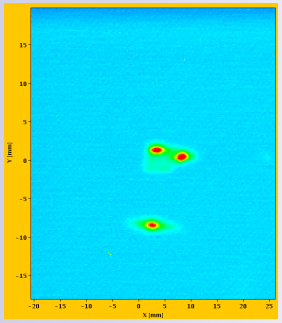
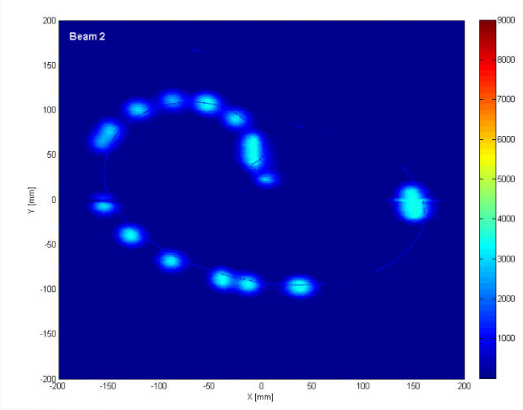
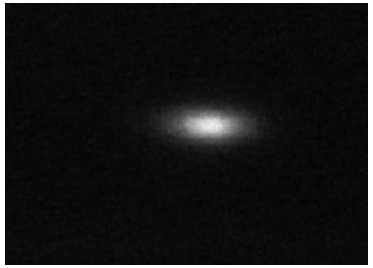
LHC status and plans







Mike Lamont
for the LHC team

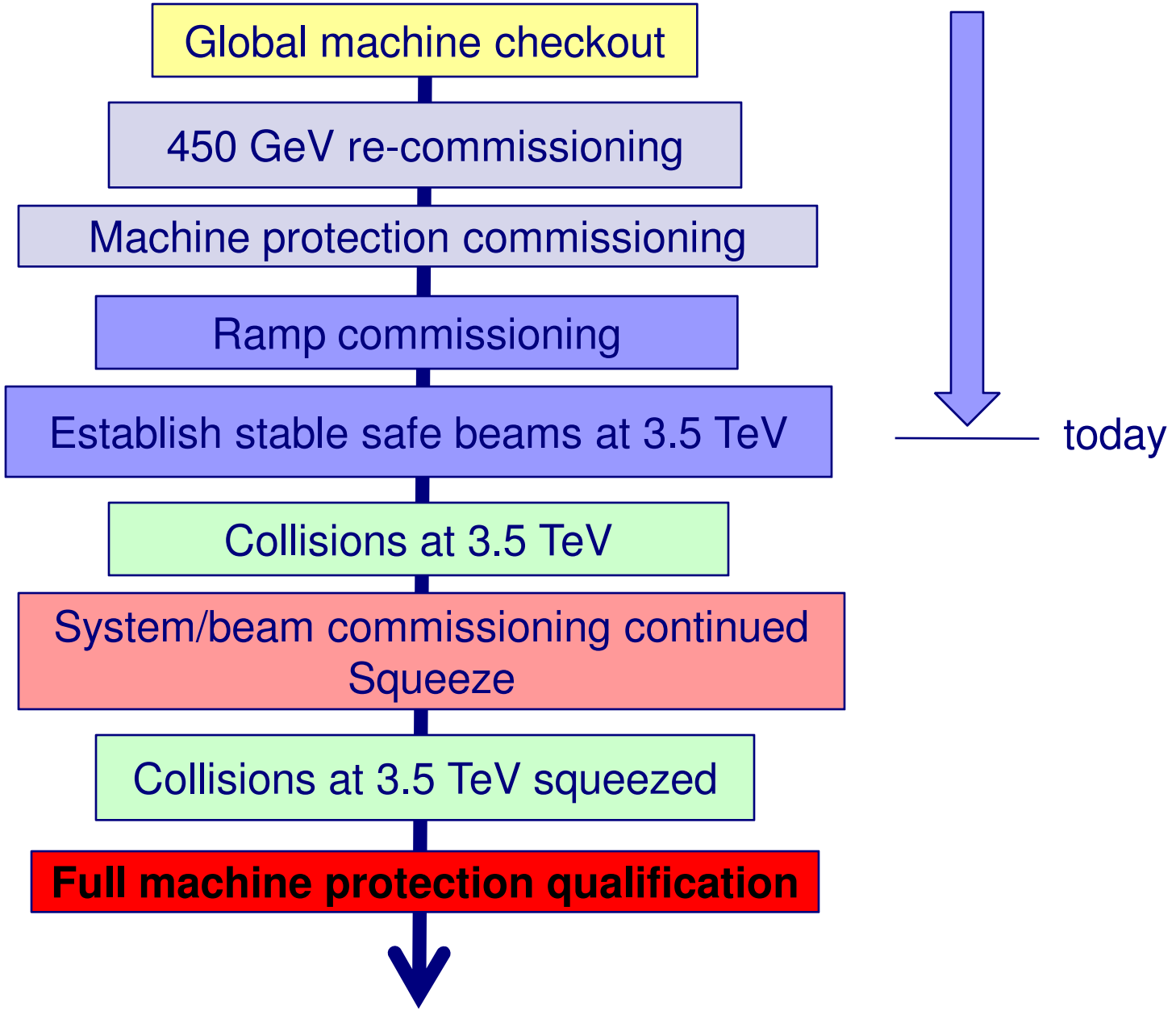
Outline

- Hardware Commissioning
- Status of beam commissioning
  - 450 GeV
  - Ramp to 3.5 TeV
  - 3.5 TeV
- Plans
  - Short term goals
  - Medium term planning
- Conclusions

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 in about 4 weeks
  - di/dt of MB limited to 2 A/s in the meantime – system tested in this configuration

Beam commissioning strategy 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

Typical pictures

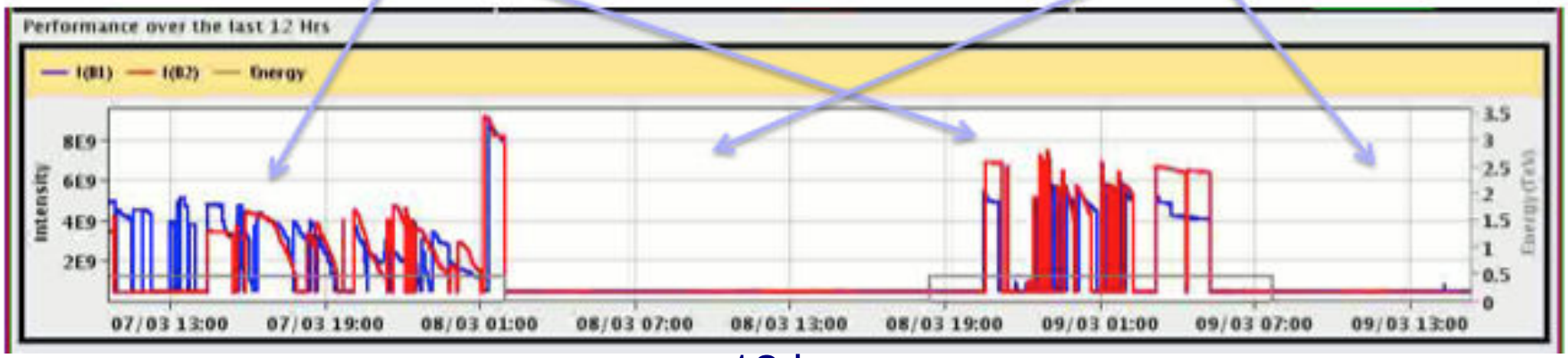
Beam 1
Beam 2

Very busy beam work by CCC team

and many experts (single bunch up to 1e10 p)

Very busy hardware

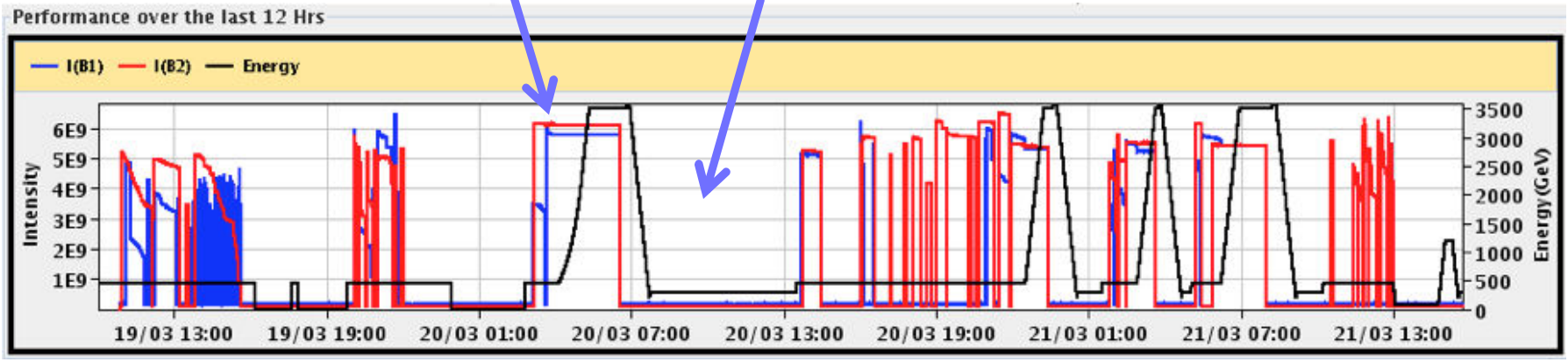
work by experts: no beam



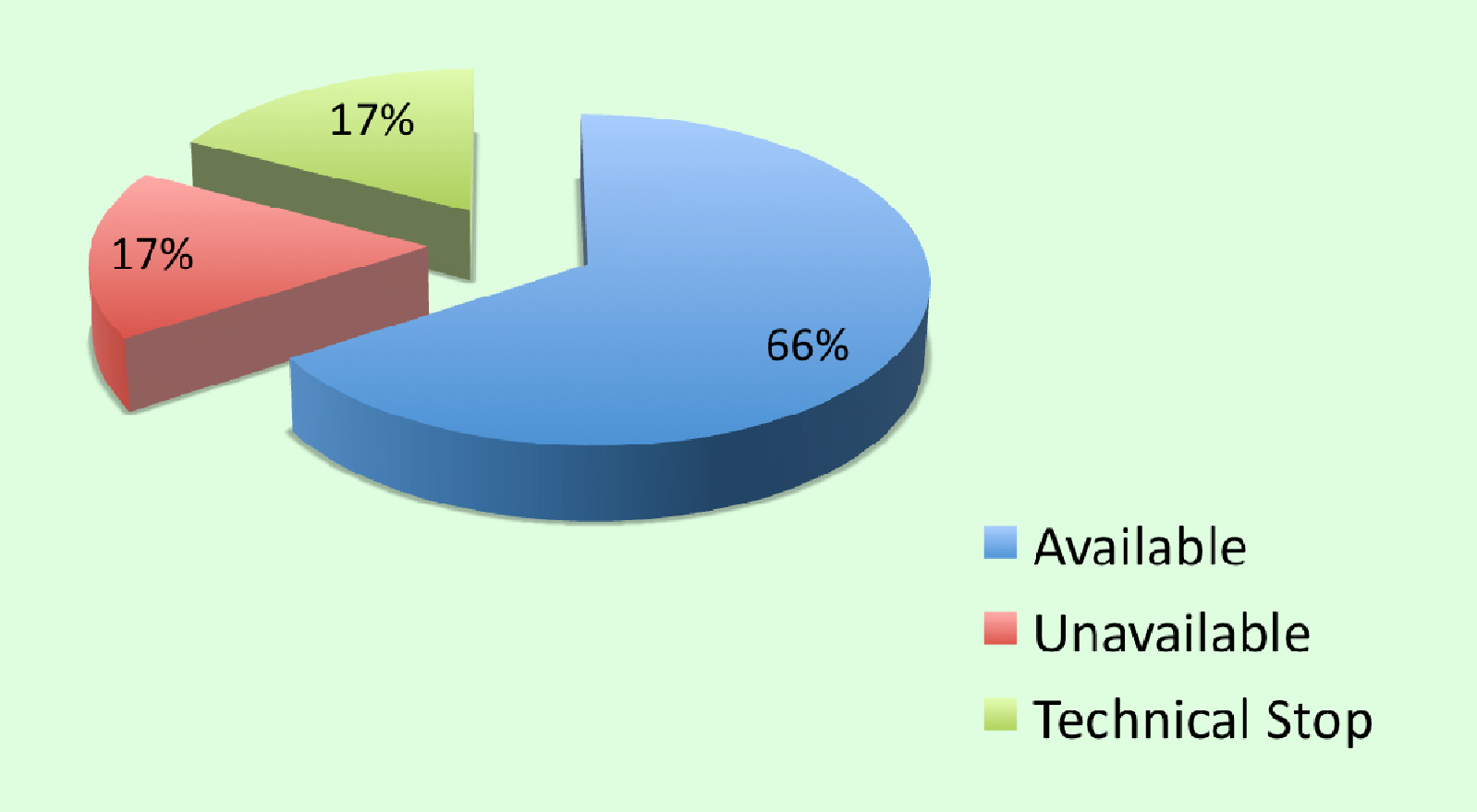
12 hours

Ramp

Problems



LHC Availability (Week 10)



All technical systems contribute to very promising LHC availability

Successful running-in of the accelerator systems.

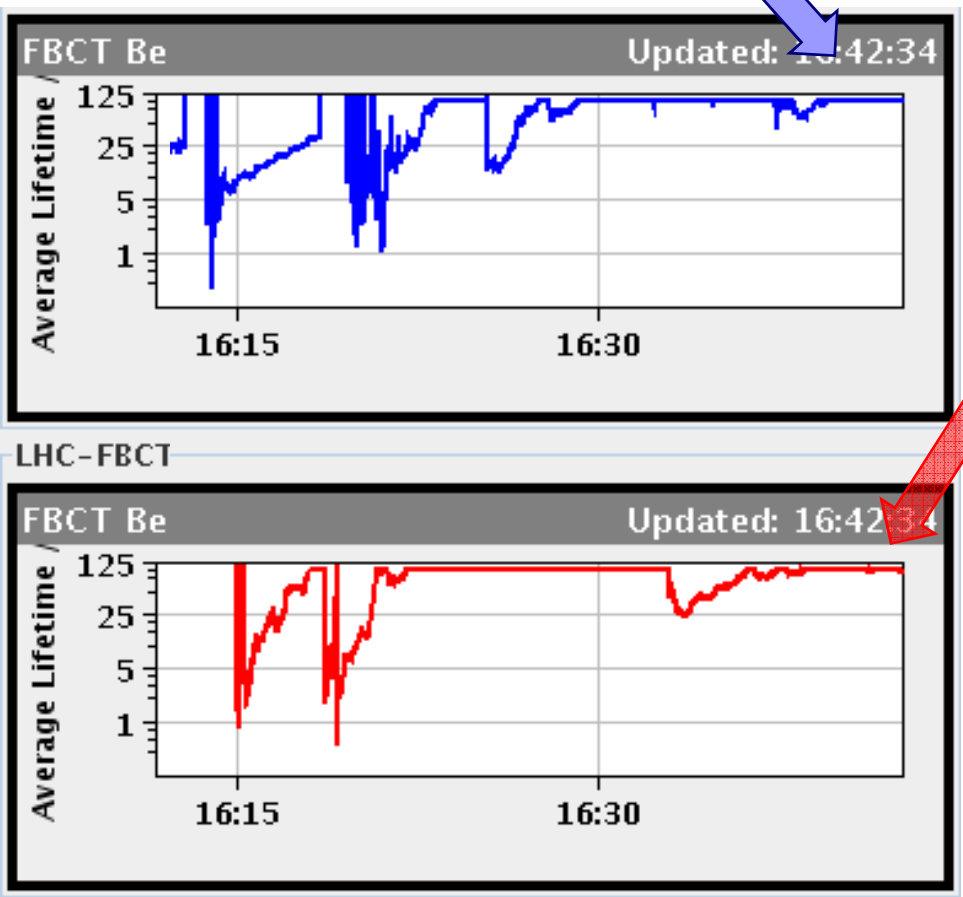
Status – 450 GeV

- Tunes & chromaticity adjusted and controlled to nominal values routinely. Good beam lifetimes. Lower than nominal emittances.
- Optics verified and corrected to a maximum beta beat of 20-30%. Almost in specification.
- Dispersion measured and verified (in vertical plane: 3 cm rms).
- Closed orbit adjusted to an rms of ~0.45 mm (about +-2 mm peak to peak)
- Golden reference orbit defined for collimation and machine protection.
- Aperture Beam looks good. Some measured bottlenecks agree with model predictions

Excellent reproducibility

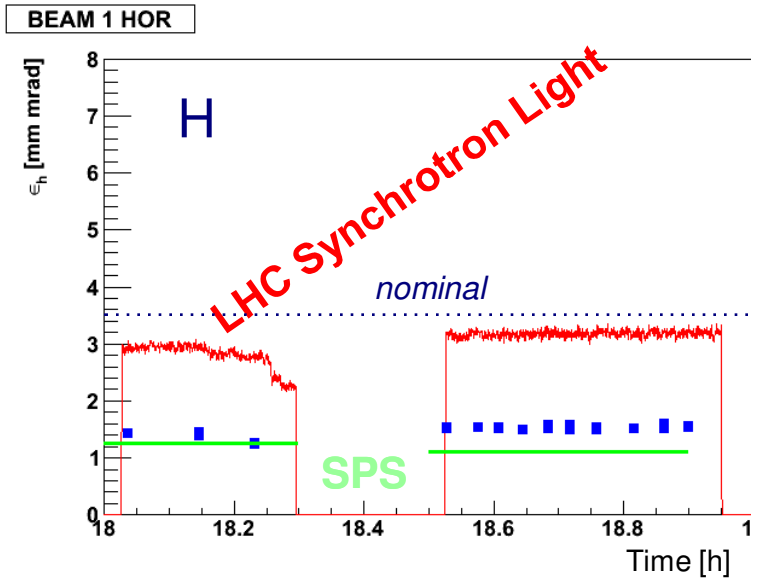
Intensity Lifetime Pilot Bunches at 450 GeV

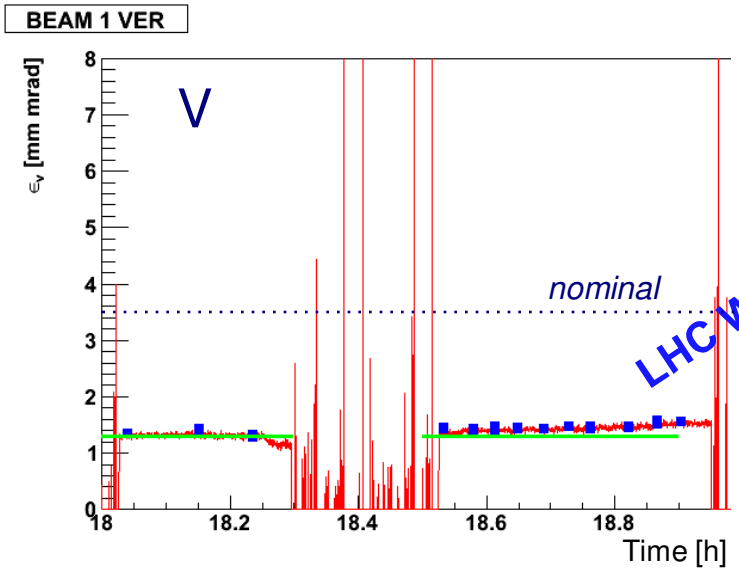
LHC FBCT Beam Lifetime				
I(total) B1:	4.91e+09	I(total) B2:	4.14e+09	13-03-2010
Average lifetime B1:	100.00 h	Average lifetime B2:	88.32 h	16:42:34



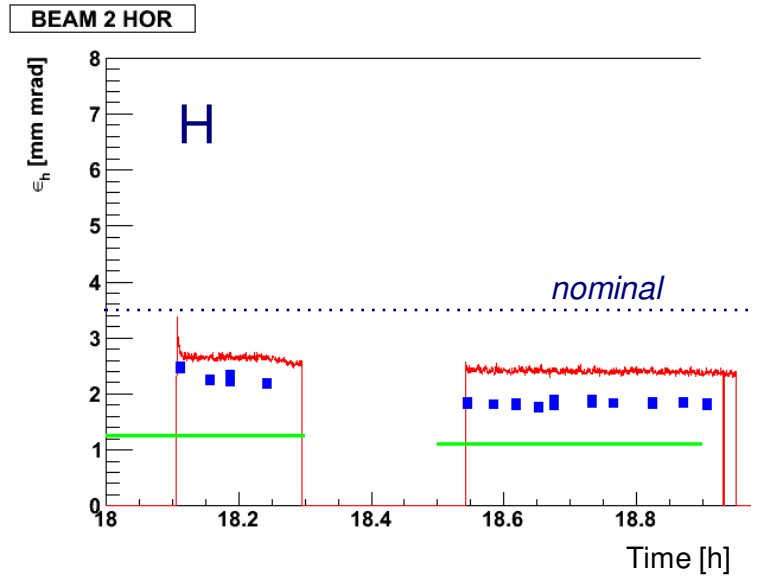
- Corrected to golden orbit with separation bumps ...
- All perturbations & excitations switched off.
- Tunes to nominal.
- Chromaticity to +4.
- Collimators to nominal injection settings.
- No trims & corrections.
- Emittance measured…

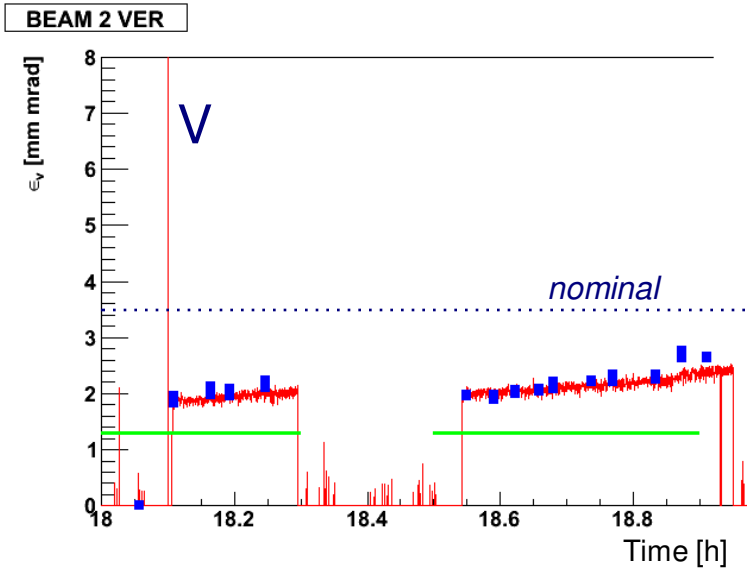
Transverse emittance versus time (2 fills)





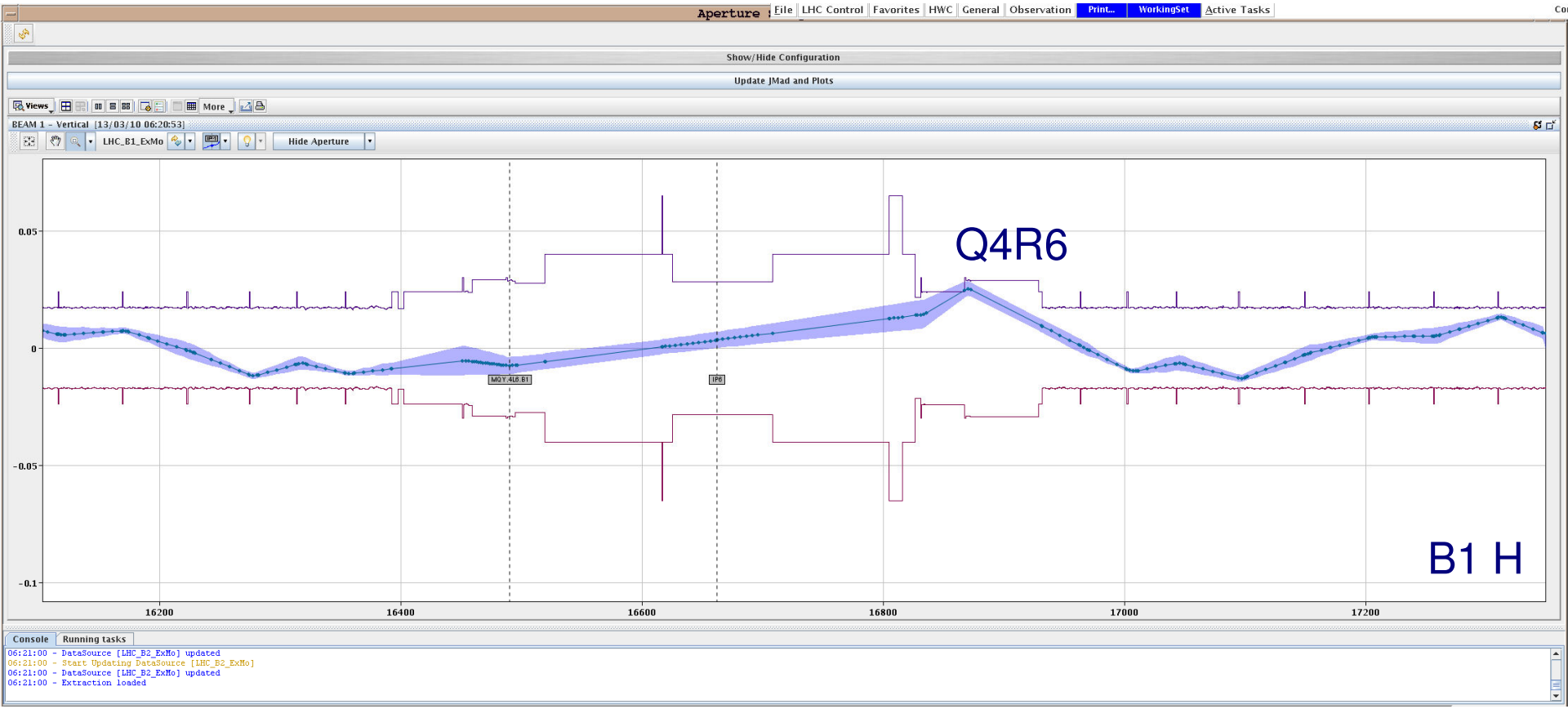
Beam 1

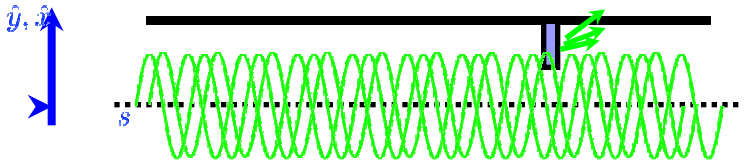




Beam 2

Aperture at 450 GeV: Kick Method





Stefano, Massimo et al

Beam 1

Optics from β-beat team:

$\beta_x = 117.7$ m $\rightarrow \sigma_x = 0.93$ mm $\Rightarrow$ **$A_h = 10.8\ \sigma$**

$\beta_y = 249.3$ m $\rightarrow \sigma_y = 1.35$ mm $\Rightarrow$ **$A_v = 11.1\sigma$**

Status – 450 GeV

- Spectrometer and compensators set up and corrected with beam.
- Nominal separation bumps set up and included into the corrected closed orbit.
- Beam feedback commissioning partially completed, still ongoing.
  - Tune feedback: OK.
  - Orbit feedback: to be completed.
  - Transverse feedback: to be completed.
- Grazing events delivered to ATLAS and CMS. Many splash events to all experiments.

Status – 450 GeV

- Collimation system (all ring collimators) set up with ~0.2mm accuracy. Cleaning and protection hierarchy verified with beam (efficiency: > 99%, limited by BLM resolution with this intensity).
- Beam instrumentation working very well
- Injection, beam dumps, machine protection commissioning well advanced (but not finished)
- Higher intensities – work in progress
  - Pilot (5e9) and fat pilot (2.5e10) OK with very small losses.
  - 3.5e10 p into beam 2 OK . Some losses..
  - 6e10 p (B1) produced significant losses and BLM triggered beam dump.
  - 1.1e11 bunch fine to end of the transfer lines

450 GeV machine in good shape

Magnet model

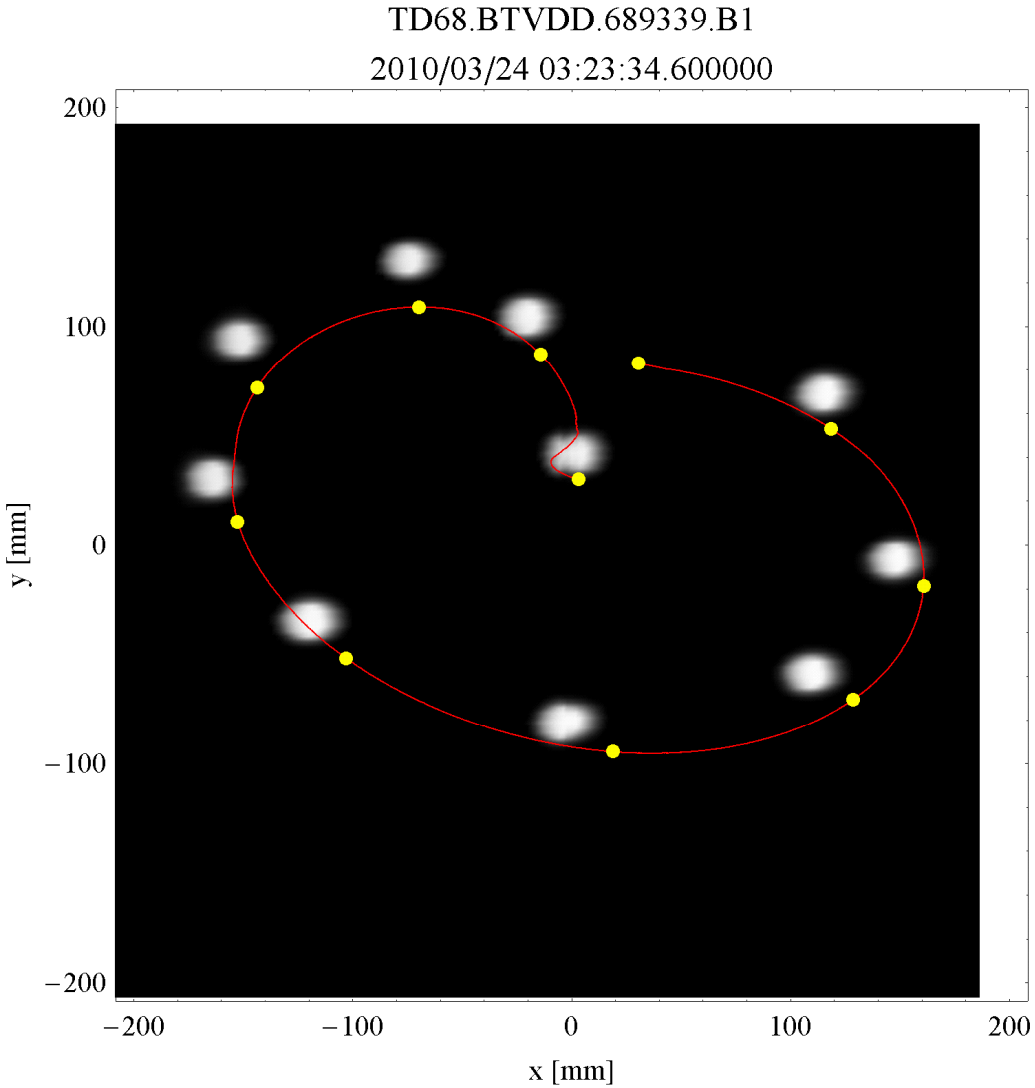
- The knowledge of the magnetic model of the LHC is remarkable and has been one of the key elements of a very smooth beam commissioning
- Huge parameter space, mistakes made, lessons learnt etc but…
- Tunes, energy matching, optics remarkably close to the model already
- Bodes very well for the future.

Largest momentum offsets by sector:

- -0.27 per mil in sector 56 / beam1
- +0.32 per mil in sector 78 / beam2

Beam dump

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

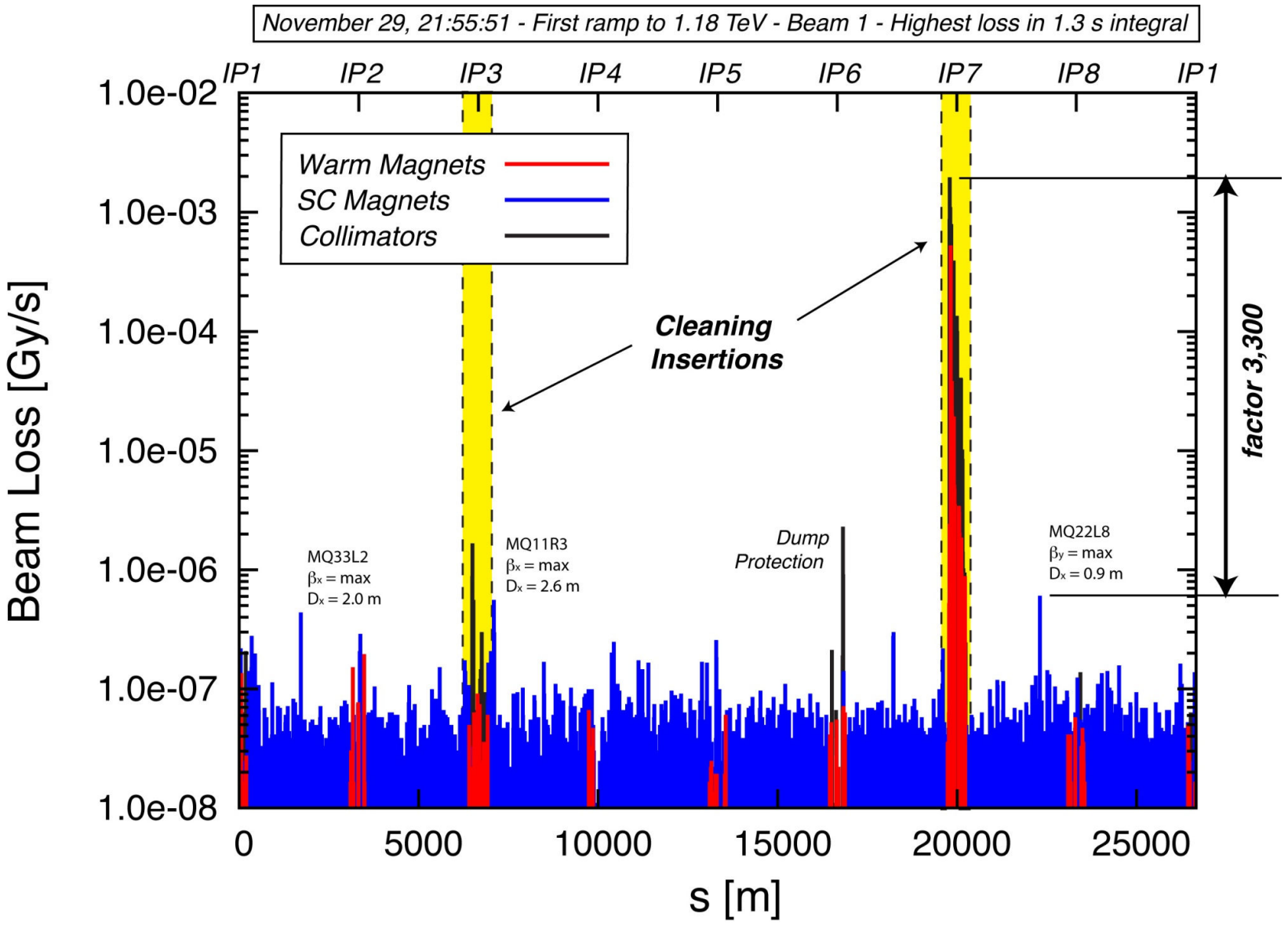


Collimation

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

Collimation

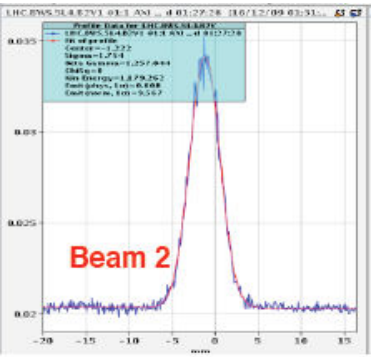


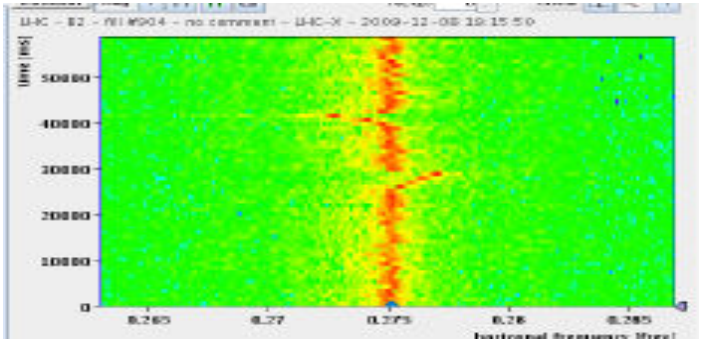
Beam Instrumentation

The enabler – excellent

- Beam Position Monitors
  - Excellent performance
  - Very stable orbit (V drift ~ 15µm/h)
- Beam Loss Monitors
  - BLMs correctly removes the BEAM PERMIT signal if measurements are over threshold. Almost no reliability issues observed.
- Profile monitors
  - Synchrotron light, wire-scanners operational

Base-Band-Tune (BBQ) system was a work horse from day one giving tune, chromaticity, coupling, feedback.





LHC report

Machine Protection System

Provides the mechanism to dump the beam in around 3 turns if anything out there decides it's had enough

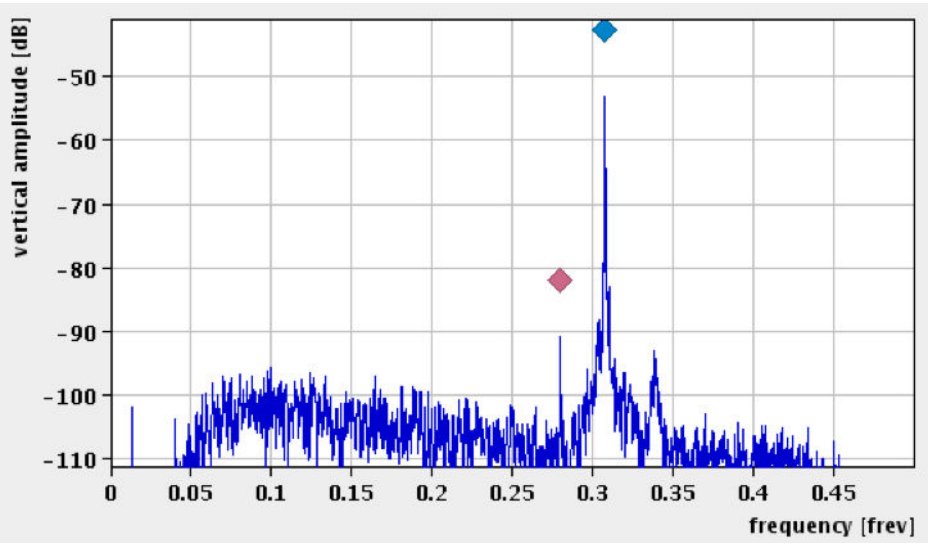
- Mission critical backbone
  - Beam Interlock System
  - Safe Machine Parameters
  - Plus inputs to/from other systems (e.g. timing, BCT)
- A large multitude of user inputs
- The beam driving a subtle interplay of:
  - Beam dump system, Collimation, protection devices, RF…
  - Instrumentation (BLMs, BCT, BPMs…)
  - Aperture
  - Optics

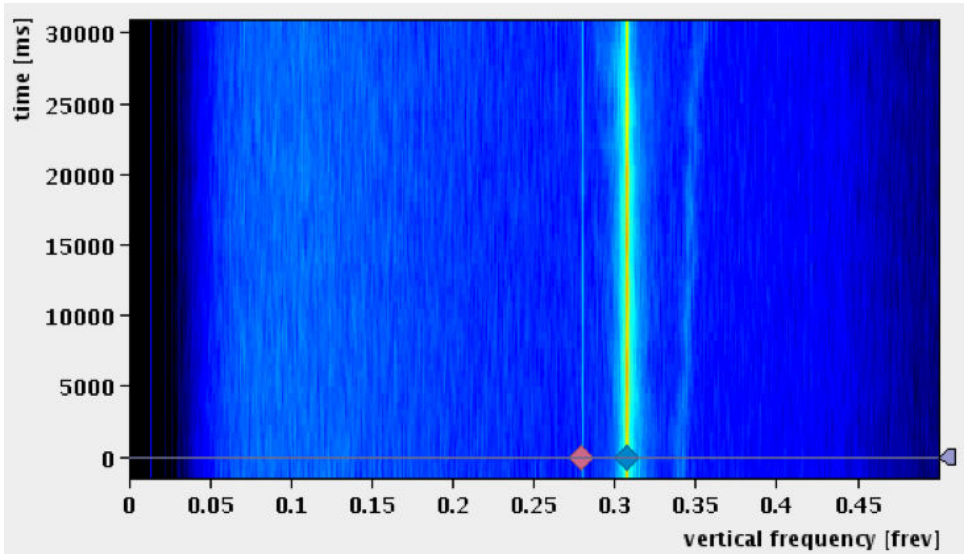
Careful testing before beam

Full set of beam based tests – performing well

Clearly the critical path

The hump – a real mystery



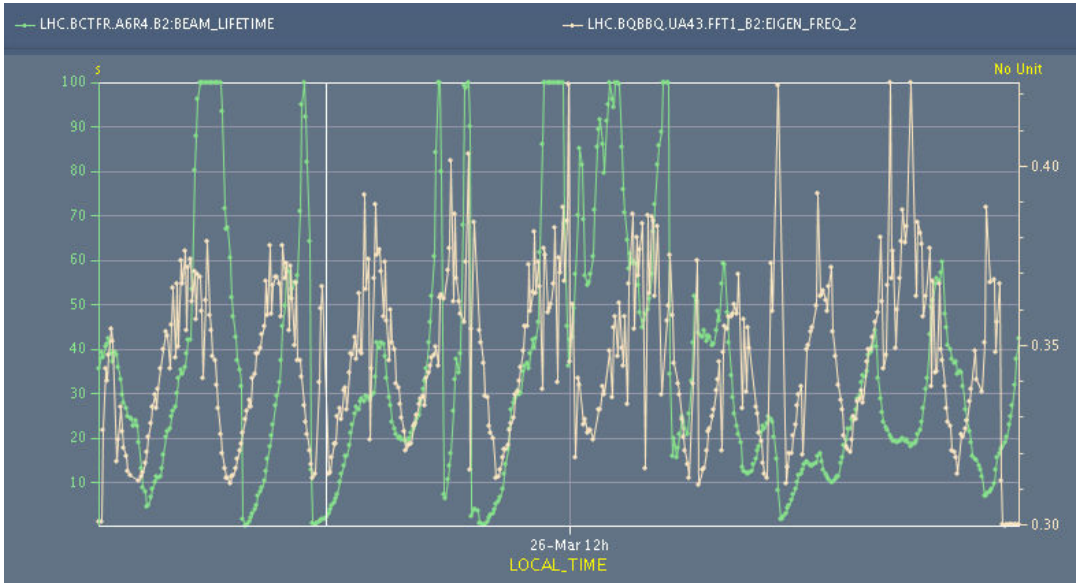


Broad frequency "hump" driven beam excitation → emittance blow-up

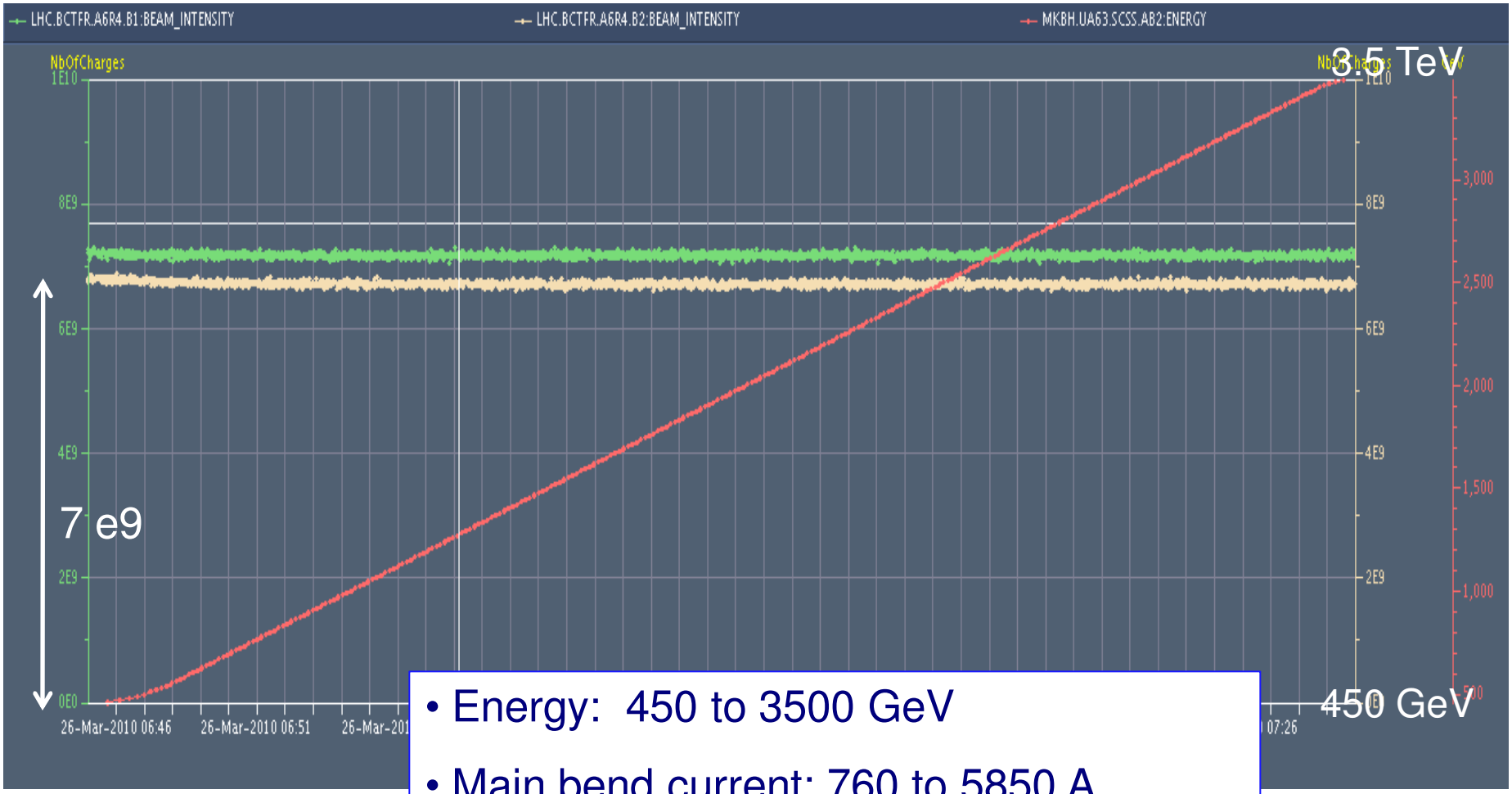
Vertical plane, worse for beam 2

Actually a fast frequency shifting oscillation with the mean drifting slowly

We are open to suggestions!



Ramp – this morning

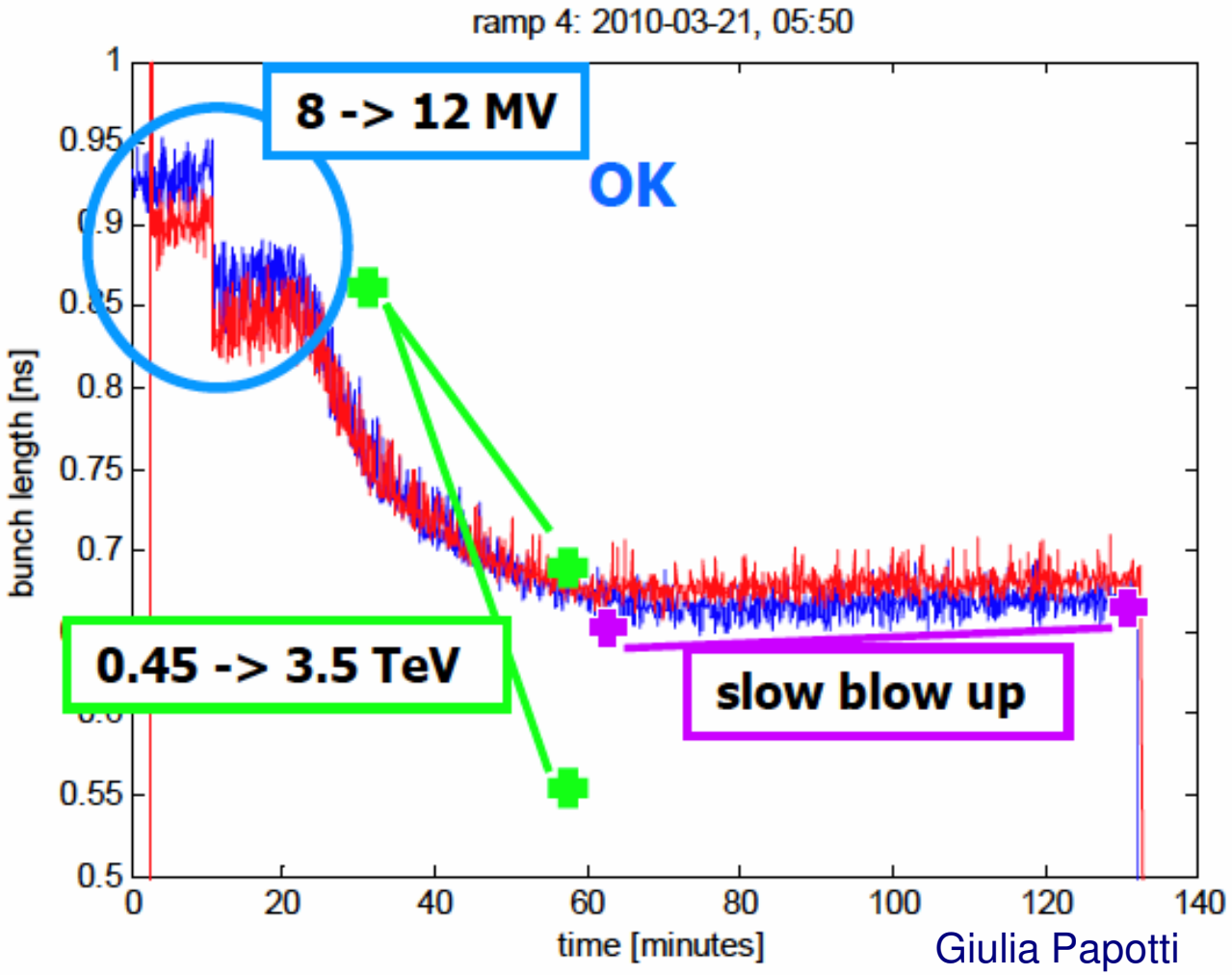


- Energy: 450 to 3500 GeV
- Main bend current: 760 to 5850 A
- Ramp rate: 2 A/s
- Length: 47 minutes

Ramp to 3.5 TeV

- Successfully ramped two pilots to 3.5 TeV on first attempt (impressive!)
- Routinely ramp without loss
- Separation bumps on
- Tune feedback operational
  - Some problems with real time input to trim quadrupole power converters - tripping QPS – measures taken.
- Orbit looks stable and reproducible
  - Incorporation of 450 GeV settings into ramp
  - Orbit feedback – commissioning in progress.
- Coupling was an issue for beam 2 but has been successfully measure and corrected.

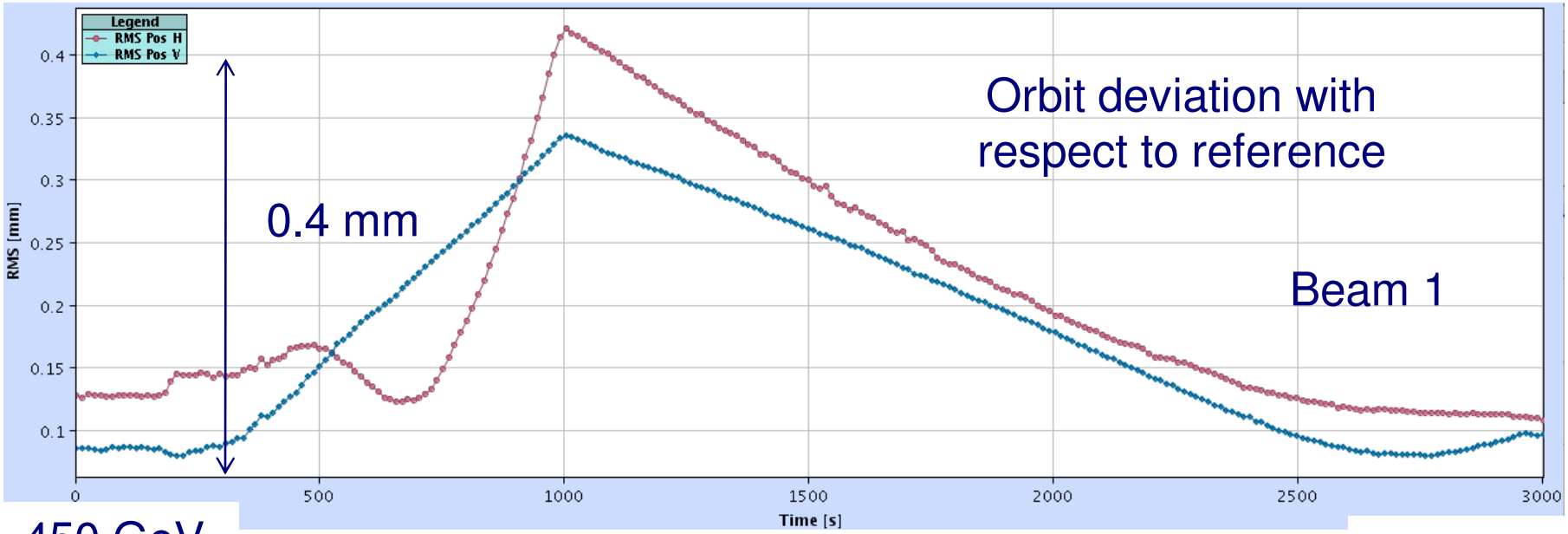
Bunch length during ramp



(RF system performing very well)

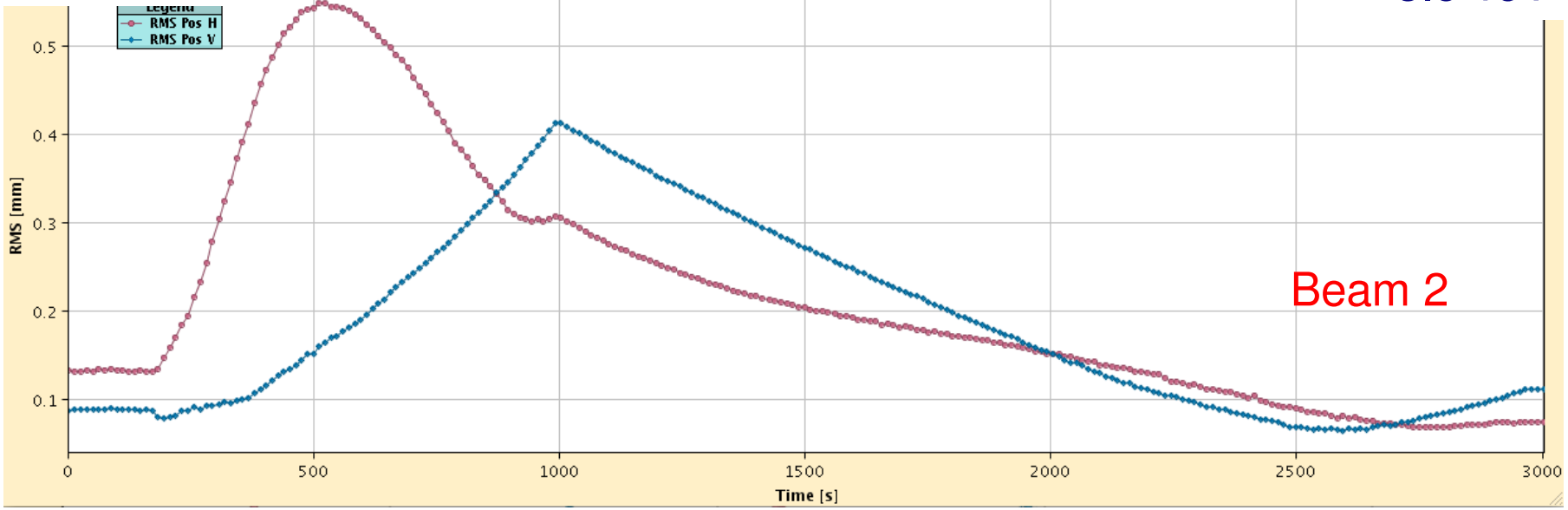
Orbit in ramp

Kajetan Fuchsberger

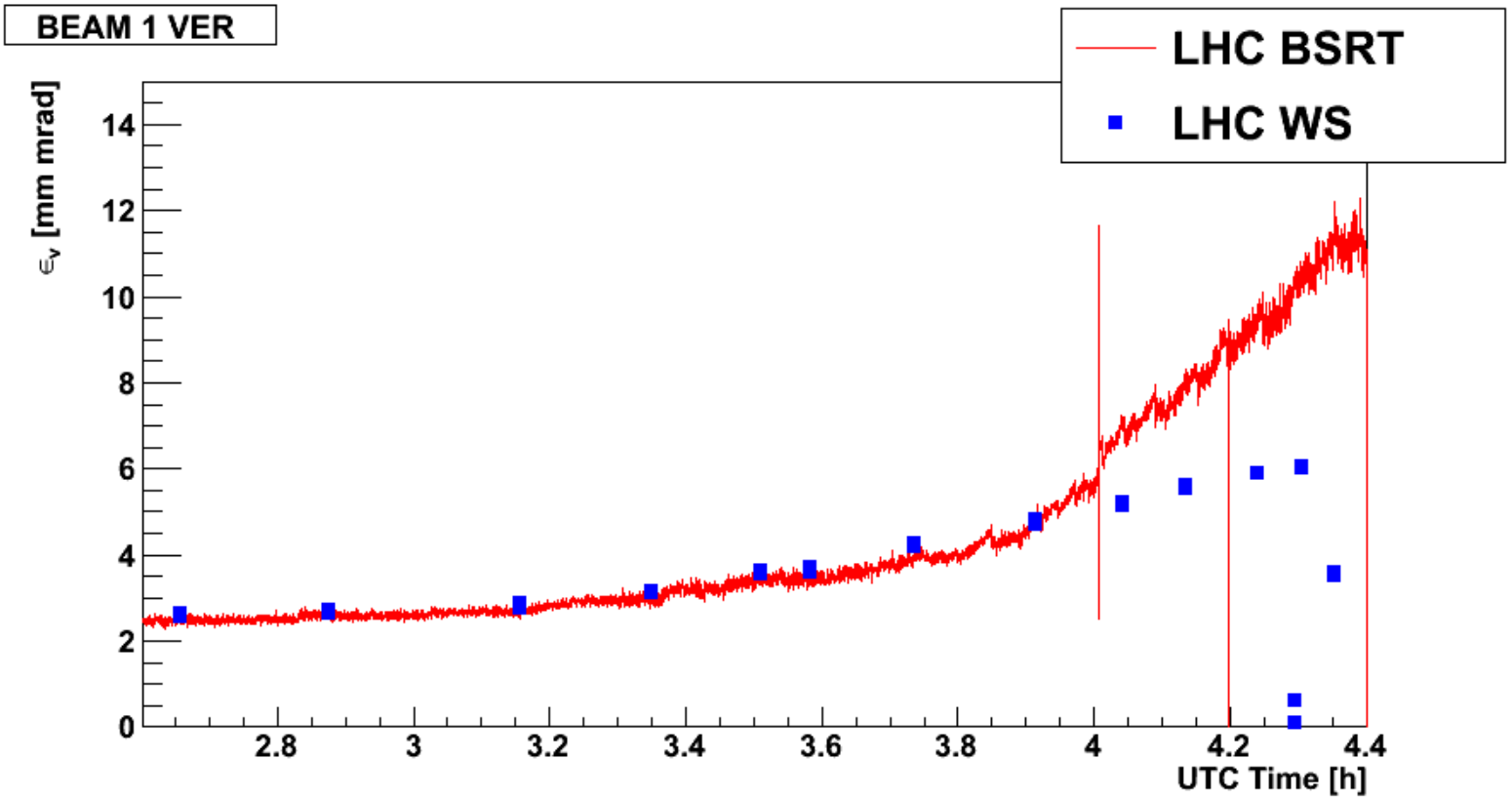


450 GeV

3.5 TeV



Beam size in ramp



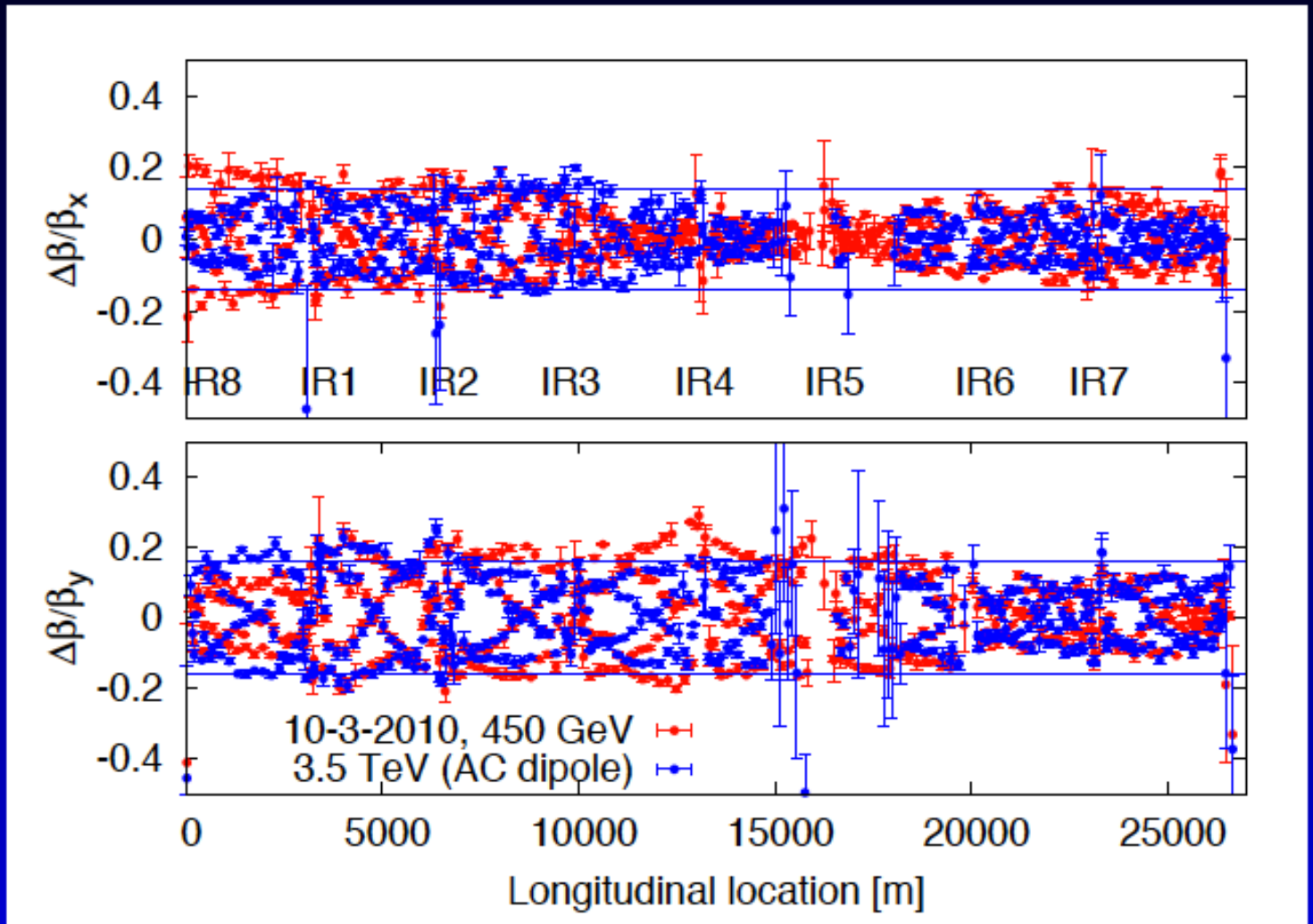
B1 emittance evolution during the first ramp to 3.5TeV

Sync light versus wire scanner
Vertical excellent up to ~ 2.5 TeV,
thereafter sync light calibration with D3 light to be studied

3.5 TeV

- Beating comparable with corrected 450 GeV. With no correction already in tolerance.
  - Optics in good shape
- Tune, orbit, chromaticity under control.
- Coupling
  - Brought under full control by local coupling correction for beam 2 arc-by-arc
- Separation bumps collapsed, collision tuning tested and incorporated into settings
- Beam Dump & Collimation commissioning ongoing
  - Prerequisite for “stable beams”

Beam 2, 3.5 TeV beta-beating

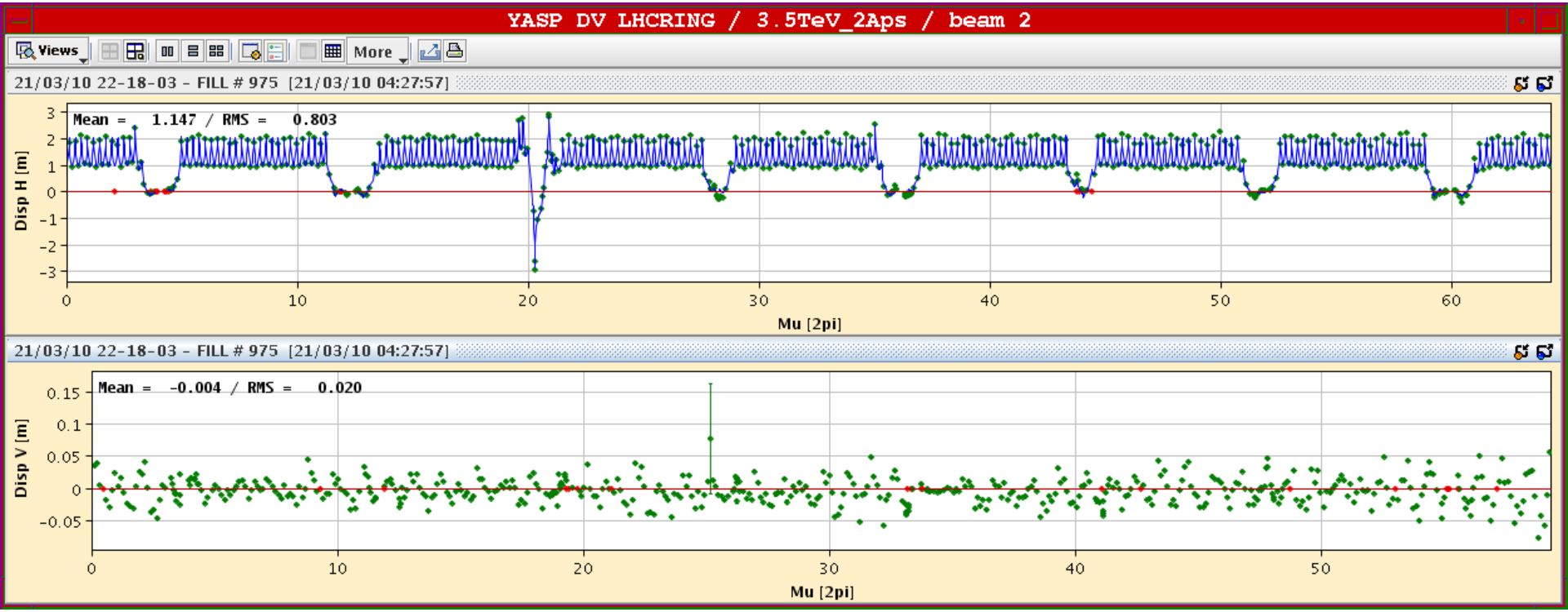


20% beating!

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

Dispersion

Dispersion B2 at 3.5 TeV



This is very good!

Summary 3.5 TeV

- Excellent stability and reproducibility
  - Good lifetimes
  - No signs of transverse diffusion
  - Some bunch length increase
  - Orbit – rock solid
  - Optics within tolerance and reproducible
- Machine protection has caught everything so far
  - Set-up and tests still in progress.

The beams definitely like it up there!

Next few days

- Establish 3.5 TeV stable beams 2x2 pilots
  - Protection device and collimator setting-up 3.5 TeV
  - Beam dump set-up 3.5 TeV
  - Two beam set-up - 2x2, 3.5 TeV
  - 2-3 hours non-colliding 3.5 TeV stable beams
- Deliver collisions at 450 GeV
  - 1-2 shifts to establish collisions in stable beams mode
  - Good for 2 to 3 e10 at the moment
- First collisions at 3.5 TeV
  - Around 09:17 next Tuesday morning…
  - One hopes that this is a case of “who dares, wins”.

Tuesday 30th March

- 2 bunches per beam
  - Collisions in all four experiments
- Pilot intensities
  - 6 – 7 e9 protons per bunch
  - Well below safe beam limit
- Aim to be ramped and well adjusted in very good time
- Collapse separation bumps in all four experiments at the same time
  - Not expecting lifetime/beam-beam issues
  - Fine adjustments as required. Beam sizes of order 100 um
- Head off for a stiff drink

2010 continued

- Beam commissioning
  - Pilot runs un-squeezed
  - Through to colliding, safe, stable, squeezed beams
- Consolidation & pilot physics
- Full machine protection qualification
- Phased intensity increase and associated machine protection qualification
  - Establish secure and reproducible operations and fully field test
  - Moving very, very carefully

To 2 MJ

Main challenge will be learning to operate safely with destructive beams

Approved steps to 2 MJ

	Bunch intensity	Number of bunches	Energy per beam [MJ]	Peak luminosity [$cm^{-2}s^{-1}$]	Days	Integrated luminosity per month [pb^{-1}]
4 bunches	5 e9	4	0.01	4.5 e27	14	0.001
4 bunches	2 e10	4	0.05	7.1 e28	14	0.002
4 bunches	5 e10	4	0.11	4.5 e29	14	0.13
8 bunches	5 e10	8	0.22	8.9 e29	14	0.27
4 x 4 bunches	5 e10	16	0.45	1.7 e30	14	0.55
8 x 4 bunches	5 e10	32	0.9	3.6 e30	30	2.3
43 x 43 bunches	5 e10	43	1.2	4.8 e30	14	1.5
8 trains of 6 bunches	8 e10	48	2.2	1.3 e31	14	4.0
					128	

Jorg Wenninger

TT40 Damage during 2004 High Intensity SPS Extraction / Goddard, B ; Kain, V ; Mertens, V ; Uythoven, J ; Wenninger, J

Or what you can do with 2.9 MJ

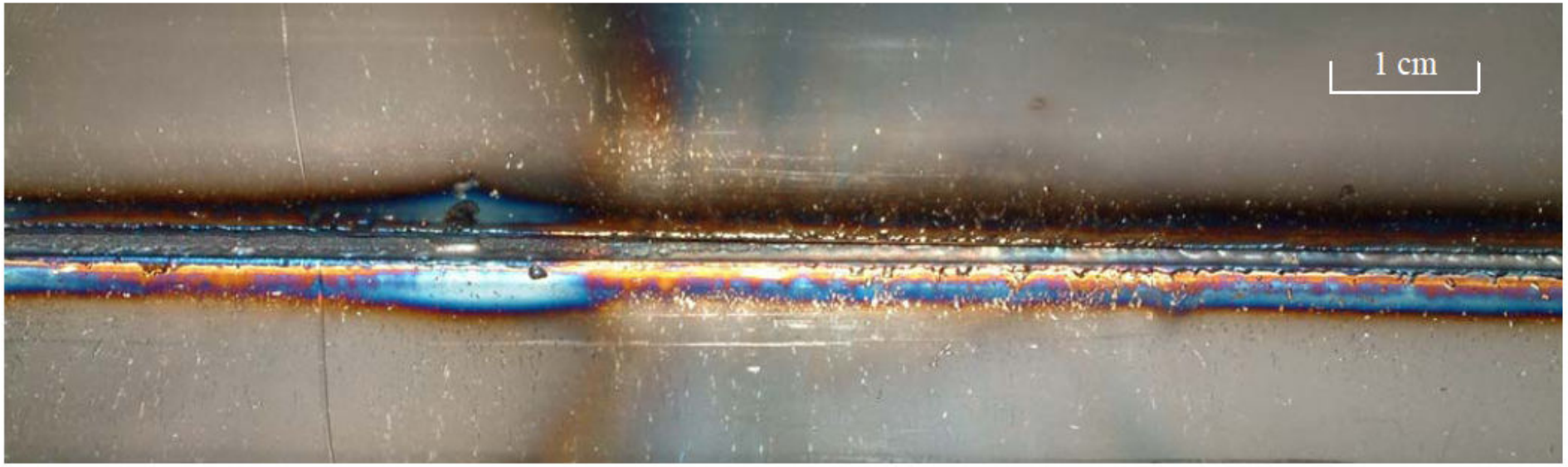
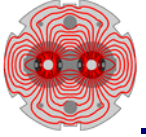


Figure 4. Damage observed on the inside of the vacuum chamber, on the beam impact side. A groove approximately 110 cm long due to removed material was clearly visible, starting at about 30 cm from the entrance.

During high intensity extraction on 25/10/04 an incident occurred in which the vacuum chamber of the TT40 magnet QTRF4002 was badly damaged.

The beam was a 450 GeV full LHC injection batch of 3.4 10^{13} p+ in 288 bunches, and was extracted from SPS LSS4 with the wrong trajectory

4.4 e12 at 3.5 TeV



Conclusions 1/2

- A lot of hard work over the years has enable a truly impressive period of initial commissioning with beam.
- Initial indications are that the LHC:
  - is reproducible;
  - magnetically well understood;
  - optically in good shape;
  - is armed with a mighty set of instrumentation, software, and hardware systems.
- Lots still to sort out, in particular…
- Operations, controls, instrumentation etc. have the capability to unnecessarily stress the machine protection system – issues must be resolved.

Long way to go before we are ready to move too far above the safe beam limit

Conclusions 2/2

- First collisions at 3.5 TeV next Tuesday (with a bit of luck)
- Thereafter continued commissioning including squeeze
- Followed by a running period around the safe beam limit:
  - With blocked commissioning periods as required

- A very careful stepwise increase in intensity through the year with each step up in intensity to be followed by an extended running period.

Big thanks are due to all the teams involved.

A remarkable effort has been repaid with remarkable progress.