Status of LHC operations

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Outline

State of operation for physics

New operation mode

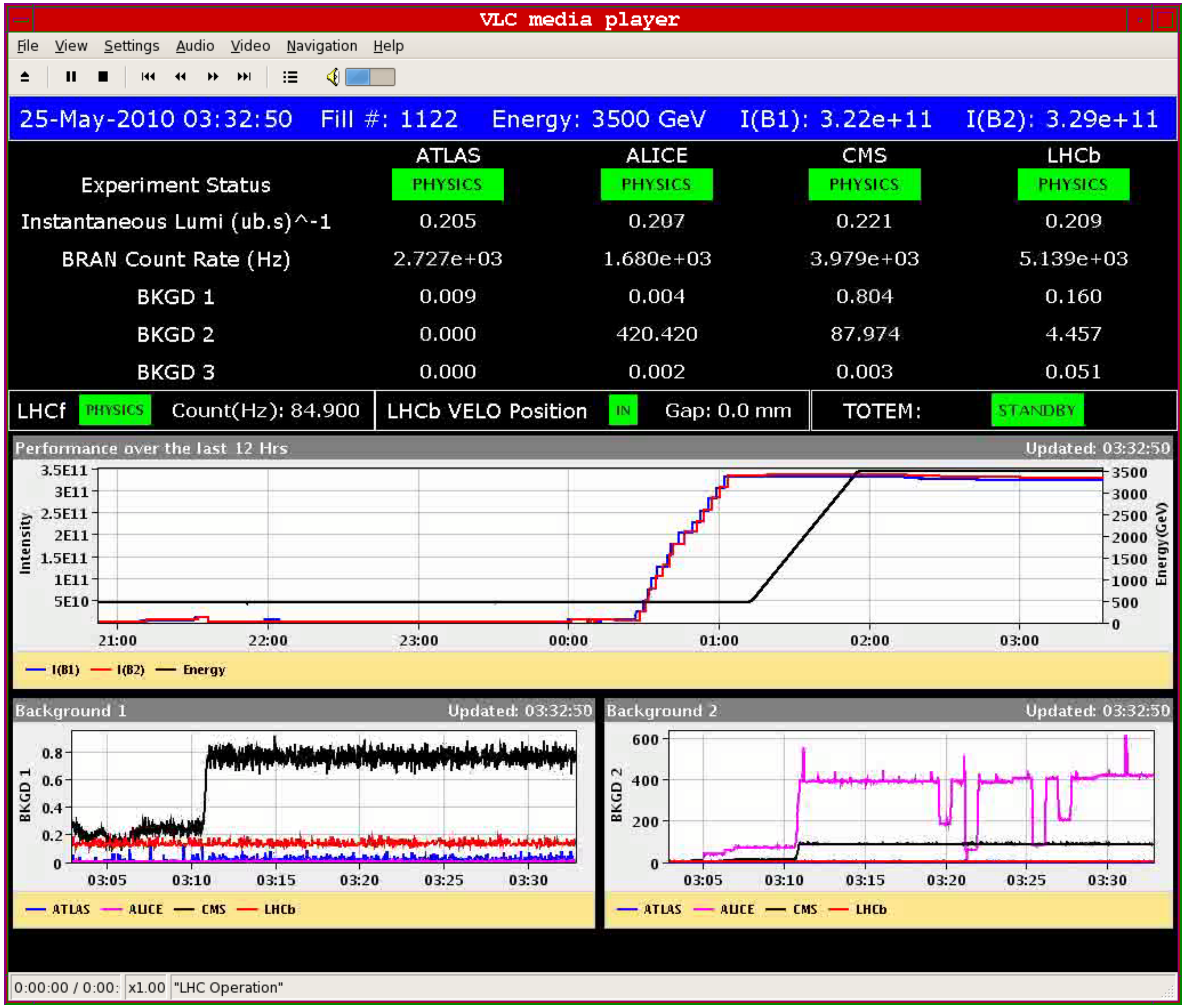
Preparation for operation with nominal bunches

Outlook for coming weeks

Latest state of physics operation

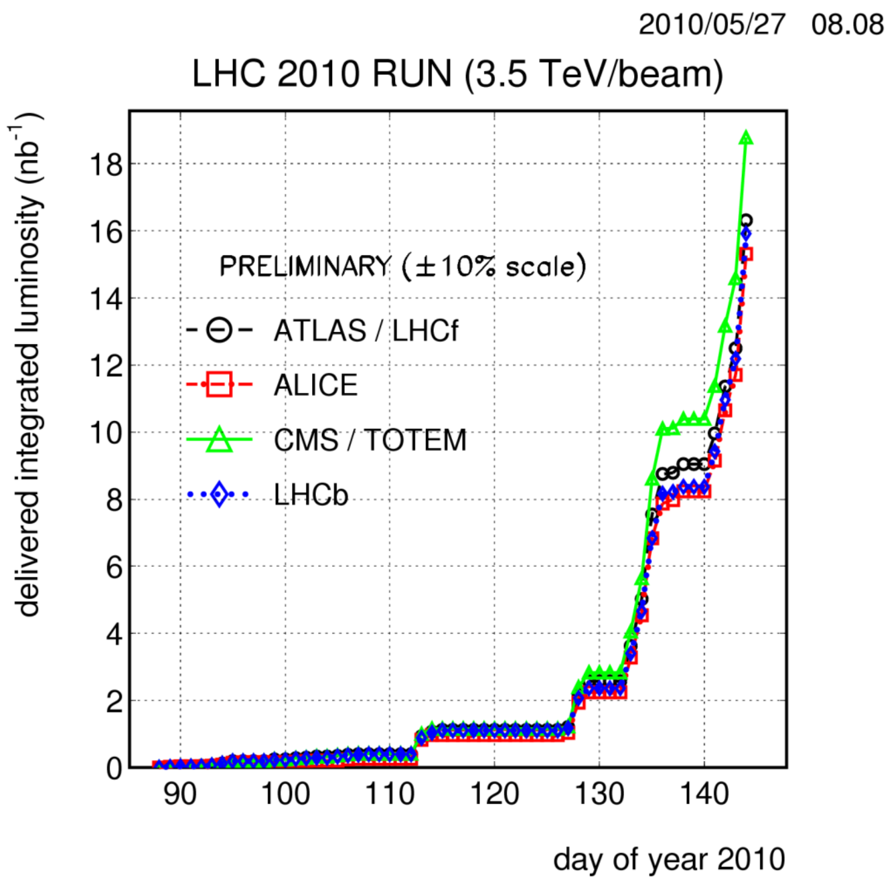
13 bunches 2.4E10 p/b, β* 2 m ➔ ca. 170 kJ

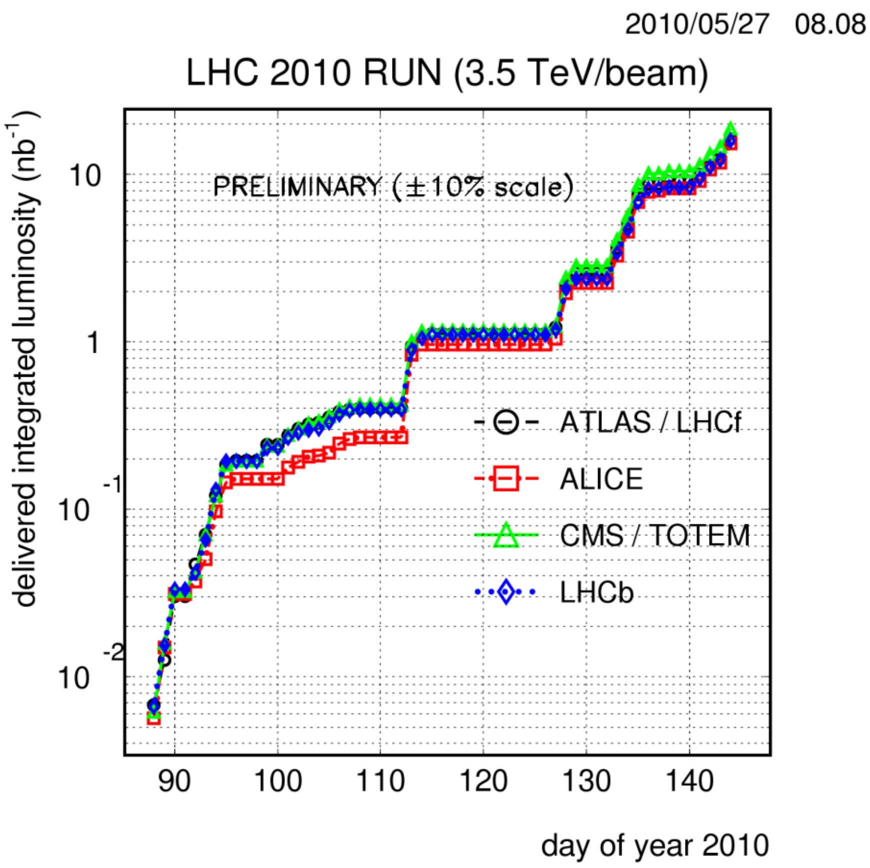
Luminosity **~ 2 × 10^{29} cm^{-2} s^{-1}**



Integrated luminosity

Courtesy M. Ferro-Luzzi





Commissioning – Strategy

- Main goal for LHC run in 2010 & 2011: integrated luminosity of 1 fb^{-1}
  - ➔ implies flat out operation with 100 pb^{-1} per month in 2011
  - ➔ implies routine operation with L > 10^{32} cm^{-2} sec^{-1} in 2011!
- Main goal for 2010: Commissioning of peak luminosity of 10^{32} cm^{-2} sec^{-1}
  - ➔ not achievable with 2 10^{10} bunch intensity
  - ➔ requires ca. 800 bunches with N_b > 8 10^{10} ppb and β^* = 3.5m

    or ca. 400 bunches with N_b > 8 10^{10} ppb and β^* = 2m
  - ➔ implies operation with stored beam energies above 30 MJ

    compared to operation with ca. 2 MJ in Tevatron and

    operations with ca. 170 kJ for operation with 13 bunches of 2 10^{10}

    ➔ Still 2 orders of magnitude to go within 6 month!!!!

Commissioning – machine protection

Courtesy of Jörg Wenninger

- From the machine protection side, we would like to reach a target of around 1-2 MJ of stored energy by mid-July.
  - *No show-stoppers in sight.*
  - *Achievable from present situation (150 kJ) in 3 steps of factor ~2 in stored energy.*
  - *Corresponds to 20-40 nominal bunches, L ~ few x 10^{30} $cm^{-2}s^{-1}$.*
- We would also like to have a ~4 week stable running period in the 1-2 MJ regime – ideally in August.
  - *Constant machine conditions: β*, crossing angle.*
- Why 1-2 MJ?
  - It's the present state-of-the-art (Tevatron,SPS).
  - With 1-2 MJ it is even possible to damage the robust primary and secondary collimators!

Commissioning – new strategy

- In May we had moved to an operation mode with commissioning Monday-Friday, physics over the weekends ➔ 10 nb^{-1} in time for PLHC2010 at DESY.

- 2 weeks ago (9th June) it was decided at the LMC to change strategy and to focus 100% on the commissioning of operation with nominal bunch intensities.
  - *It was estimated that the new high setup for High Intensity operation would take approximately 3 weeks.*
  - *New collimation and machine protection device setup for high intensity operation*
  - *Validation of loss hierarchies.*
  - *Optimization of beam parameters during the ramp: Q; Q' and orbit*
  - *Commissioning of new machine systems:*

    orbit feedback; transverse feedback and longitudinal emittance blow-up during ramp and octupole correction circuits.

- We have almost finished the new setup and are now ready for high intensity operation with 'Stable Beams'!

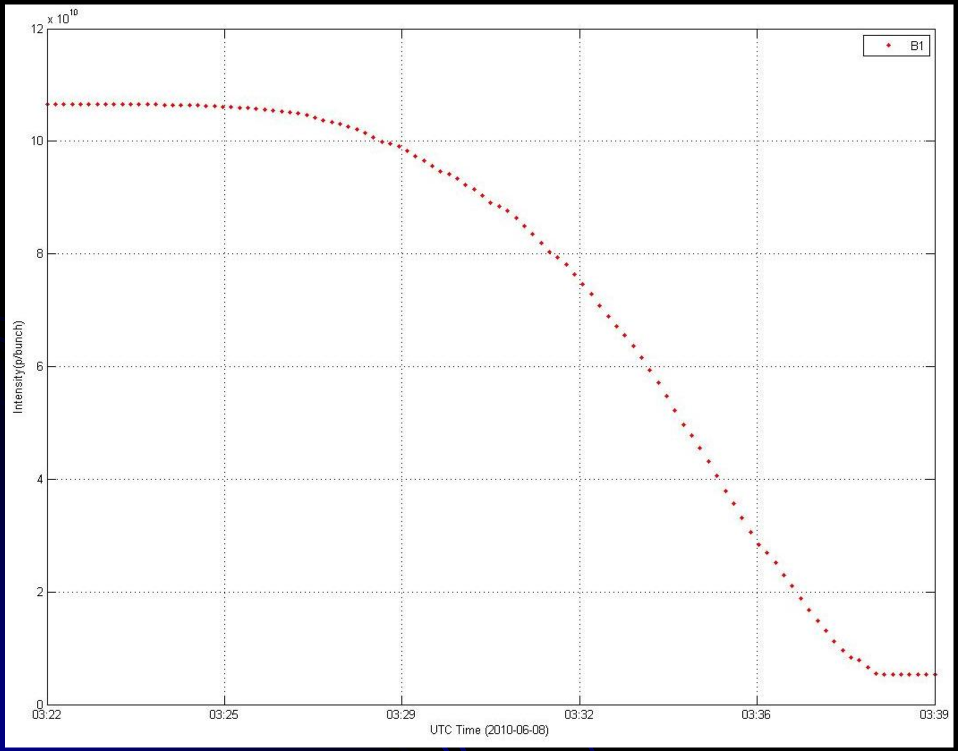
Commissioning – new strategy

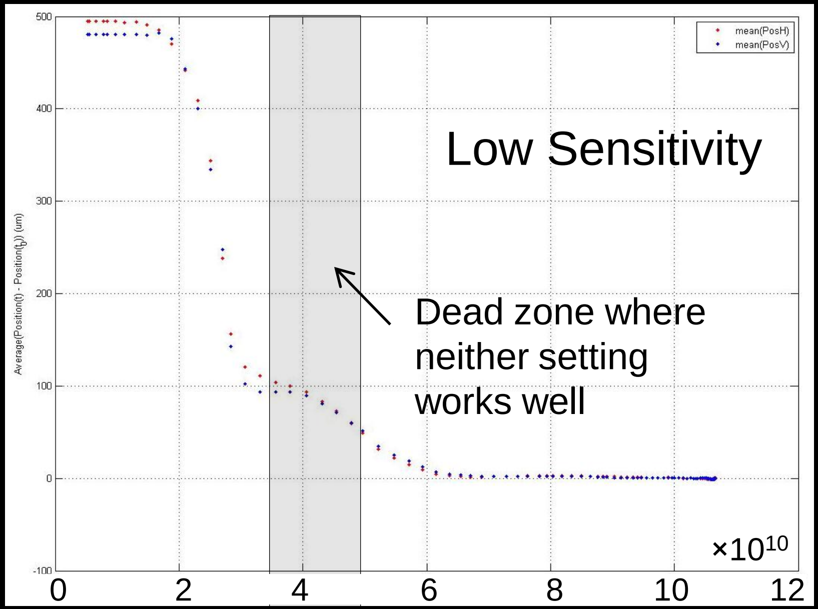
- Why do we need a new setup for 'High Intensity' operation?
  - *Operation with 13 bunches a 2 10^{10} ppb has more beam intensity than operation with 2 nominal bunches!*

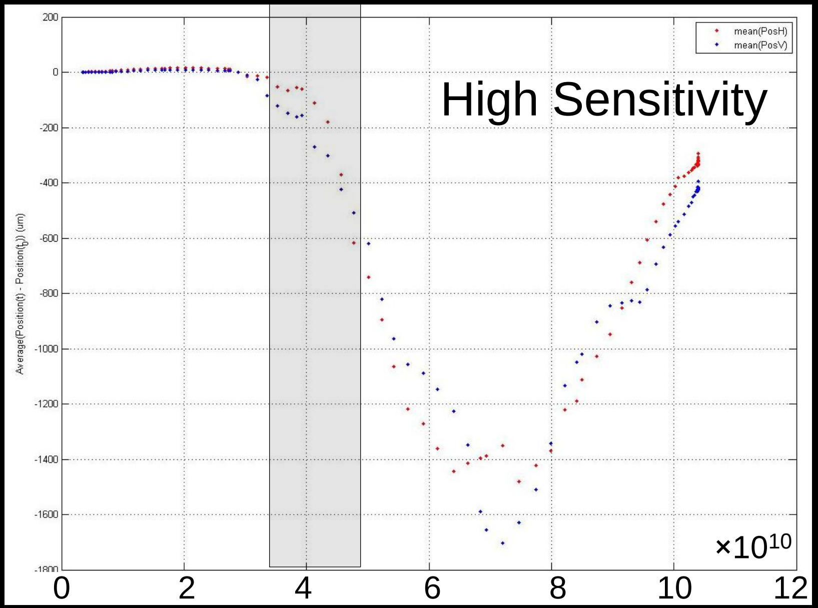
- **Some key performance contributors depend on bunch intensity rather than total beam current**
  1. *The LHC BPM system changes between two operation modes (high- and low-sensitivity mode at around 5 10^{10} ppb).*
  2. *High bunch intensities can trigger collective instabilities.*
  3. *High bunch intensities imply larger beam emittances during operation which in turn can imply un-proportionally larger losses as compared to operation with low bunch intensity operation.*

1) BPM Dependence on Intensity - Beam 1

- One nominal bunch of 1×10^{11} slowly scraped away using a primary collimator
  - 2 fills – one for low sensitivity and one for high sensitivity

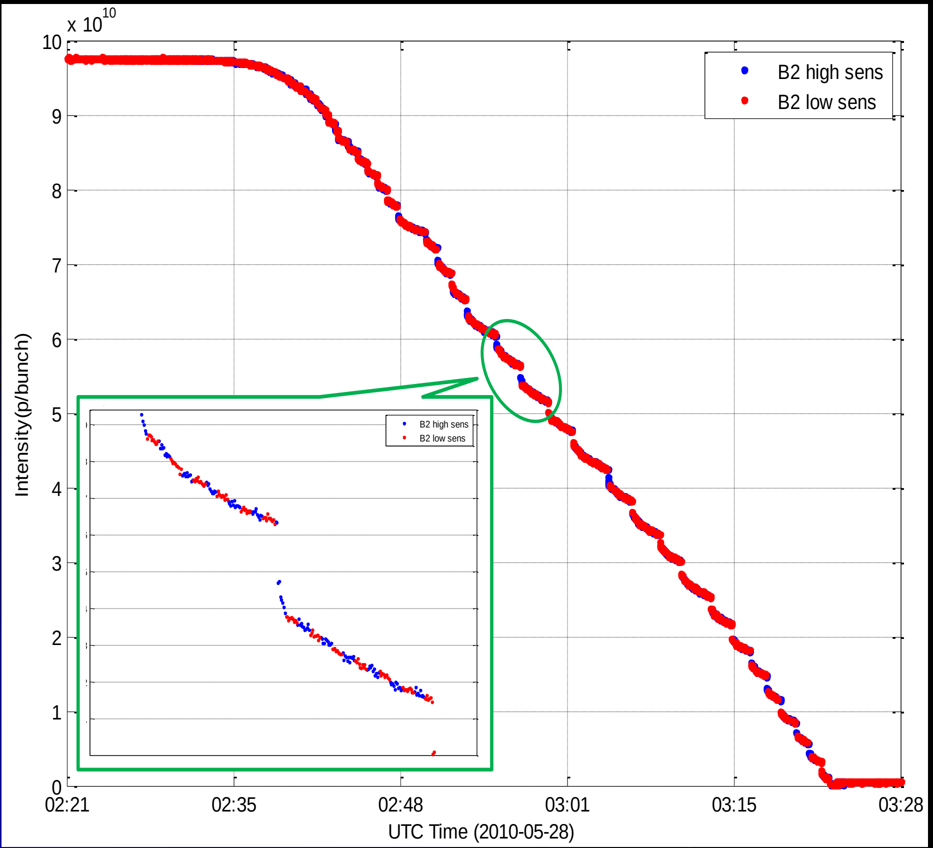


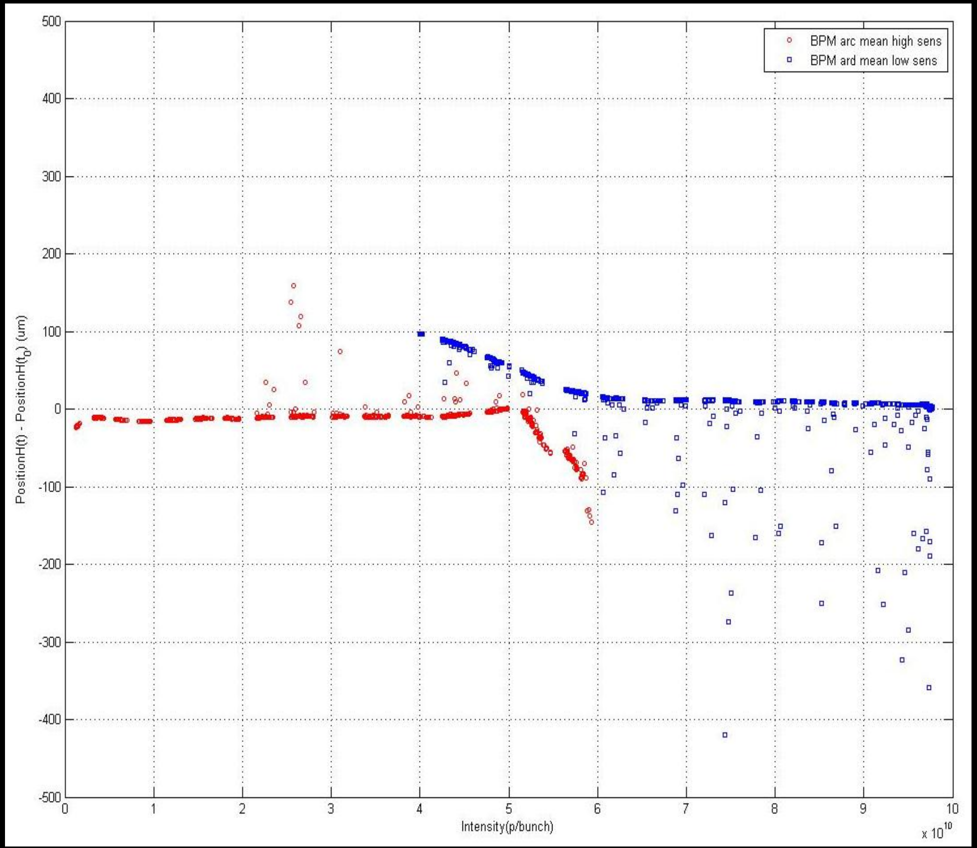




1) BPM Dependence on Intensity - Beam 2

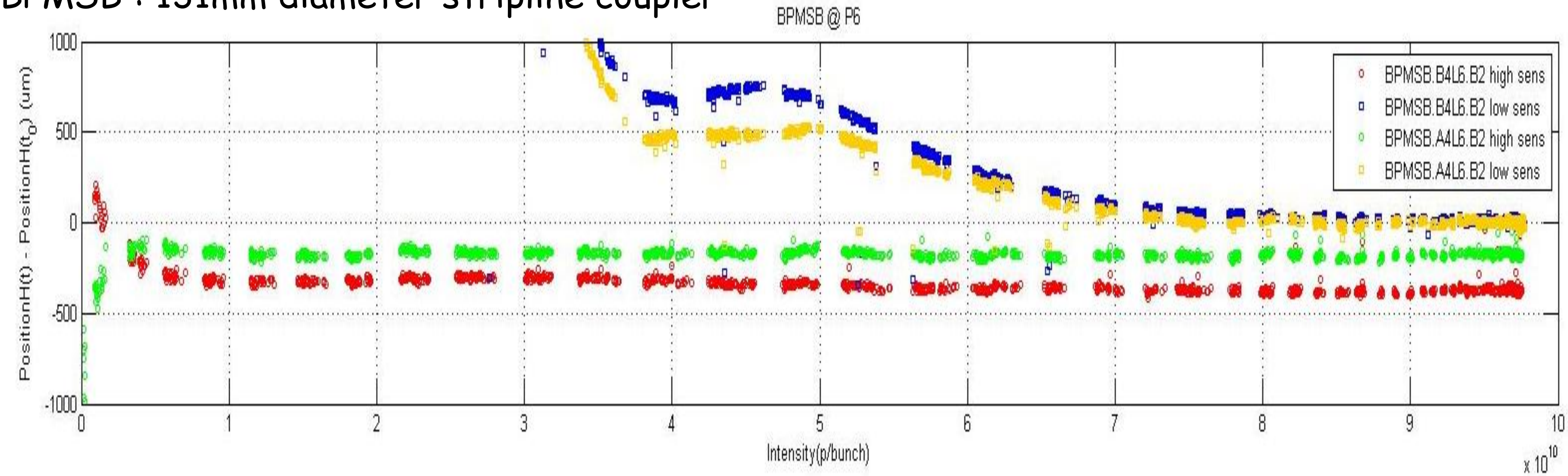
- One nominal bunch of 1×10^{11} slowly scraped away using a primary collimator
- Sensitivity constantly changed from high to low
  - Outliers due to acquisition overlapping two sensitivity ranges
- Sensitivity ranges seen to overlap as expected at around 5×10^{10}



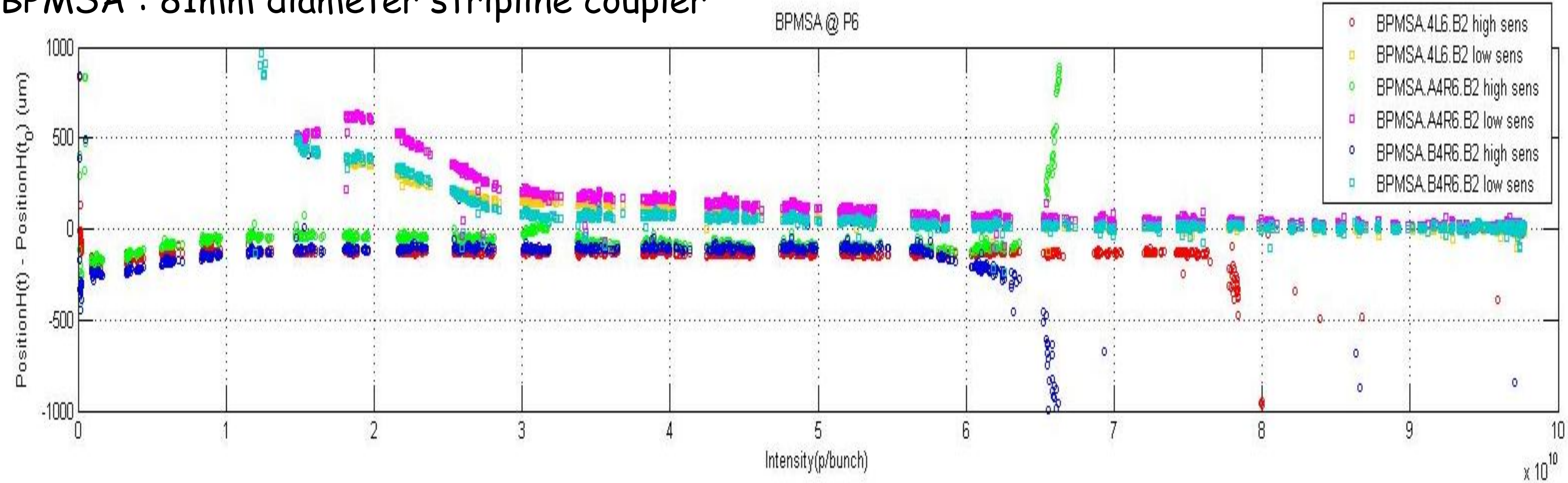


1) Interlock BPMs in LSS6 – Beam 2

BPMSB : 131mm diameter stripline coupler



BPMSA : 81mm diameter stripline coupler



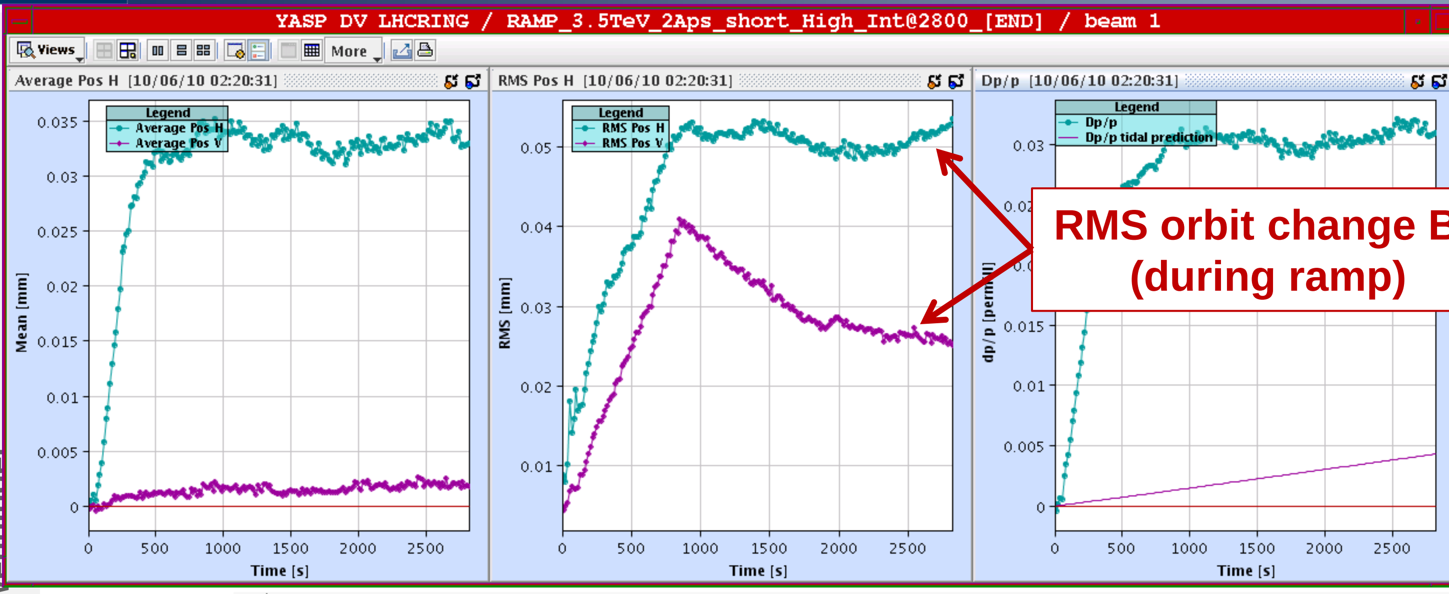
1) BPM Response versus bunch intensity

- In principle the actual orbit does not change when the BPM system changes its sensitivity mode. Only the reading changes.
- However, we now routinely operate the LHC with orbit feedback system on. ➔ Any change in the BPM reading will be automatically transferred to the actual orbit.
- In dedicated zones (e.g. beam dump and triplet magnets) the machine protection system monitors continuously the central orbit and aborts the beam if orbit shifts are too large (+/- 3.5mm in dump region and +/- 2mm in triplet magnets).

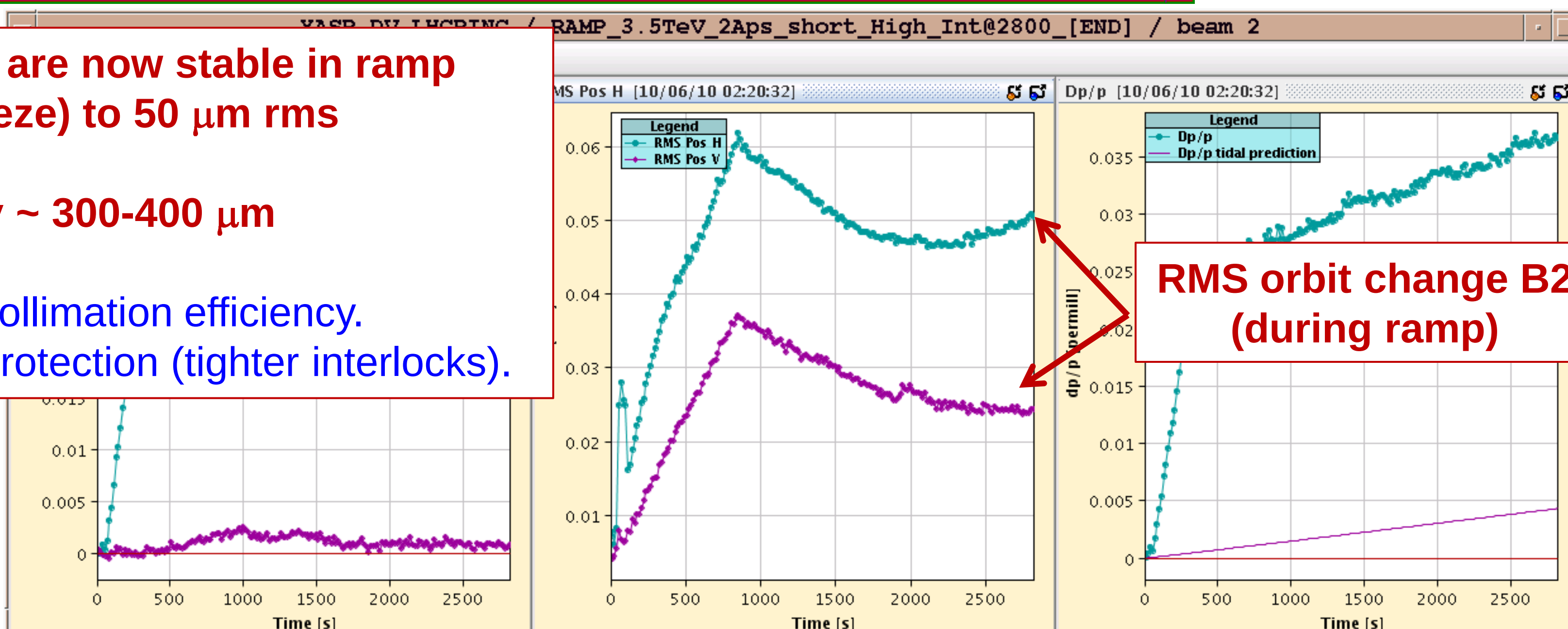
➔ large orbit excursions will trigger a beam abort!

➔ need to perform the setup with high bunch intensity and ensure the intensity does not drop below values of BPM sensitivity change while the feedback is on

1) Cleaned Ramp (and squeeze) with orbit feedback



RMS orbit change B1 (during ramp)



RMS orbit change B2 (during ramp)

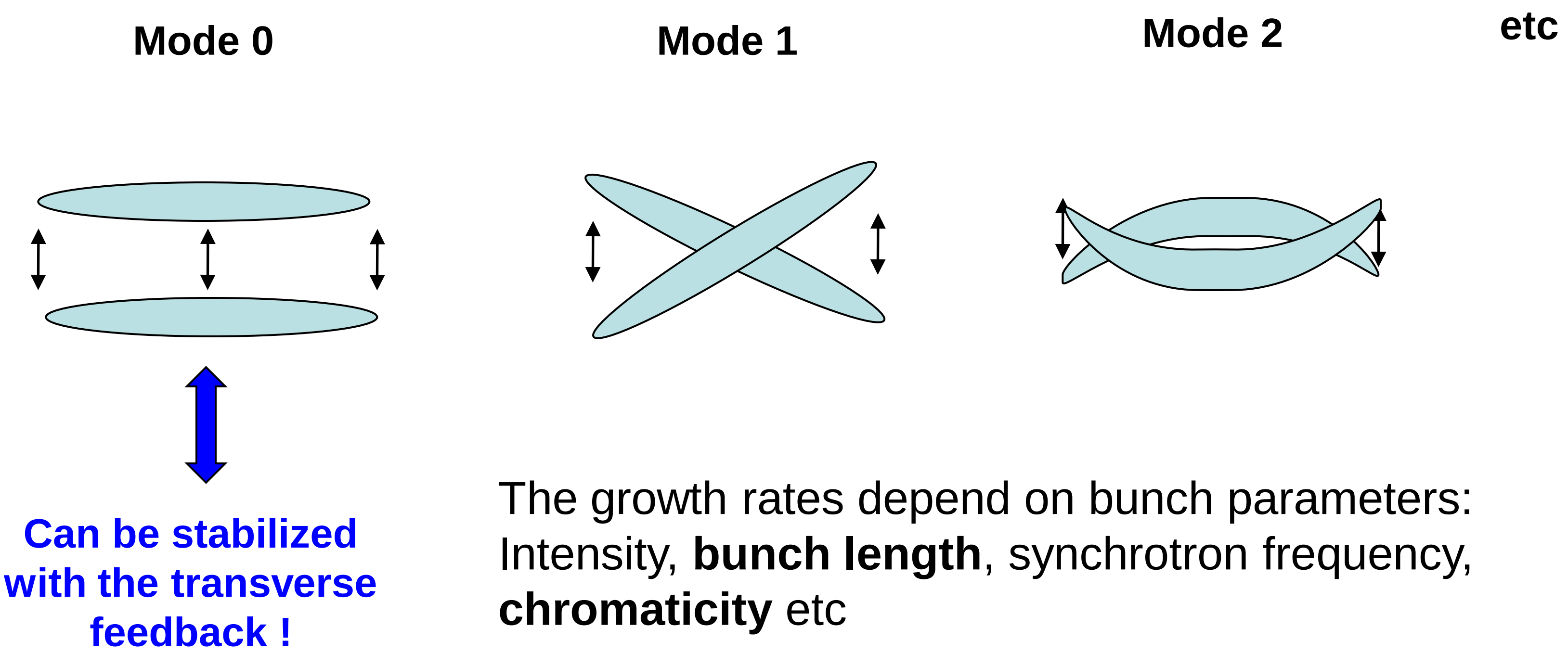
The orbits are now stable in ramp (and squeeze) to 50 µm rms

Previously ~ 300-400 µm

>> Better collimation efficiency.
>> Better protection (tighter interlocks).

2) Head-tail instability

- The instability observed on the nominal bunches seems to be a 'classical' head-tail instability.
  - *Simulations reproduce the observations rather well.*
- The head-tail instability/movement is characterized by a number of bunch oscillation modes. *Simplified* description:



The growth rates depend on bunch parameters: Intensity, **bunch length**, synchrotron frequency, **chromaticity** etc

courtesy of Jörg Wenninger

2) Curing the Head-Tail Instability

- How can we cure – stabilize the Head-Tail instability?
- Four strategies for operation:
  - *The first mode is stable as long as Q' is positive*
  - *Higher-order modes are stable as long as Q' is not too large*

    1) ➔ target Q' value between 1-2 units (order of magnitude smaller than uncorrected change during ramp)

    ➔ requires accurate Q' control during ramp ✓
  - *2) The transverse damper can stabilize first mode*

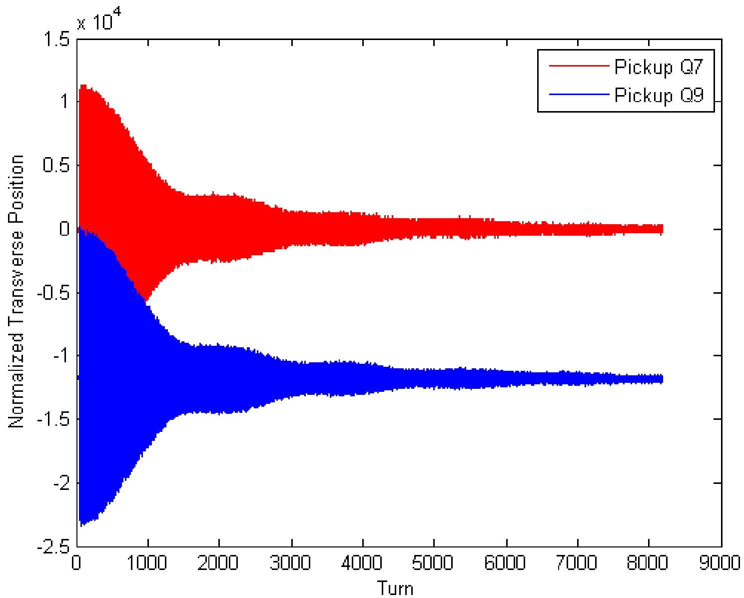
    ➔ commissioning of damper vital for high intensity operation ✓
  - *3) Lower chare density reduces instability threshold*

    ➔ commissioning of the controlled longitudinal emittance blow up increases instability threshold ✓
  - *4) Transverse frequency spread can partially stabilize the Head-Tail mode*

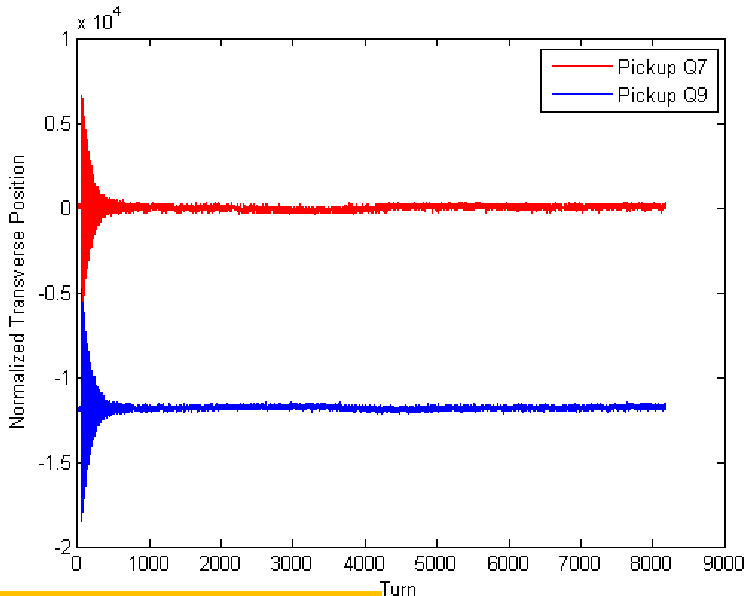
    ➔ incorporation of octupole settings into the ramp tables ✓

- Chromaticity at injection set to 2 for both planes both beams

- Transverse damper ON, at 450 GeV: very effective
  B1: H= 2.4μm & V= 2.5μm B2: H= 3.8μm & V= 3.1μm after injection compared to nominal value of 3.75μm.

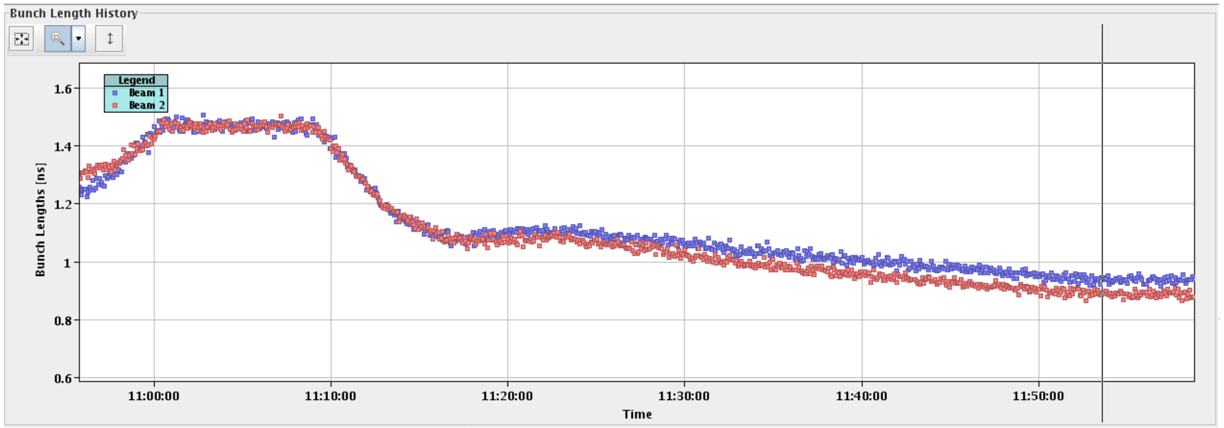


Damper OFF

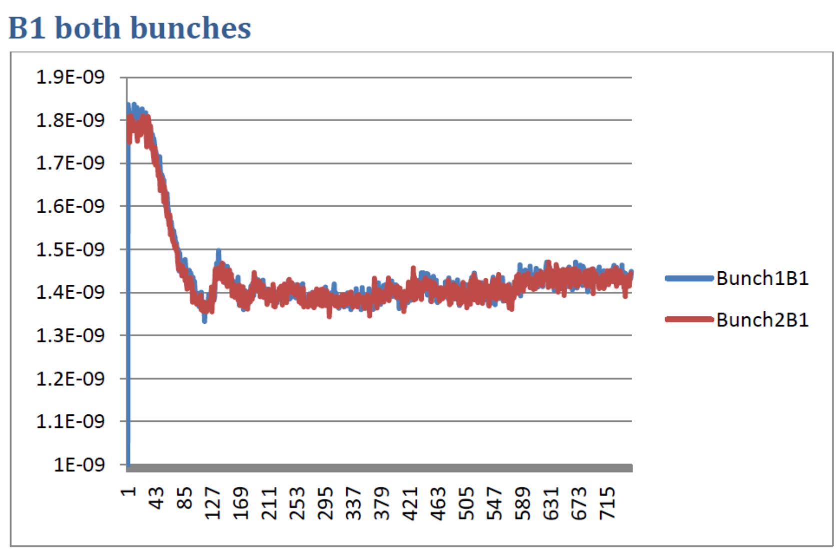


Damper ON

2) Bunch lengths in the ramp



Single bunches with controlled emittance blowup



Controlled emittance blowup with multiple bunches

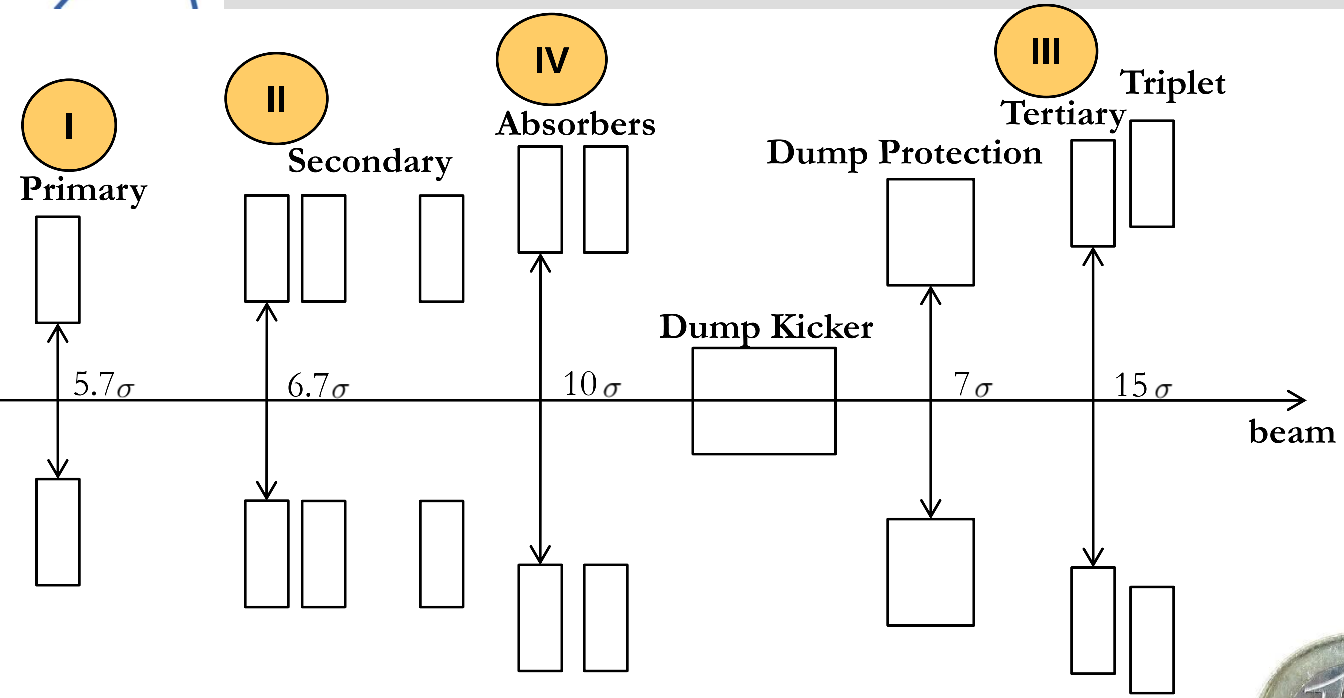
3) Setup for High Bunch Intensity Operation

- New 'golden Orbit' reference implies new setup of collimation system and protection devices: Setup at 3.5 TeV involves 76 collimators
- Why is setting up the machine with high bunch intensities more challenging or different from setting it up with low bunch intensities?
  - *Operation with bunch intensities above 3 10^{10} ppb exceeds the 'safe beam' limit for the LHC at 3.5 TeV!*
  - *Several Machine Protection System channels can no longer be masked → operation during the machine setup is more prone to be terminated by interlocks!*
  - *Different beam emittances imply different loss behavior when scraping the beam.*
  - *New effects are present (e.g. instabilities) that require robust operation of additional machine components (e.g. long. blow-up & octupoles)*

3) Setup for High Bunch Intensity Operation

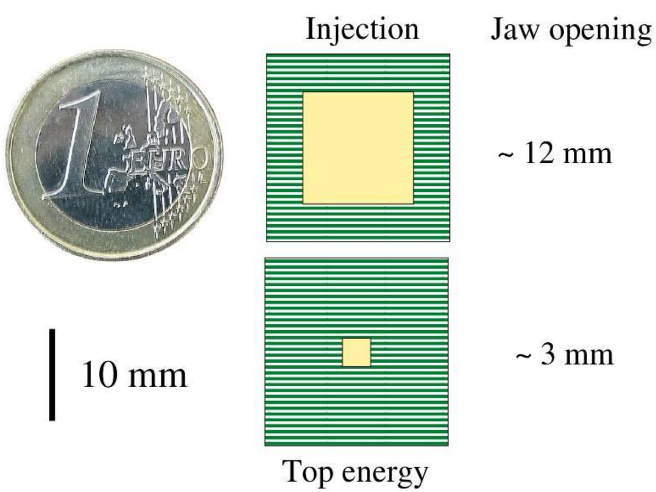
- Collimation:
  - Had to perform 108 collimator setups at 3.5 TeV.
  - Each setup takes 15 min ➔ 27 hours of beam time at 3.5 TeV required (without overhead – efficiency adjustments).
    - Reduced by factor 2 by doing both beams in parallel.
    - Losses of time due to beam efficiency. Several beam dumps due to loss of 0.1% of intensity, when touching the beam halo.
  - In the end it took ~30 h of beam time with single bunch of 1e11 p at 3.5 TeV. Time distributed over 10 days with ~1 collimation shift per day.
  - Finally, setup of smooth ramp functions including interlock thresholds.

4-stage cleaning with collimators (schematic)



$1\,\sigma$ (450GeV) ≈ 1mm

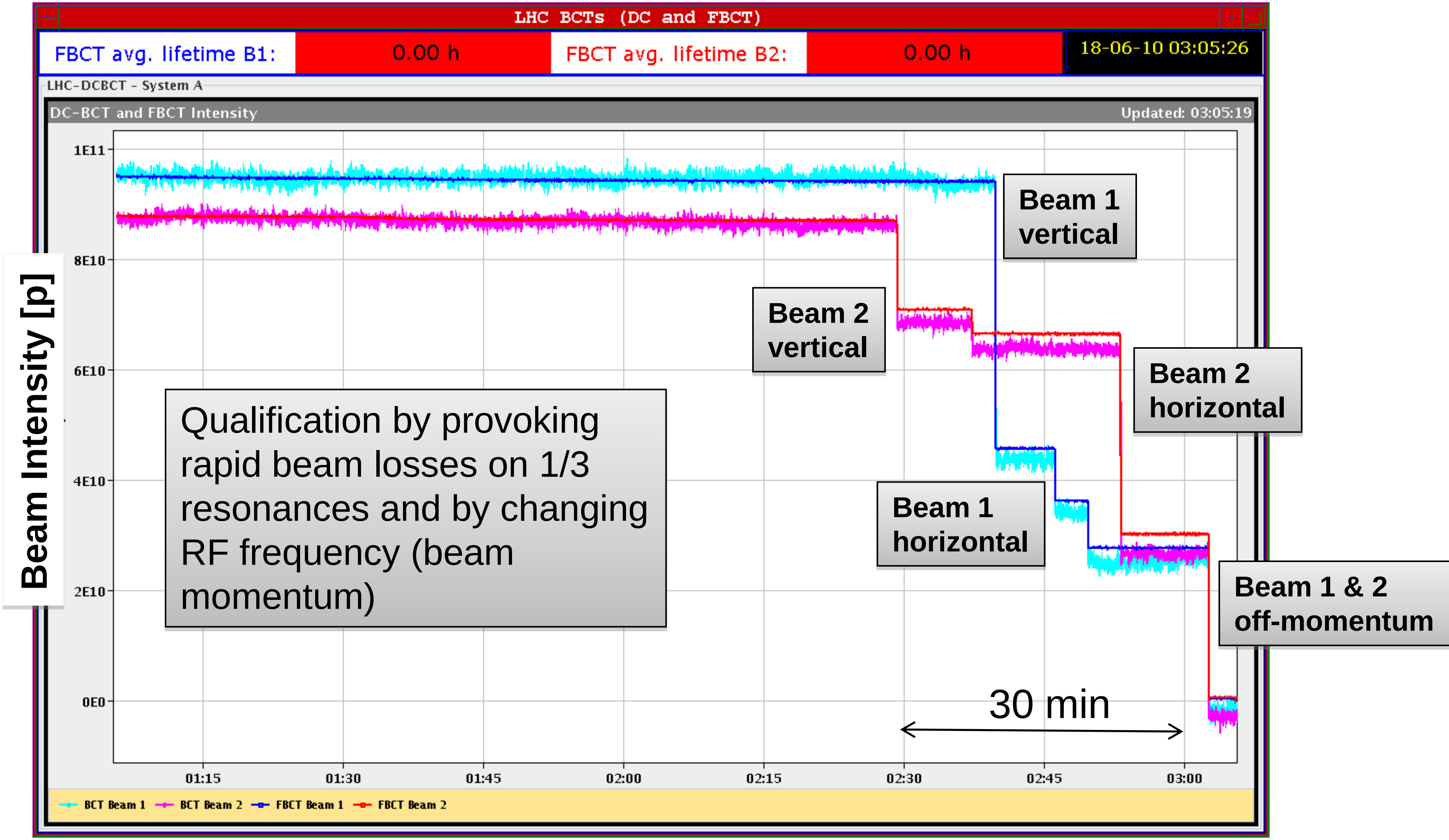
Collimator type	N_i	Collimator type	N_i
TCP IR3	8 σ	TCDQ IR6	8 σ
TCSG IR3	9.3 σ	TCSG IR6	7 σ
TCLA IR3	10 σ	TCLI IR2/IR8	6.8 σ
TCP IR7	5.7 σ	TCT IR2/IR8	25 σ
TCSG IR7	6.7σ	TCT IR1/IR5	15 σ
TCLA IR7	10 σ	TCL IR1	20 σ



Courtesy R. Assmann

Qualification of Collimation Setup

(3.5 TeV, squeezed, separated, 18.6.2010)



courtesy of Ralph Assmann

Collimation Setting Overview

(in terms of β beam size, status 25.6.2010)

Condition	Unit	Plane	Set 1 Injection optics	Set 2 Injection optics	Set 3 Collision optics, separated	Set 4 Collision optics, colliding, crossing angle
Energy	[GeV]		450	3500	3500	3500
Primary cut IR7	[σ]	H. V, S	5.7	5.7	5.7	5.7
Secondary cut IR7	[σ]	H, V, S	6.7	8.5	8.5	8.5
Quartiary cut IR7	[σ]	H, V	10.0	17.7	17.7	17.7
Primary cut IR3	[σ]	H	8.0	12	12	12
Secondary cut IR3	[σ]	H	9.3	15.6	15.6	15.6
Quartiary cut IR3	[σ]	H, V	10.0	17.6	17.6	17.6
Tertiary cut experiments	[σ]	H, V	15-25	40-70	15	15
TCSG/TCDQ IR6	[σ]	H	7-8	9.3-10.6	9.3-10.6	9.3-10.6

Last campaign established the collimation settings for set 2, 3 and 4!

Ramp functions move smoothly from set 1 to set 2 during energy ramp!

courtesy of Ralph Assmann

Beam Parameters for nominal bunch OP

- For low bunch intensities we operated the machine without crossing angle and with $\beta^* = 2m$.

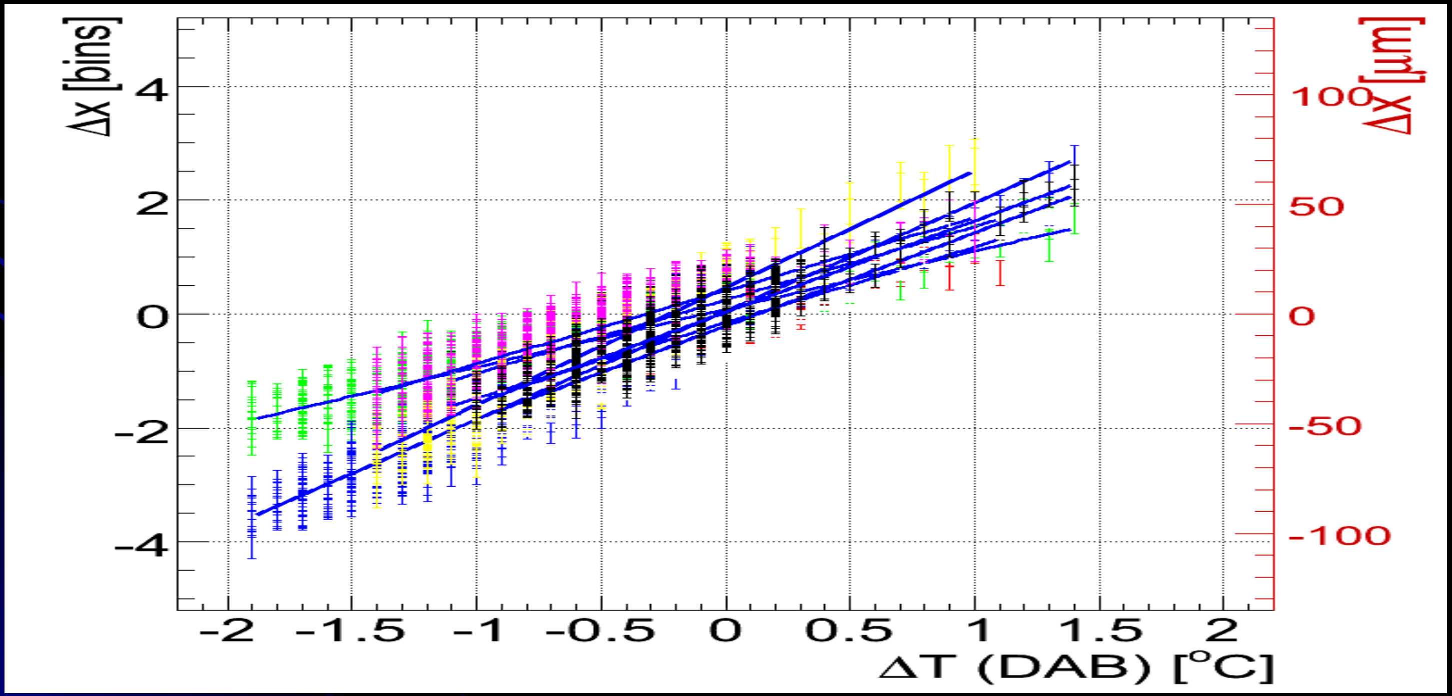
- For high intensity operation we want to introduce a crossing angle (LHCf and operation experience with parasitic long range collisions).

- In order to maintain sufficient tolerances for the triplet protection the target β^* value was revised and the new target was set to **3.5 m in combination with a 100μrad crossing angle**.

- Why do we want to maintain larger margins?
  - *Temperature variation of BPM system (currently being addressed on hardware side).*
  - *Lack in experience with optics reproducibility:*
    - *Orbit and optics stability (IPs; cleaning insertions and protection devices.*
    - *Stability of collimator and dump protection setup.*

BPM Position Dependence on Temperature

- Main component known to suffer temperature dependence is the wide band time normaliser integrator card
  - Located on surface
    - Prone to relatively large temperature variation
  - Position encoded in pulse length 10 ± 1.5ns
    - Temperature affects offset & hence integral
      - position dependence should be minimal
  - Clear correlation between acquisition card temperature and position



Beam Parameters for nominal bunch OP

- Intensity ramp up:
  - Start with 3 x 3

    First fill yesterday night with L ≈ 2.5 10^{29} cm^{-2} sec^{-1}!
  - Move on to 6 x 6, 12 x 12, 24 x 24 (1.5 MJ) over 4 weeks until end of July.
  - We need a 4 week stable running period in August under constant conditions.
  - Constant β^* and Xing angle.
  - Experience with machine reproducibility:

    ➔ orbit, collimation setup, etc.
  - Bunch train operation in September