LHC Beam Instrumentation
-
First Results & Next Steps

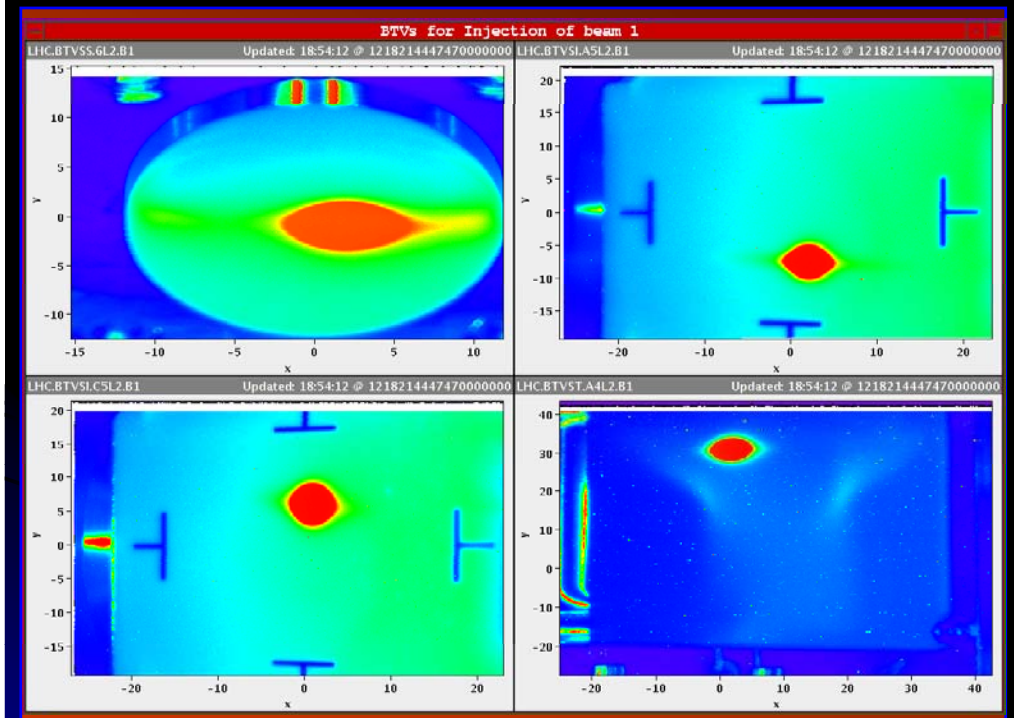
Session 07 - What did we learn with beam in 2008?

LHC Performance Workshop
Chamonix 2009

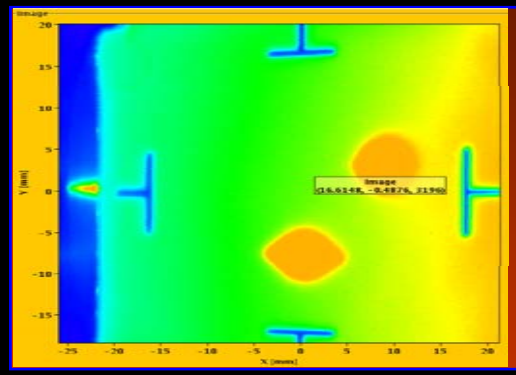
Rhodri Jones on behalf of BE/BI & all our collaborators

LHC BTV System

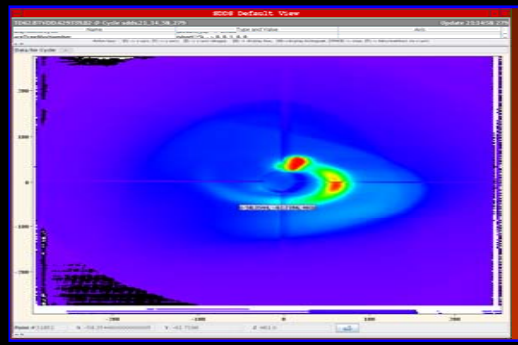
- All screens fully commissioned
  - 18 BTV in the LHC transfer lines
  - 13 BTV in the LHC ring
  - 6 BTV in the LHC dump lines
- Both video link and digitised data acquired on first shot



First Beam in the LHC 8/8/2008



First full turn as seen by the BTV 10/9/2008

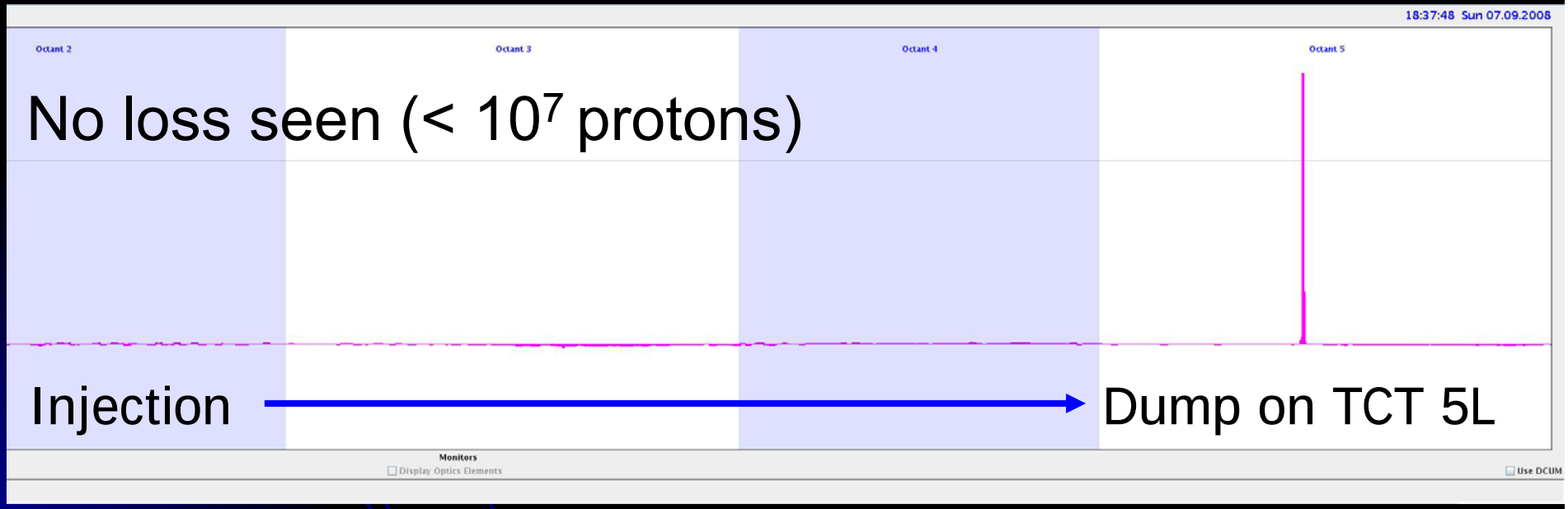


Uncaptured beam sweeps through he dump line

- Still to do
  - Gradual replacement of the 13 LHC ring CCD cameras with rad hard cameras
  - Turn by turn acquisition for matching measurements using fast cameras

LHC BLM System I

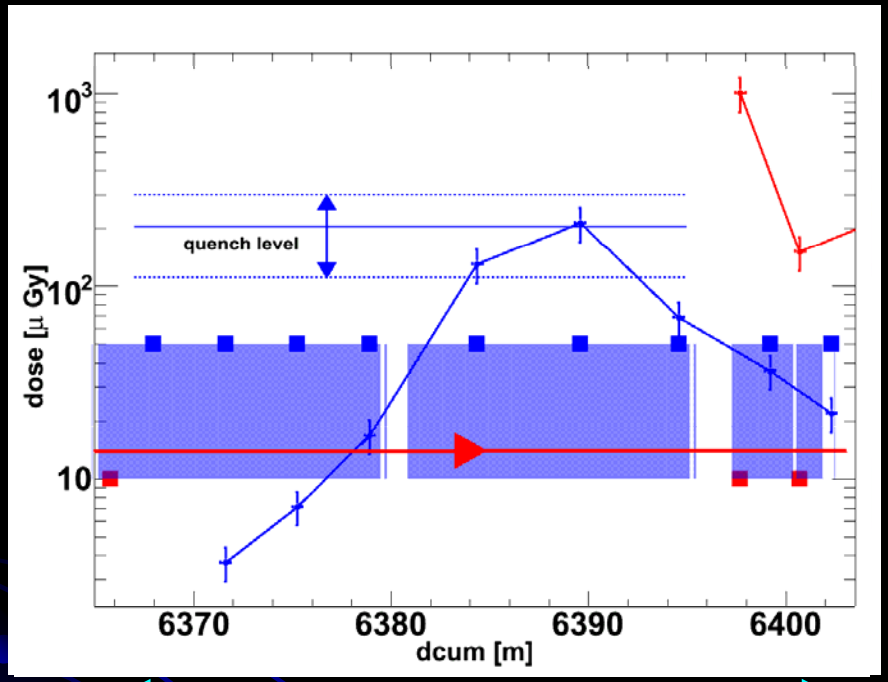
- Worked well from first injection tests
  - Logging issues (linked to data rates) sorted out early on
  - Data concentration
    - on-demand capture & continuous monitoring tested



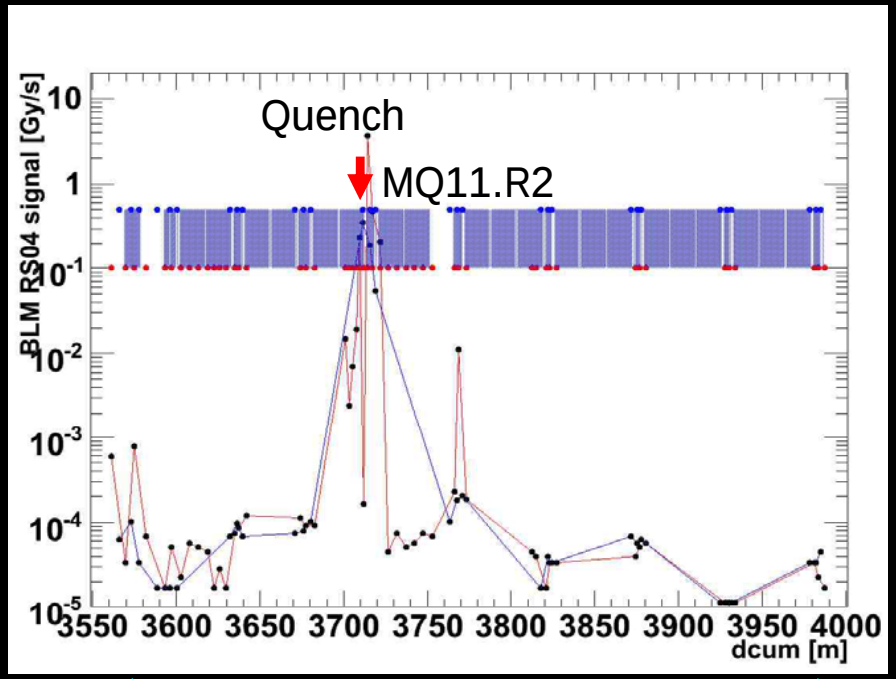
Clean injection (IP2 to IP5)

LHC BLM System II

- 2 beam induced triggers of quench protection system during injection tests
  - Loss of between 2 - 4 $\times$ 10^9 protons with very different loss patterns



700m



450m

- Quench reconstruction
  - One quench occurred at end of MB magnet $\Rightarrow$ not useable for analysis
  - One in middle of dipole ideal for analysis
    - Beam current, impact location & loss distribution width used to constrain simulations
    - Result factor 2 lower compared to value obtained by calculating enthalpy of the coil
      - ~15 mJ/cm^3 estimated compared to 30 mJ/cm^3 expected

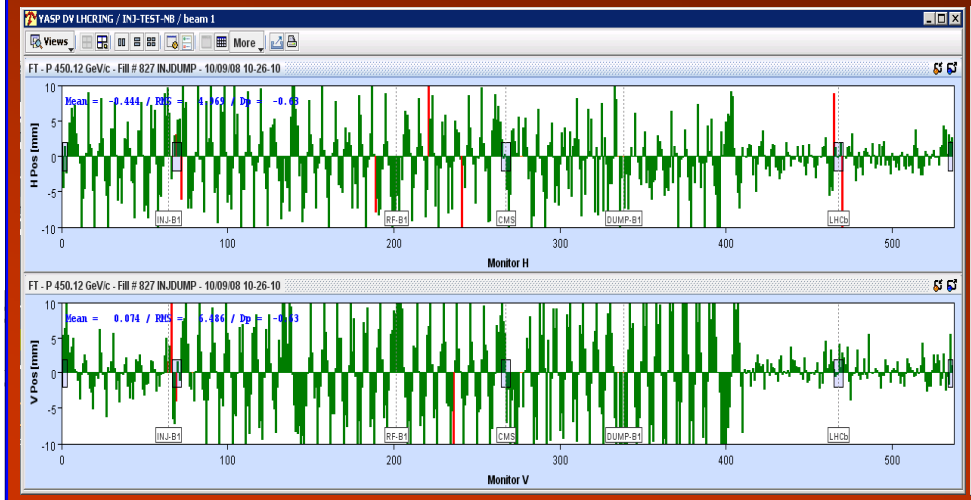
LHC BLM System III

Next Steps

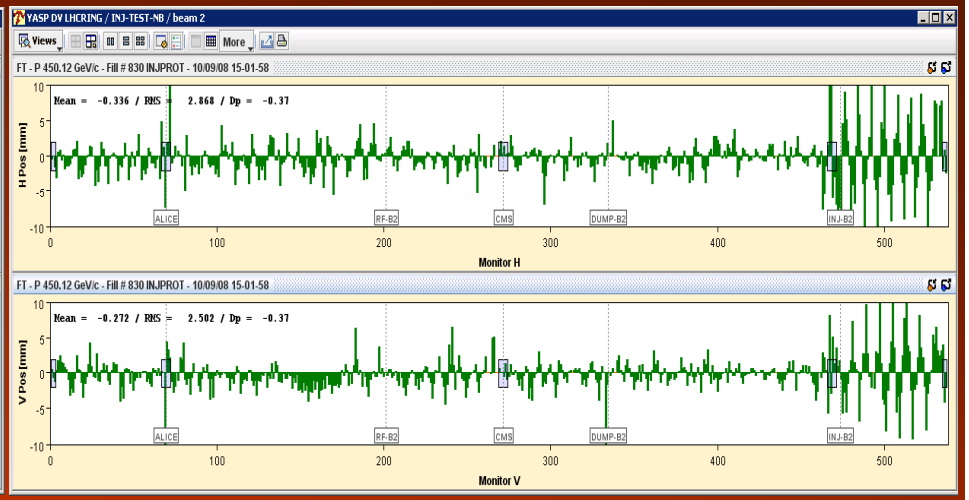
- Hardware:
  - Dismantling & re-installation (sector 3-4 & all warm sectors)
    - Opening of W-bellows ⇒ dismounting large fraction of BLM cable trays & monitors
  - Separation of HV supply cables for SEM & ionisation chambers
    - Aimed at reducing observed cross talk between the two systems
  - Implement possibility of full reset of front-end electronics
    - Addition of small mezzanine card to all front-end electronics cards
  - Noise check of signal cable network
    - Repair and replacement of poor connectors and cables
  - Increase spare parts with new production of electronics boards
- Software
  - BLM threshold settings
    - Design of application to load and check threshold settings in database
    - Test of software package for handling machine critical settings
    - Definition of procedures for manipulation of critical settings
  - FPGA code
    - Construction of PASS/FAIL regression test bench to allow full qualification of software updates before any global deployment

LHC BPM System I

- Asynchronous bunch by bunch (FIFO) mode
  - Used for threading & first few 100 turns (no bunch or turn tagging)
    - AB/CO BPM concentrator groups data from 66 front-end VME crates
  - Worked first time on both beams for injection tests & on 10th September
    - Problem encountered with first turn overwritten by subsequent turns
      - FIXED in FPGA code of the hardware the same day



First full turn for Beam 1

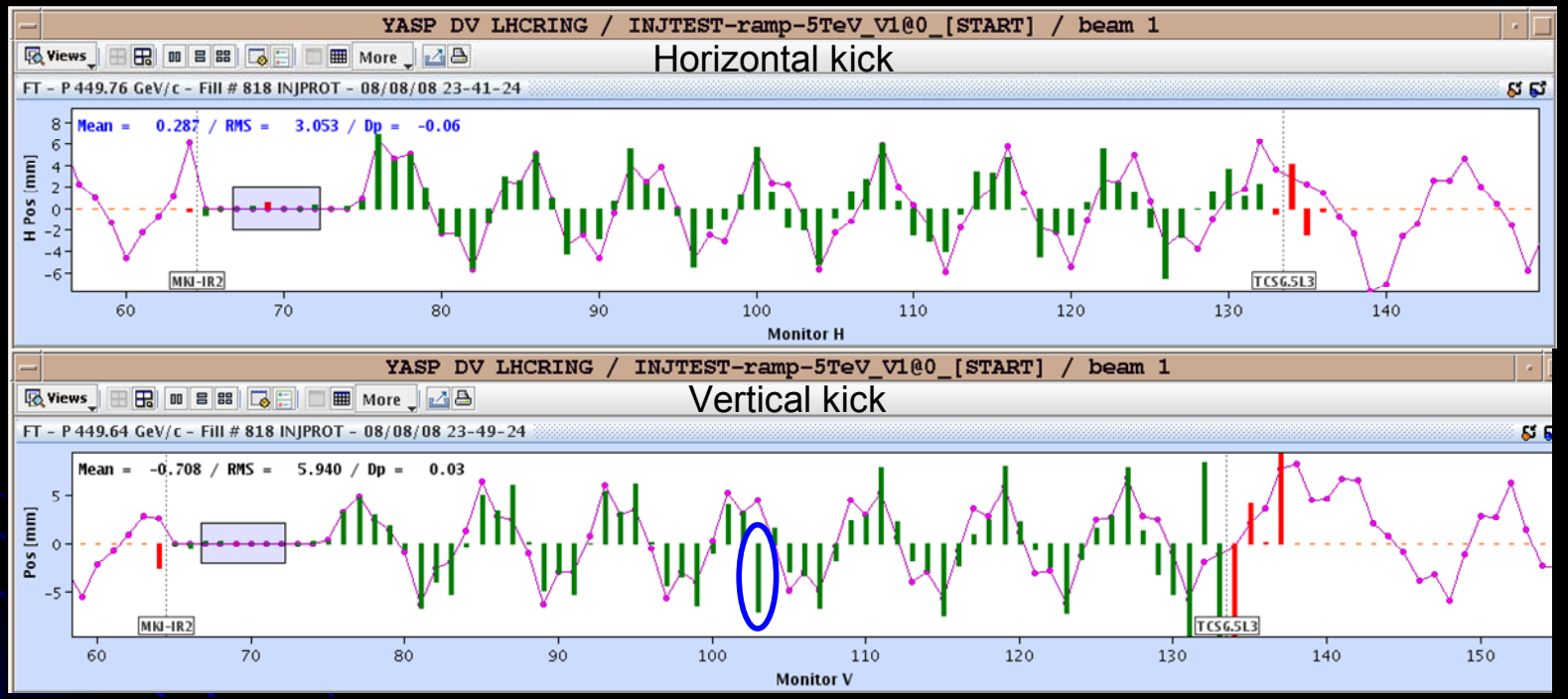


First full turn for Beam 2

- Asynchronous orbit (IIR) mode
  - Provided filtered data for 1Hz orbit update to YASP & feedback controller
    - Routed via orbit feedback concentrator
  - Worked as soon as beam was circulating for more than a few seconds

LHC BPM System II

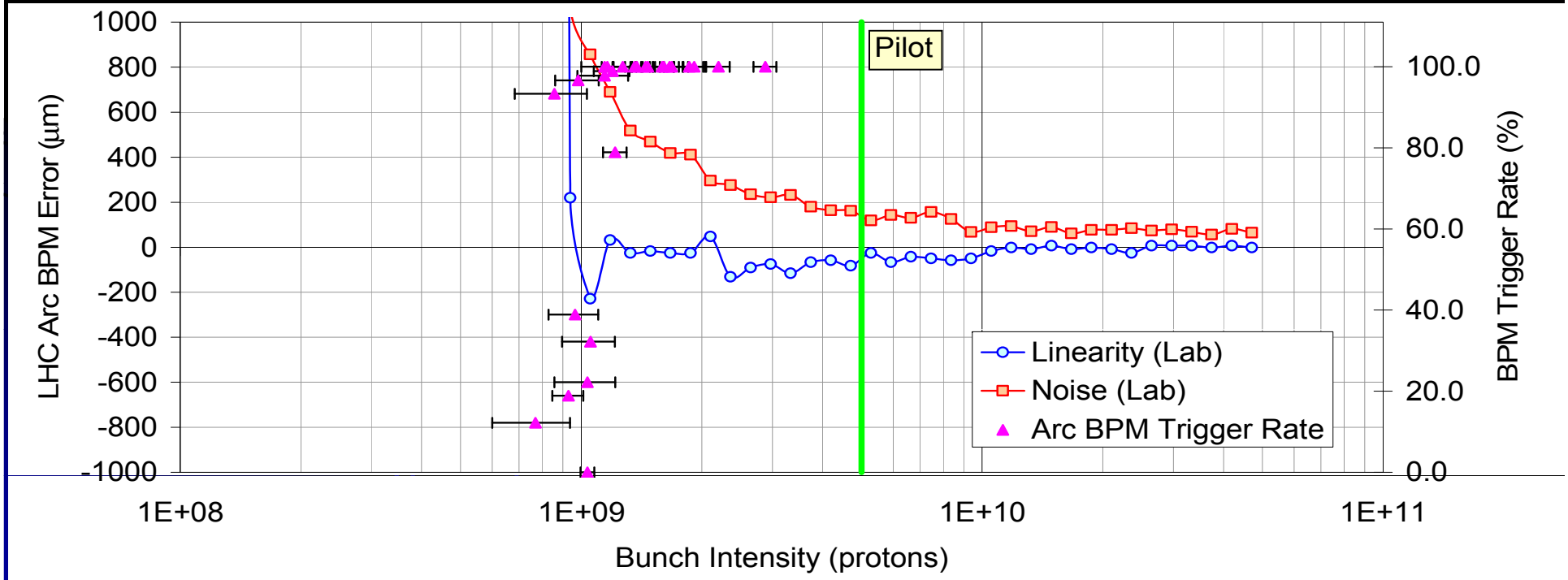
- On line analysis of BPM Data
  - Powerful on-line tools developed by AB/OP
  - Polarity errors easily identified with 45° BPM sampling
  - Quick indication of phase advance errors



- Some statistics to date
  - 4 polarity errors
  - 2 H to V inversions & 7 BPM mapping errors (LSS8L)
  - 1 B1 to B2 inversion
  - Some 10 remaining suspect BPMs (noisy or incoherent data)
  - Total of ~24 out of 2156 channels (~1%)

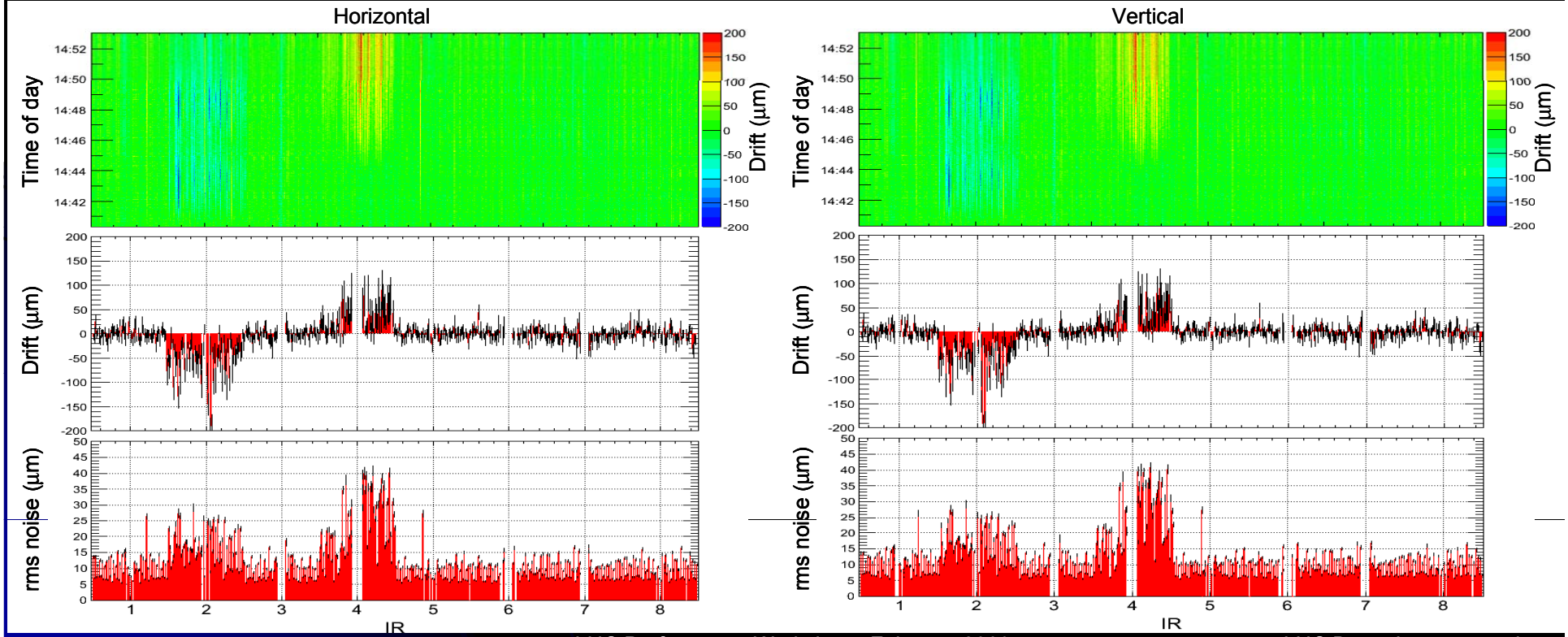
LHC BPM System III

- Check of BPM Threshold Levels
  - Threshold determined to be 1.5×10^9 protons
    - Compared to pre-declared limit of 2.0×10^9
  - Initial values did not correspond to lab measurements
    - Threshold was 6dB lower in the laboratory
    - Accurate re-measurement of electronics & cables for final bandwidth & signal loss
    - Final model now agrees with beam measurements
      - Understanding important for intensity card



LHC BPM System IV

- Orbit & BPM Stability
  - Short term stability (15 minutes) better than 10μm
  - Alternating high/low peaks follow the beta function indicating that:
    - large fraction of this noise results from beam itself (COD power supplies ⇒ 5-10μm orbit rms)
    - resolution & stability of BPM system in orbit mode with single pilot bunch is ~5μm
  - BUT - Surface electronics sensitive to temperature variations (~50μm per degree)
    - Point 4 – electronics in BI control room so much more sensitive to variations
    - Point 2 – electronics in standard SR outbuilding where source of fluctuation is unclear
  - Several solutions being looked into to solve this problem

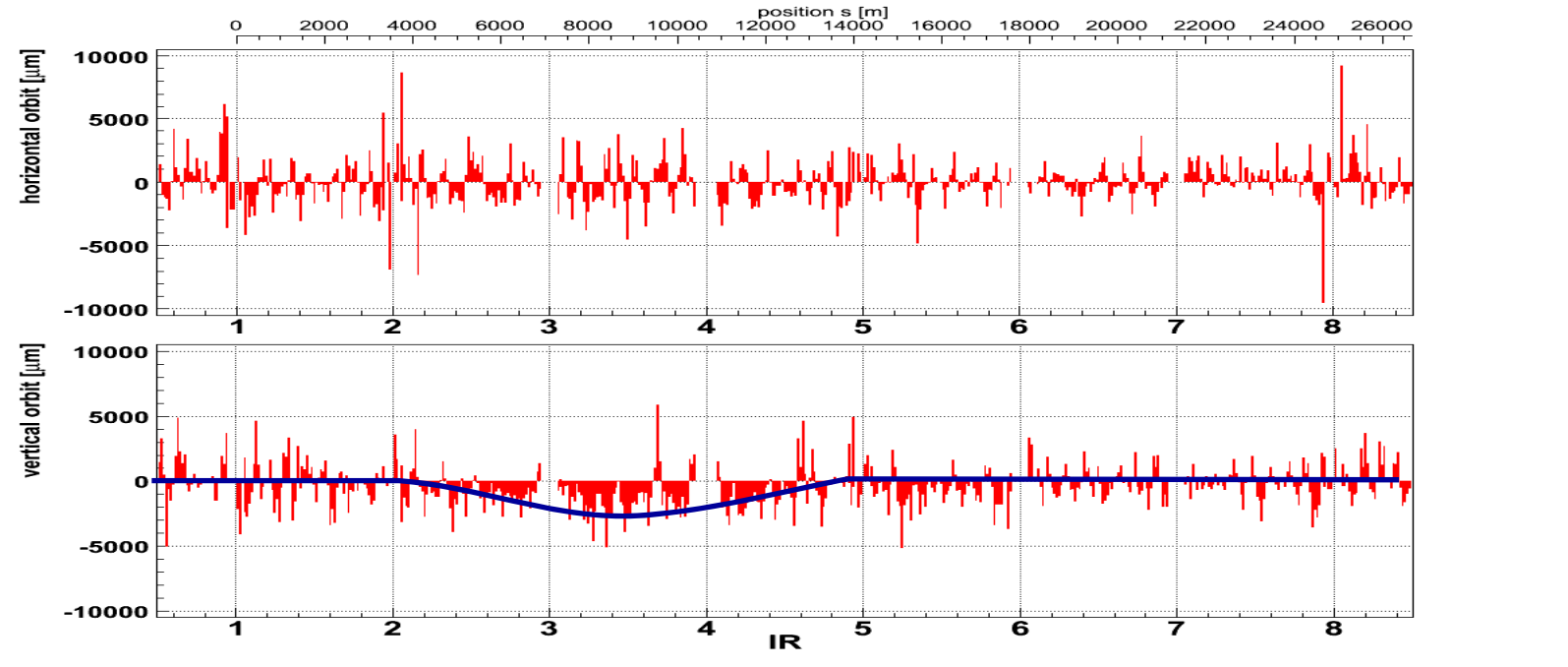


LHC BPM System V

- Next Steps
  - Sector 3-4
    - Dismount, test & re-install BPMs & electronics in damaged area
    - Test all BPM electrodes for MLI or soot contamination after cleaning
  - Other Shutdown Work
    - Addition of spring clamps on BPM ports
      - Foreseen for all sectors remaining cold (danger of damage to cryo cables?)
      - Implies disconnection & re-connection of ~2000 external BPM cables
      - Sectors will have to be re-commissioned for polarity etc
    - Installation of intensity cards throughout the ring
  - Commissioning in 2009
    - Commission Capture Mode (bunch & turn tagging)
      - Automated software & hardware routines being put in place to phase in BPMs
    - Commission Position Interlock BPMs for the dump channel in IR6
    - Commission Feedback System
      - Acquisition system already commissioned (same orbit data as YASP)
      - Attempt at feedback requires completion of
        - Corrector polarity checks – to be re-done
        - Optics checks – to be re-done
        - Feedback controller to PC mapping - still to do

Analysis of BPM Data

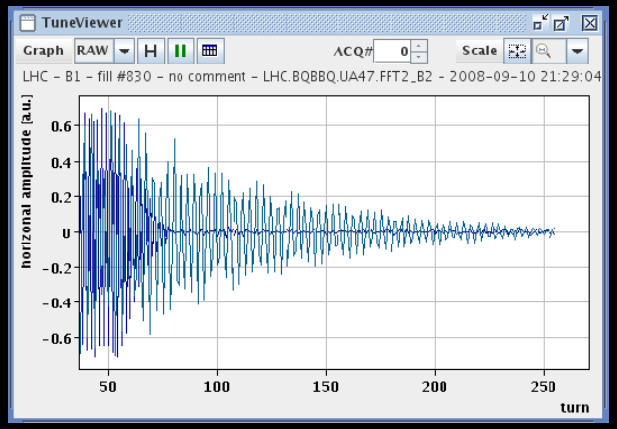
- LHC alignment estimates
  - Overall very good! : 200 - 500μm rms
    - Assumed orbits are given by Quad misalignments
      - Quad rms to orbit rms propagation & correcting orbit using Quad shifts gave same results

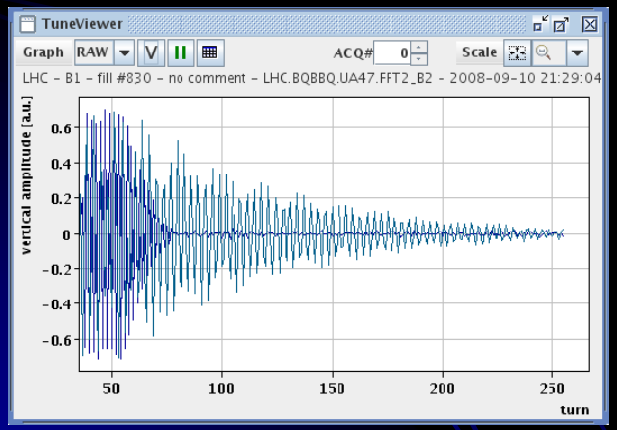


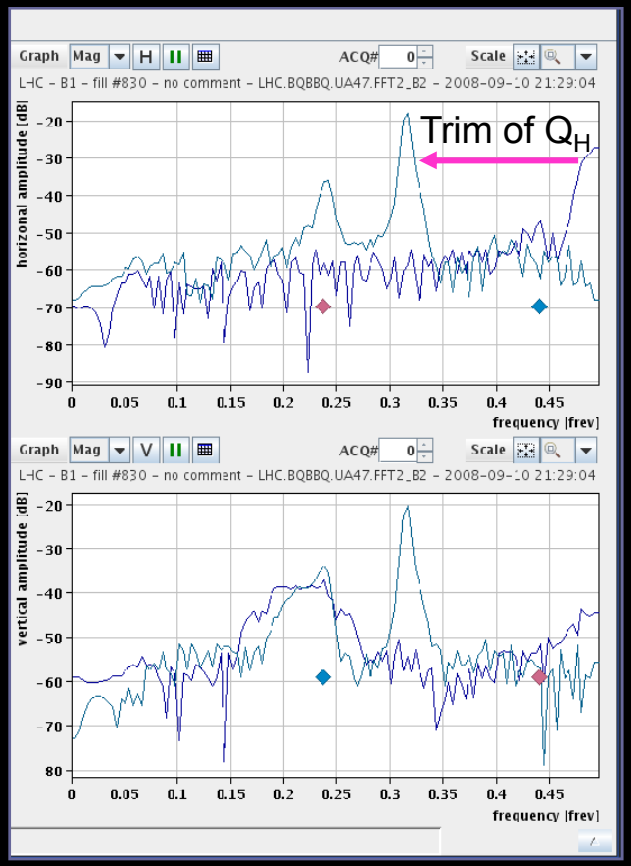
  - Systematic vertical offset from IR2 to IR5 is visible
    - Source not yet understood & no obvious explanation
      - Systematic misalignment or thermal drift of BPMs unlikely
      - Machine optics or magnet imperfections (b1 to a1 tilt) unlikely
      - Machine alignment – no obvious explanation according to APB/SU Section

LHC Q, Q' & C Systems I

- BBQ Tune Measurement Systems Commissioned for Beam 2
  - Observed nice signals for injection oscillations
    - Allowed tune to be adjusted early-on to improve initial lifetime
  - Visible in residual non-excited circulating beam spectra with S/N ratio > 10dB







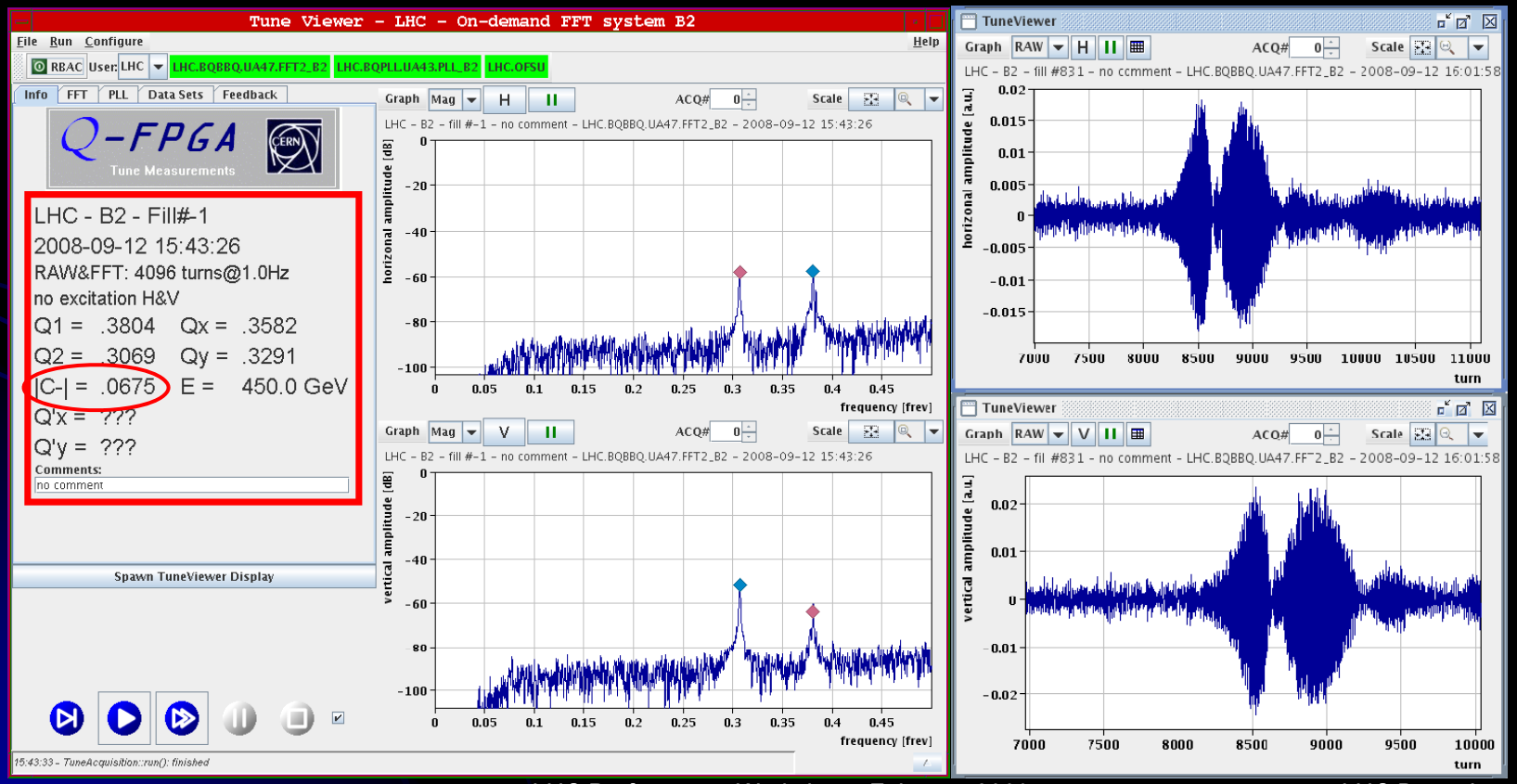
- Initially
  - No RF capture
  - $Q_H \approx 0.50$
  - $Q_V \approx 0.24$
- Trim of ΔQ_H by -0.2
  - $Q_H \approx 0.50 \rightarrow 0.32$
  - Moving from the half-integer resonance increases circulation time to 300+ turns (still no RF capture)

Before correction

After correction

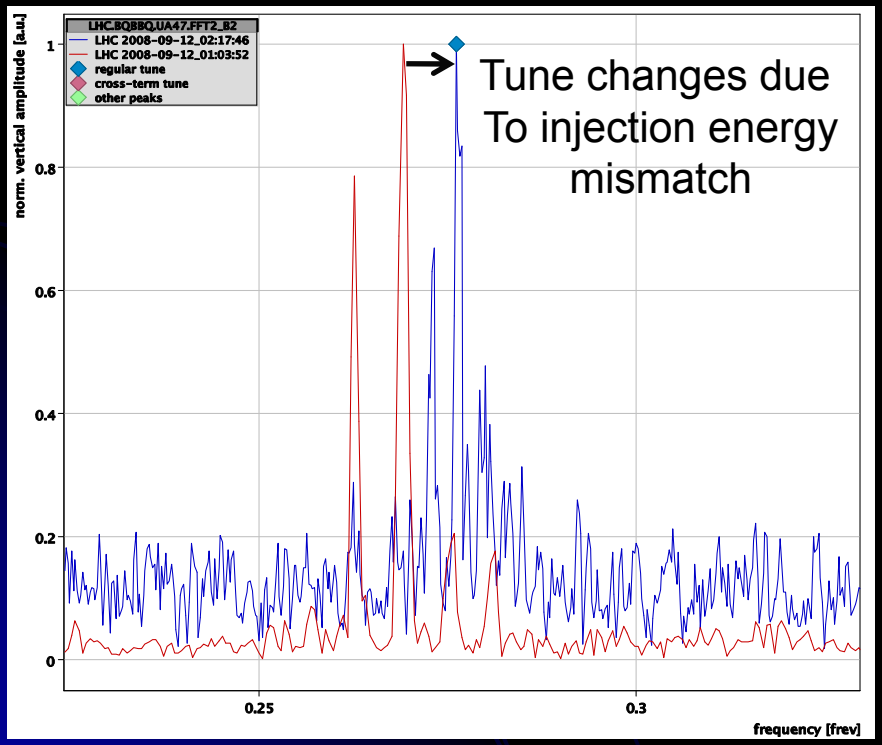
LHC Q, Q' & C Systems II

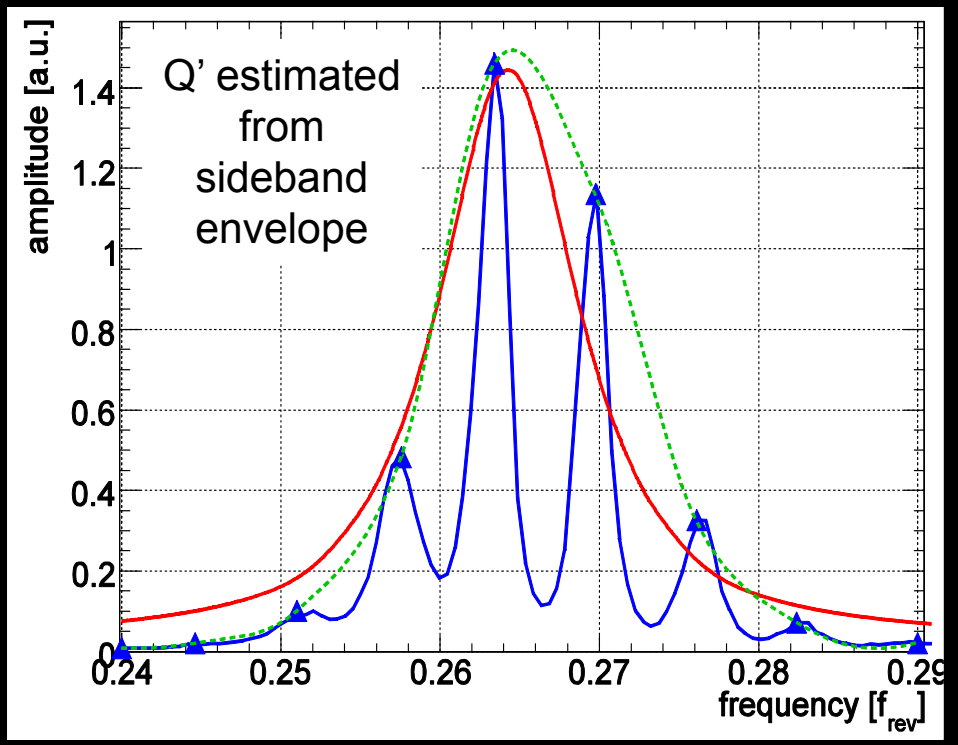
- BBQ Tune On-Demand system commissioned
  - Chirp excitation using transverse damper
    - Polarities verified to be correct (excitation & acquisition)
  - Allowed first measurement of coupling
    - Measured coupling |C-| ≈ 0.07



LHC Q, Q' & |C| Systems III

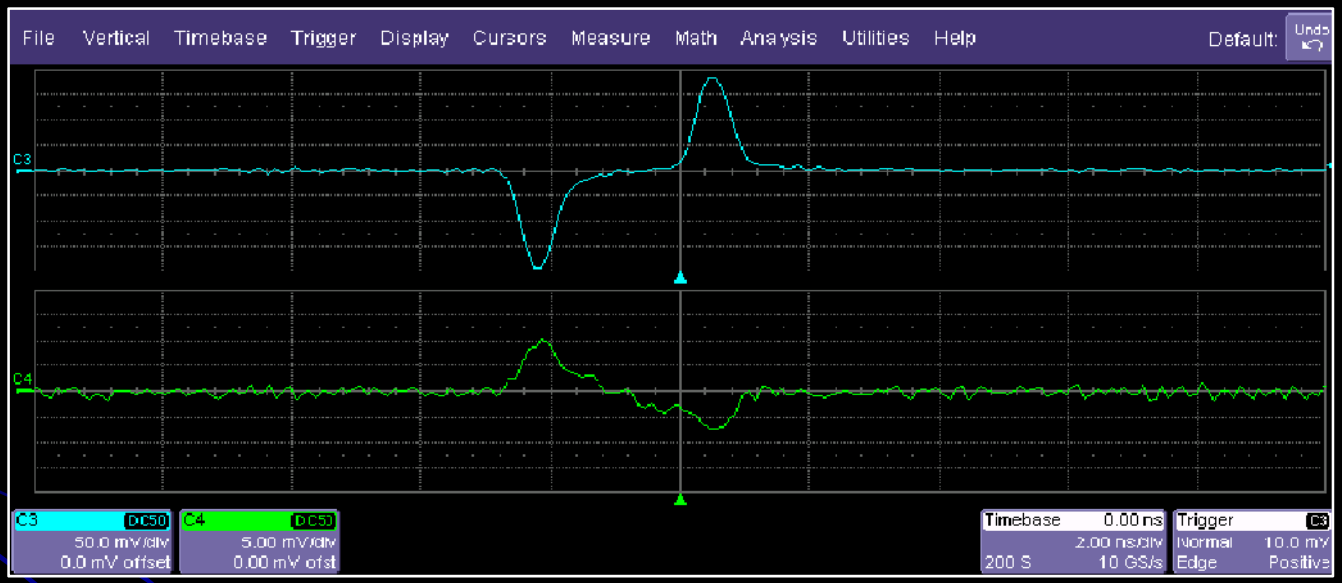
- First Estimates of Chromaticity
  - Tune shift due to injection momentum offset
    - Comparison of injection tunes to circulating beam tunes
      - Inconclusive as no systematic logging of momentum mismatch
  - Estimates from tune to synchrotron sideband amplitude ratio
    - Measured chromaticity $Q_H' \approx Q_V' \approx 32$





LHC Q, Q' & C Systems II

- Head-Tail / Instability Monitor
  - Beam 2 system tested but acquisition software to be finalised & tested
    - Will give same functionality as SPS Head-Tail system
    - Used for head-tail chromaticity measurement & as instability monitor

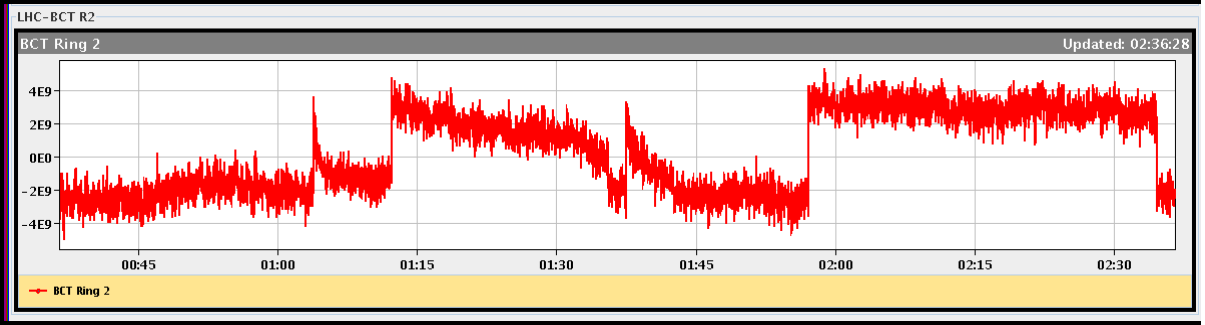


- Next Steps for Q, Q' and C Measurement Systems – commissioning of:
  - Beam 1 and Beam 2 PLL Systems
  - Chromaticity measurement using PLL & RF modulation
  - Tune and Coupling feedback
  - Schottky system

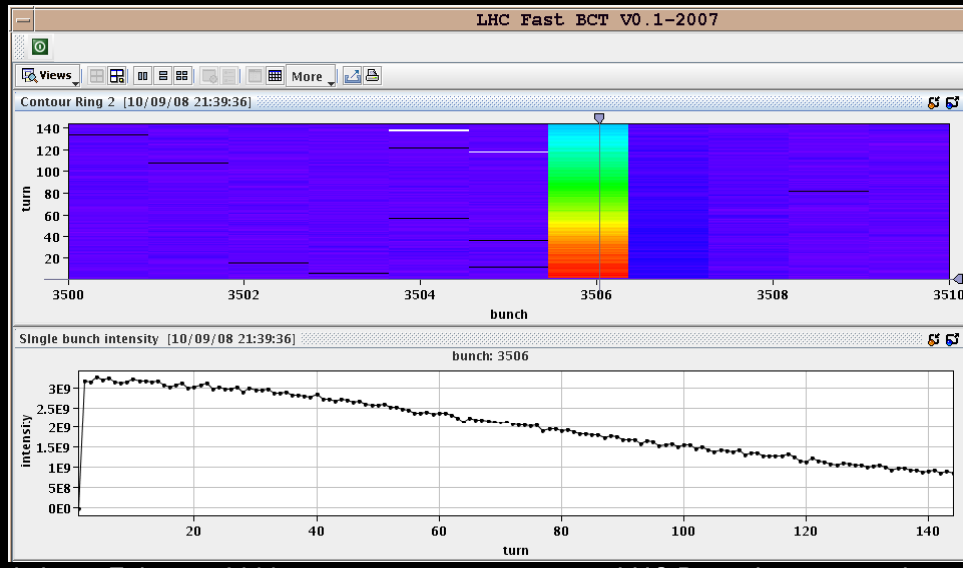
LHC BCT Systems

- BCTDC (DCCT)
  - Main Beam 2 acquisition system commissioned
    - Automatic range selection was blocked in highest sensitivity setting
    - Beam 2 circulating current measured using fixed display
    - SAFE BEAM flag & DIP transmission to experiments tested but not yet activated
  - Beam 1 system still to be commissioned with beam

Beam 2
DCCT sees first
circulating beam



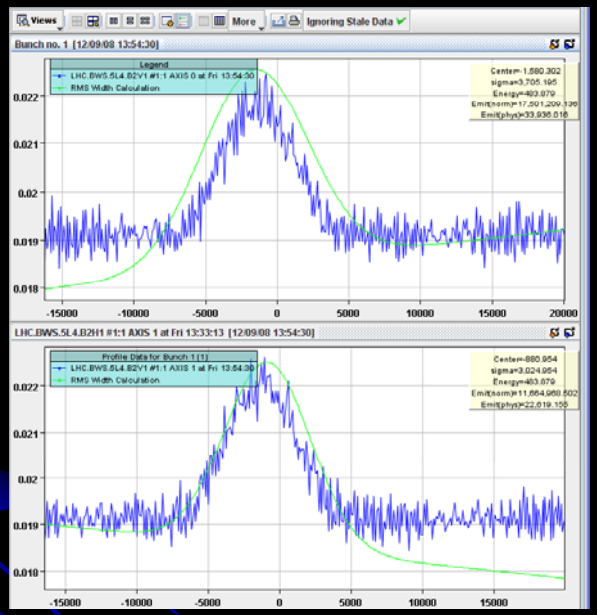
- BCTFR (Fast BCT)
  - Beam 1 & Beam 2 high sensitivity channels have seen beam
    - Calibration looks OK
  - Still to do
    - Full timing in of system for bunch to bunch measurements
    - Full commissioning of dump line systems
    - Commissioning of the beam presence flags
    - Adaptive lifetime algorithm
    - dI/dt link to MPS

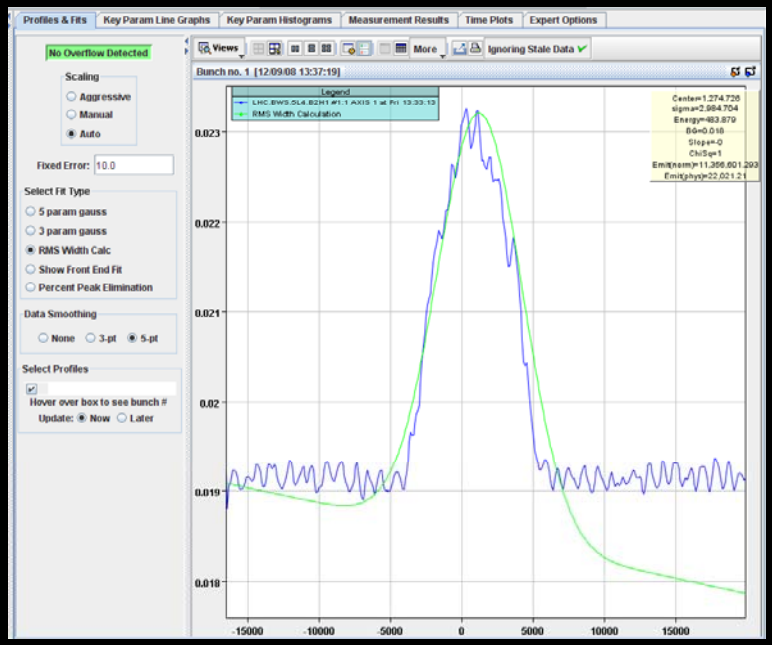


LHC Wire Scanner System

- Beam 2 System Commissioned
  - Low intensity single bunch gives expected noisy signals
    - Beam size seems to be too large
      - Calibration verified & looks to be OK

Vertical In / Out Scan on Beam 2





Horizontal Scan on Beam 2

- Still to do
  - Commissioning of Beam 1 system
  - Accurate timing in of acquisition systems
  - Bunch by bunch acquisition
  - Commissioning of wire protection system software

The Undulator Story

- Undulators required to give enough synchrotron light below 2TeV
  - Used for synchrotron light monitor & abort gap monitor
  - Above 2TeV the D3 produces enough light
    - Undulators should be ramped down to minimise effect of light from 2 sources
- Undulator for beam 1 (4R) commissioned in 2008
- Undulator for beam 2 (4L) commissioning started in 2008
  - Resistor in II to coil found to be defective after transport to tunnel
    - Acts as energy extractor & distributes the produced heat in case of quench
    - Also equipped with standard external energy extraction system
      - Is sufficient to protect the magnet without internal resistor (tested in lab)
  - This NC proved a problem for PC & QPS system for ramp-up / ramp down
    - Can probably only be ramped up or down very very slowly – i.e run in DC
    - Should be possible to add external resistor to allow ramping with existing undulator
  - This is a known Non-Conformity
    - Can this NC degrade to cause e.g. short & so disable undulator?
    - Should we not change it while we have the chance?
- What back-ups do we have?
  - None for the abort gap monitor below 2TeV
  - BGI could replace synchrotron light BUT
    - Requires gas injection (system currently being installed by TE/VSC)

Summary

- A Good Start for all BI Systems
  - Thanks to years of planning, testing & HW commissioning within the BI Group, with the help of many other Groups & external collaborators
- Next Steps - Still a lot to do!
  - Main Shutdown Work
    - BPM & BLM consolidation with considerable dismounting & remounting
    - Improvements to the synchrotron light monitor optical layout
    - Installation of US-LARP luminosity monitors (fast ionisation chambers)
  - Commissioning in 2009
    - Full commissioning of the already tested systems
      - Systematic measurements & fine timing
        - Fast Timing System already used for many systems and has worked very well
    - Commissioning of
      - BSRT – synchrotron light monitor (requires undulator)
      - BSRA – abort gap monitor (requires undulator)
      - BGI – as back-up for BSRT (requires gas injection)
      - PLL Tune measurement & Q' with RF modulation
      - Orbit, tune, coupling and chromaticity feedback systems
      - Schottky & finally Luminosity monitors!

Analysis of BPM Data

- Orbit transients
  - Primary sources found to be in IR2 and IR8
    - Likely candidate
      - Residual MSI b1 imperfections (0.006 Tm)
    - Originally believed to be "easily correctable“ via orbit correction
      - True if static but MSI is pulsed causing drifts of ~200 μm/s
  - Solution
    - BT proposal to operate in DC mode for injection
      - When do we ramp MSI up & down? (residual corrected by feedback)