Status of LHC operations

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Outline

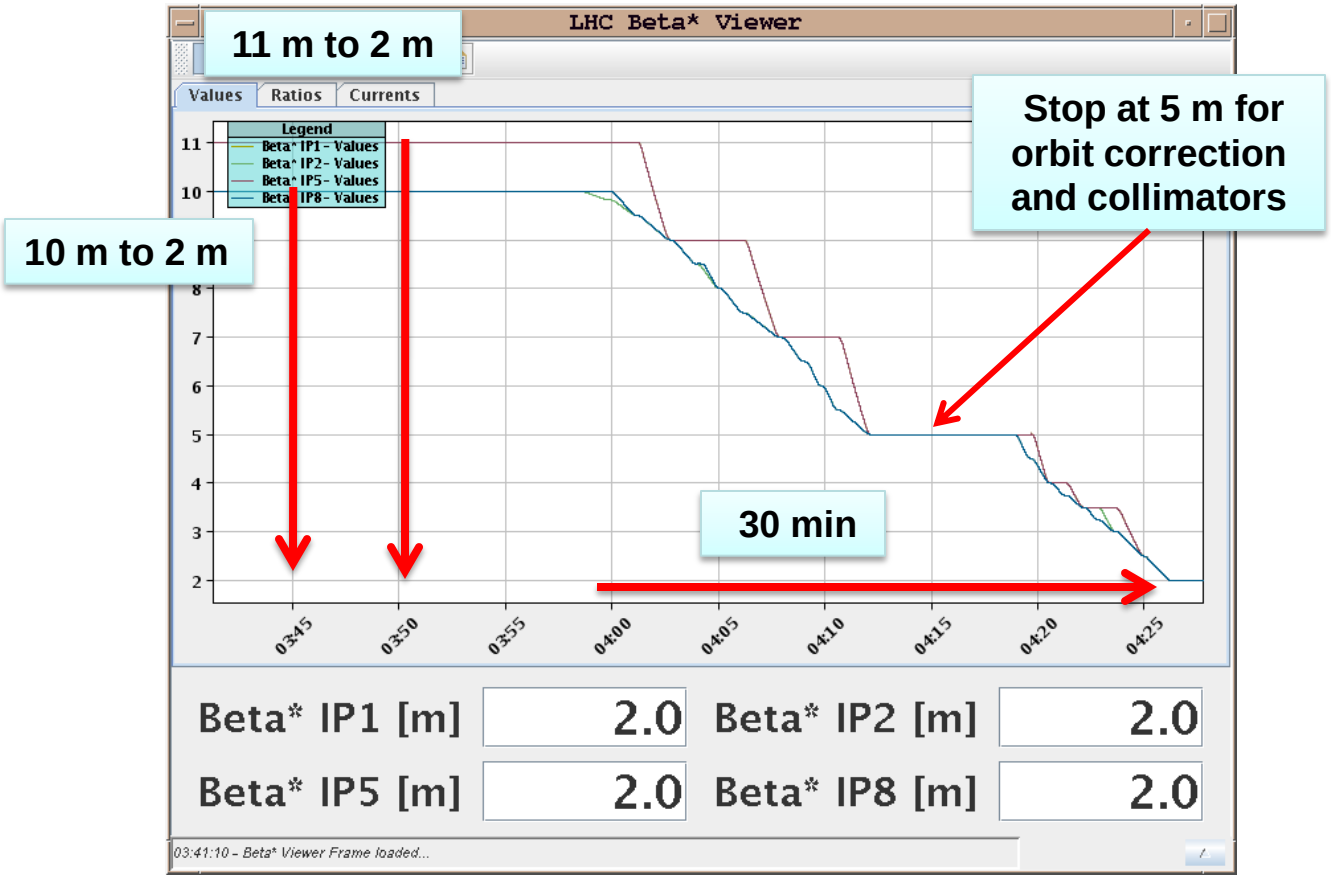
Current operation for physics

Operation with high bunch population

Conclusions

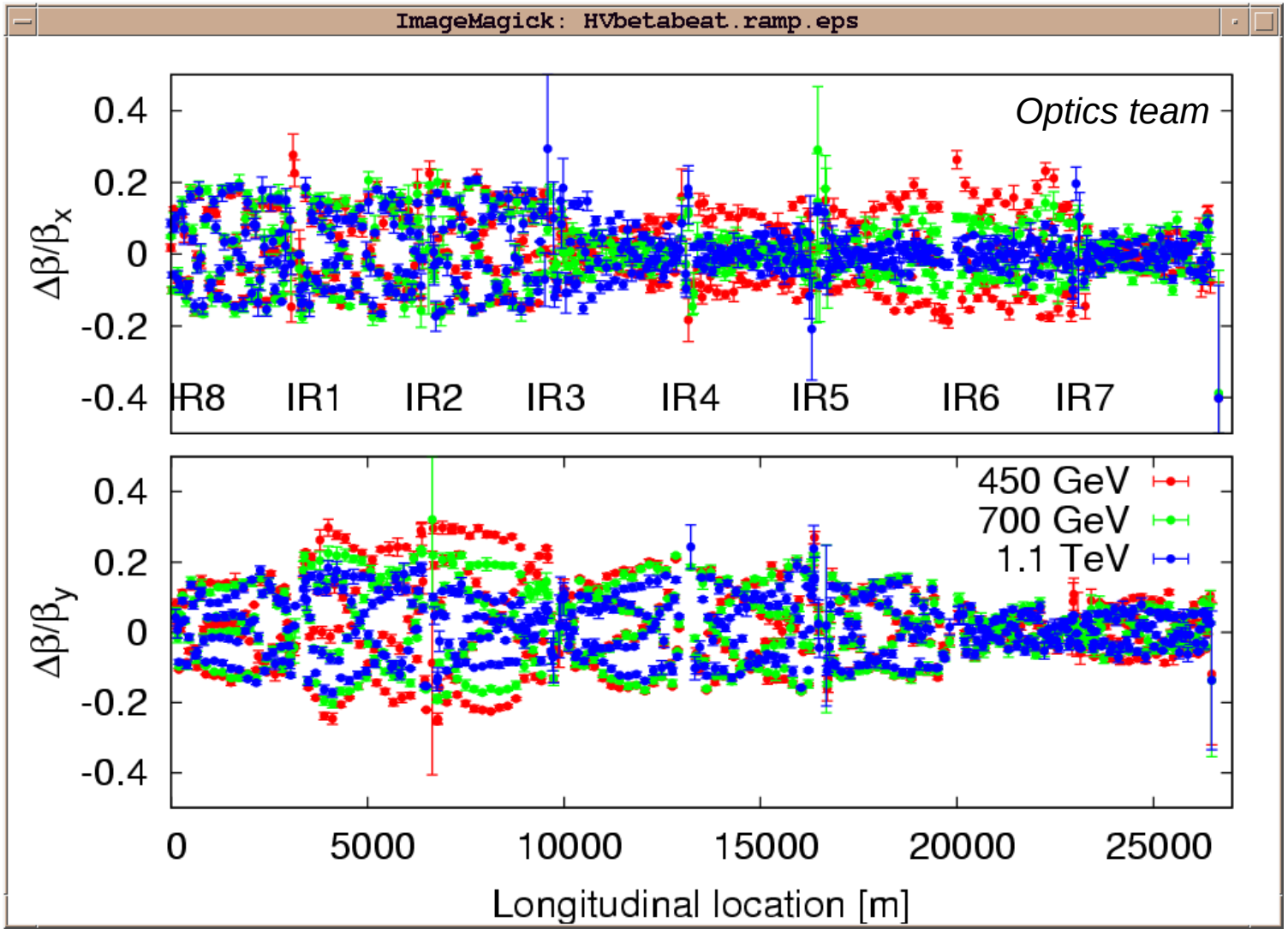
Optics and β*

- Since a few week we routinely squeeze β* at the IPs all in parallel to 2 m.
- One intermediate stop for orbit correction & final collimator (tertiary collimators near IRs) adjustment.



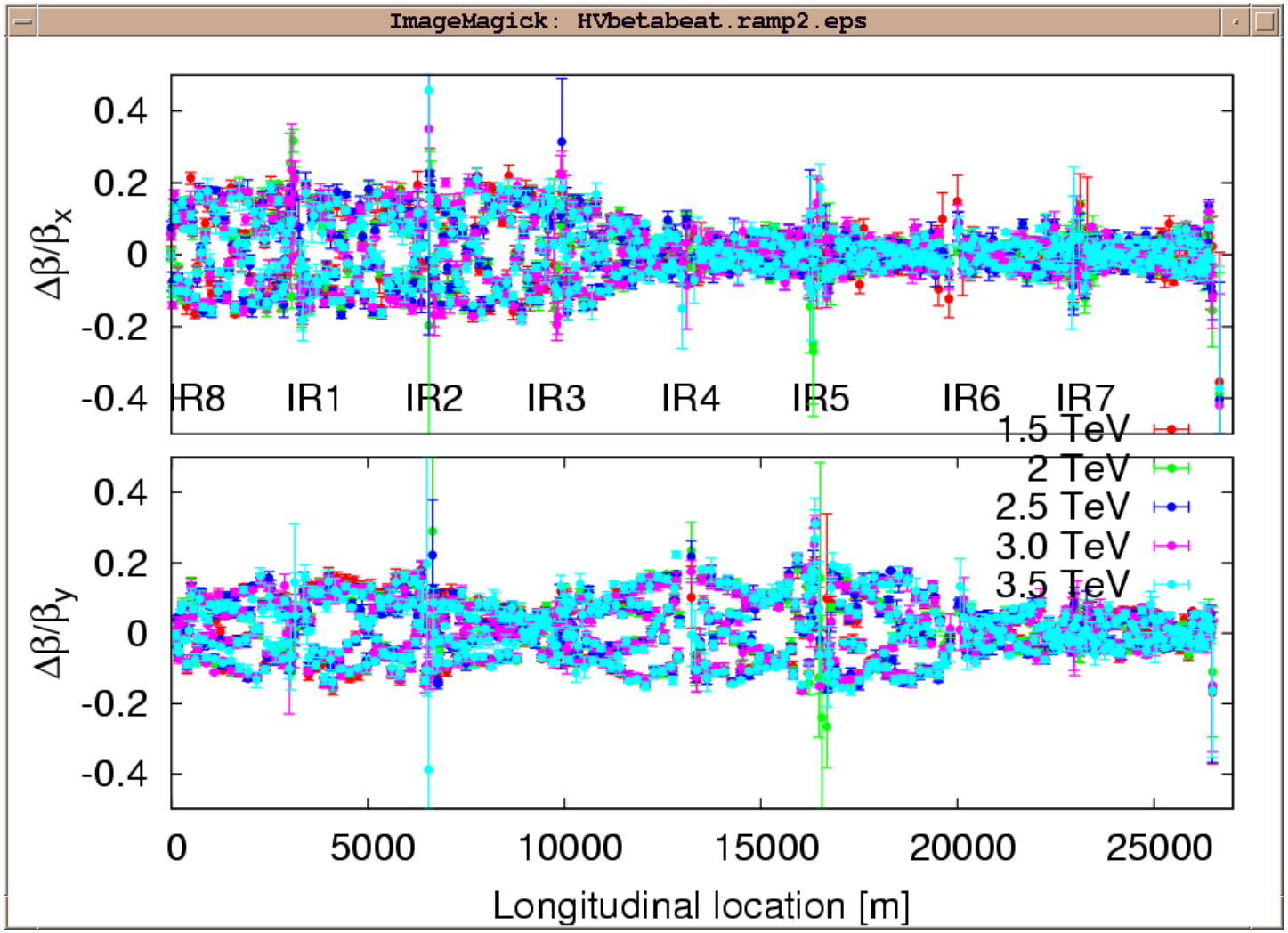
Optics : 450 to 1.1 TeV

- A stable and well measured optics is important for aperture, and can significantly affect the time required to setup (e.g. collimators).

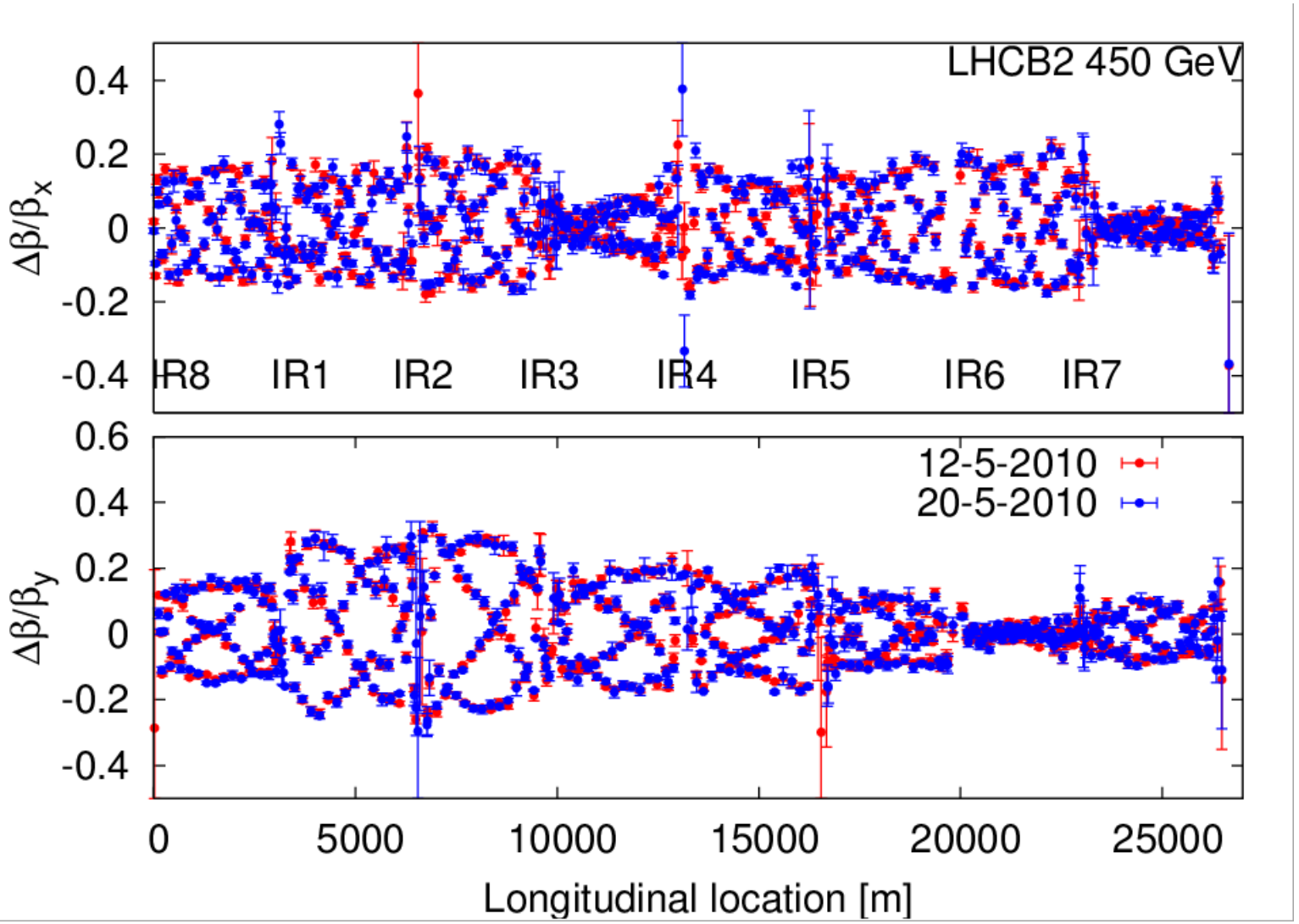


Optics stable from 1.5 to 3.5 TeV

- Impressive stability (and reproducibility) of the optics, thanks to remarkable work on magnet transfer functions by the magnet groups.



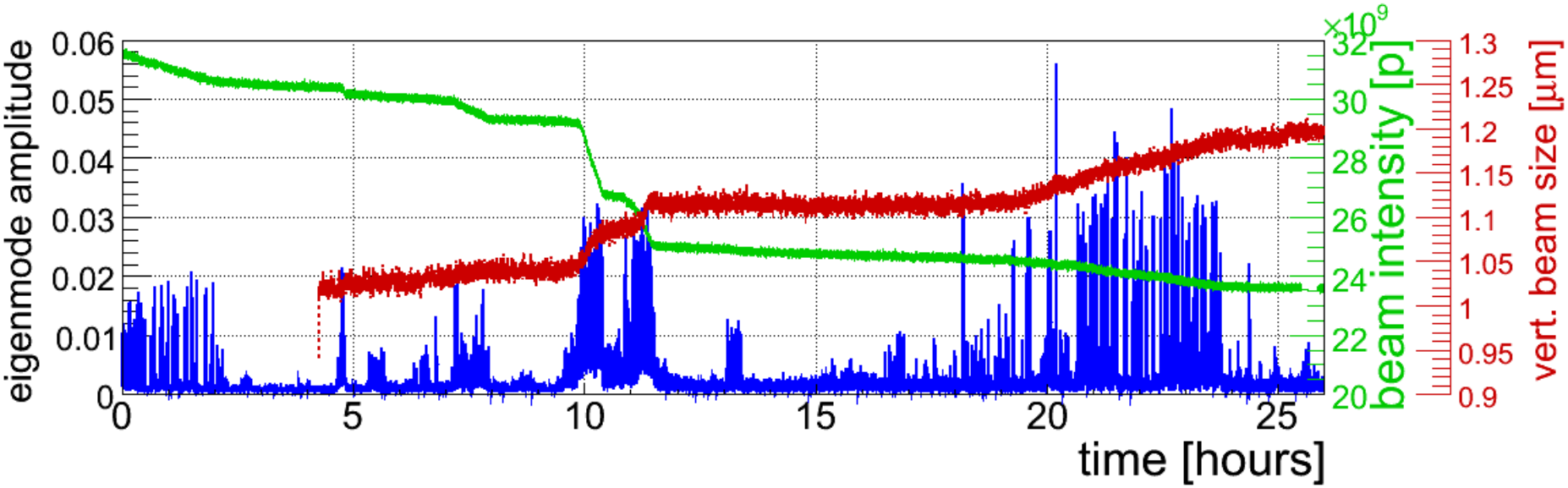
Optics reproducibility



The hump…

- Fast (but low amplitude nm to μm) vertical oscillation of the beams.
- Sometimes it is present, sometimes it is not.
- Beam 2 is more affected…
- The frequency changes slowly (7-8 minute period), and when the frequency coincides with the tune it leads to emittance blow-up.

>> we are still hunting for the source….



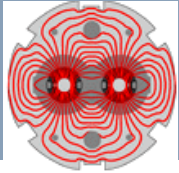
Courtesy R. Steinhagen

Increasing intensity & luminosity

- We have a plan of step-wise increase of intensity (factor 2 to 4), interleaved with operation periods of ~14 weeks at constant intensity.
  - *LHC is still in a phase of early commissioning.*
  - *Need time to ensure protection systems work flawlessly.*
  - *Need time to train all people on shift to run the LHC safely, fill holes in the control system, etc…*
- The LHC sometimes forces (or advises) us to adapt the route to higher intensity:
  - *At constant total intensity (~ kN), we can trade number of bunches (k) versus bunch population (N).*
  - *Increasing N brings more gain !*

$$L = \frac{kN^2 f}{4\pi\sigma_x^*\sigma_y^*}$$

The initial road



- After the media day, we have been pushing total intensity (and luminosity) with:
  - *moderate bunch populations (up to 2×10^{10}),*
  - *β^* of 2 m.*
- Machine protection systems, collimator and absorbers were setup and validated for β^* of 2 m.
  - *Present operation mode for physics.*
- Present parameters for collisions:

  $N = 2\times10^{10}$, k=6 , β^*=2 m - 3 colliding pairs per IR

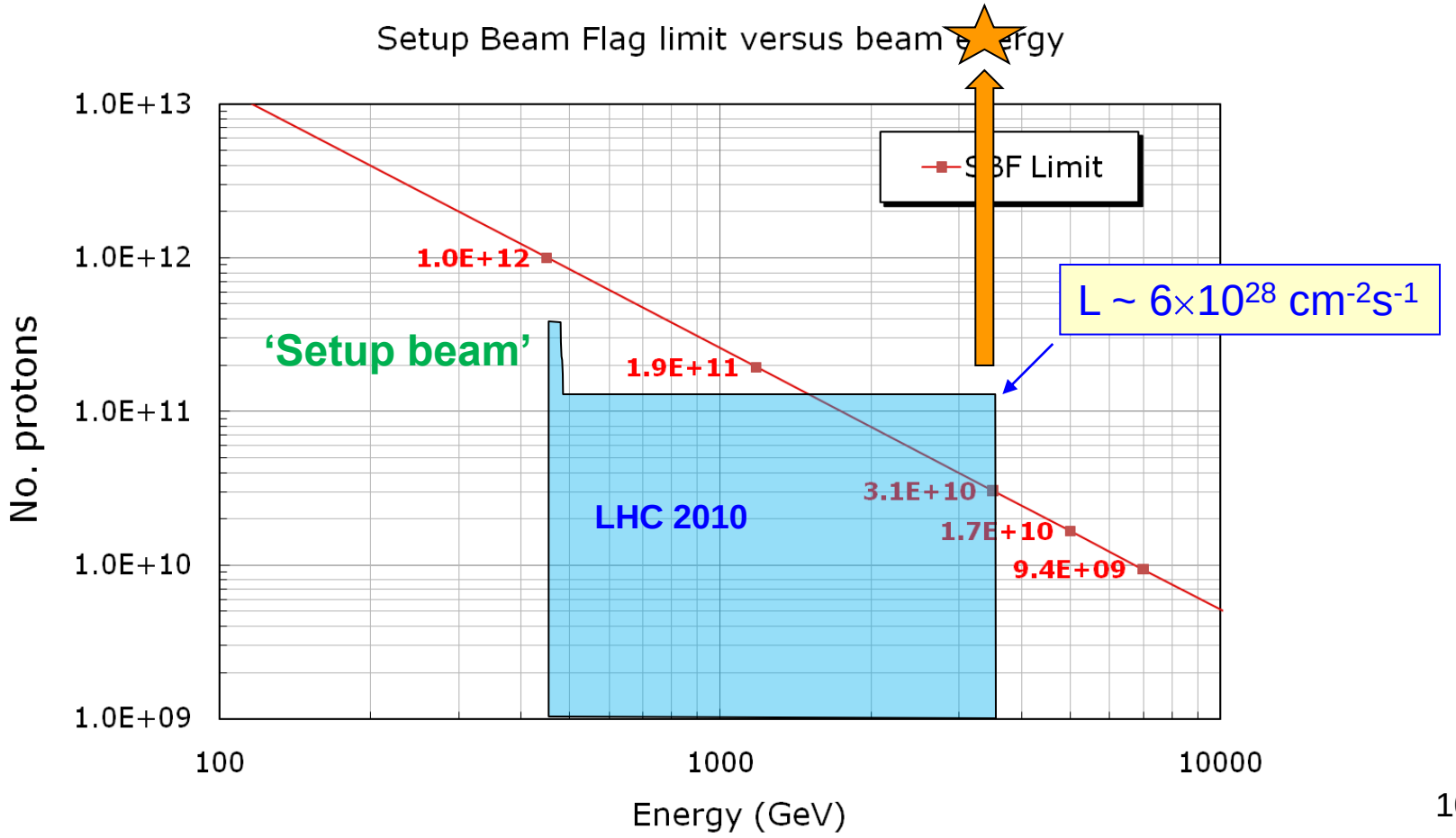
  >> Peak L ~ 6×10^{28} cm^{-2}s^{-1}

  >> if all goes well we will move to k=13 bunches during the coming weekend – 8 colliding pairs per IR.

Setup beams

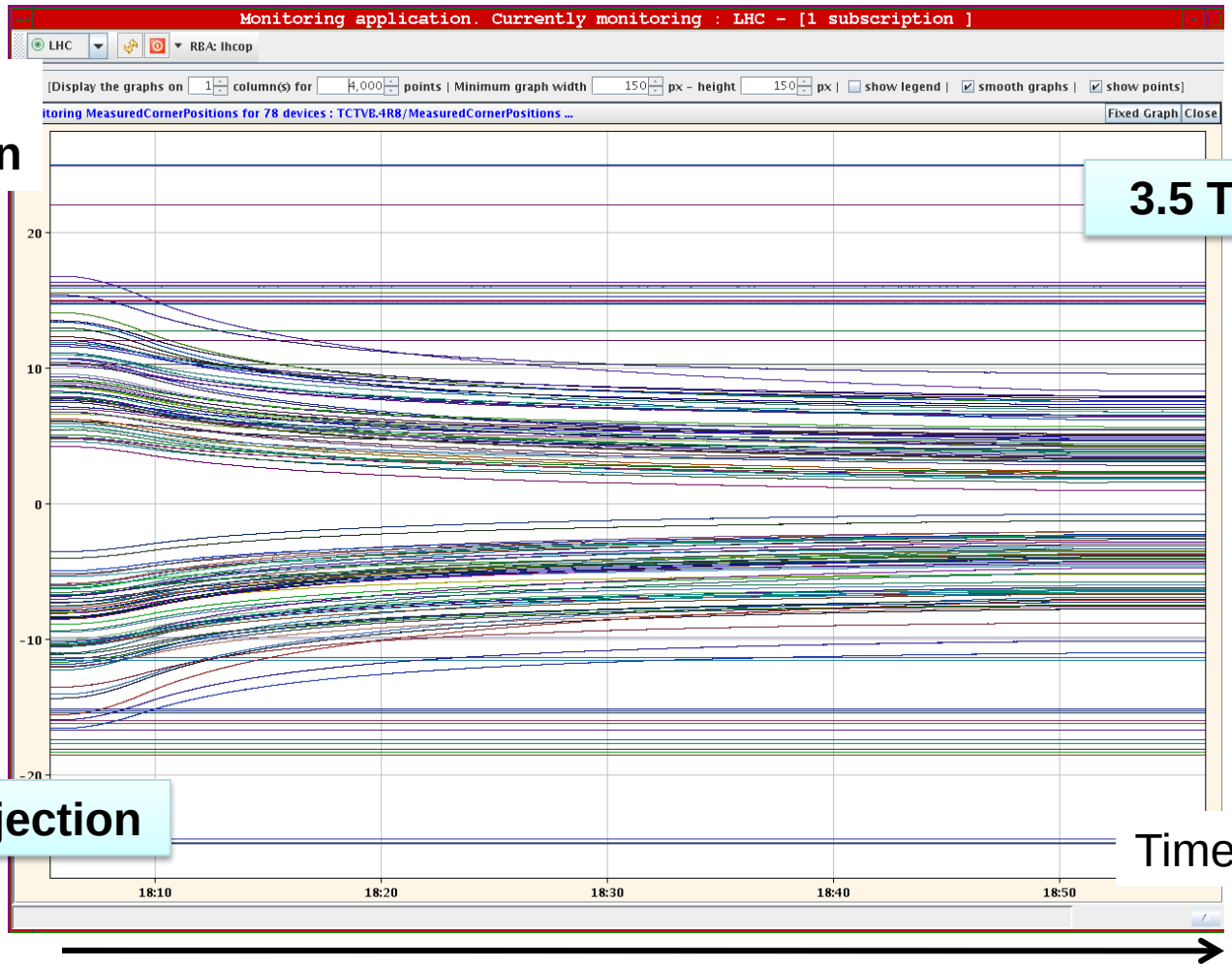
- To ease commissioning, certain interlocks in the machine protection system are maskable when the beam intensity is below a limit, the Setup Beam (flag) Limit = function (energy):

Beam represents 'small' risk to the machine below this limit



Collimators in the ramp

- Collimators are now ramping with the magnets to limit the aperture more tightly: requirement for operation with beams significantly above the setup beam limit.



Jaw position

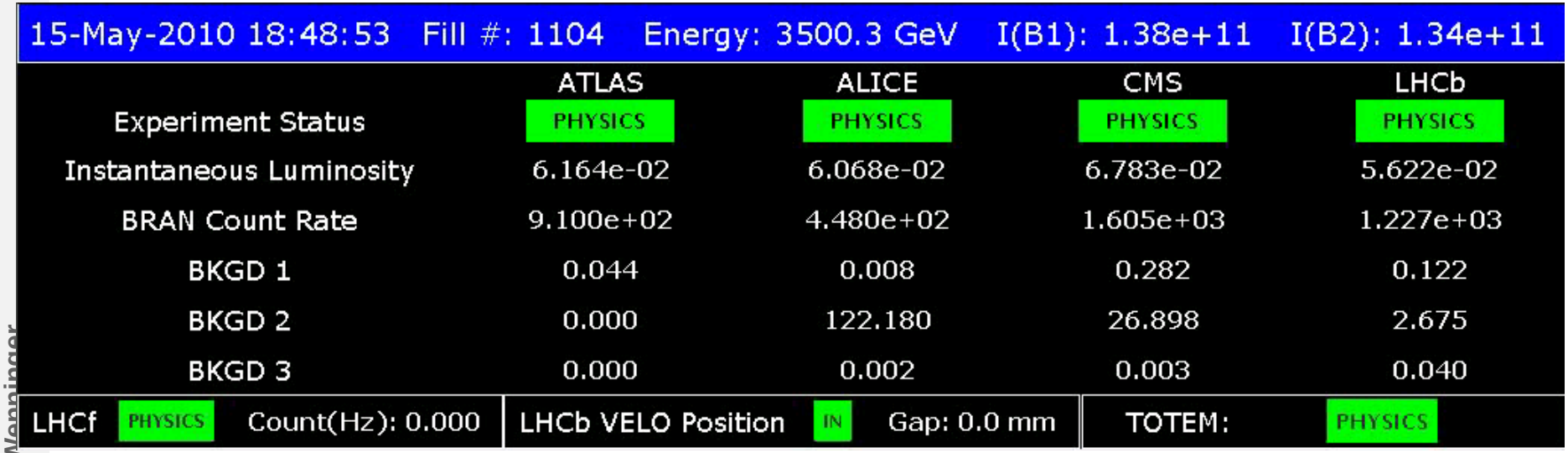
Collimation team

3.5 TeV

Injection

Time/energy

Luminosity



15-May-2010 18:48:53 Fill #: 1104 Energy: 3500.3 GeV I(B1): 1.38e+11 I(B2): 1.34e+11

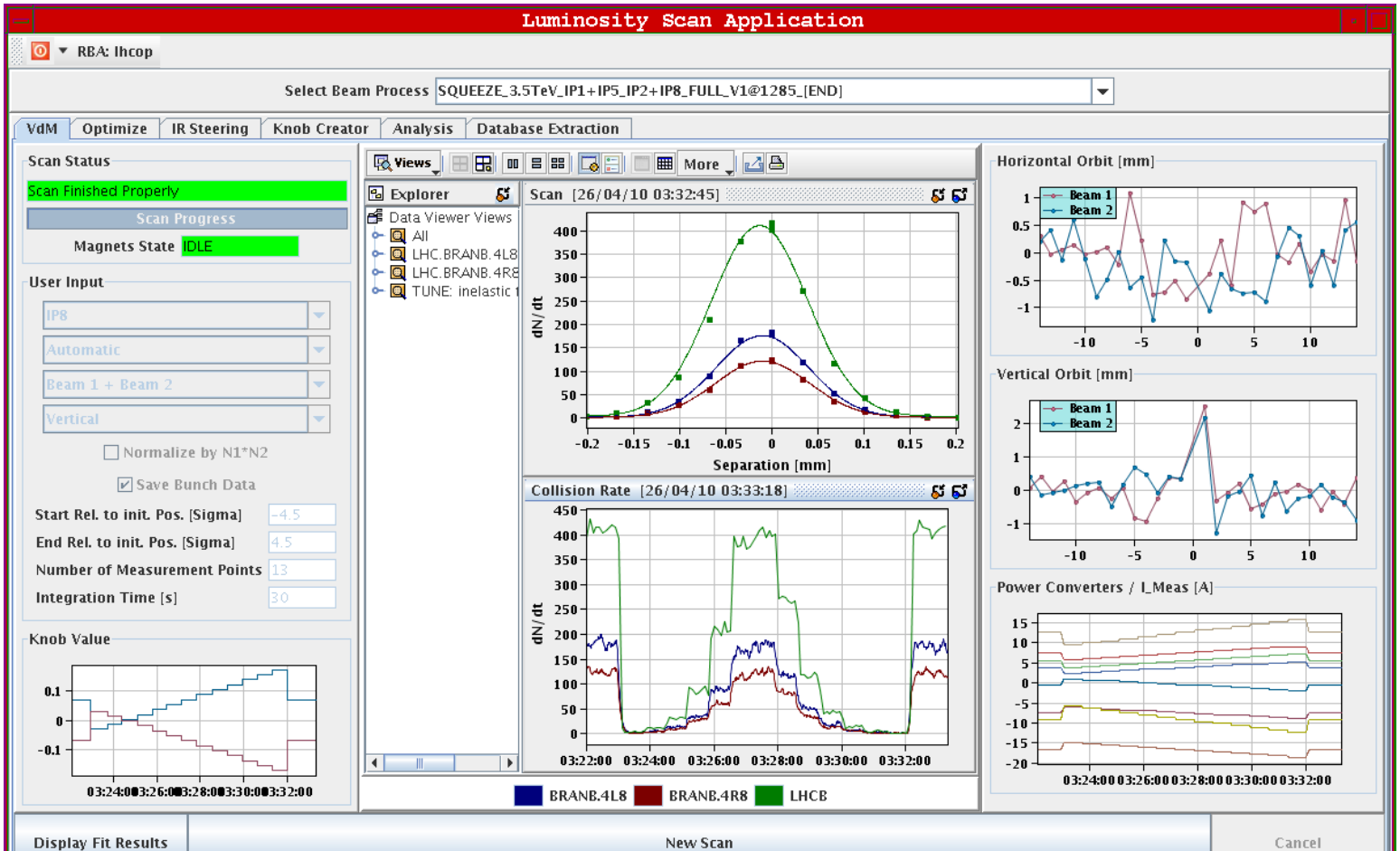
	ATLAS	ALICE	CMS	LHCb
Experiment Status	PHYSICS	PHYSICS	PHYSICS	PHYSICS
Instantaneous Luminosity	6.164e-02	6.068e-02	6.783e-02	5.622e-02
BRAN Count Rate	9.100e+02	4.480e+02	1.605e+03	1.227e+03
BKGD 1	0.044	0.008	0.282	0.122
BKGD 2	0.000	122.180	26.898	2.675
BKGD 3	0.000	0.002	0.003	0.040

LHCf PHYSICS Count(Hz): 0.000 | LHCb VELO Position IN Gap: 0.0 mm | TOTEM: PHYSICS

Luminosity **~ 6 × 10^{28} cm^{-2} s^{-1}**

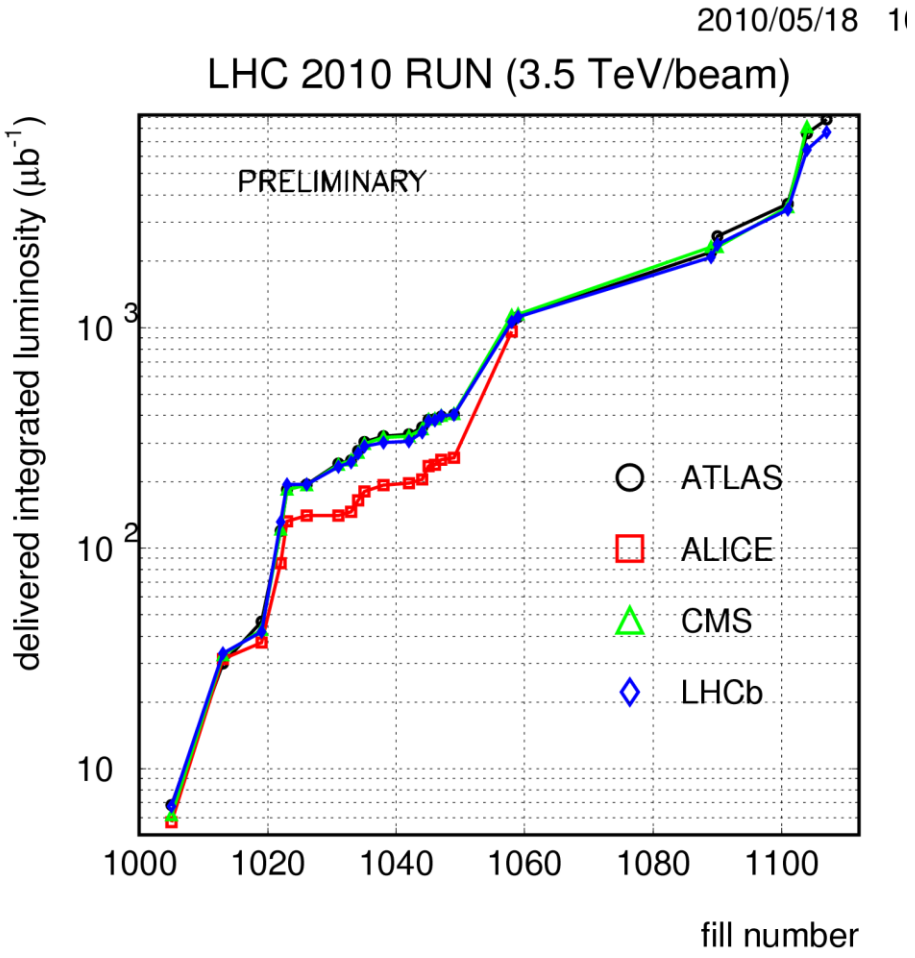
Luminosity optimization

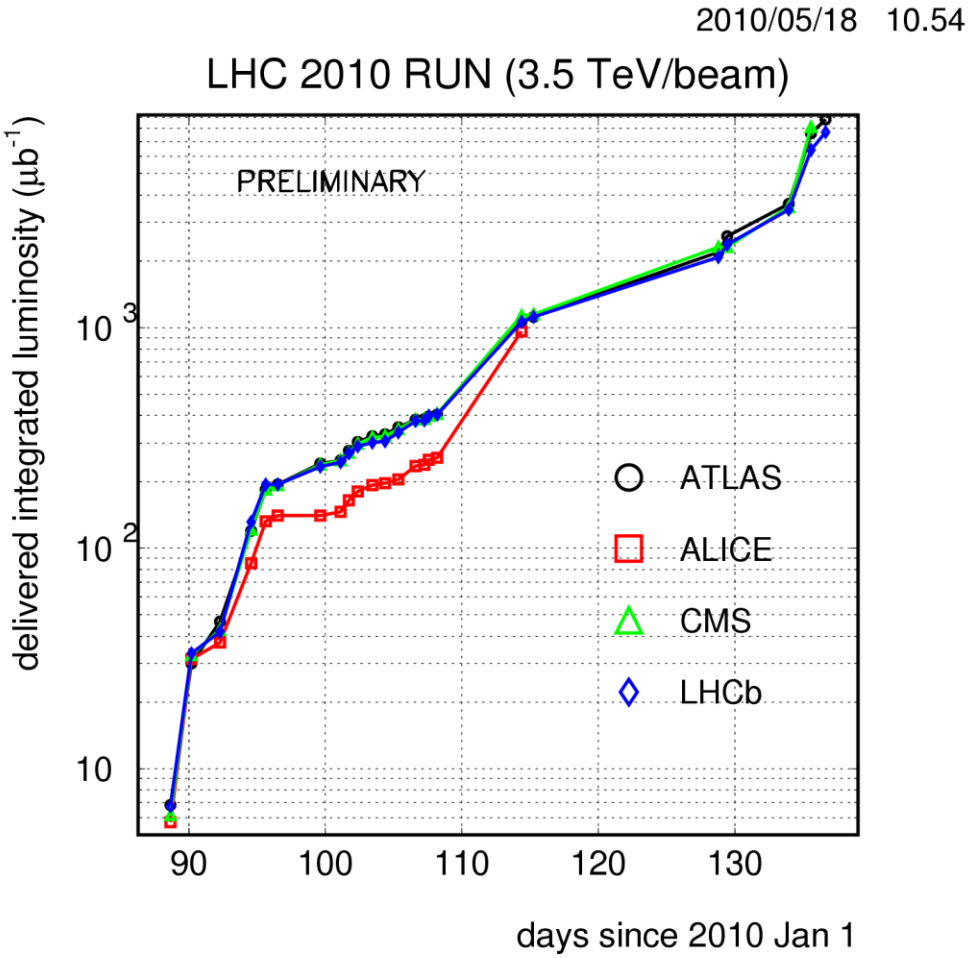
- Collision points are reasonably stable (more experience needed…) and luminosity optimization scans are performed regularly in all experiments.
- A series of Van de Meer scans to determine the absolute luminosity have been made recently: errors of less than 10% in sight, dominated by knowledge of bunch population



Integrated luminosity

Courtesy M. Ferro-Luzzi





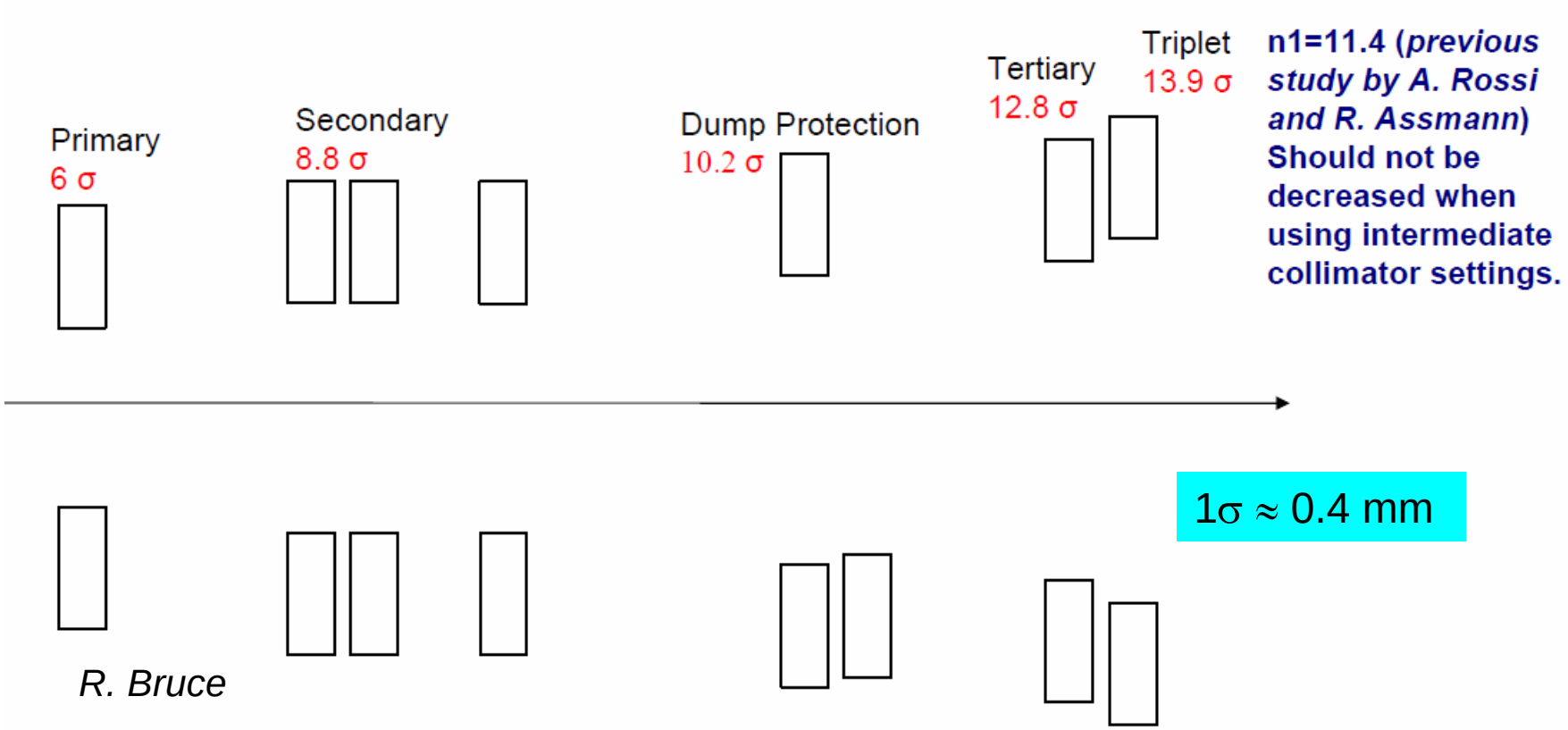
Towards nominal bunches

- In parallel to the first physics runs, bunch populations were pushed up to nominal (1.2×10^{11}) at injection, and collisions were delivered at injection for detector calibration.
  - *No issues with beam-beam interaction at injection – good outlook for 3.5 TeV.*

>> Paved the way for collisions of nominal bunches at 3.5 TeV

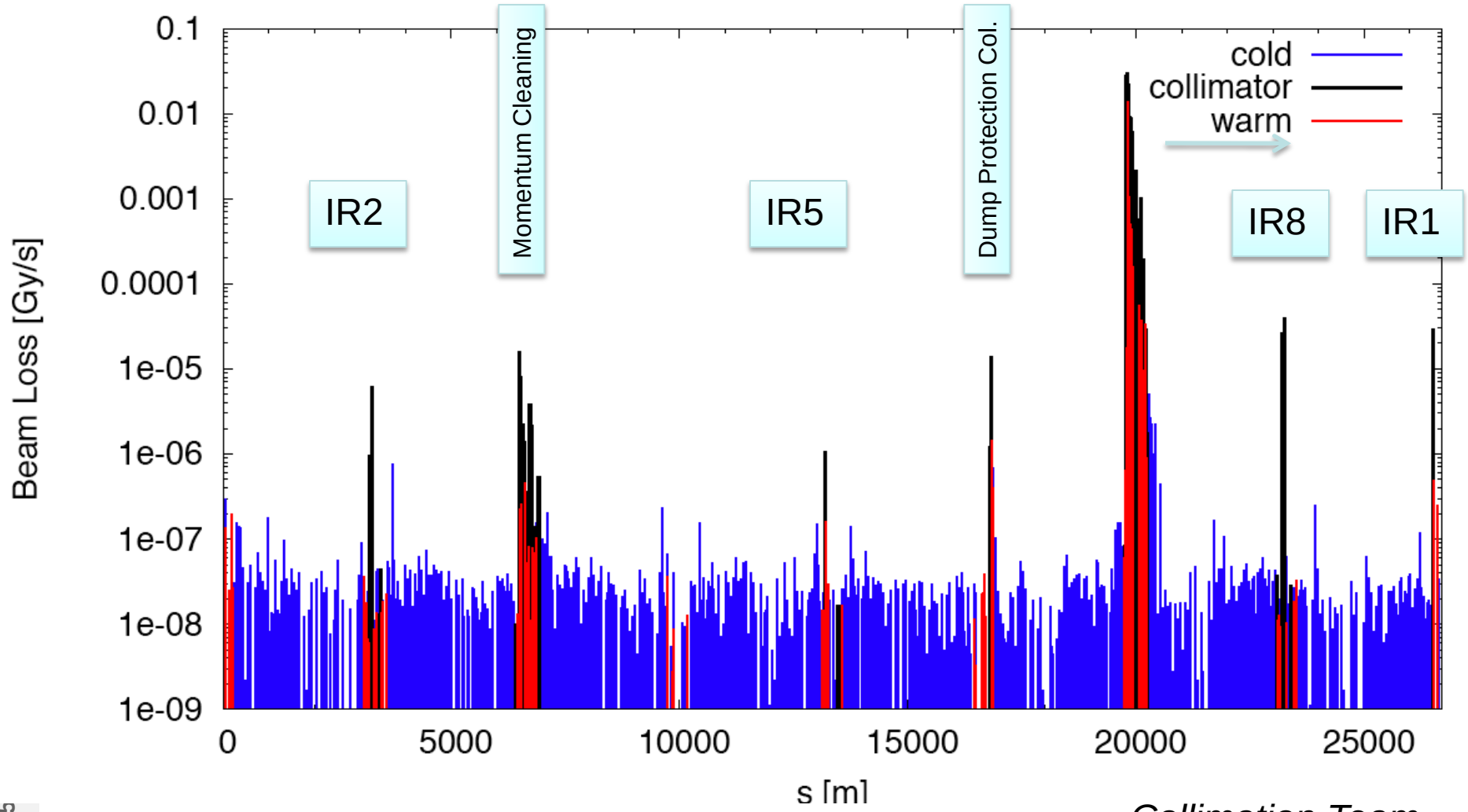
Aperture considerations

- With squeezed beams at 3.5 TeV, the aperture limit of the LHC is in the triplet quadrupoles around the 4 experiments.
- With β* 2 m, the tolerances are already very tight (orbit etc)
  - *Little margin to accommodate crossing angles without requiring very tight protection (interlocks).*



Collimation performance : provoked loss

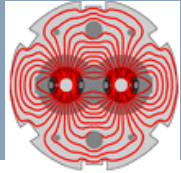
2m optics exposes IR's as expected! Protected by tertiary collimators.



Already presented by R. Assmann, 23.04.2010

Collimation Team

More protons, higher β*



- To mitigate the risk associated with a single nominal bunch at 3.5 TeV (asynchronous dump) without requiring tolerances that are beyond our present capabilities, it was decided that:

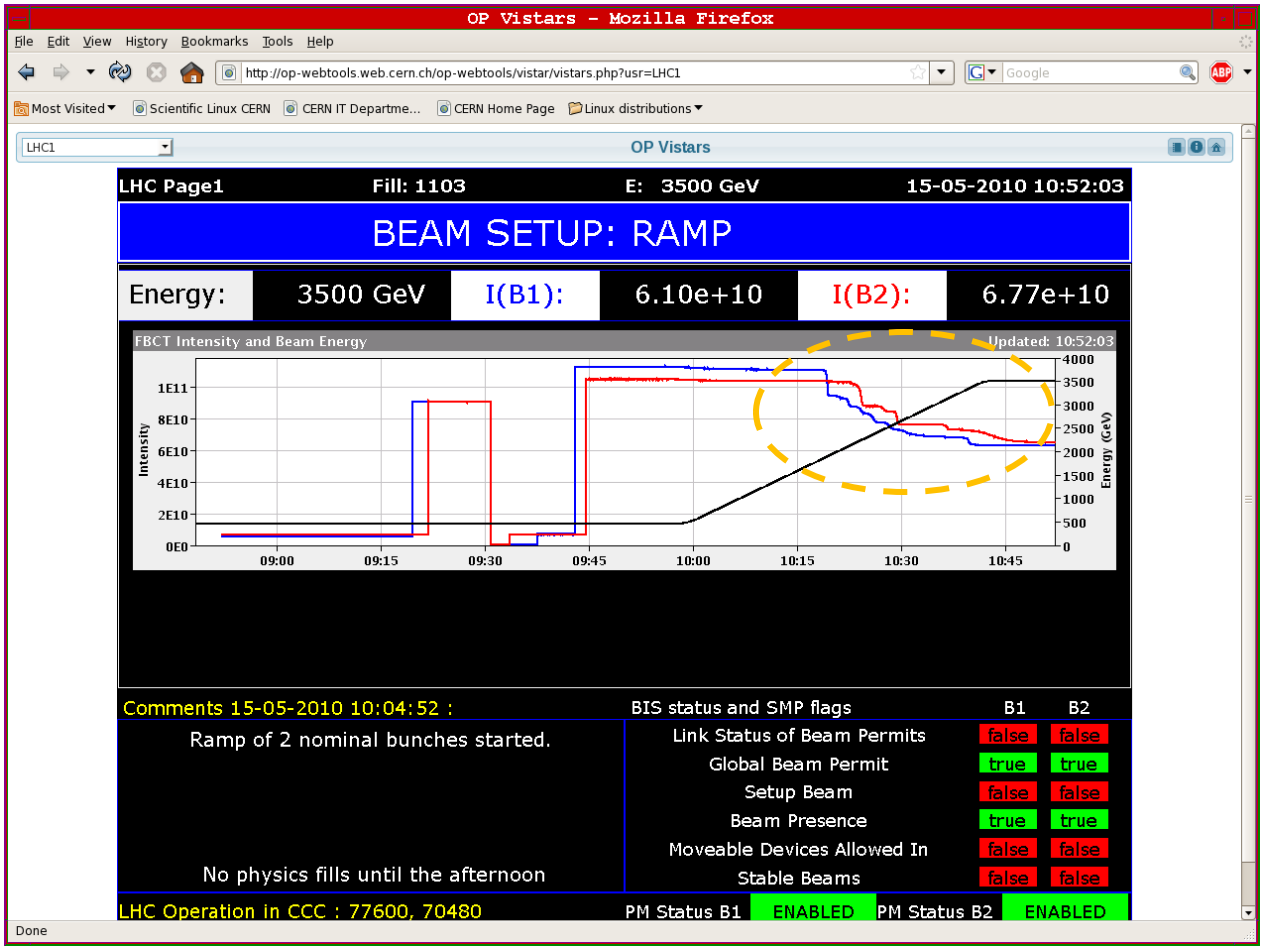
  >> operation with nominal bunches will start with β* = 5 m

  - *IR aperture shadowed by arc, ~20 σ.*

- We give up a factor 2.5 in luminosity and trade it for:
  - *higher bunch populations,*
  - *more flexibility (without too much risk),*
  - *easier transition to operation with crossing angles (needed when k reaches 20-40 bunches).*
- As we gain more experience and better control over the beams, we will try to push β* down again, probably towards 3-3.5 m.

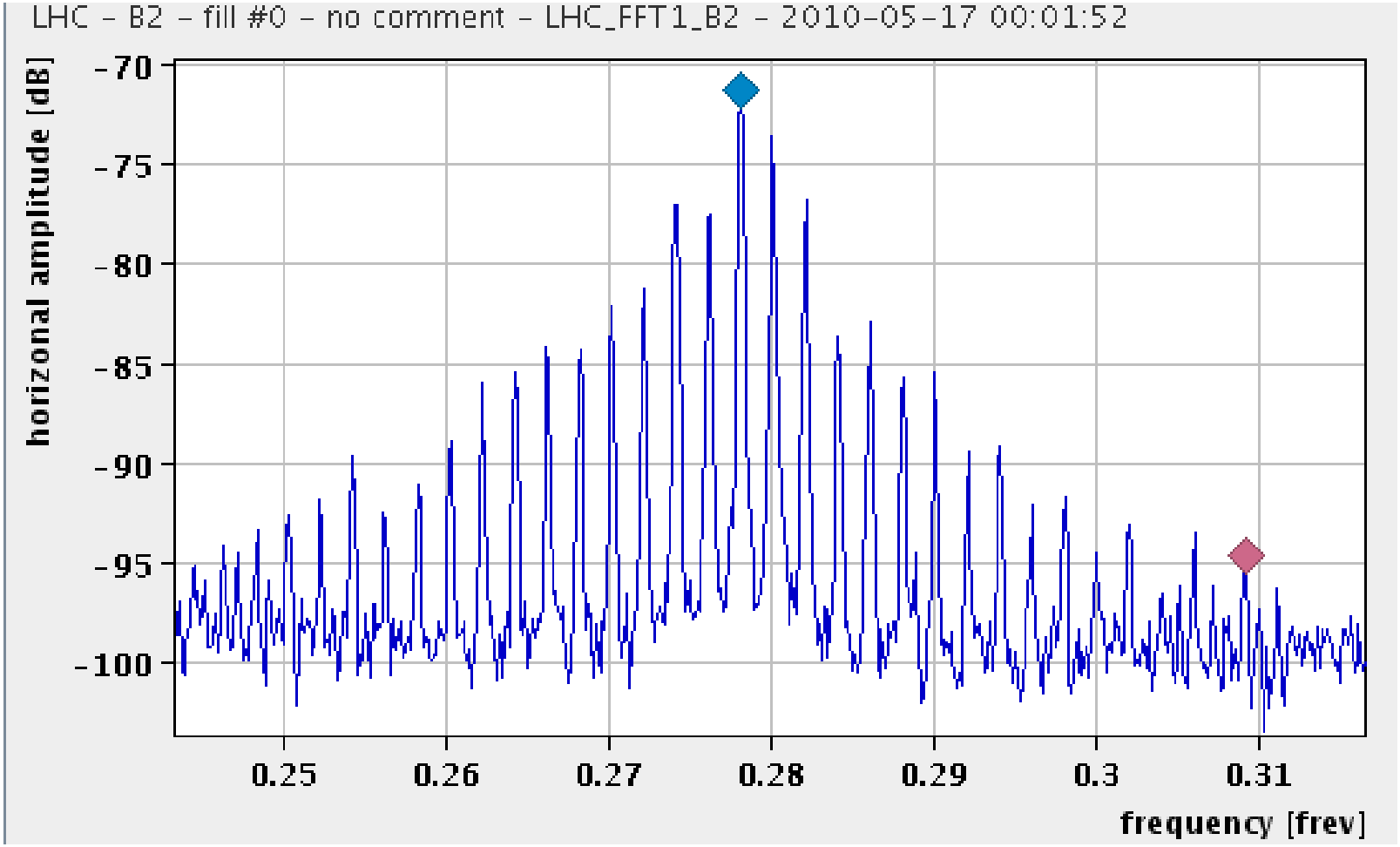
Nominal bunches – first ramp

- Smooth start of the ramp…
- … but beams became unstable around 1.8 TeV: ~40% of the beam lost.

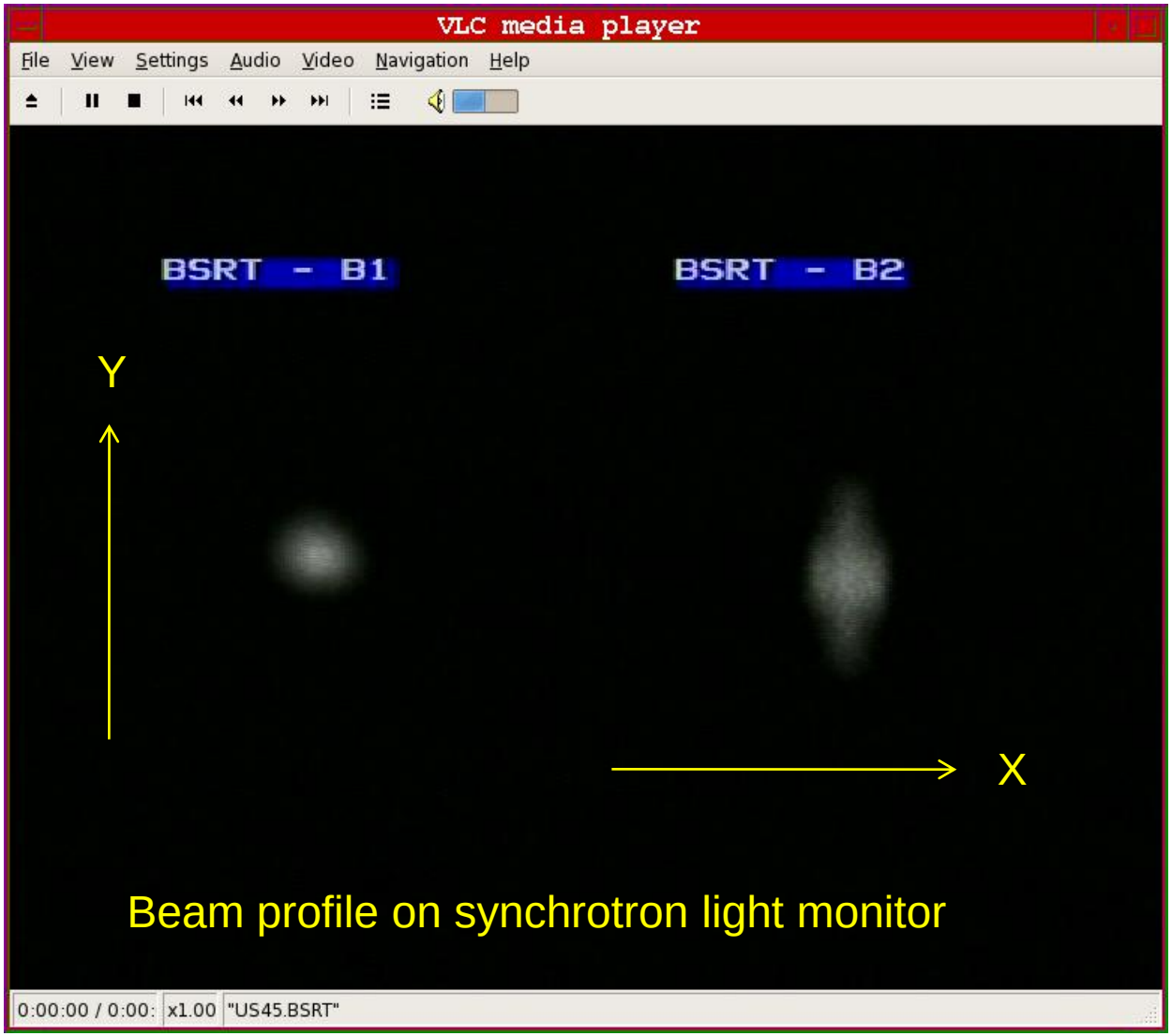


Higher intensity – mode Xmas tree

- Many modes at ± n Qs (synchrotron frequency) appear in the tune spectrum (normally only the central line).



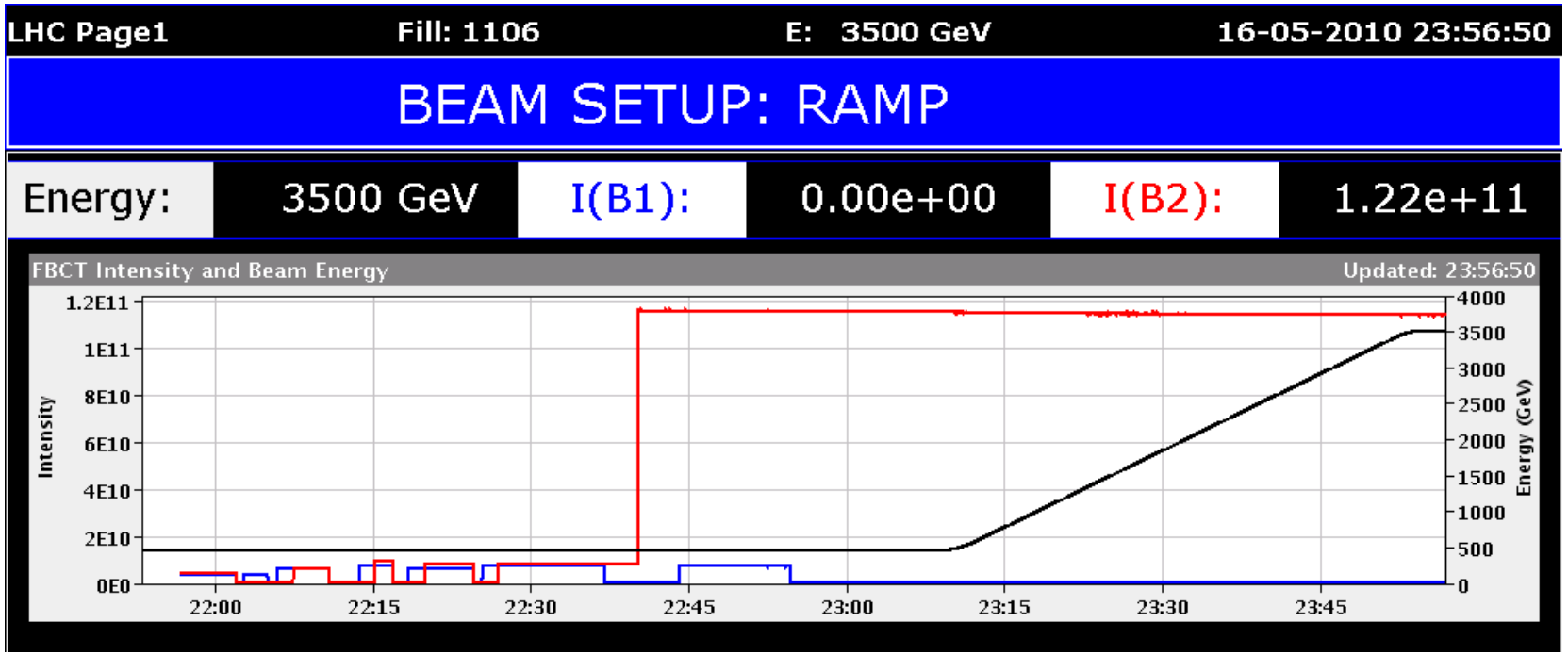
‘Saturn’ instability @ LHC



Stabilization with octupoles

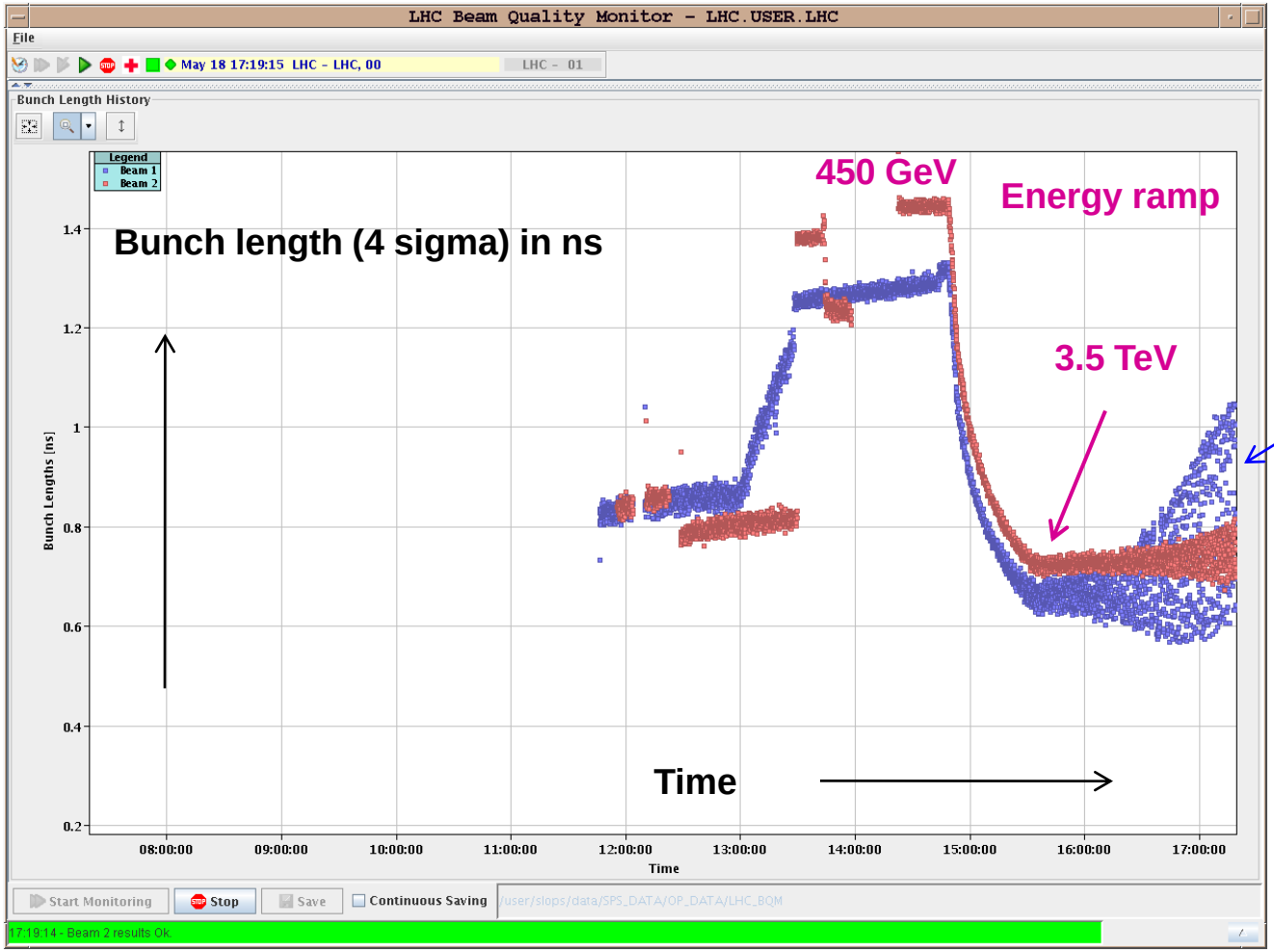
- Beams can be stabilized with octupoles: increases the tune dependence on particle amplitude.
  - → *Increases the tune (frequency) spread.*
  - → *Prevents coherent motion of the protons in the bunch.*

  But too strong octupoles can also drive resonances and reduce lifetimes…
- Ramp with octupoles: 1 bunch of 1.2E11 protons at 3.5 TeV – OK !
  - *But the beam emittance blows up rapidly to 2-3 x nominal !!*



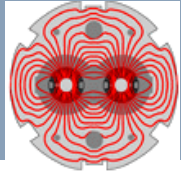
‘Dancing’ bunches at 3.5 TeV

- Another way to improve stability is to increase the longitudinal emittance (bunch length and energy spread).
- The instability manifests itself by unstable bunch shapes.



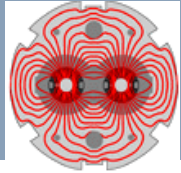
Beam 1 (blue) is very unstable: the length / shape is oscillating

Work on nominal bunches (1)



- Understand the instability.
  - *Hypothesis: **head-tail** mode exited by a too large chromaticity.*
- Stabilization by an increased longitudinal emittance:
  - *Larger emittance from SPS (for the moment we have << nominal values)*
    - *Transfer more delicate for RF – higher risk of of un-captured beam, ghost bunches.*
  - *Emittance increase in the LHC*
    - *Need to put tools in place.*
- Stabilization by octupoles and chromaticity:
  - *Determine optimum setting of octupoles.*
  - *Reduce chromaticity: can be tricky since other modes may become unstable → transverse damper.*
  - *Transverse damper commissioning to damp coherent modes.*

Work on nominal bunches (2)

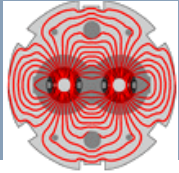


- In parallel to achieving good beam parameters with nominal bunches at 3.5 TeV, a ‘cleaning’ of machine settings for the ramp and squeeze is being made.
- The collimators will be setup again at 3.5 TeV with the higher bunch populations, and the settings will have to be validated.
- When this work is completed we can start physics operation with 2 nominal bunches. This will take at least another week…

  >> Peak L ~ 2×10^{29} $cm^{-2}s^{-1}$

- Then we will progressively add bunches, k = 4, 8, 16…

Summary (1)



- Despite the fact that the luminosity seems very moderate compared to design, we are progressing quickly:
  - We have now completed most of the machine protection commissioning steps, and are starting to increase intensities.
  - We are carefully monitoring the performance of the machine protection system before every intensity step using the post-mortem diagnostics.
  - **We need time to train the shift crews !**
- A number of systems still require commissioning time to operate reliably at high(er) intensity and with higher beam quality:
  - RF system,
  - Transverse damper,
  - Abort gap cleaning,
  - …

Summary (2)

- We are aiming now for physics operation with nominal bunches.
  - And suddenly life became more difficult (but also much more interesting for the accelerator physicist !) with the appearance of the instability.
  - It is not clear how fast we will get beams suitable for physics running, but we must invest this time now and not step back right away.
- Given the complexity of the LHC, its up-time > 50 % is quite amazing!
  - The availability of the LHC is only made possible by the remarkable performance and stability of our cryogenics system…

    …and the skills of the TE department cryo-operation team !

CERN CRYOGENIC OPERATION for LHC