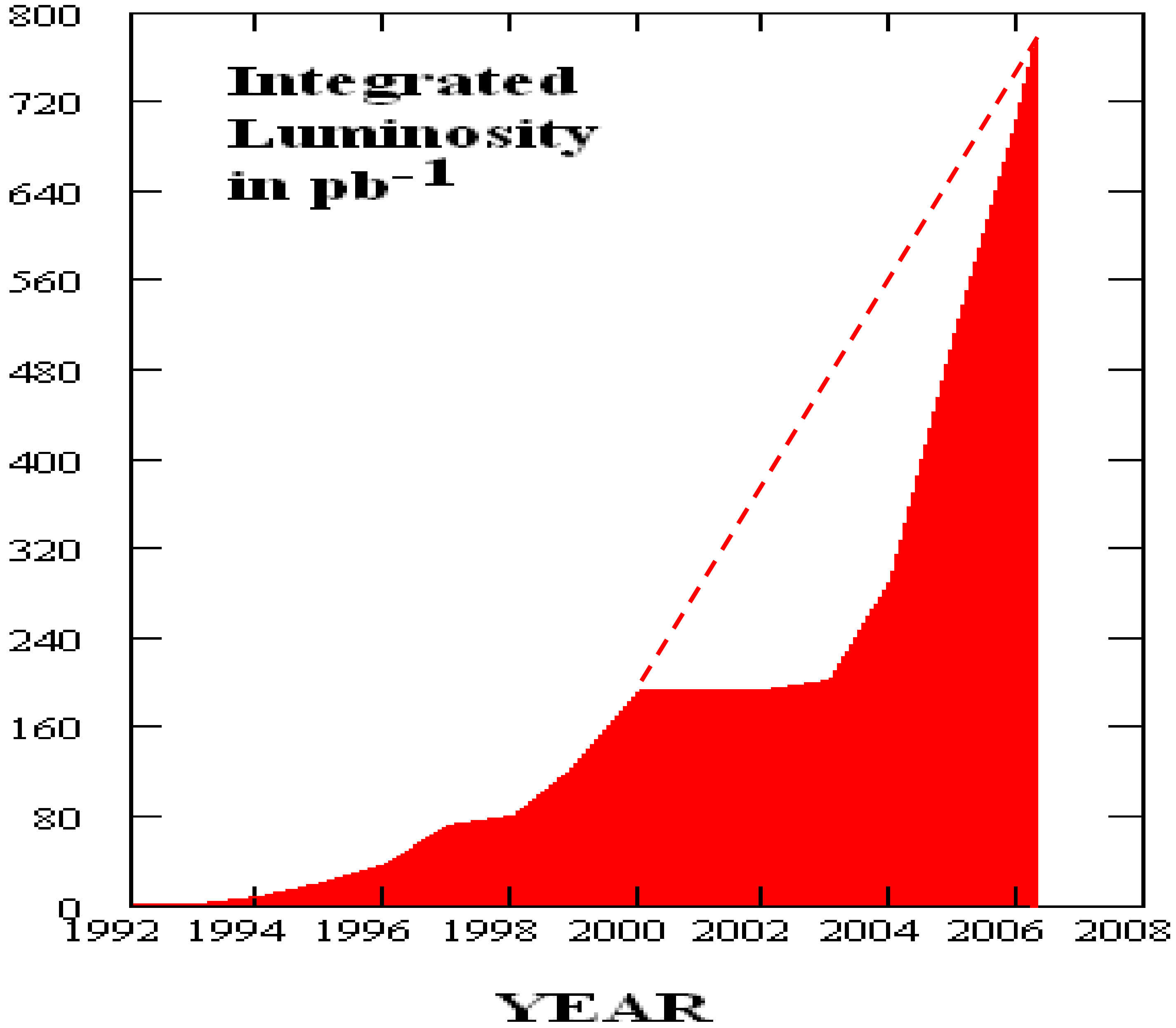
A second upgrade was also foreseen about 5-6 years after the first (2017-2018)

IR/Optics Upgrade or not



Need several years (4-6) to profit from an upgrade
Remember HERA Upgrade

HERA II



Integrated Luminosity in pb^{-1}
800
720
640
560
480
400
320
240
160
80
0
1992 1994 1996 1998 2000 2002 2004 2006 2008
YEAR

Insertion Upgrade Plans

- IT Upgrade "phase 1"
  - Goal: reliable operation at $2x10^{34}cm^{-2}s^{-1}$, intensity < ultimate and > nominal

Very similar to "ultimate"

Same resources are needed for splice consolidation!
(up to beginning 2013)

Tough Questions:

1. Will the phase 1 upgrade produce an increase in useful integrated luminosity?
    - Installation time and recomissioning a new machine afterwards
2. Do we have the resources to complete on a time scale which is reasonable with respect to phase 2?

Task force set up immediately after Chamonix
First preliminary report given: more details at next SPC.

Future Upgrade Scenarios “Phase 2”

- For LHC high luminosities, the luminosity lifetime becomes comparable with the turn round time ⇒ Low efficiency
- Preliminary estimates show that the useful integrated luminosity is greater with
  - a peak luminosity of $5x10^{34}$ cm^{-2} s^{-1} and a longer luminosity lifetime (by luminosity levelling)
  - than with 10^{35} and a luminosity lifetime of a few hours
- Luminosity Levelling by
  - Beta*, crossing angle, crab cavities, and bunch length

Detector physicists have indicated that their detector upgrades are significantly influenced by the choice between peak luminosities of $5x10^{34}$ and 10^{35}.

- Pile up events
- Radiation effects

Some additional Remarks

- Cryo Collimation scheme
- Radiation to Electronics

- We also need to study
  - How to give LHCb $5x10^{33}cm^{-2}s^{-1}$
  - Higher luminosity with lead collisions (ALICE)

Conclusions

- The Luminosity Targets set by the detectors are:
    - 3000fb^{-1} (on tape) by the end of the life of the LHC
    - → 200-300fb^{-1} per year in the second decade of running the LHC
- The Upgrades needed to attack these goals are
    1. SPS performance improvements to remove the bottleneck
    2. Aggressive consolidation of the existing injector chain for availability reasons
    3. Performance improvement/upgrades of the injector chain to allow phase 2 luminosities
    4. a newly defined luminosity upgrade which involves
        - At least one major upgrade of the high luminosity insertions
        - luminosity levelling at ~5x $10^{34}cm^{-2}s^{-1}$ (crab cavities etc…)

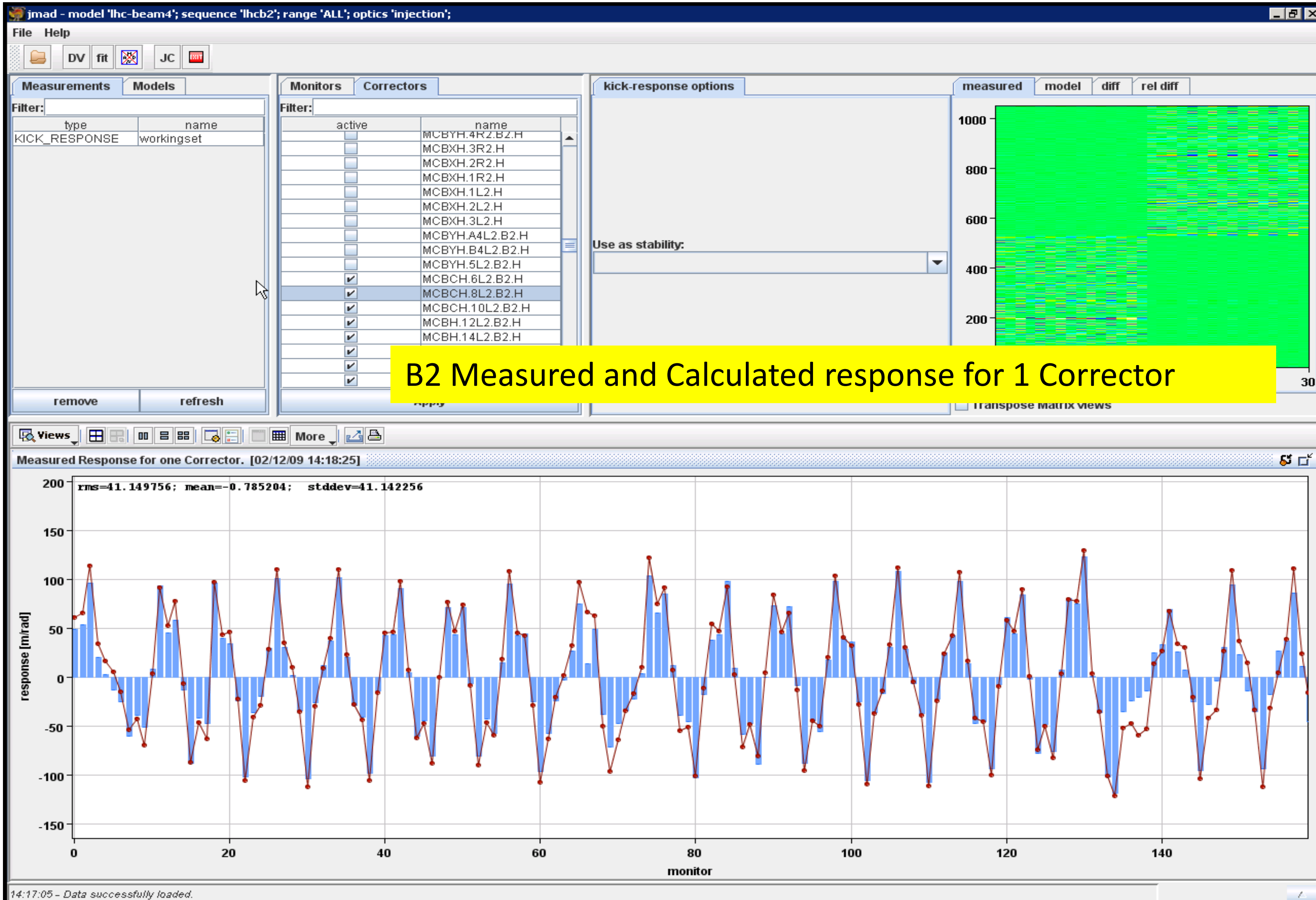
Topics

- Chamonix and Outcome
- LHC Status
  - Beam commissioning end 2009
  - Technical Stop Jan-Feb 2010
  - Hardware Commissioning March 2010
  - Commissioning and Operation March→ now
- Strategy for Performance Evolution 2010-2011

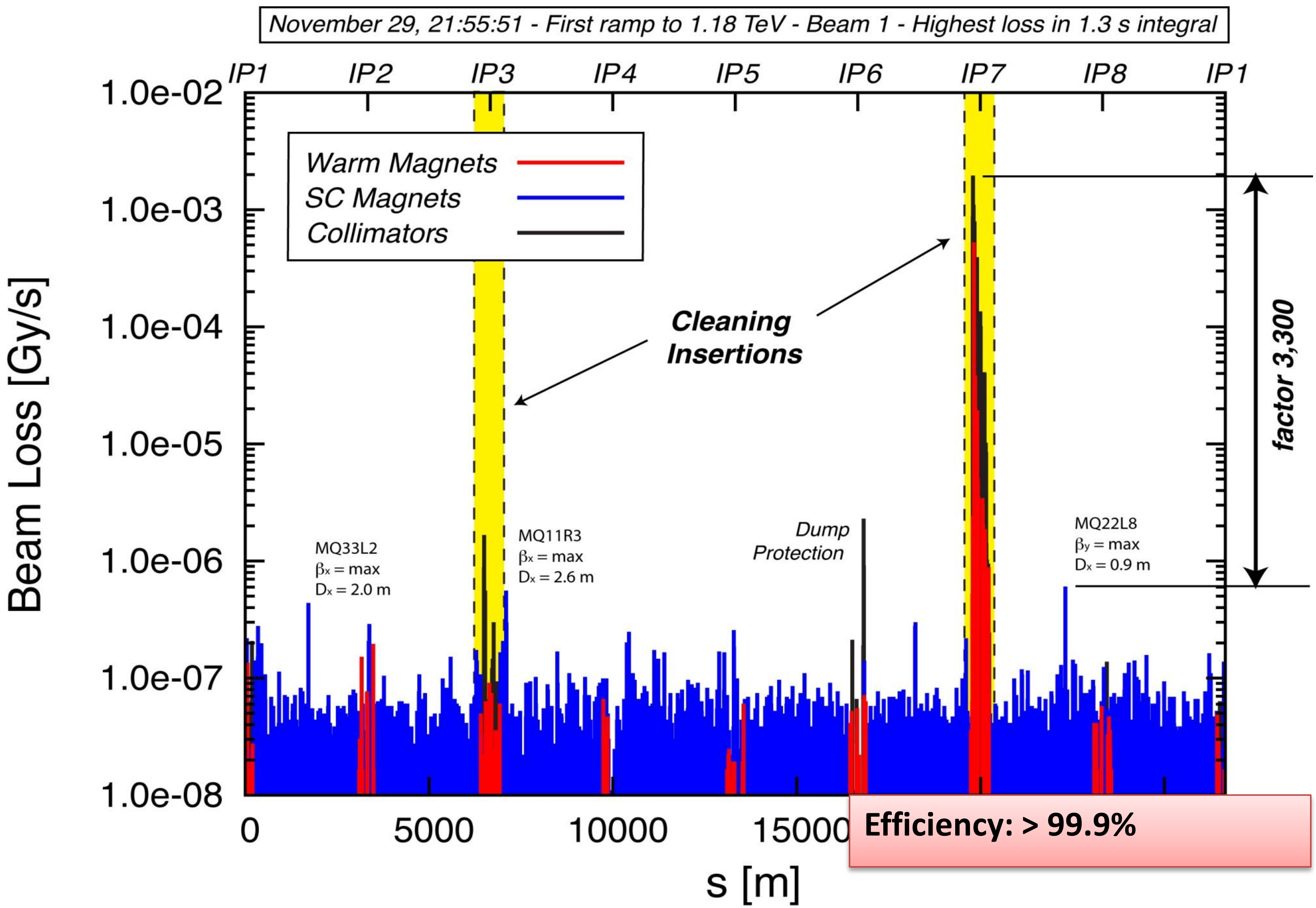
End 2009: Milestones During the 26 days

Date	Day	Achieved
Nov 20	1	Each beam circulating. Key beam instrumentation working.
Nov 23	4	First collisions at 450 GeV. First ramp (reached 560 GeV).
Nov 26	7	Magnetic cycling established (reproducibility).
Nov 27	8	Energy matching.
Nov 29	10	Ramp to 1.18 TeV.
Nov 30	11	Experiment solenoids on.
Dec 04	15	Aperture measurement campaign finished. LHCb and ALICE dipoles on.
Dec 05	16	Machine protection (Injection, Beam dump, Collimators) ready for safe operation with pilots.
Dec 06	17	First collisions with STABLE BEAMS, 4 on 4 pilots at 450 GeV, rates around 1Hz.
Dec 08	19	Ramp colliding bunches to 1.18 TeV
Dec 11	22	Collisions with STABLE BEAMS, 4 on 4 at 450 GeV, > 10^{10} per bunch, rates around 10Hz.
Dec 13	24	Ramp 2 bunches per beam to 1.18 TeV. Collisions for 90mins.
Dec 14	25	Collisions with STABLE BEAMS, 16 on 16 at 450 GeV, > 10^{10} per bunch, rates around 50Hz.
Dec 16	27	Ramp 4 on 4 to 1.18 TeV. Squeeze to 7 m.

Optics Checks (2^{nd} Dec)



Collimation after beam based set up



Efficiency: > 99.9%

Topics

- Chamonix and Outcome
- LHC Status
    - Beam commissioning end 2009
    - Technical Stop Jan-Feb 2010
    - Hardware Commissioning March 2010
    - 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)

Topics

- Chamonix and Outcome
- LHC Status
    - Beam commissioning end 2009
    - Technical Stop Jan-Feb 2010
    - Hardware Commissioning March 2010
    - Commissioning and Operation March→ now
- Strategy for Performance Evolution 2010-2011

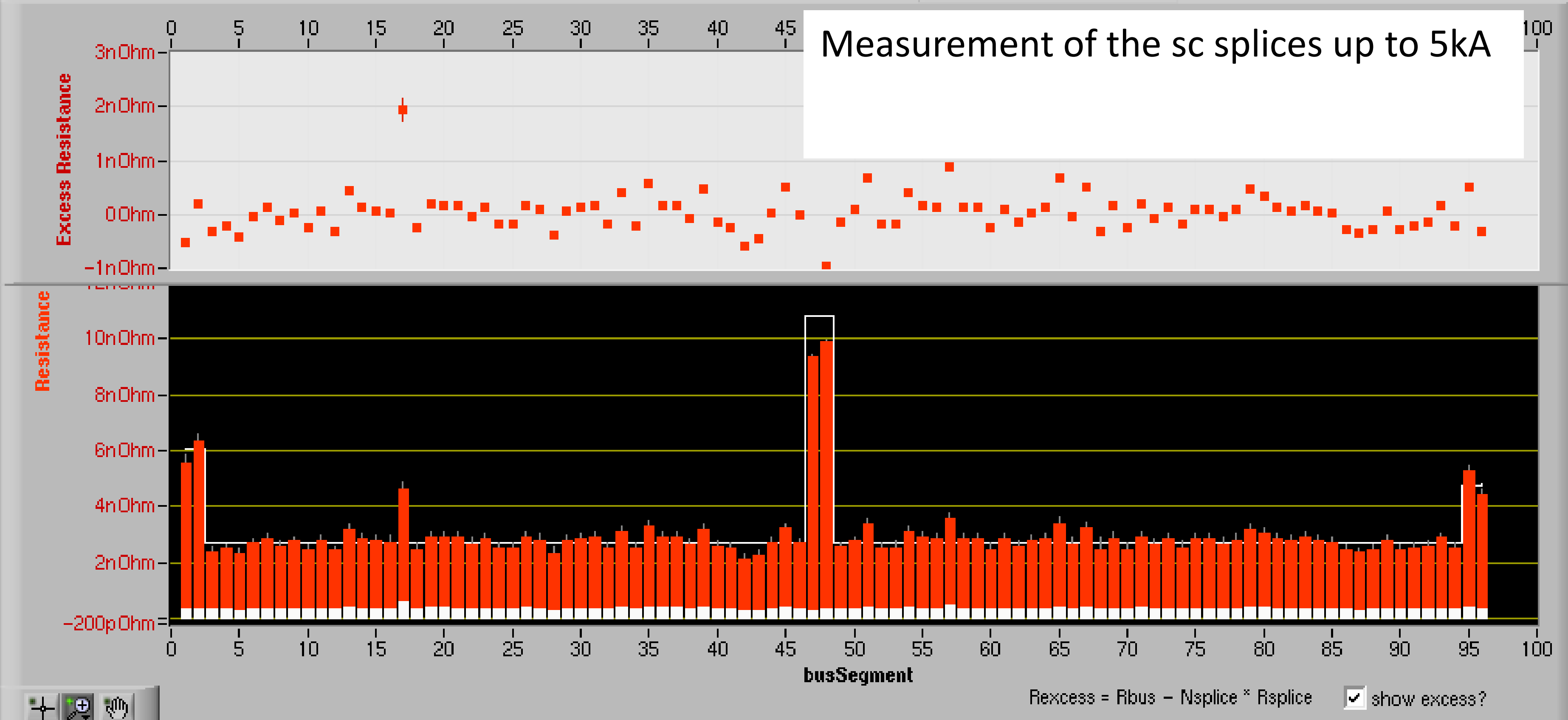
S12: RQF and RQD pyramids to 2kA and 5kA

A12_RQDRQF_20100206_130000-185959.data

Bus Splices

CLOSE

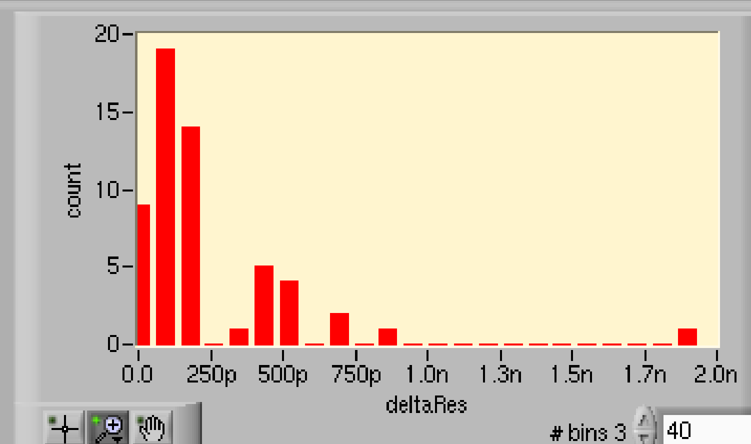
Measurement of the sc splices up to 5kA

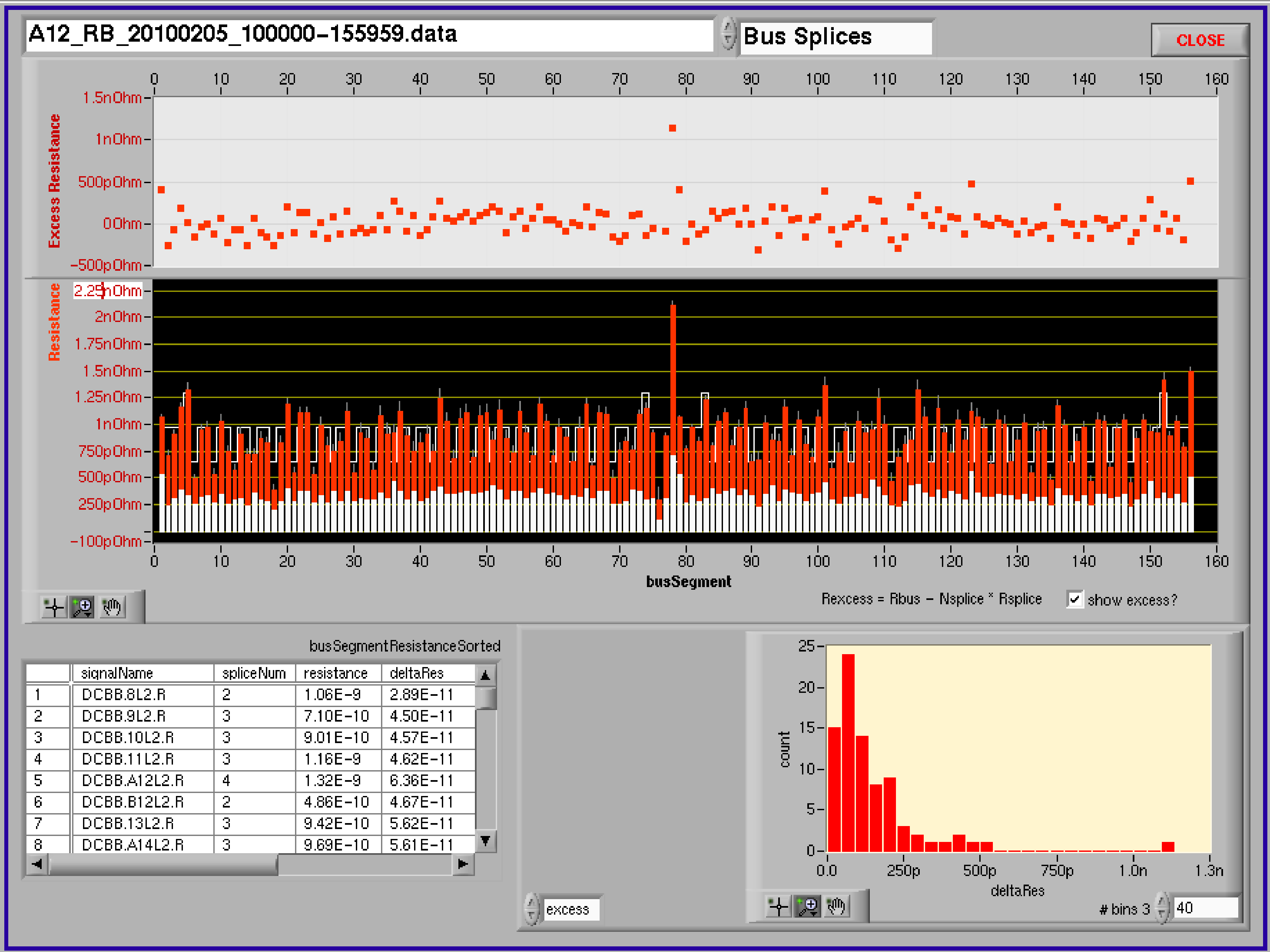


busSegmentResistanceSorted

	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





	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

Topics

- Chamonix and Outcome
- LHC Status
  - Beam commissioning end 2009
  - Technical Stop Jan-Feb 2010
  - Hardware Commissioning March 2010
  - Commissioning and Operation March→ now
- Strategy for Performance Evolution 2010-2011

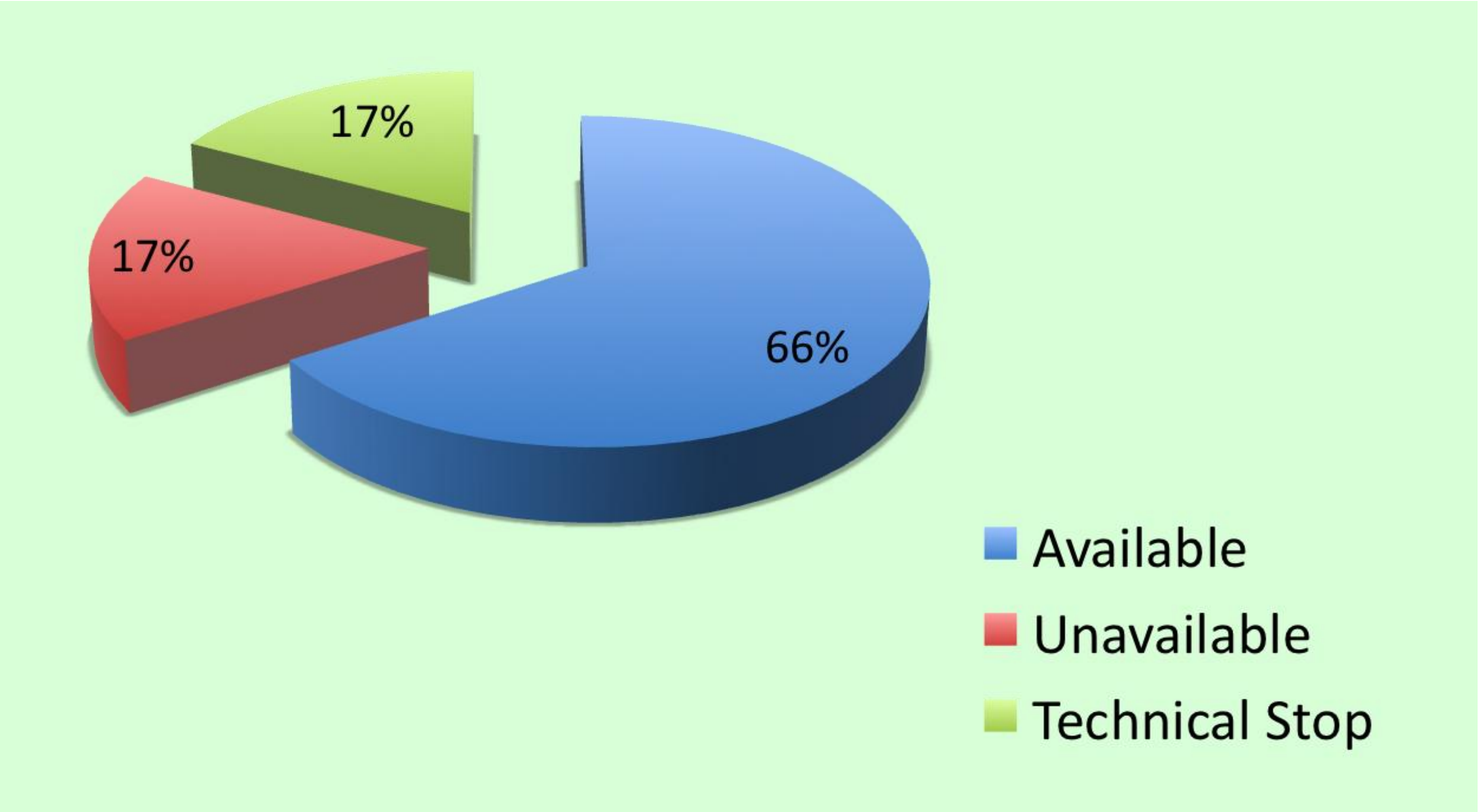
Beam milestones 2010

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

- 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.

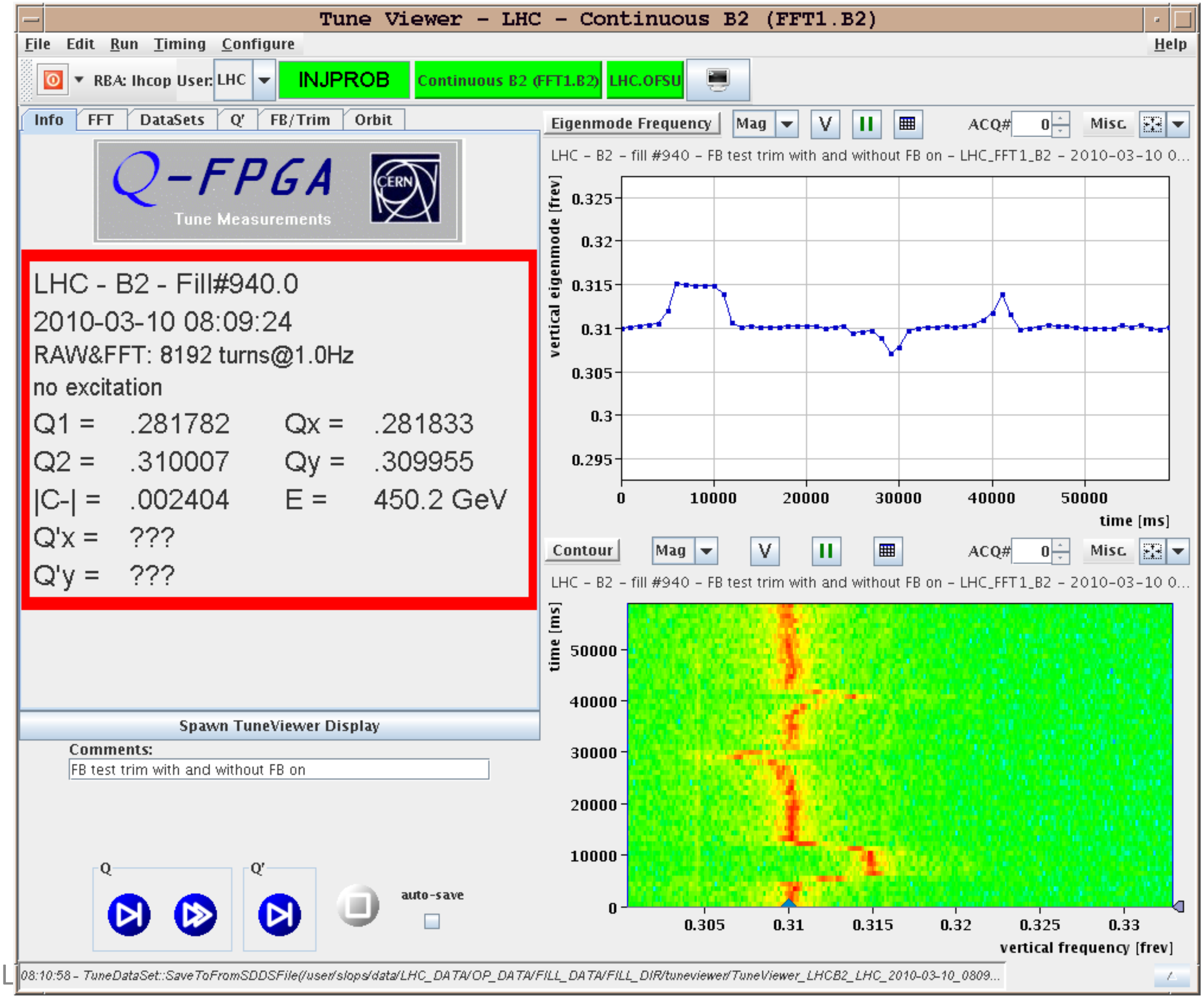
LHC Availability (Week 10)



All technical systems contribute to very promising LHC availability!

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

Tune feedback

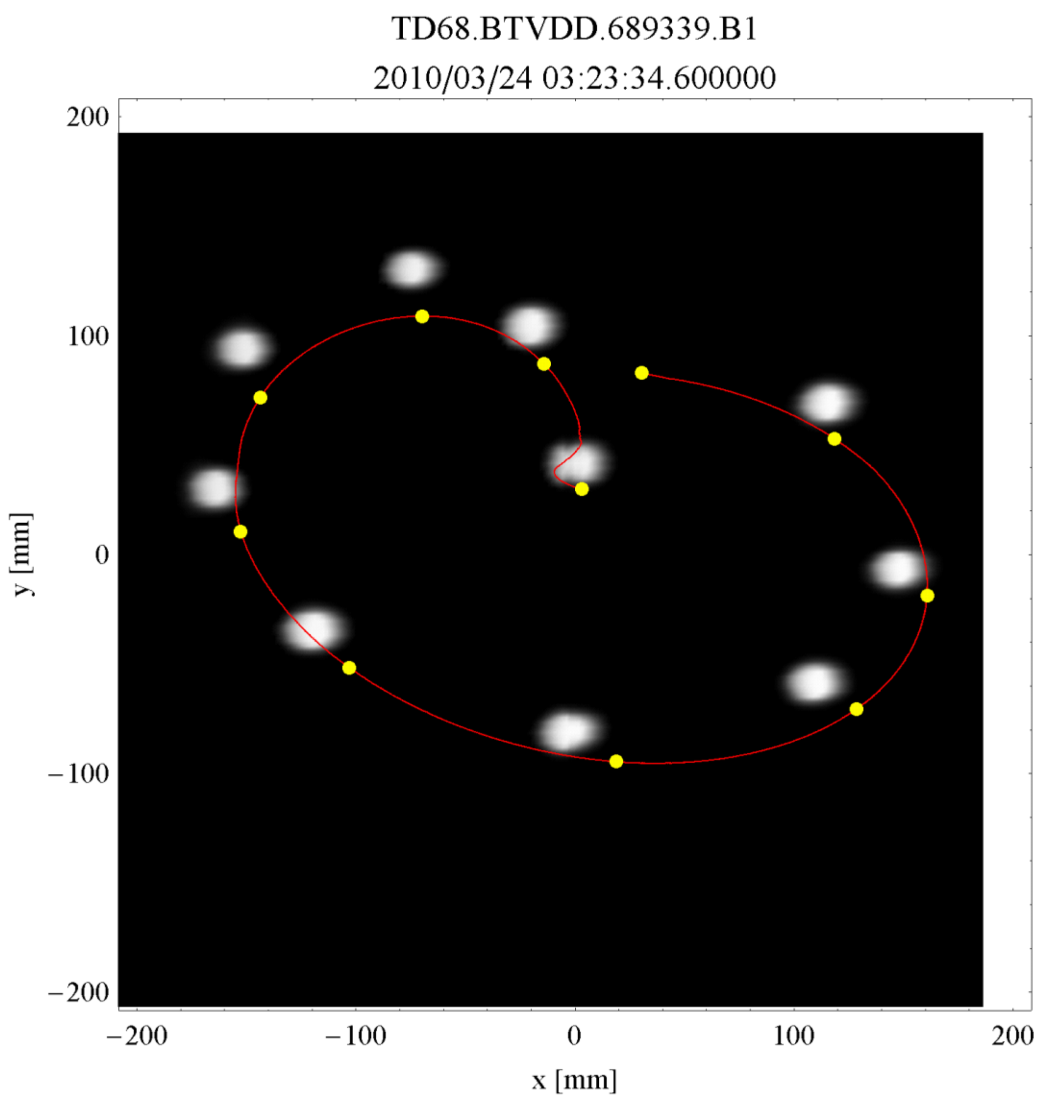


Magnet model

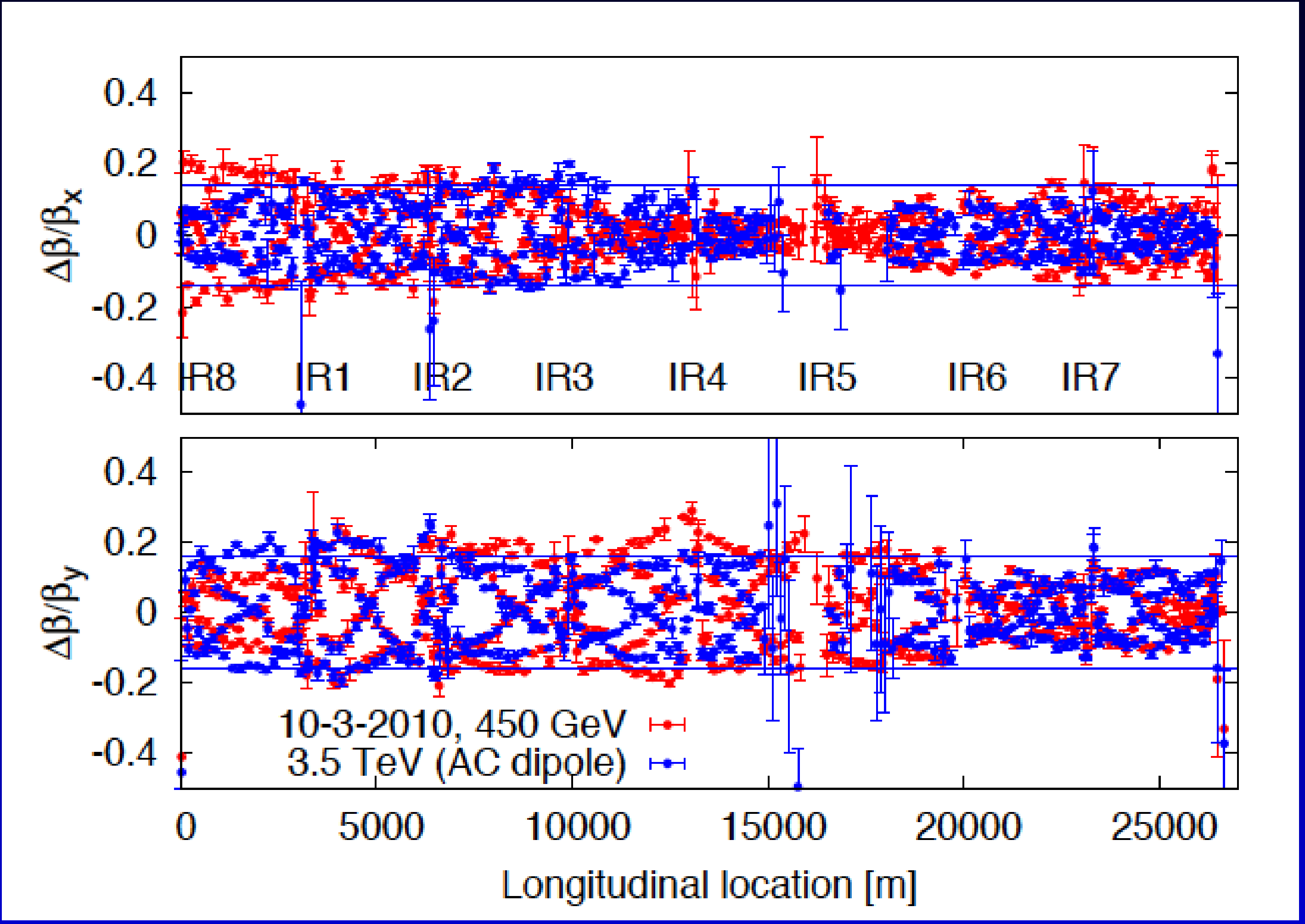
- The knowledge of the magnetic model of the LHC is remarkable and has been one of the key elements of a very smooth beam commissioning
- Huge parameter space, mistakes made, lessons learnt etc but…
- Tunes, energy matching, optics remarkably close to the model already
- Bodes very well for the future.

Beam dump

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



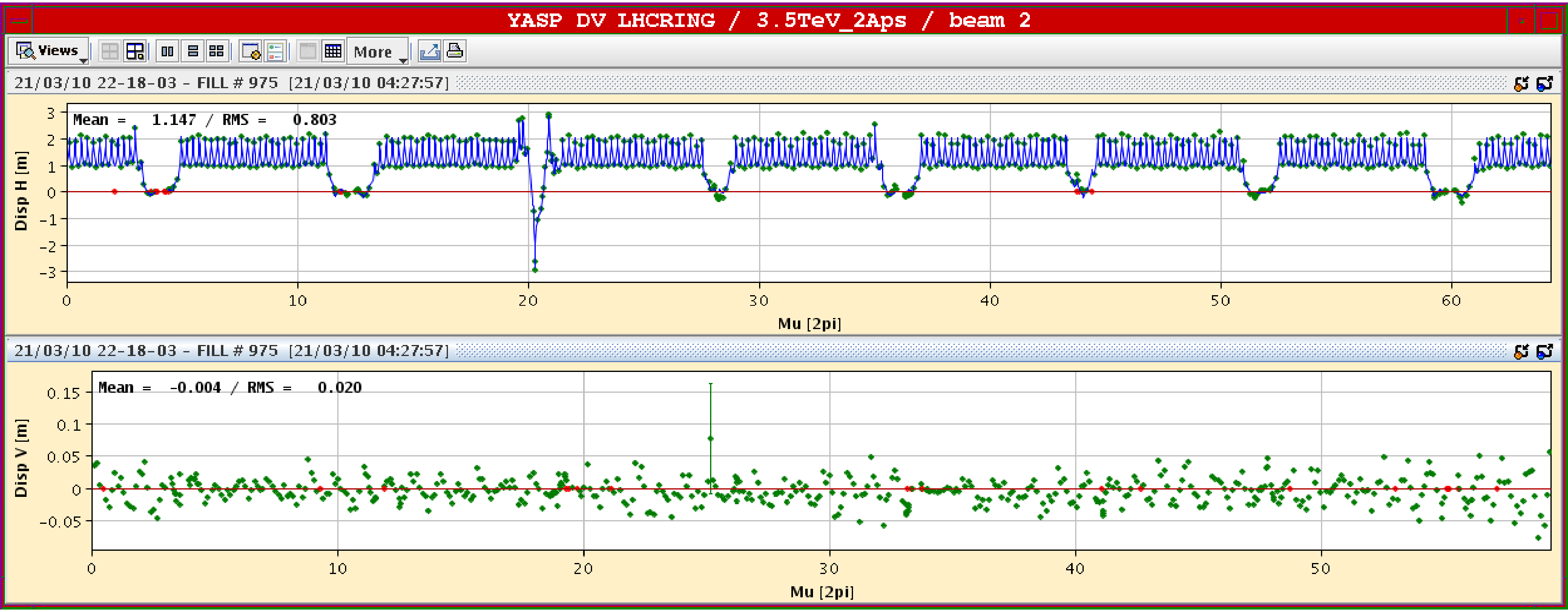
Beam 2, 3.5 TeV beta-beating



20% beating!

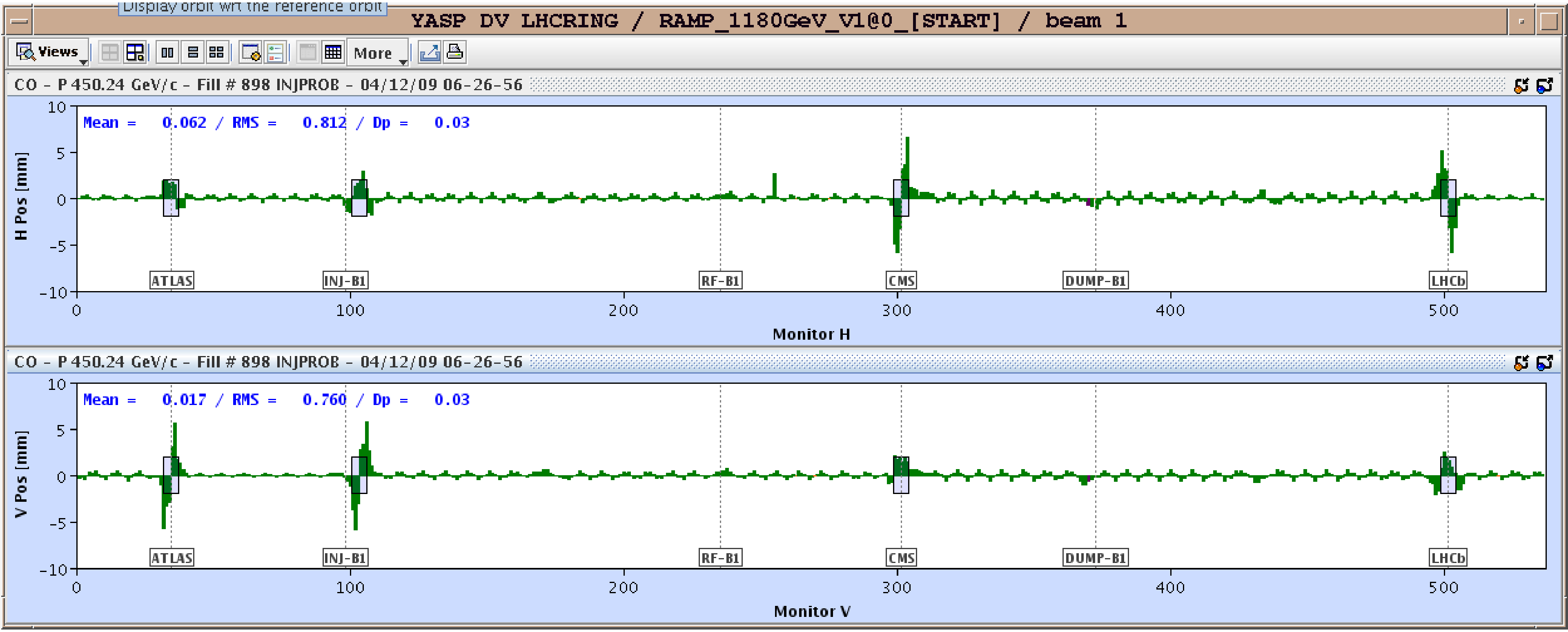
Dispersion

Dispersion B2 at 3.5 TeV



First Collisions at 7TeV cm March 30, 2010

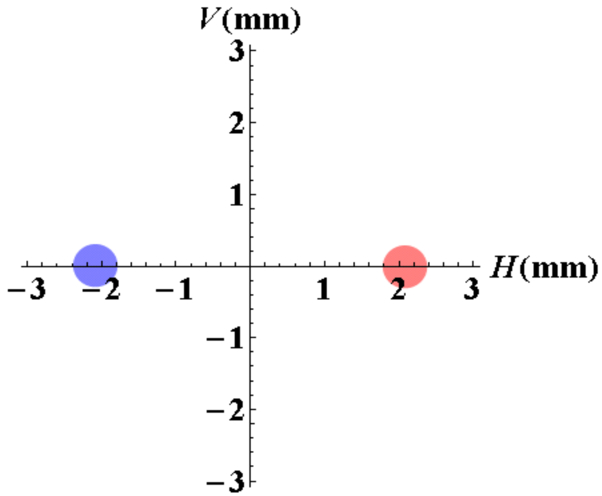
Separation bumps and crossing angle.



March 30 2010

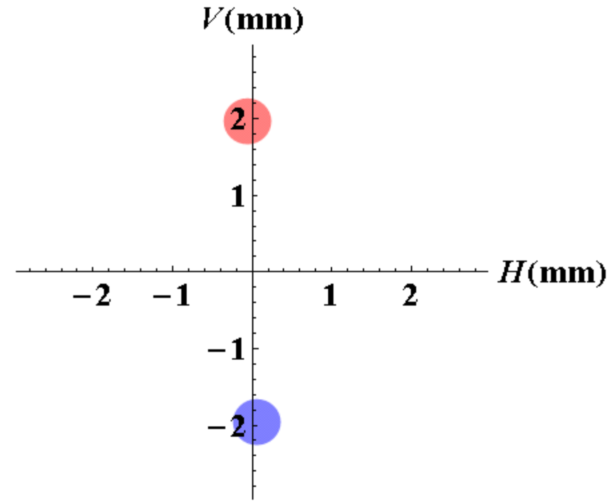
ATLAS IP Separation

H = 4.173 mm : V = 0.035 mm

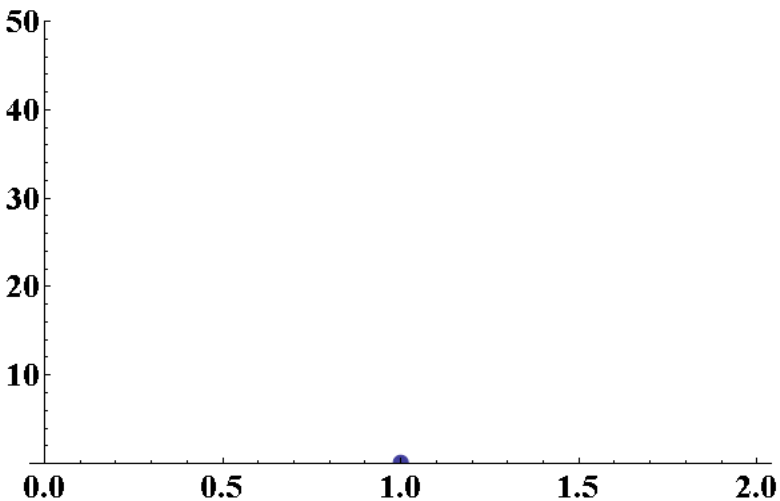


CMS IP Separation

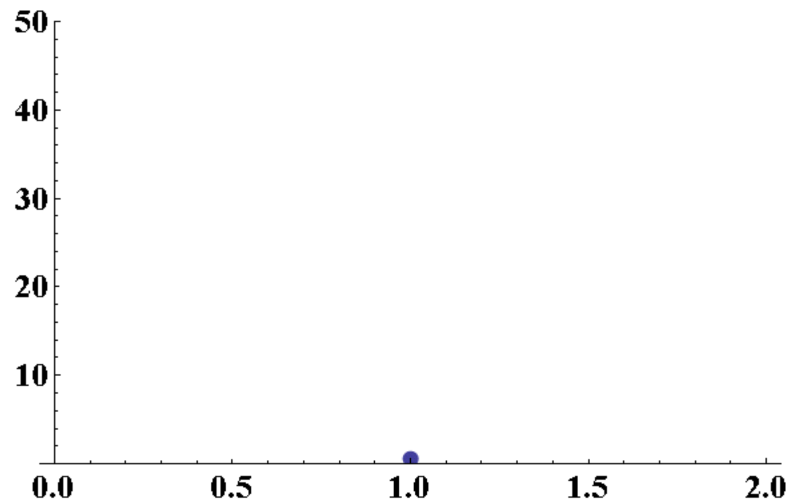
H = 0.130 mm : V = 3.925 mm



ATLAS Coll Rate Evol

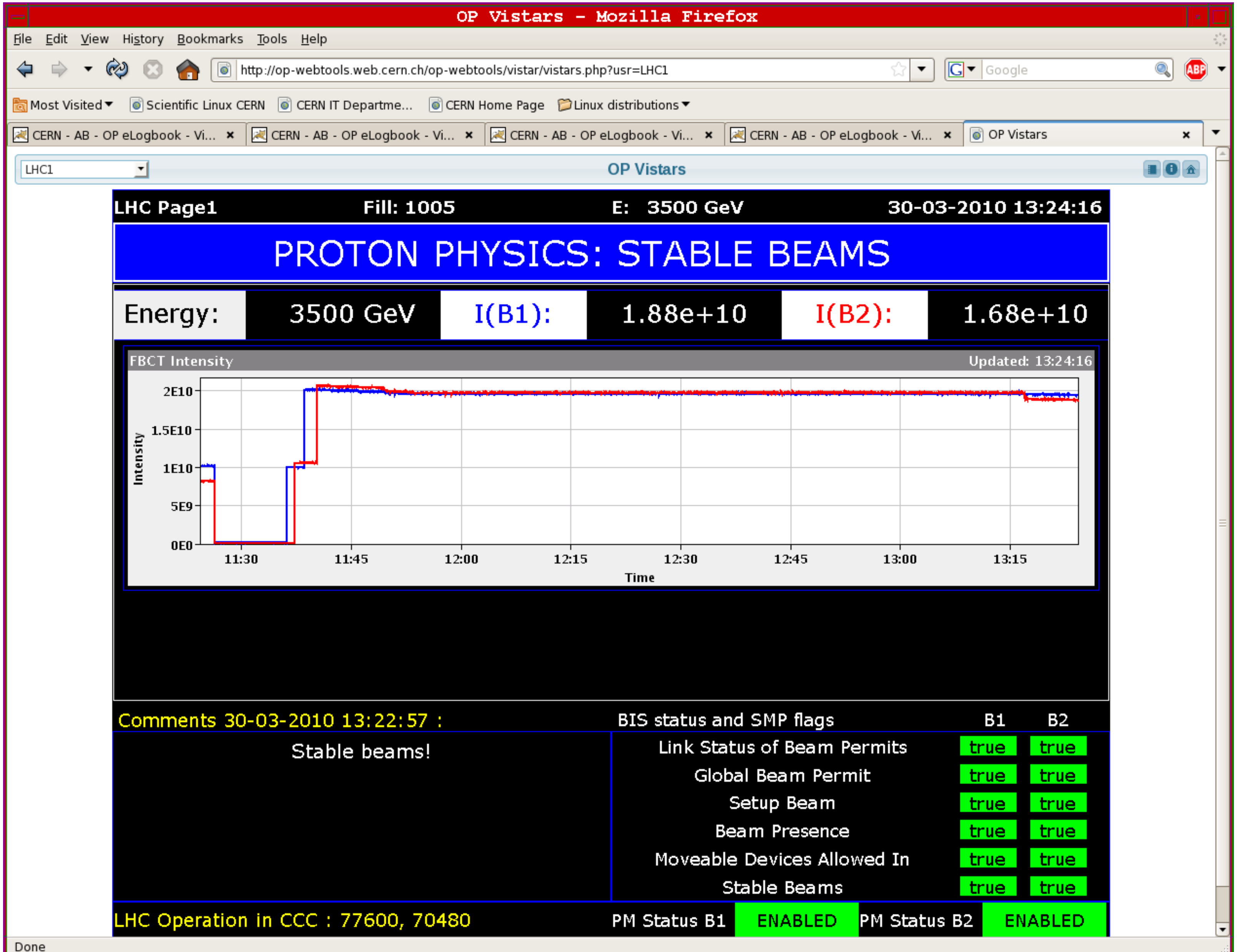


CMS Coll Rate Evol



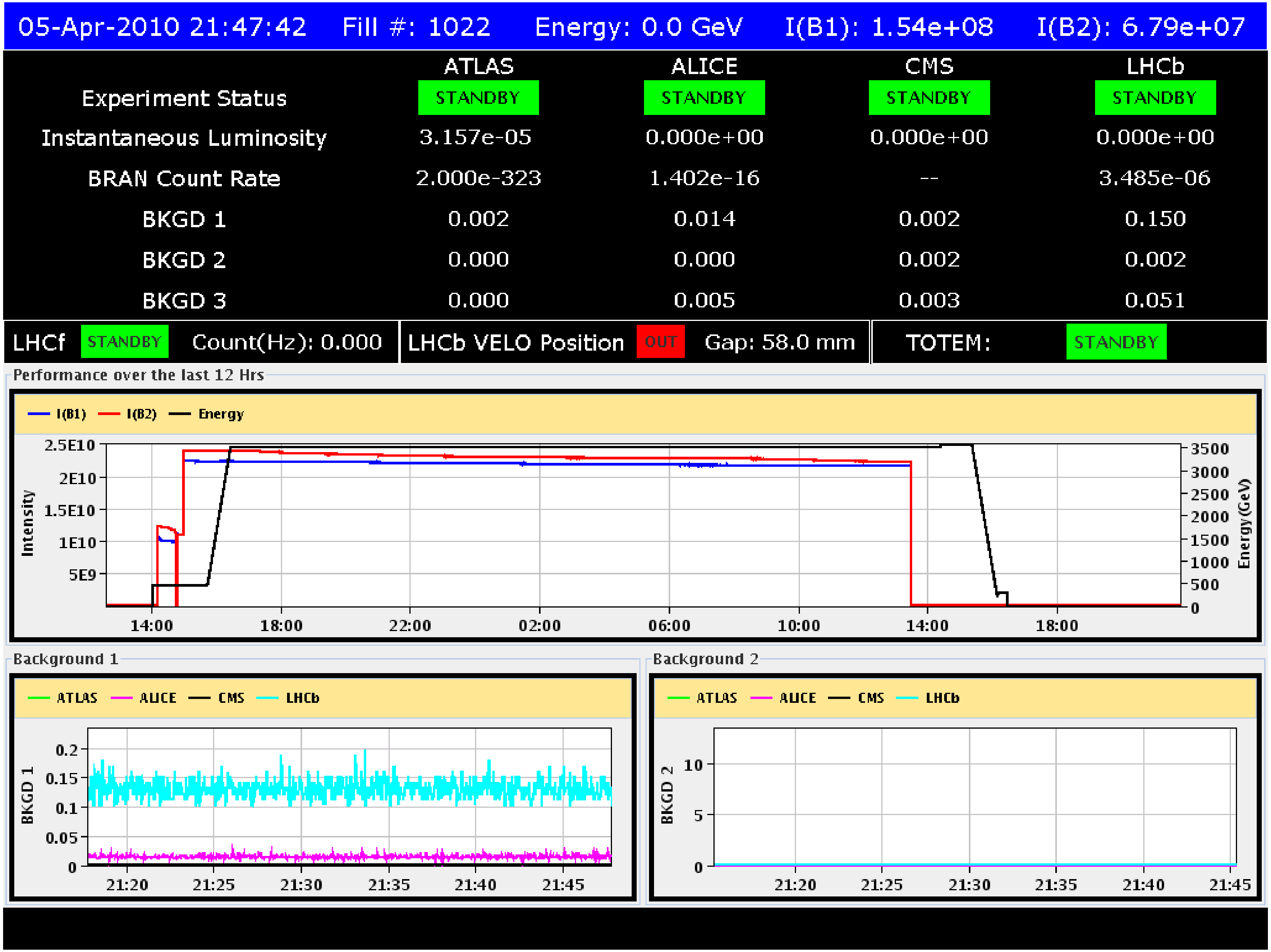
30/3/2010

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



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)

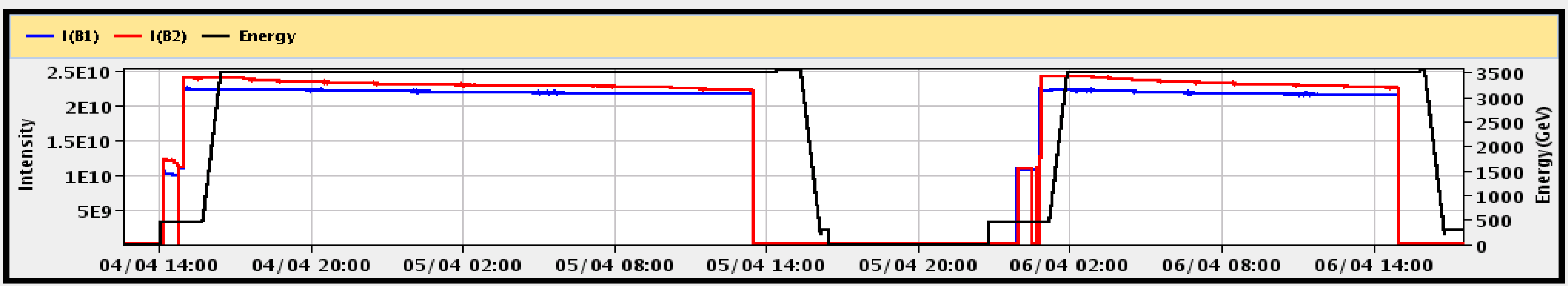
A very good 48 hour period!

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

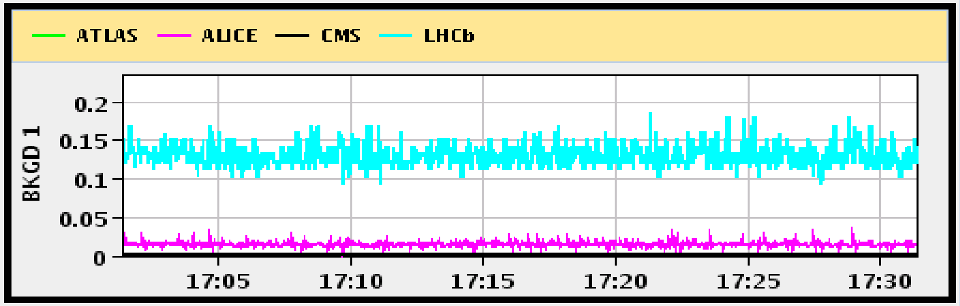
	ATLAS	ALICE	CMS	LHCb
Experiment Status	STANDBY	NOT READY	STANDBY	STANDBY
Instantaneous Luminosity	0.000e+00	0.000e+00	0.000e+00	8.989e-04
BRAN Count Rate	3.229e-07	4.059e-32	2.086e-11	1.635e-32
BKGD 1	0.002	0.014	0.002	0.131
BKGD 2	0.000	0.000	0.002	0.002
BKGD 3	0.000	0.005	0.003	0.037

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

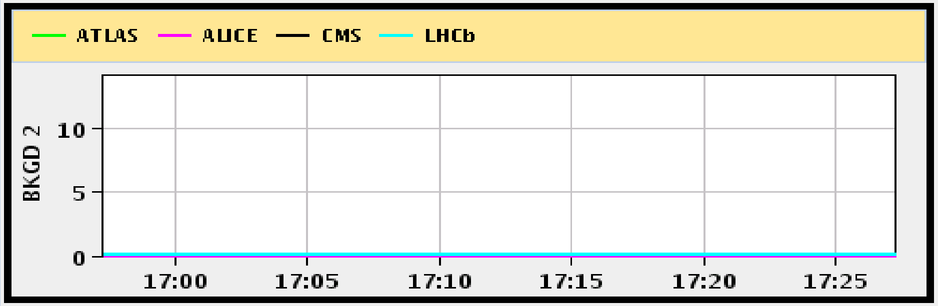
Performance over the last 12 Hrs



Background 1

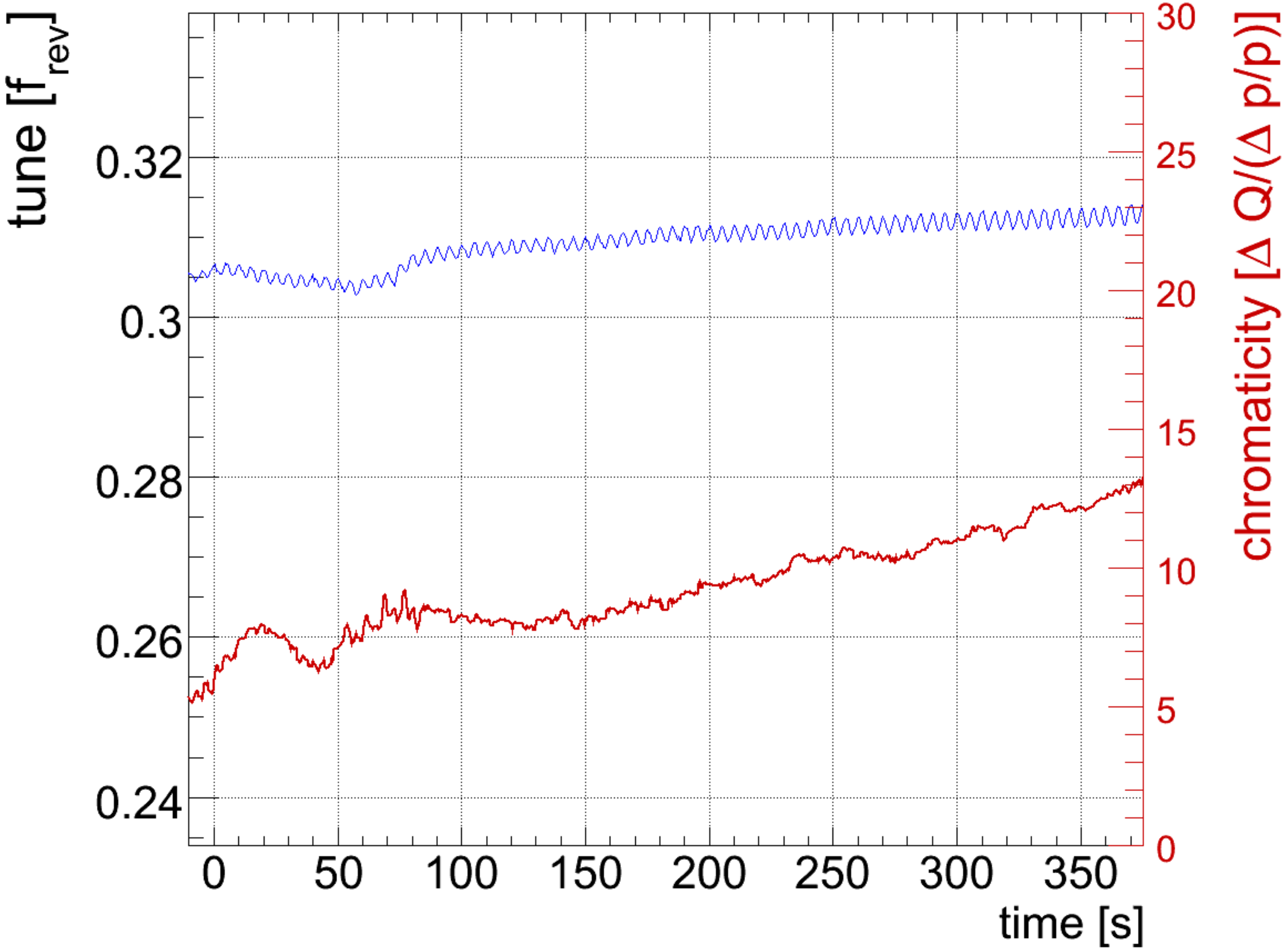


Background 2



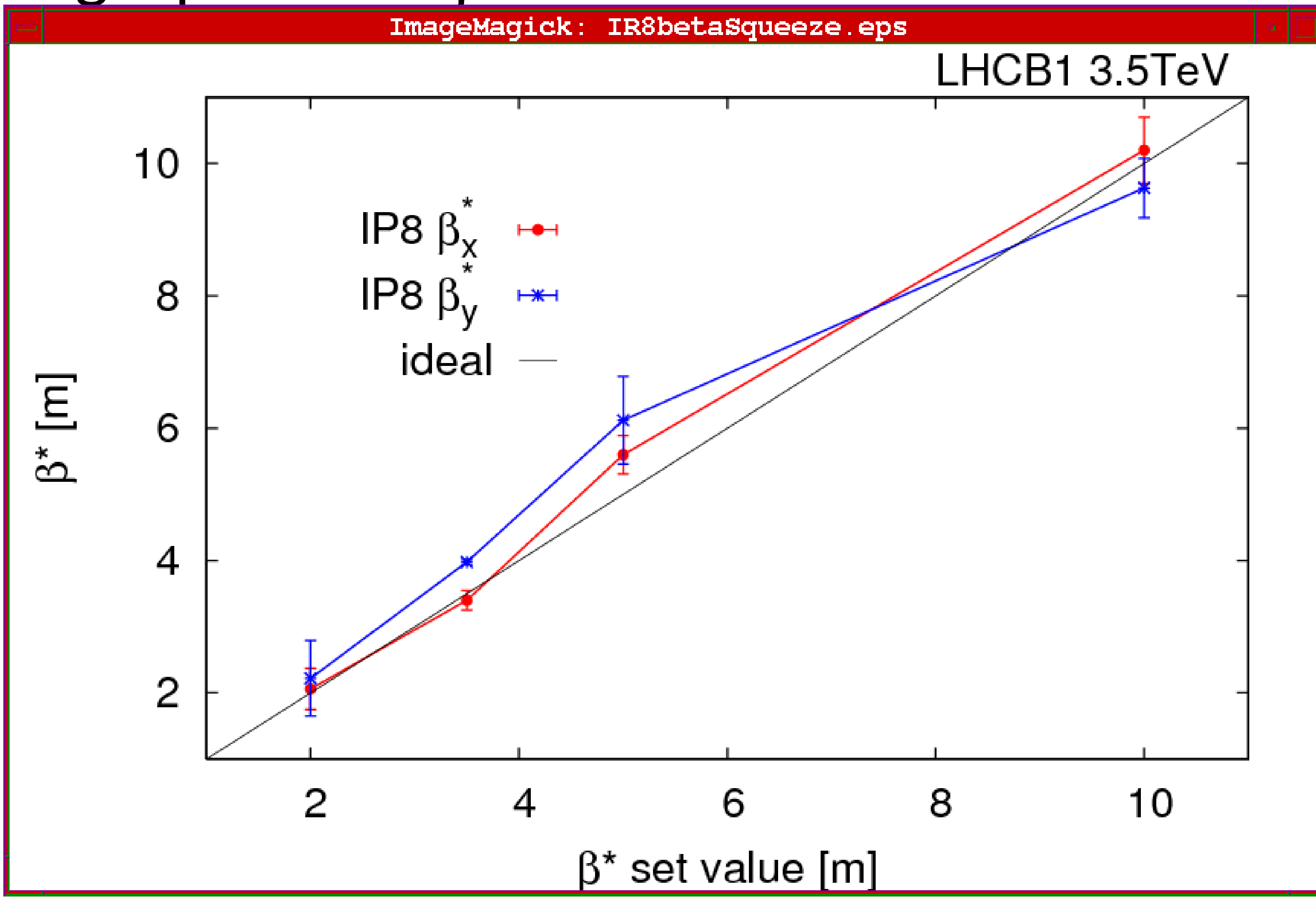
Tuesday 13.4.

- Q’ measurement during 800 GeV ramp: Beam2 Vertical



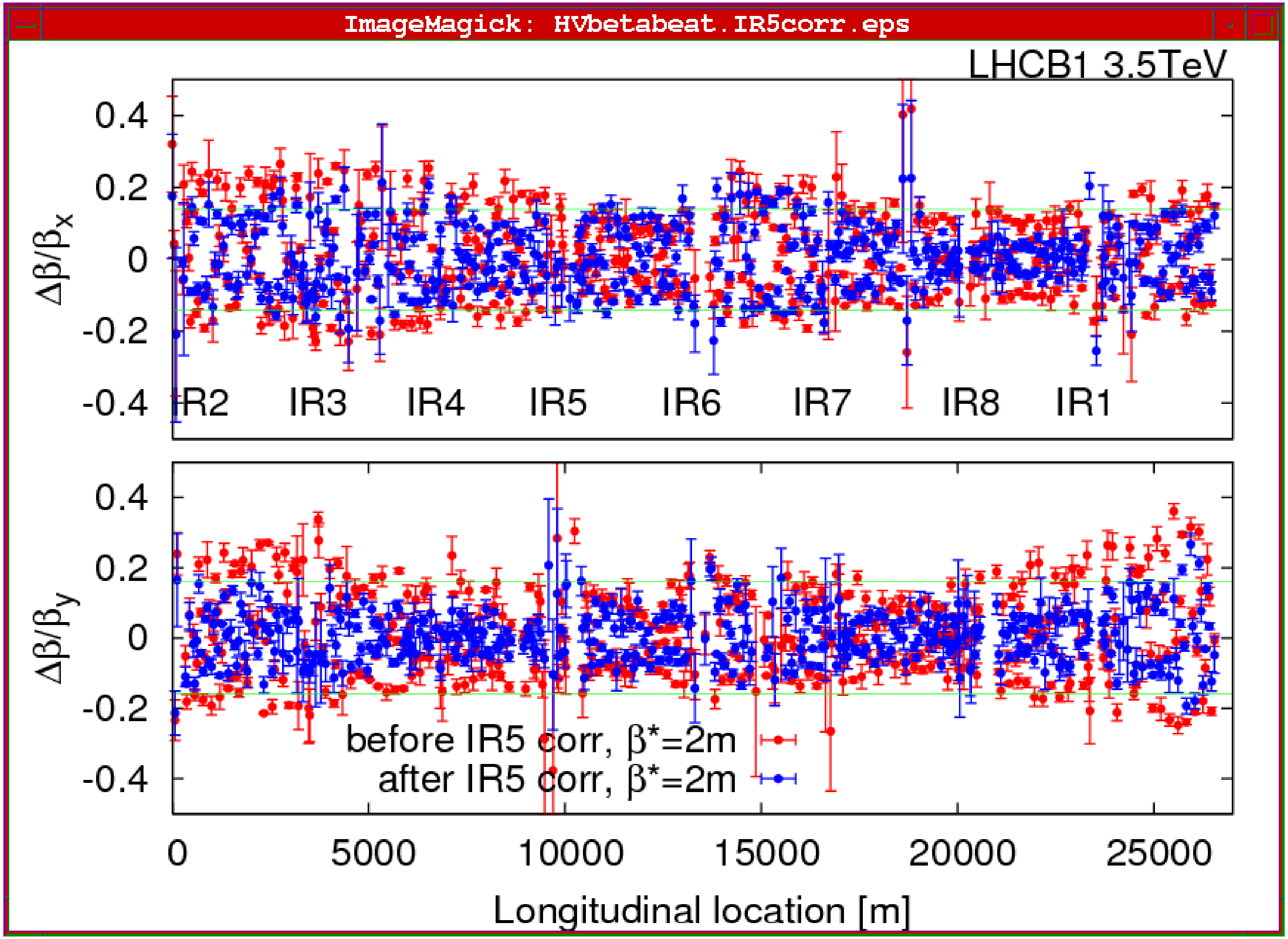
Tuesday 13.4.

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



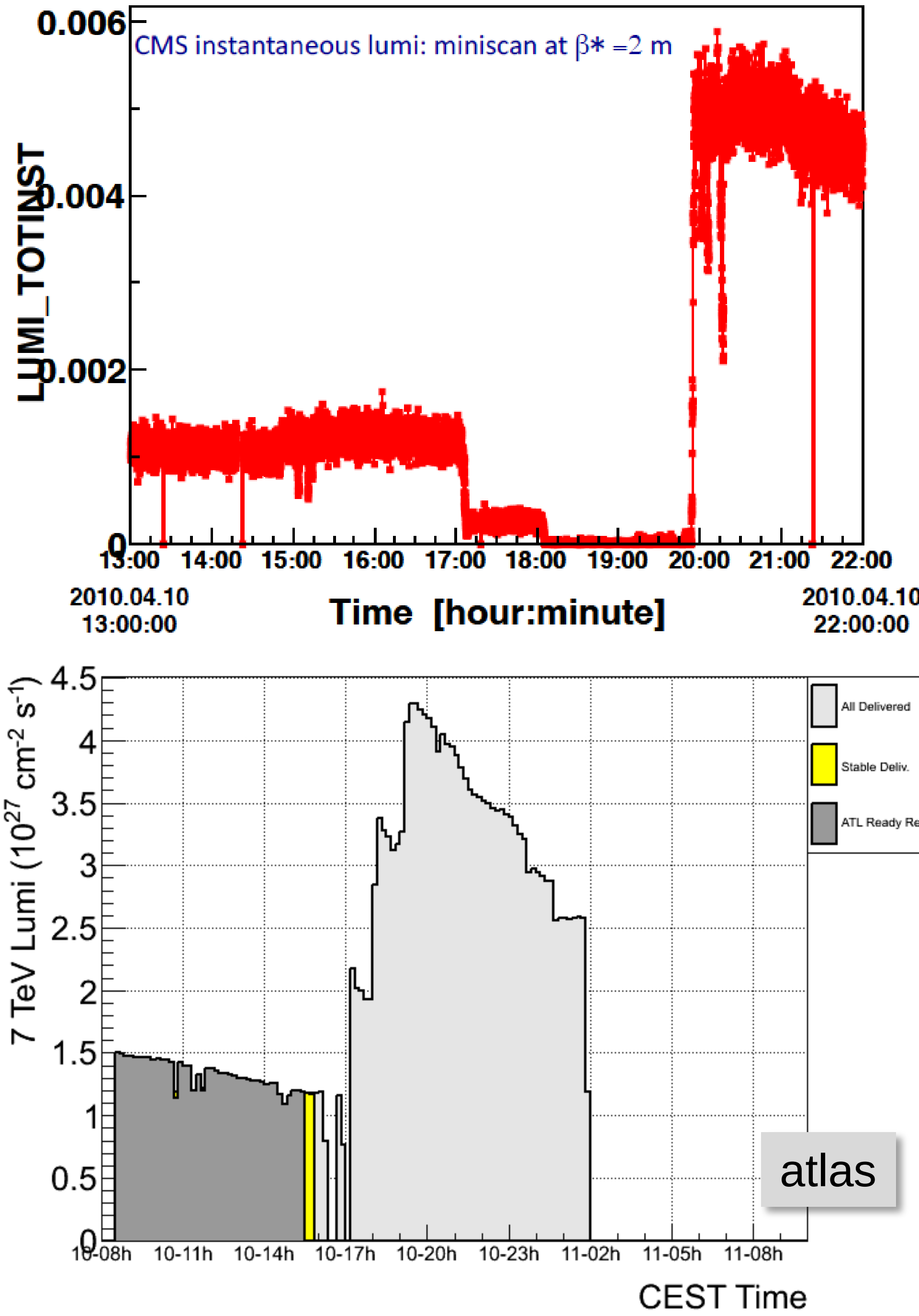
Tuesday 13.4.

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



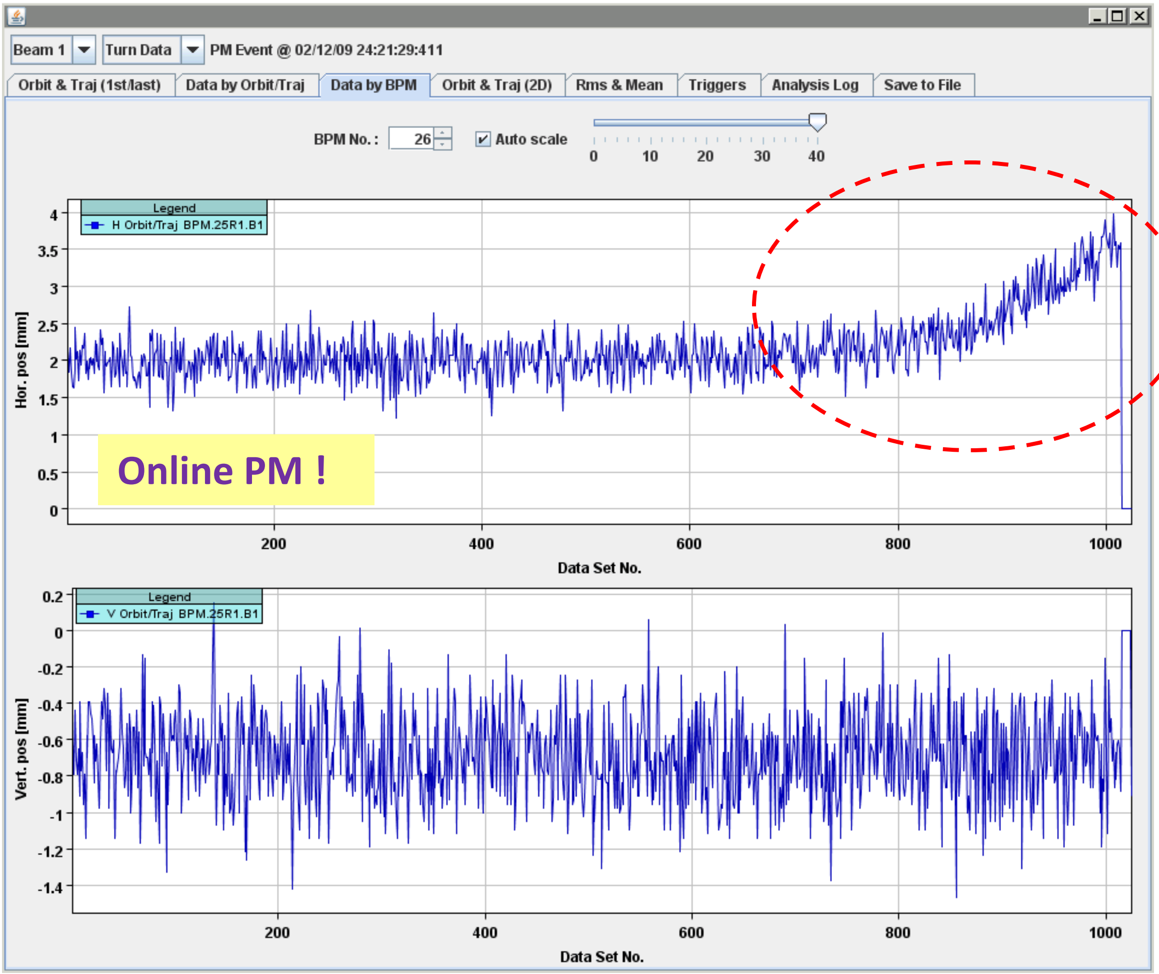
IP1&5 lumi vs squeeze

- 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

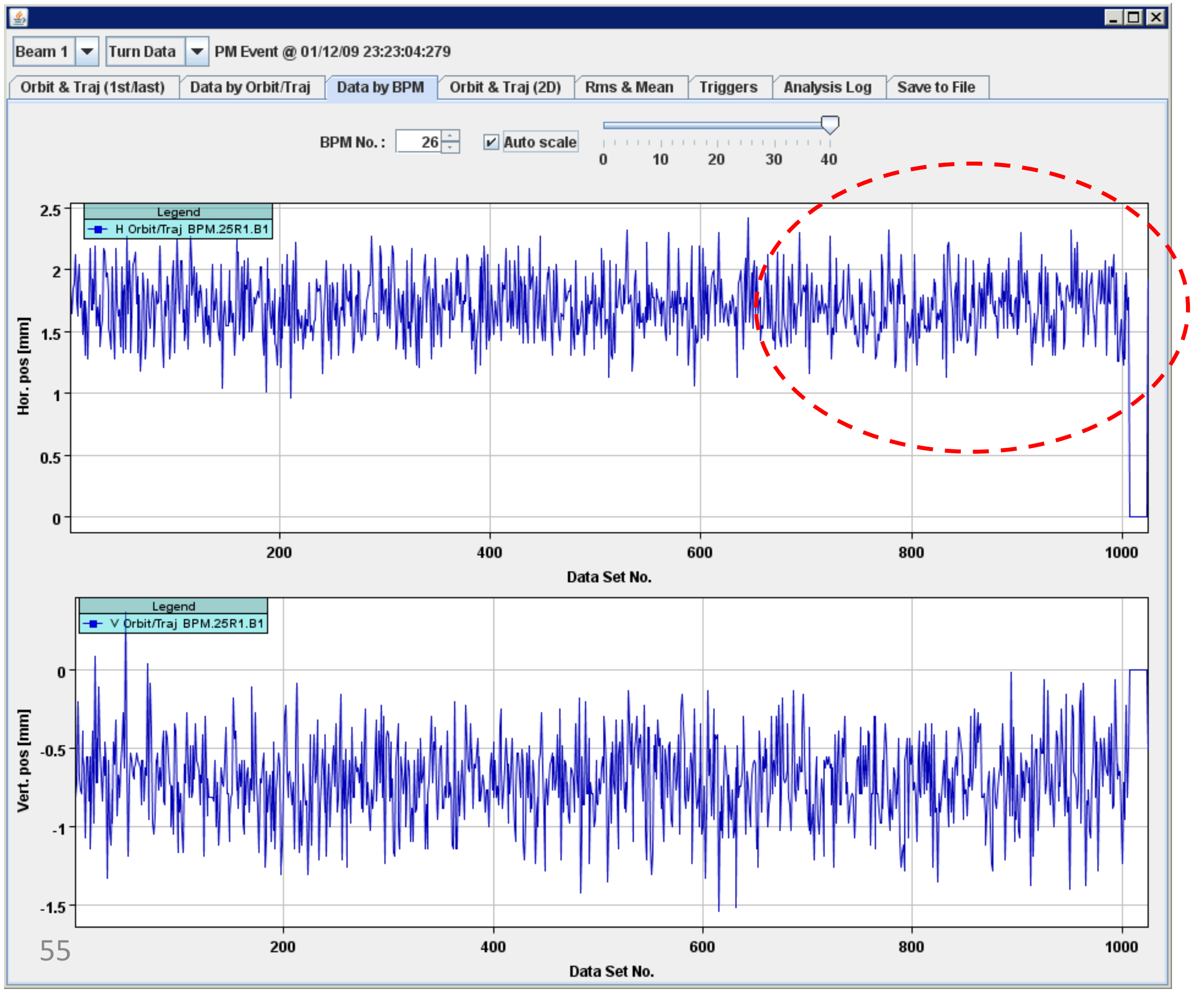
- Low intensity beam test.
- Trajectory evolution after OFF send to RD1.LR1, with FMCM masked.
- Beam dumped by BLMs in IR7.



- 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.

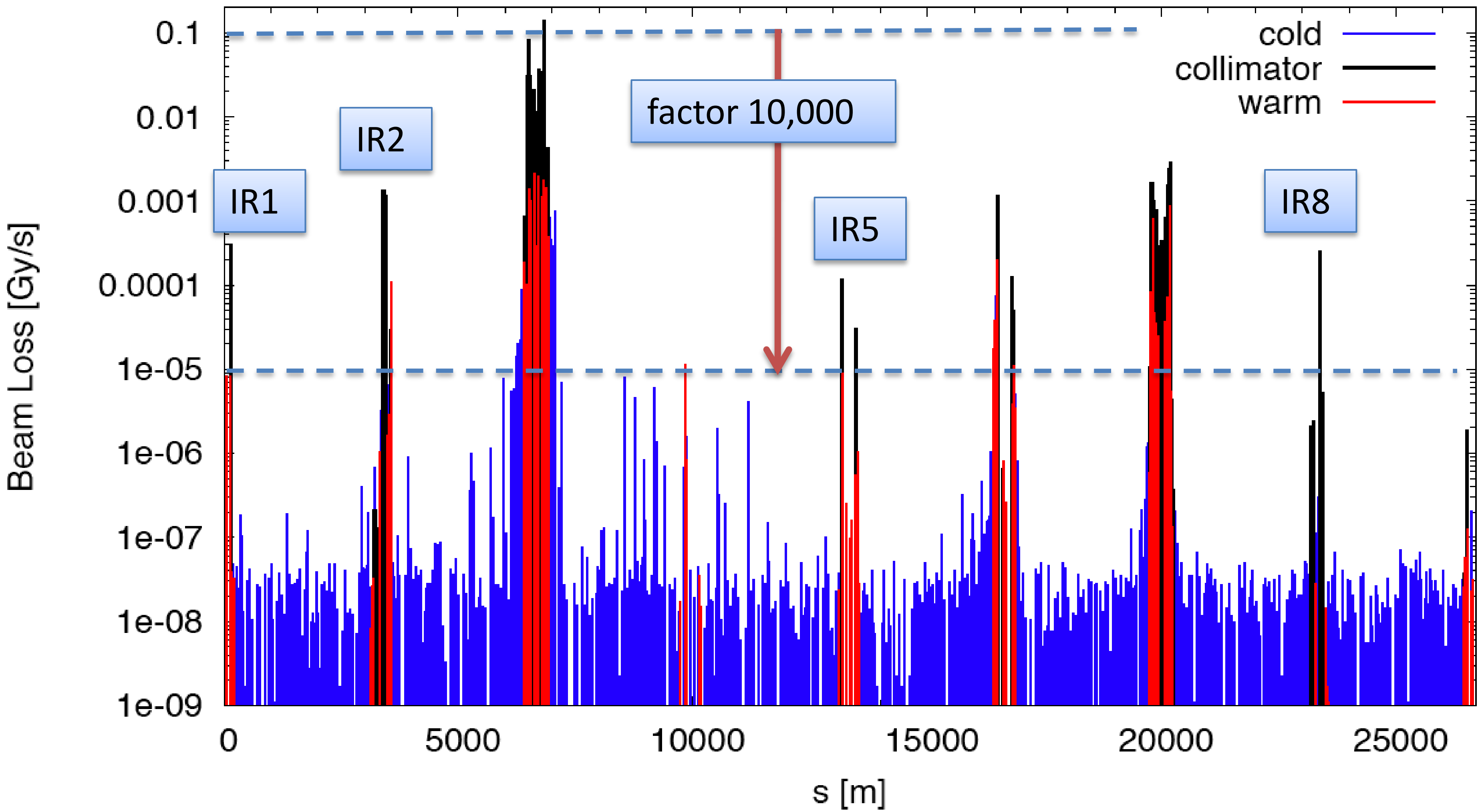


- Trajectory over 1000 turns at a the same BPM.
- No position change visible within resolution.

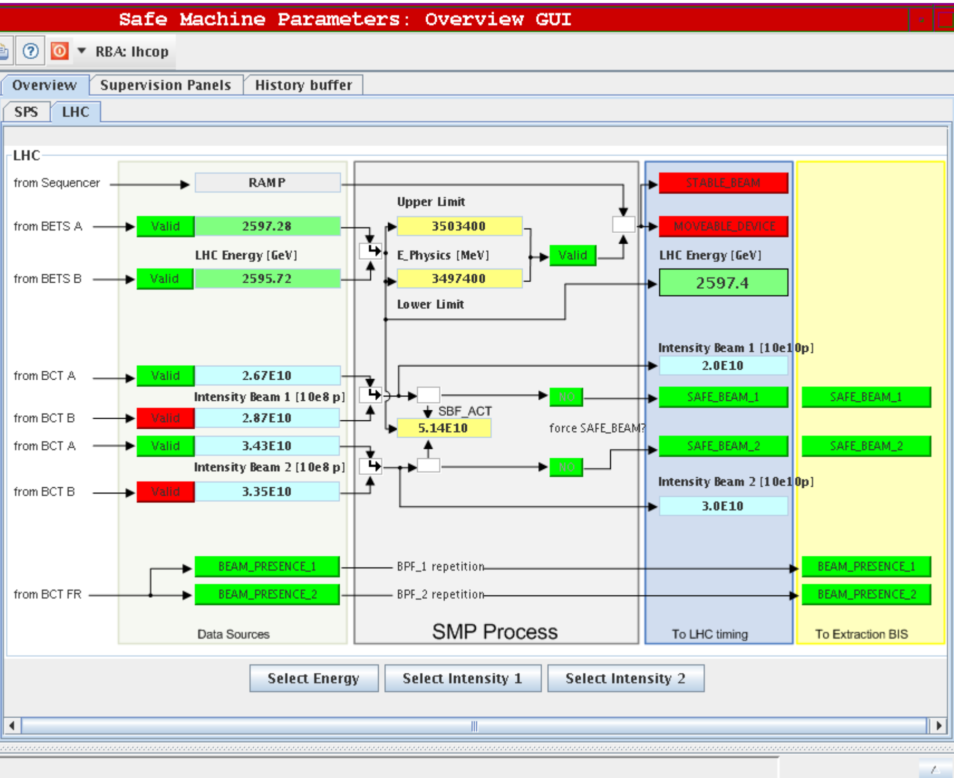
>> The redundant protection is working

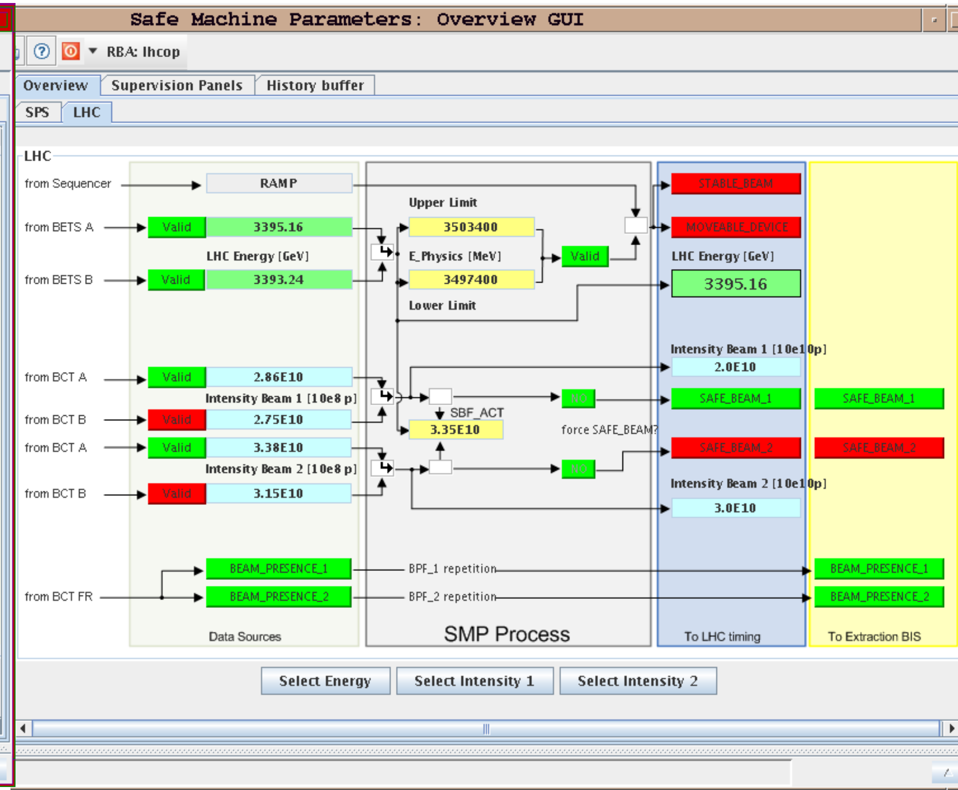
Qualification: Off-momentum collimation

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



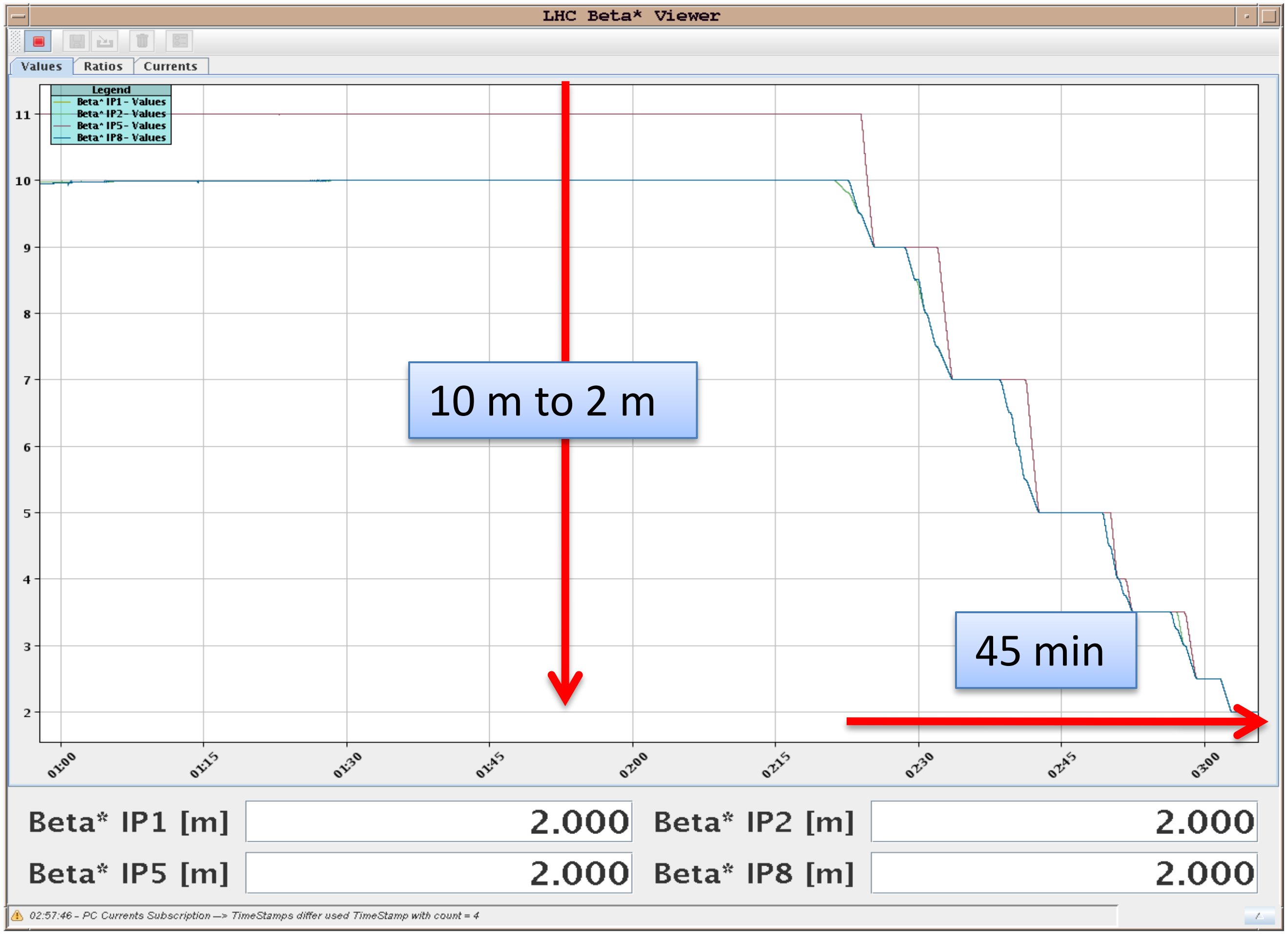
Saturday 24/4/2010



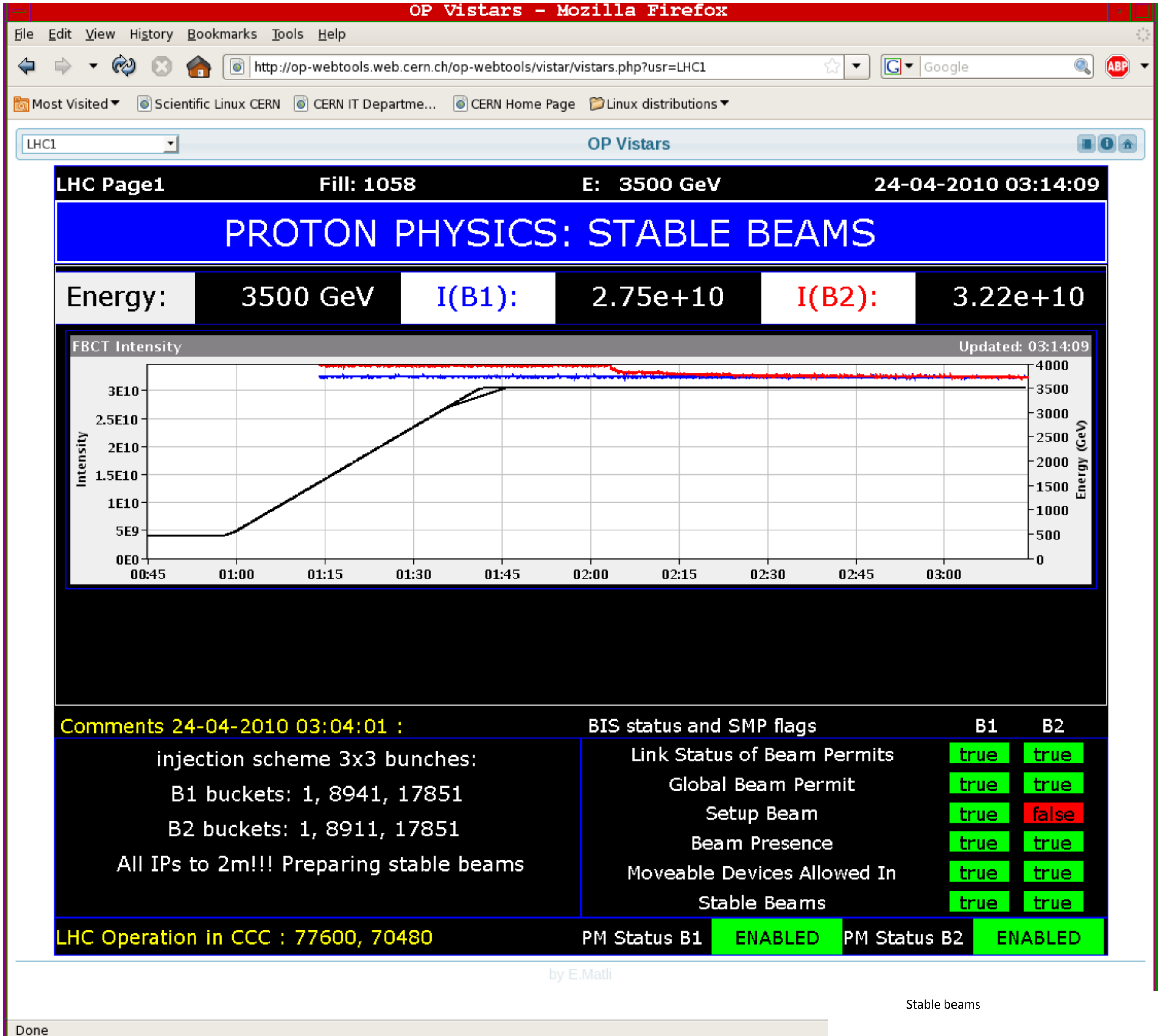


Setup Beam Flag : UNSAFE beam for the 1st time

Squeeze to 2 m: Fast and Smooth

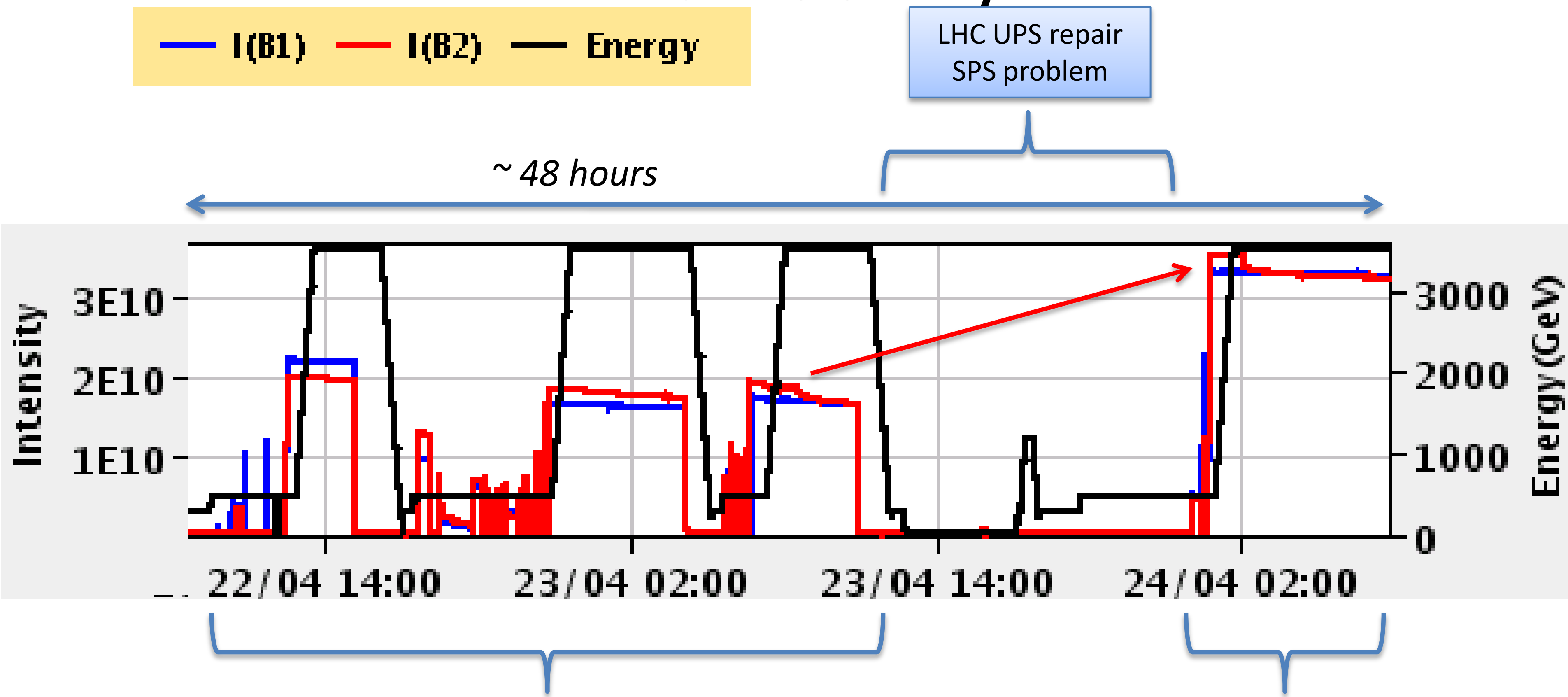


Saturday 24/4/2010



Stable beams

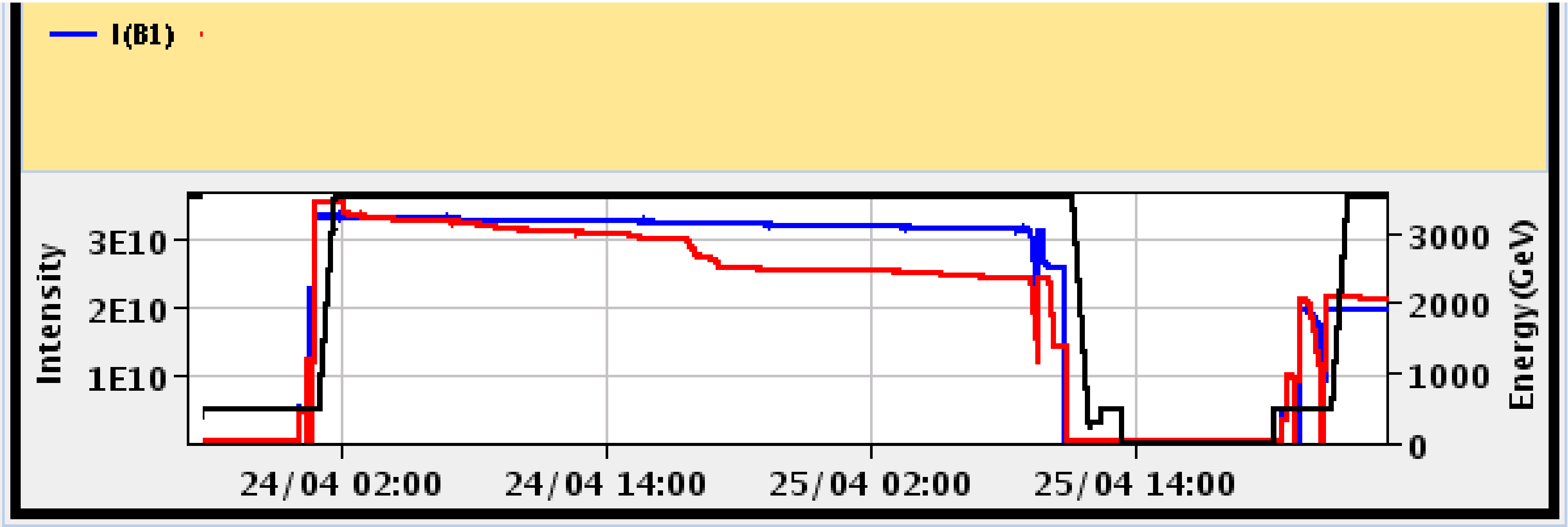
Ramp & Squeeze Start Working Smoothly



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

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.**

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

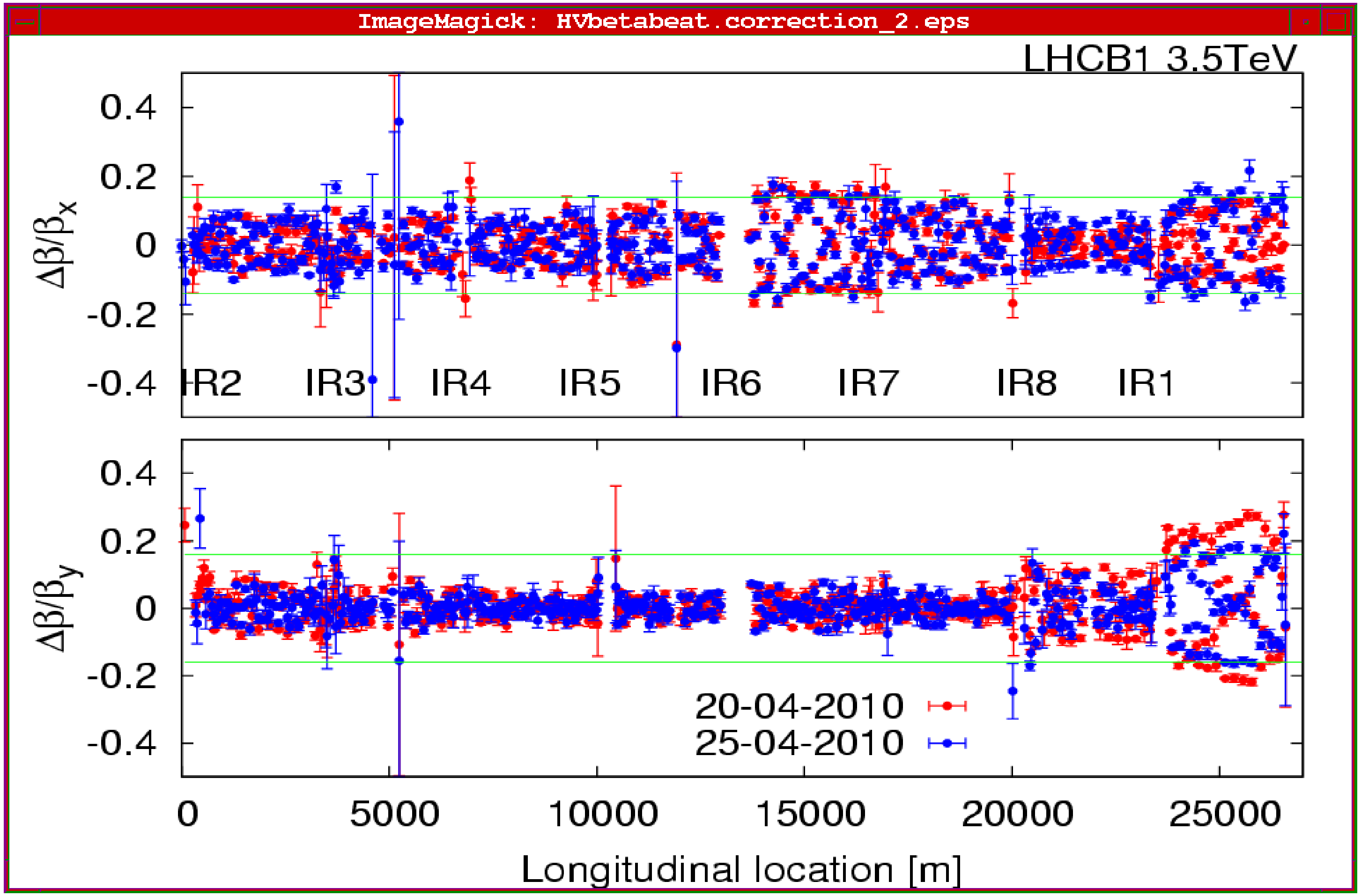
All experiments: $L > 1.1 \times 10^{28}$ cm^{-2} s^{-1}

factor ~10 achieved, as predicted

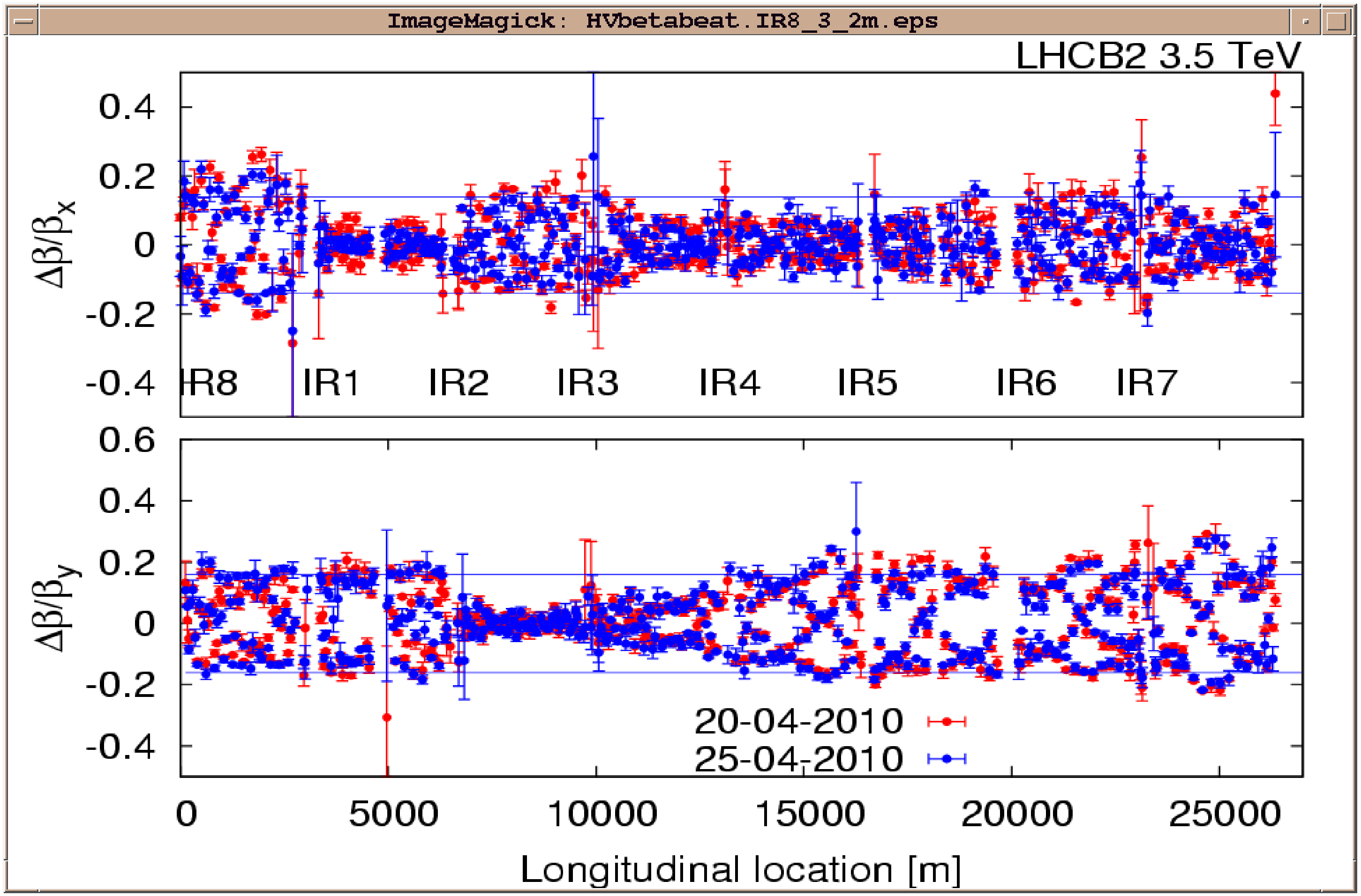
Beta Beat 3.5 TeV

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

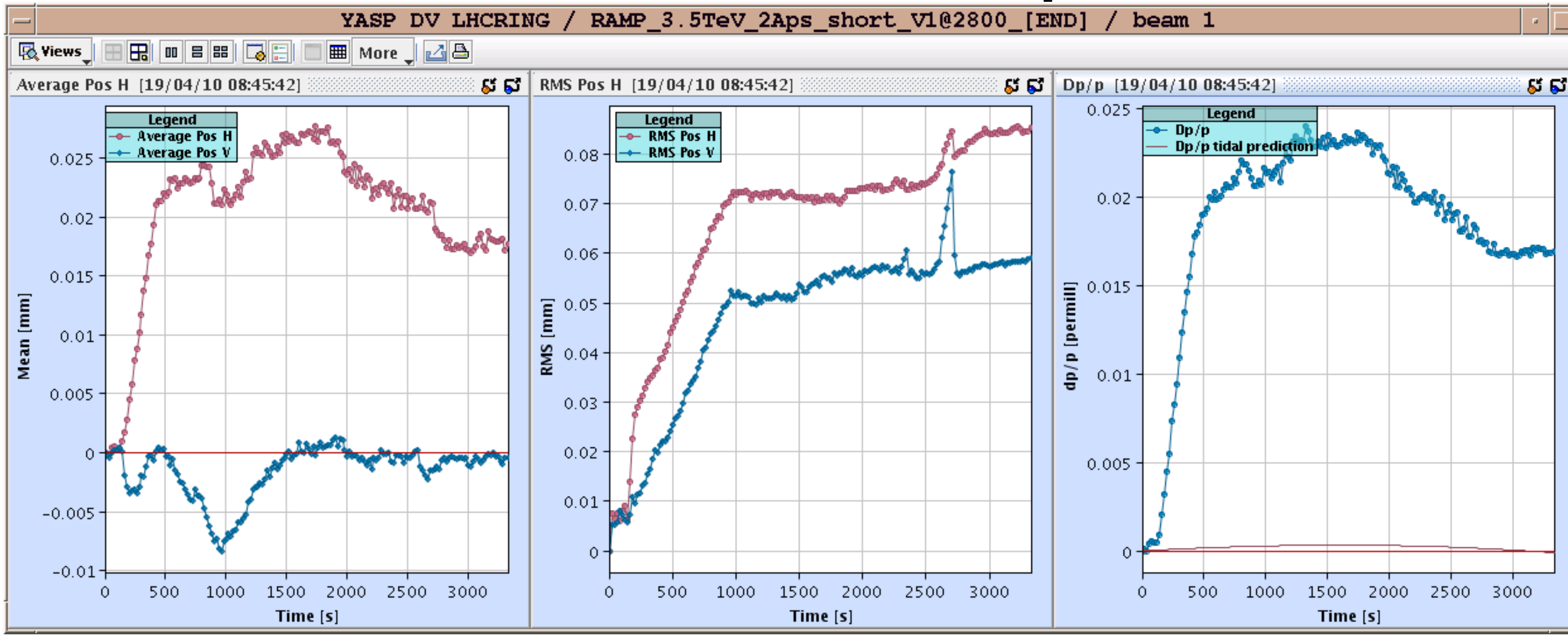
Beta Beat at 3.5 TeV – beam 1



Beta Beat: Beam 2



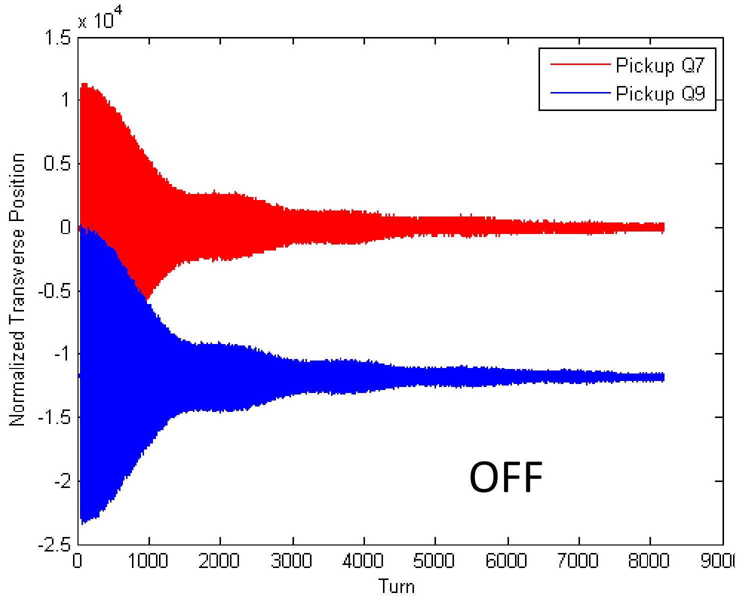
Orbit Feedback in Operation



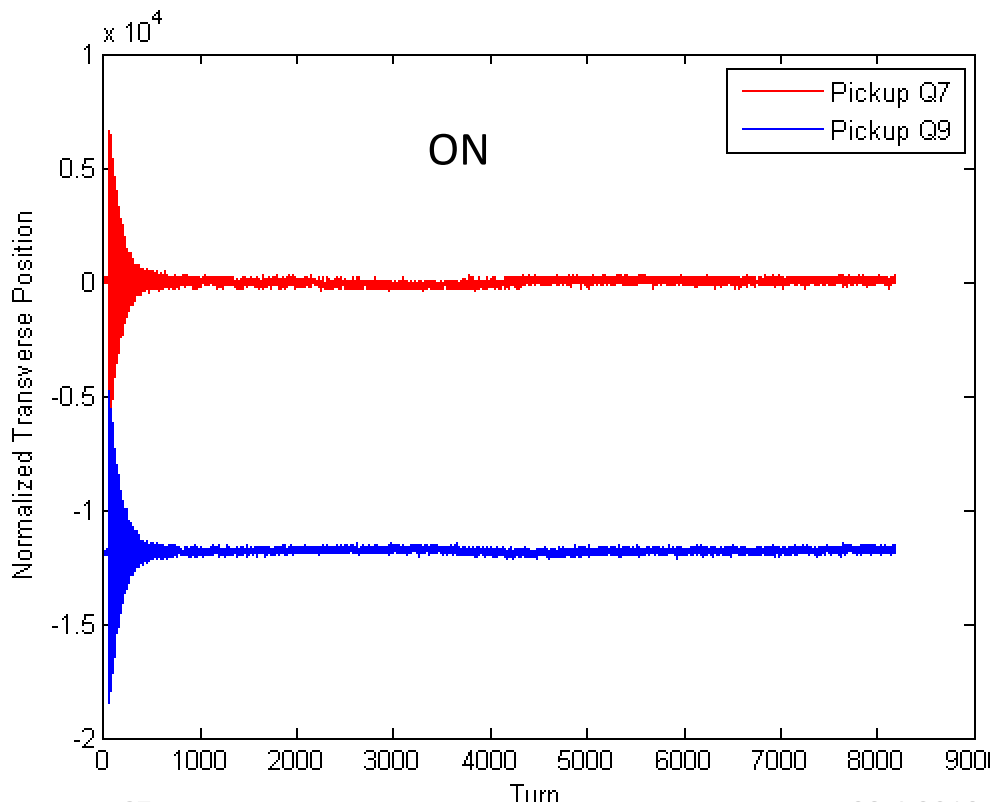
Maximum orbit change during energy ramp: **0.08 mm**

Ralph Steinhagen et al

Transv. Damper: Damping Beam Excitations

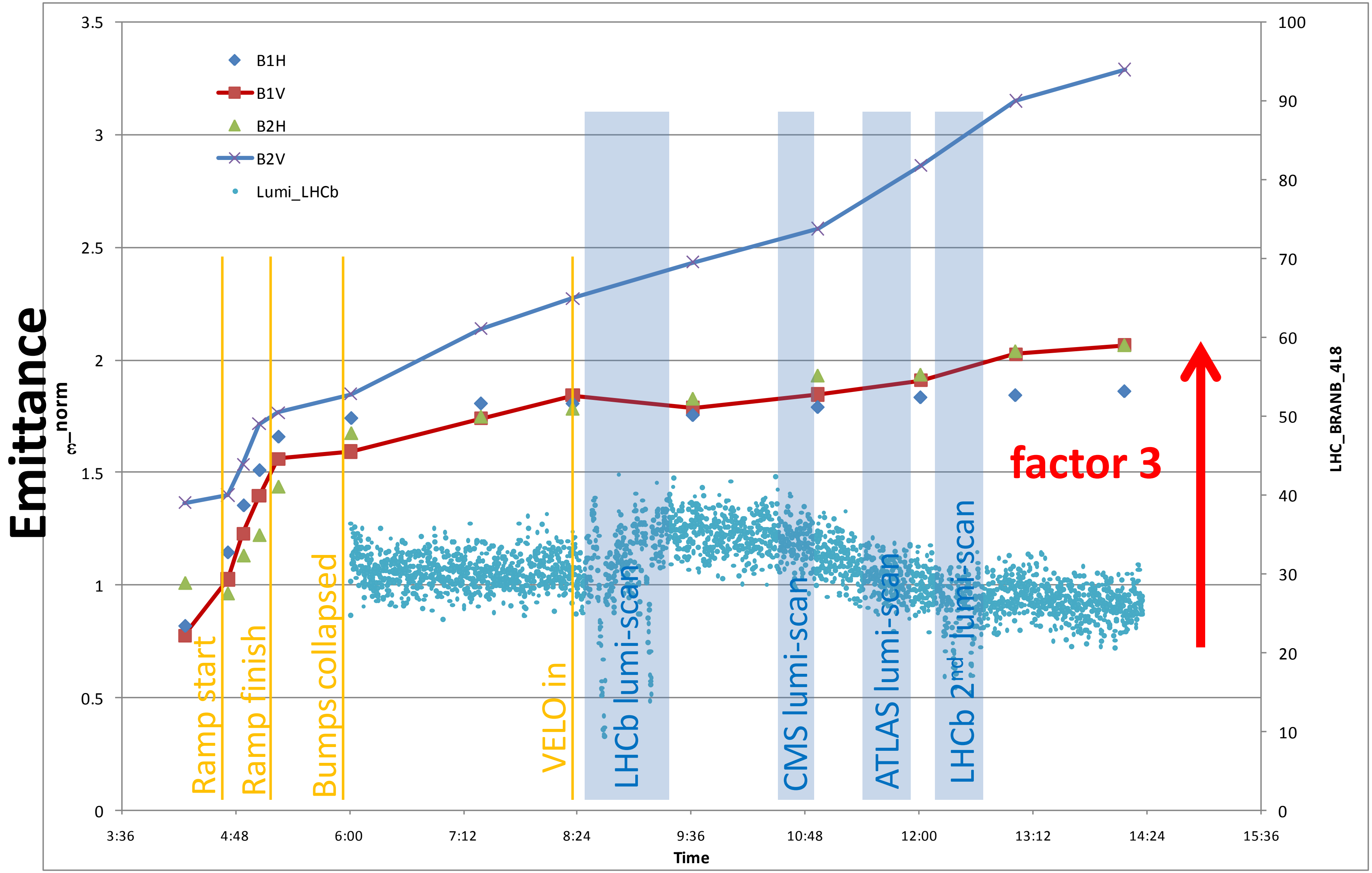


Wolfgang Hoefle et al



Crucial device to keep emittance growth under control!

Emittance Growth: Still a Problem

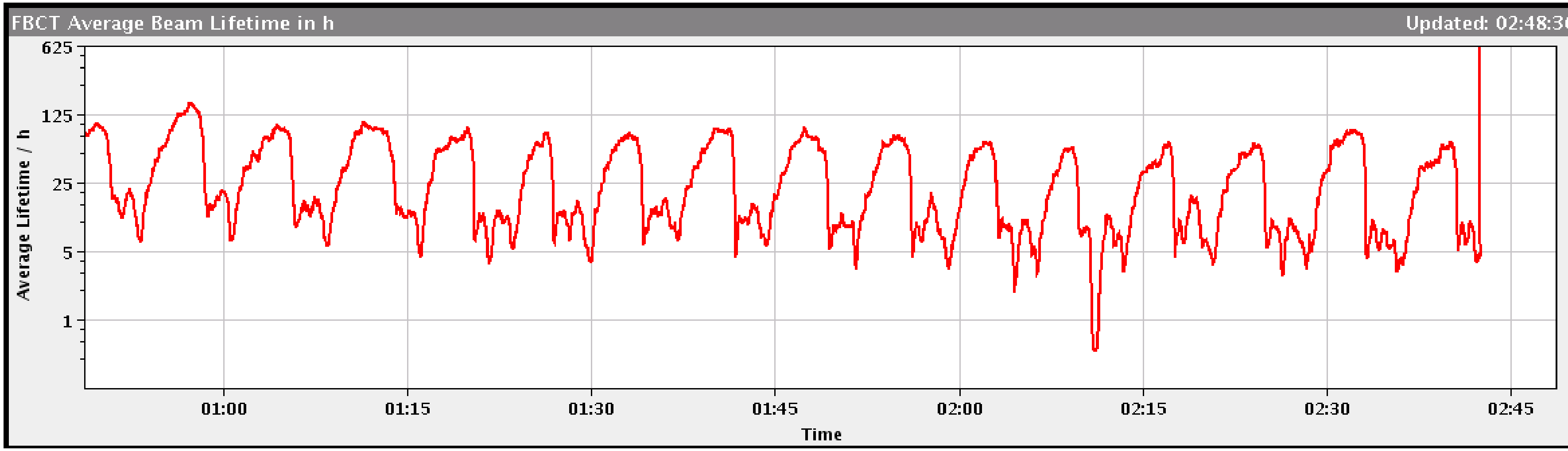


Time

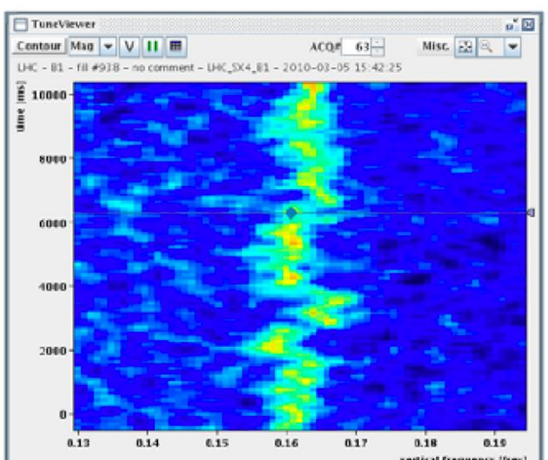
Mirko Pojer

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).

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**

today

Plan for the next days

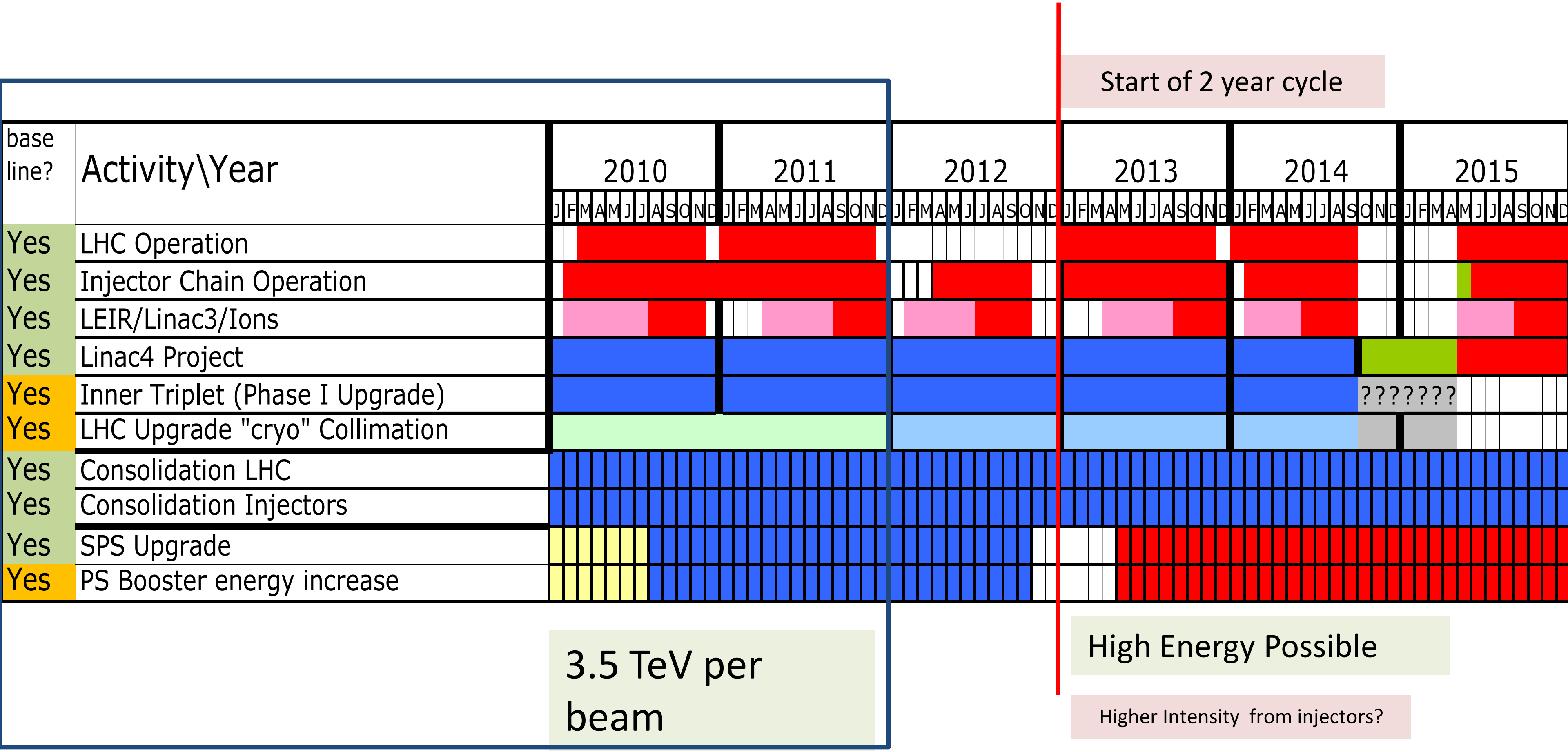
Next:

Technical Stop

Topics

- Chamonix and Outcome
- LHC Status
  - Beam commissioning end 2009
  - Technical Stop Jan-Feb 2010
  - Hardware Commissioning March 2010
  - Commissioning and Operation March→ now
- Strategy for Performance Evolution 2010-2011

Time lines (Very Preliminary)



Instantaneous Luminosity

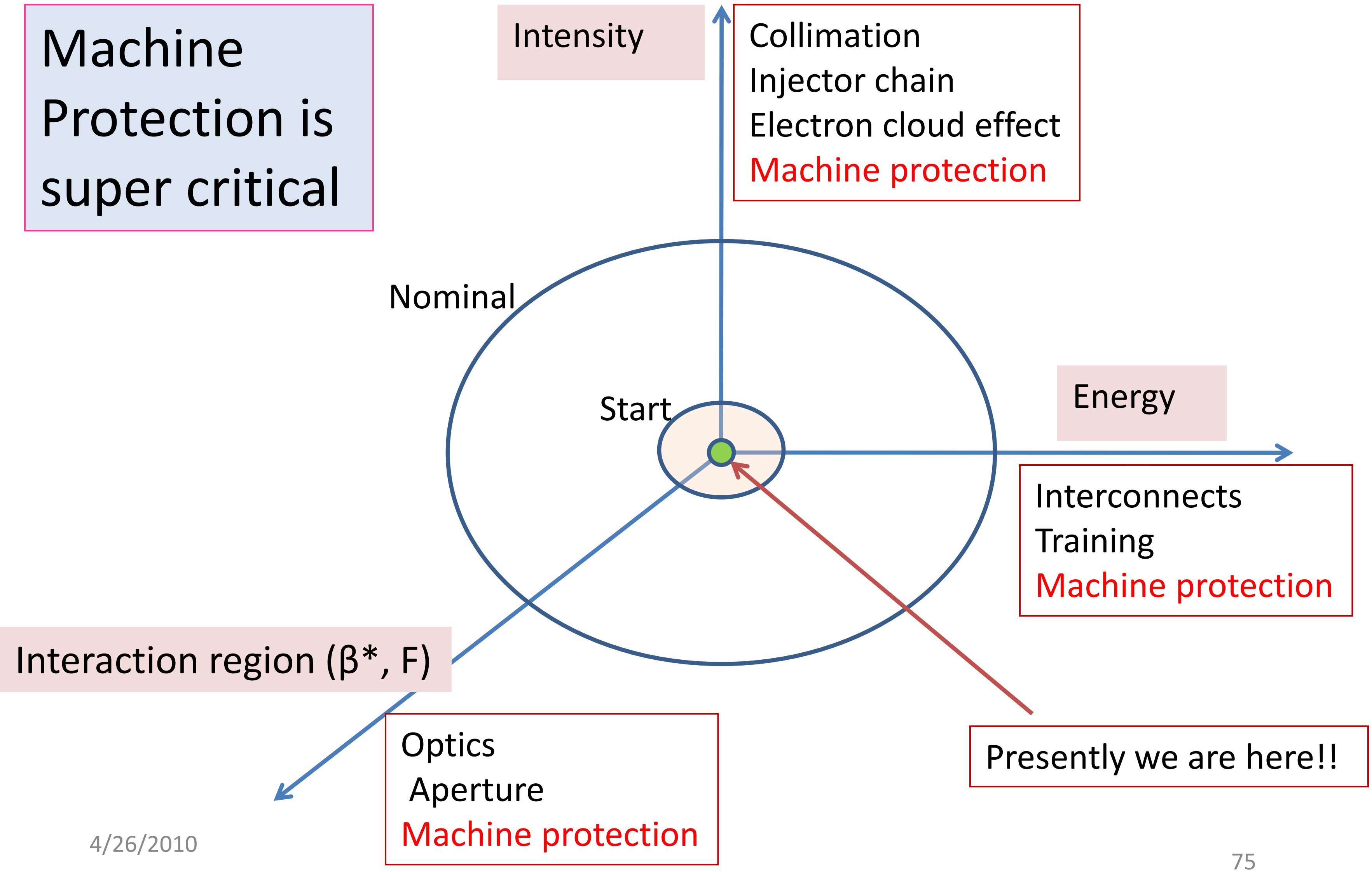
$$L = \frac{N^2 k_b f}{4\pi\sigma_x\sigma_y} F = \frac{N^2 k_b f\gamma}{4\pi\varepsilon_n\beta^*} F$$

- Nearly all the parameters are variable (and not independent)
  - Number of particles per bunch N — Intensity
  - 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^* — Interaction Region
  - Crossing angle factor F — Interaction Region
    - Full crossing angle θ_c — Interaction Region
    - 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

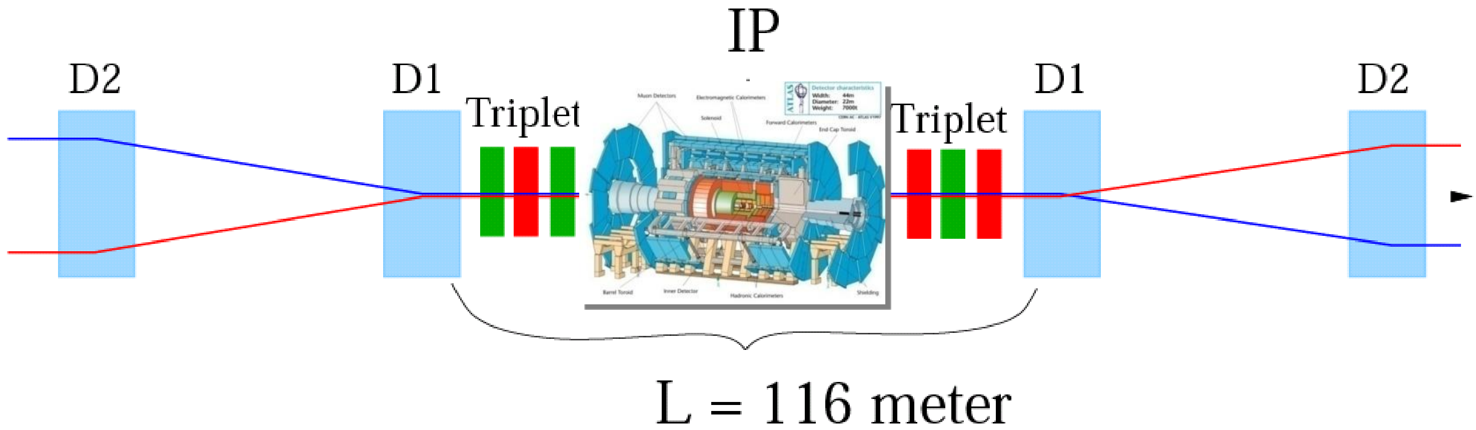
- Lower energy means bigger beams $\varepsilon_n = \varepsilon\gamma$ $\sigma = \sqrt{\varepsilon\beta}$
  - Less aperture margin
  - Higher β* (lower β^{peak})

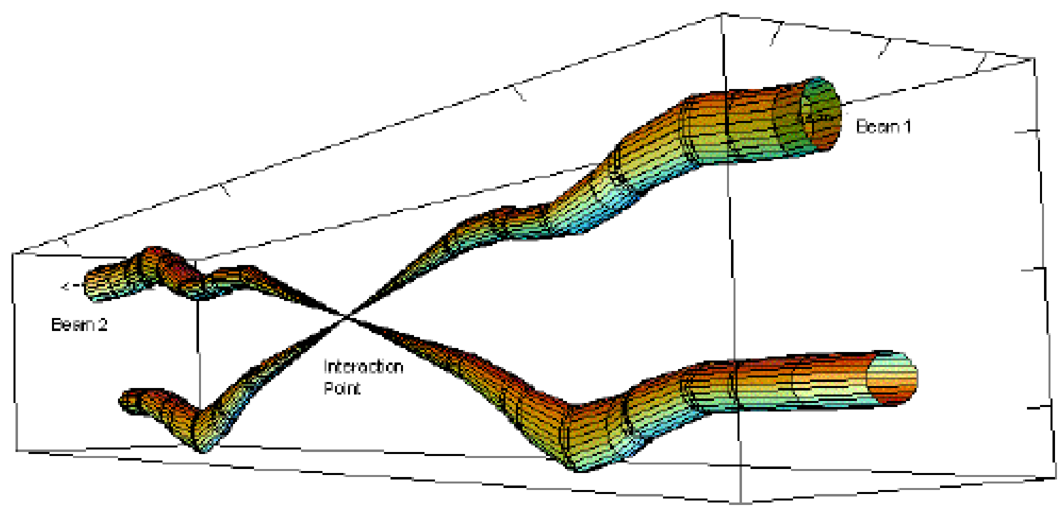
At max

- > 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





Relative beam sizes around IP1 (Atlas) in collision

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

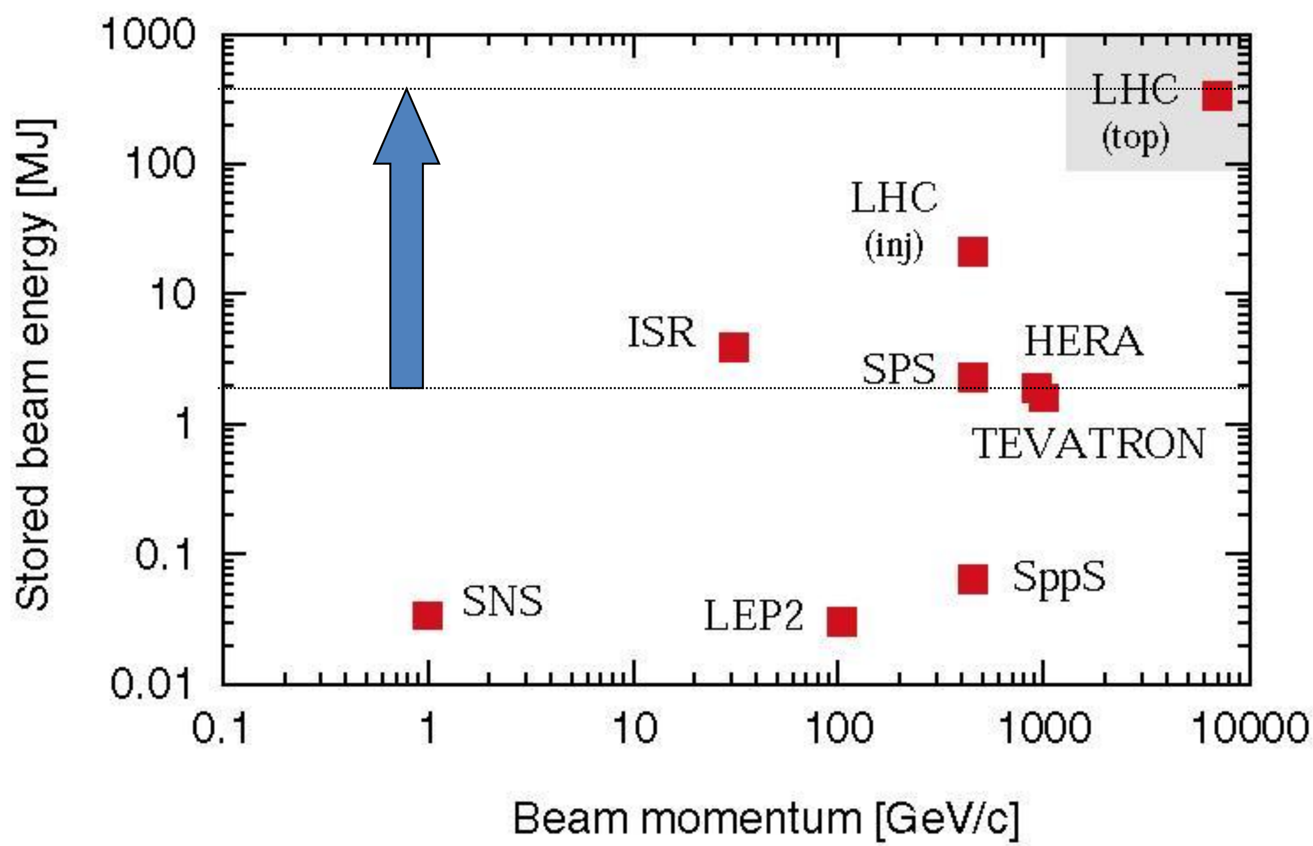
Machine Protection Strategy for intensity increase

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

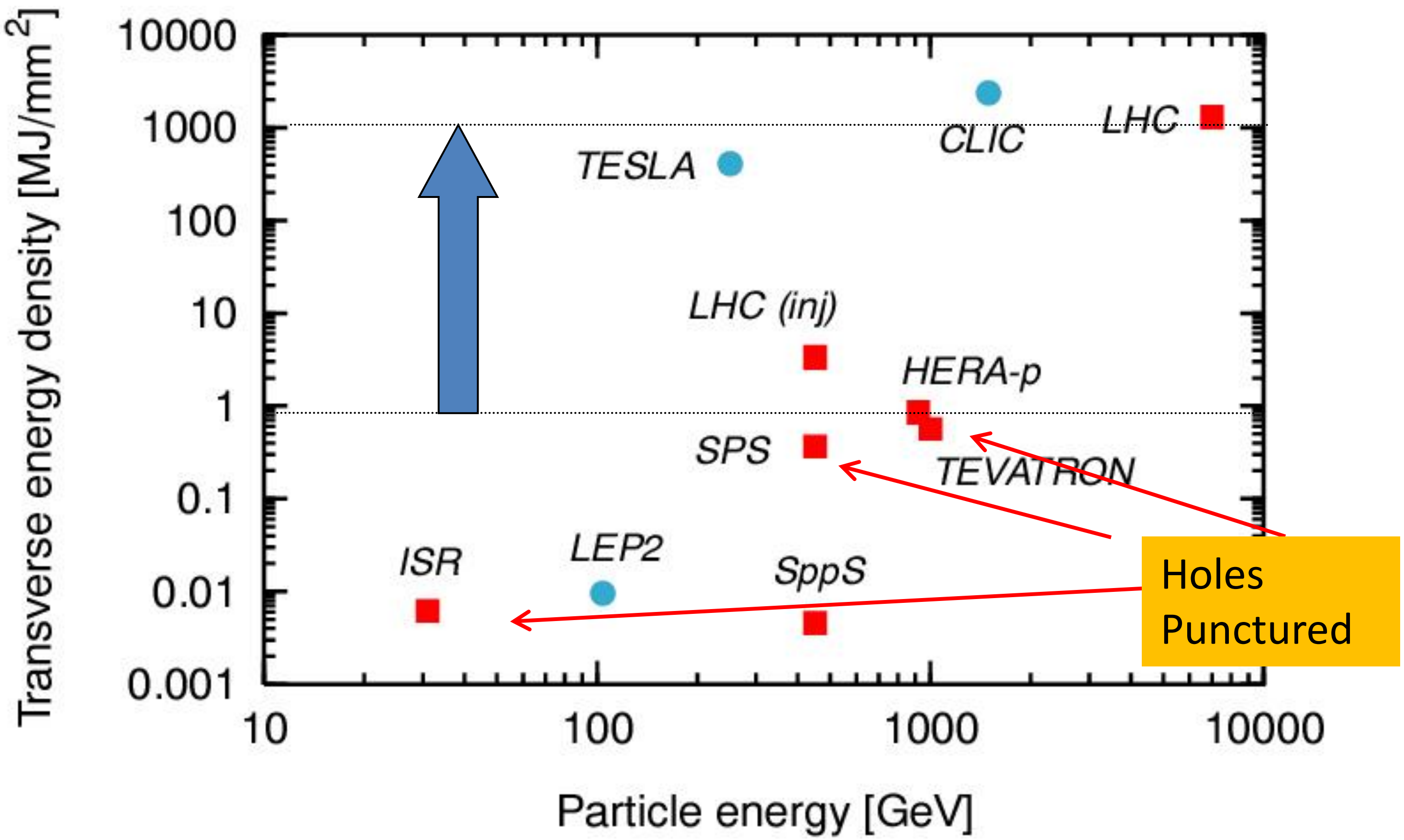


At less than 1% of nominal intensity LHC enters new territory. Collimators must survive expected beam loss…

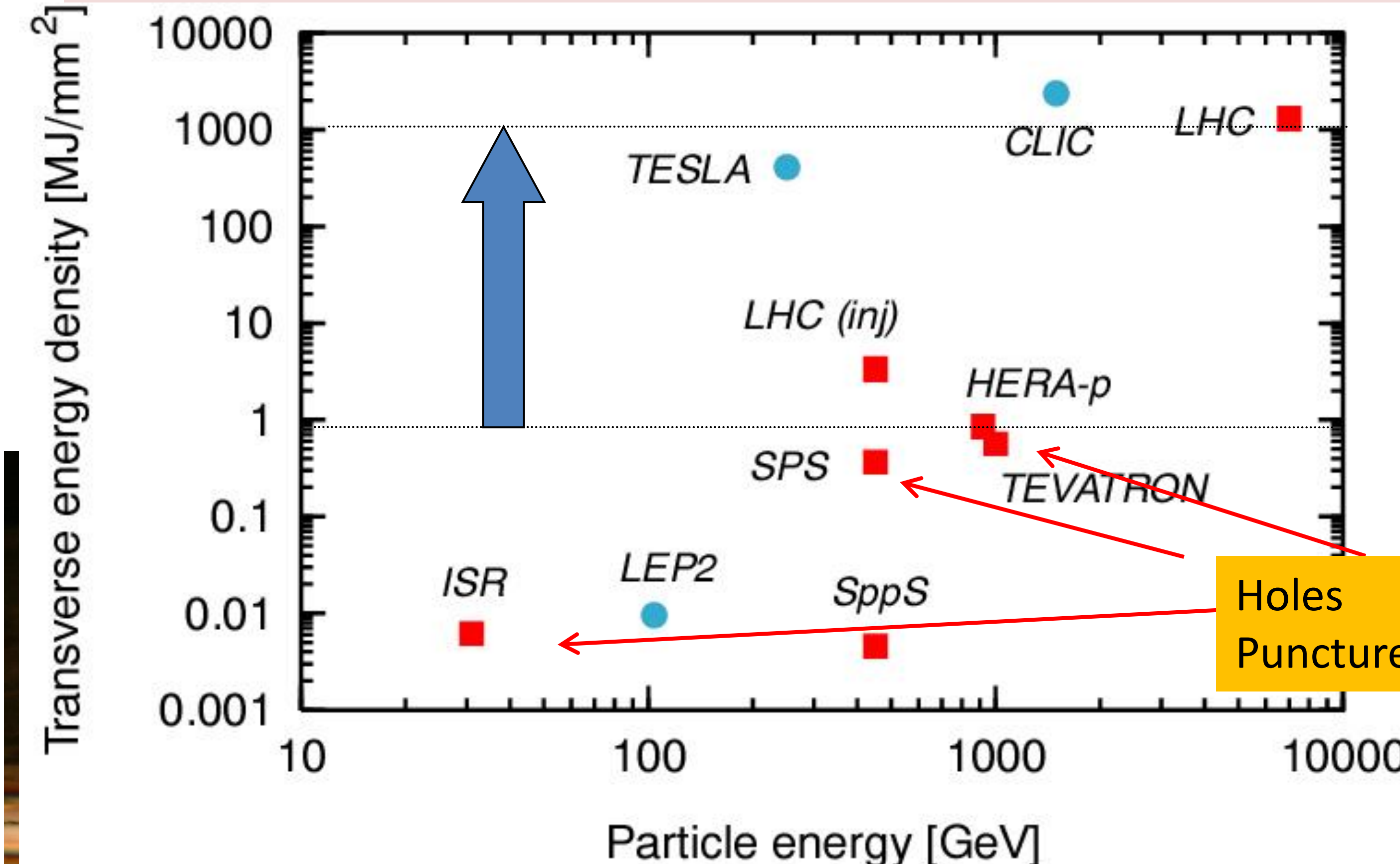
The Energy Density of the LHC beams

Transverse energy density is a measure of damage potential …

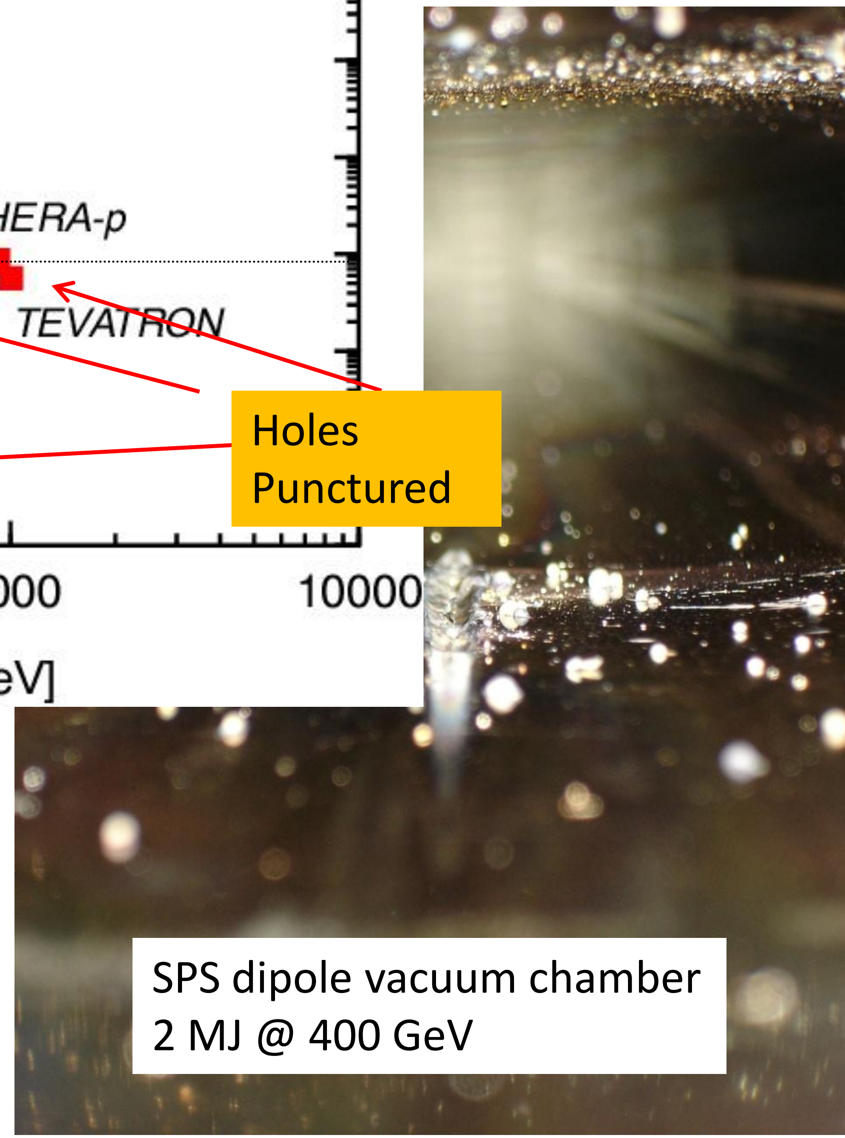
… AND proportional to luminosity!



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 $1\text{-}2 \times 10^{32}\ cm^{-2}s^{-1}$ in 2011,
  - Correspond to 8e10 ppb, 700 bunches, with a stored energy of 35 MJ (with $\beta^*=2$ 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

Tune Feedback in Operation

- Tune feedback during ramp:

Ralph Steinhagen et al