The 2011 LHC Run
-
Lessons in Beam Diagnostics

LHC Performance Workshop

Chamonix 2012

6th – 10th February

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CERN Beam Instrumentation Group

Outline

- This Presentation will focus on
  - Performance in 2011
  - Result of Studies
  - Outlook for 2012

- Distributed Systems
  - BLM (excellent performance – not discussed!)
    - Studies covered by Mariusz Sapinski in next talk
  - BPM & Feedbacks

- Individual Systems
  - BCT – DC & Fast
  - Longitudinal Density Monitor (LDM)
  - Beam Size Measurement
    - Wire scanners
    - Synchrotron Light Monitor (BSRT)
    - Beam Gas Ionisation Monitor (BGI)

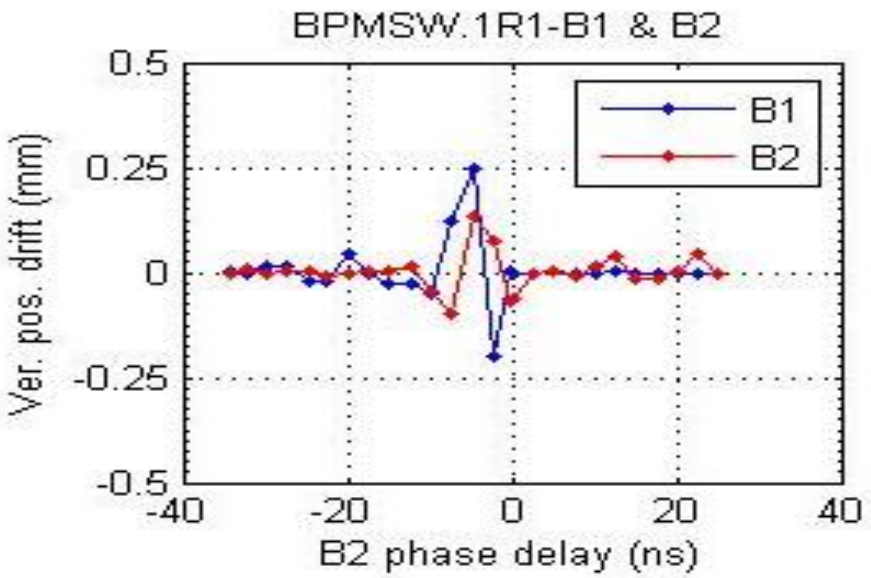
BPM & Feedback Systems

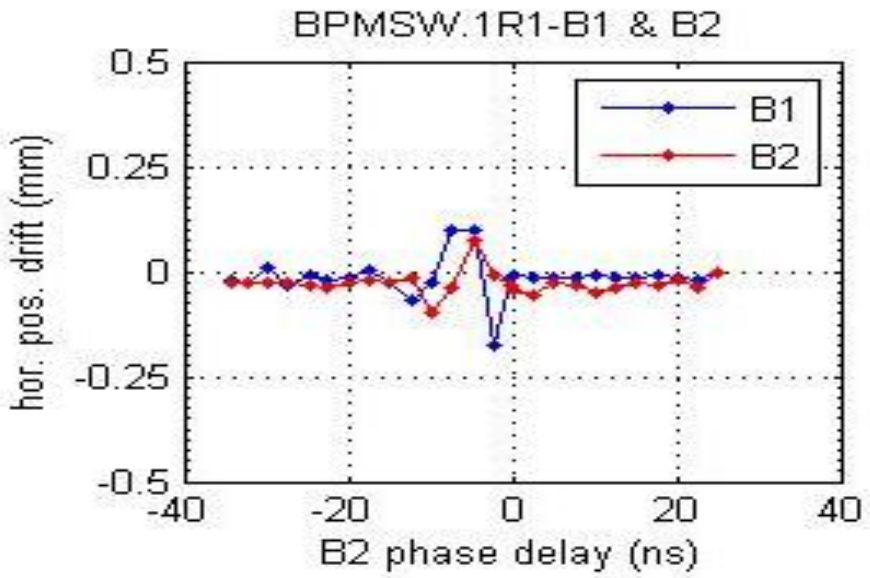
98% of BPM channels fully operational throughout 2011

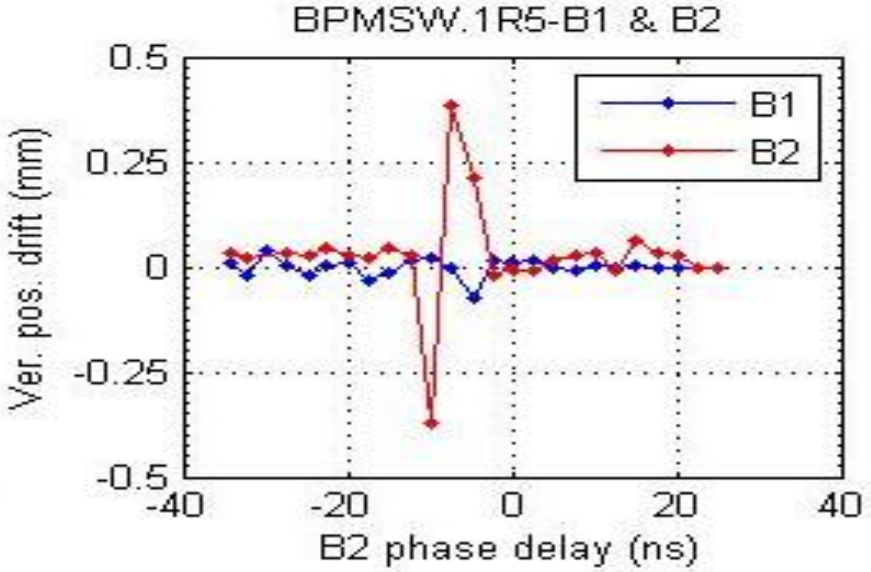
2% masked in Orbit Feedback system

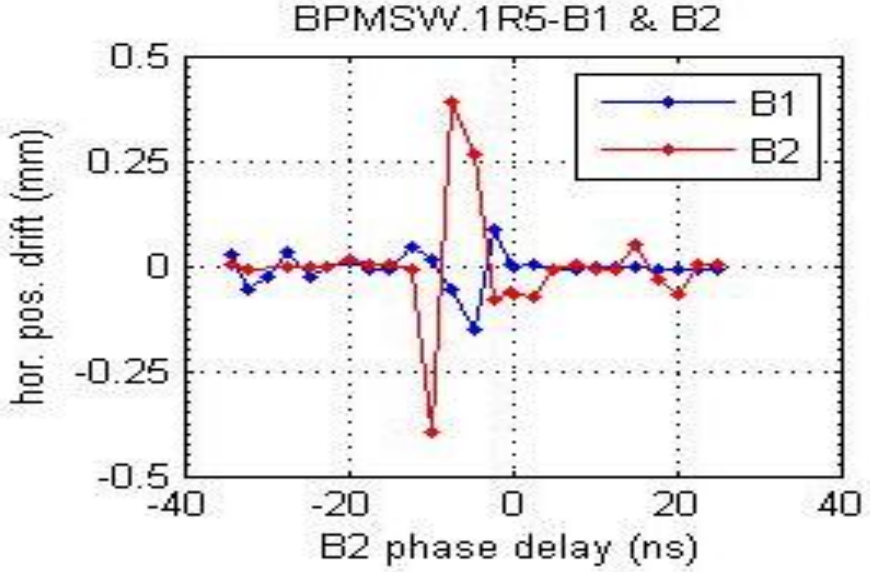
- Most of the masked monitors are in LSS

BPM Studies – Improving the LSS BPMs





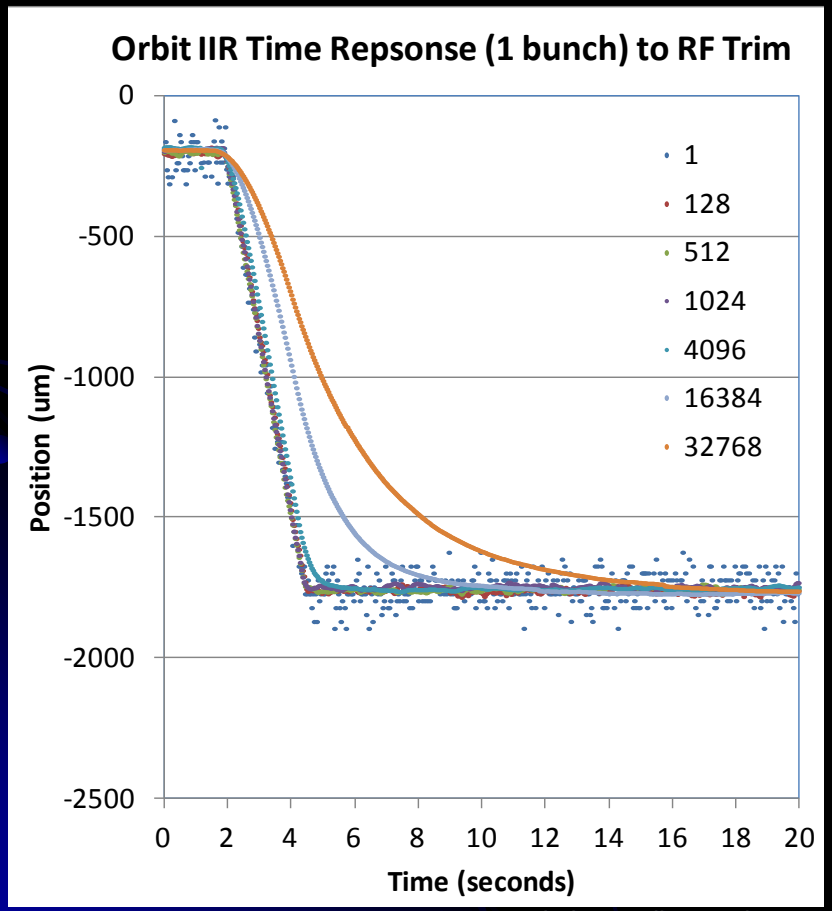


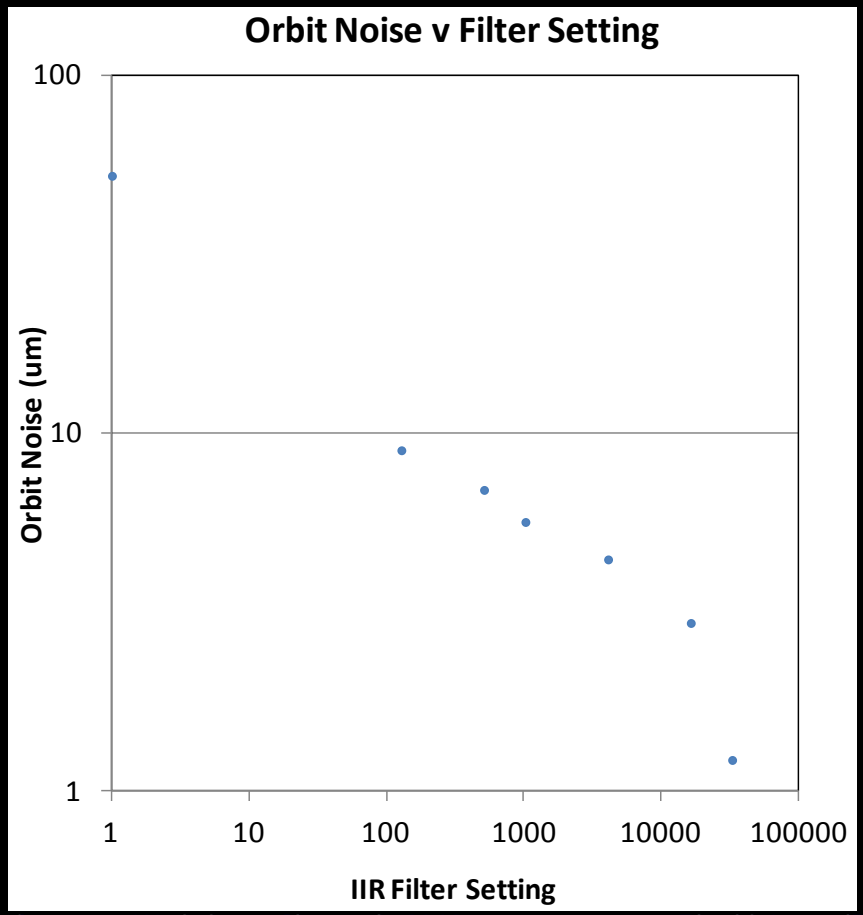


BPM Studies – Orbit Resolution

- 2012 Asynchronous mode
  - Default mode of operation for orbit system
  - Robust - requires no accurate external timing
  - Produces average via IIR filter
    - Optimises orbit resolution for given filling scheme
    - Ensures output delays acceptable for orbit feedback with small numbers of bunches
      - Limited length in 2011 led to turn by turn sensitivity for 1000+ bunches
      - Orbit feedback system becomes sensitive to instabilities

IIR filter length increased & made automatically selectable by FPGA

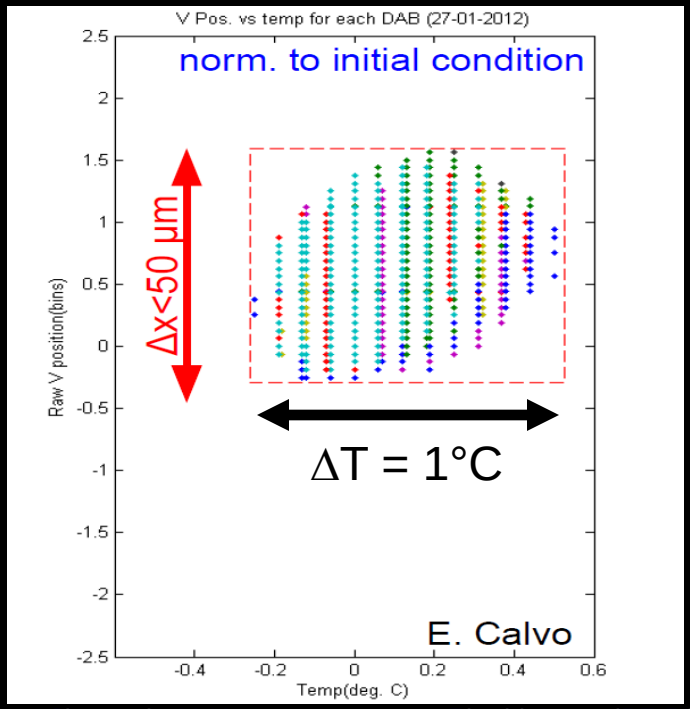




BPM Issues

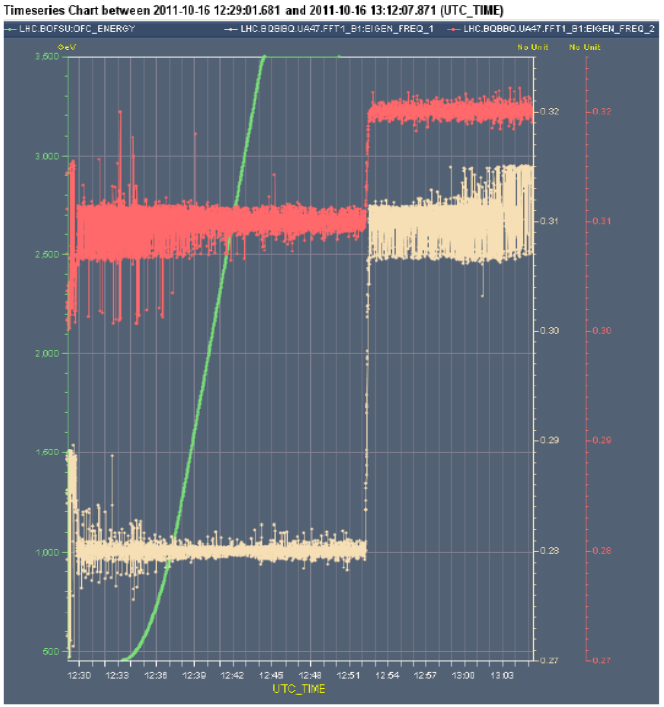
- Interlock BPMs
  - Caused several dumps when some bunches in the train lose intensity
  - Currently dumps if 70 measurements in 100 turns outside limits
    - i.e. sensitive to a single bunch
    - Can happen in low sensitivity if bunch drops below ~3×10^{10}
      - Either stops giving readings (= no impact)
      - Gives spurious readings (= dump beam)
  - Will remove 4dB attenuators for 2012 to gain some margin

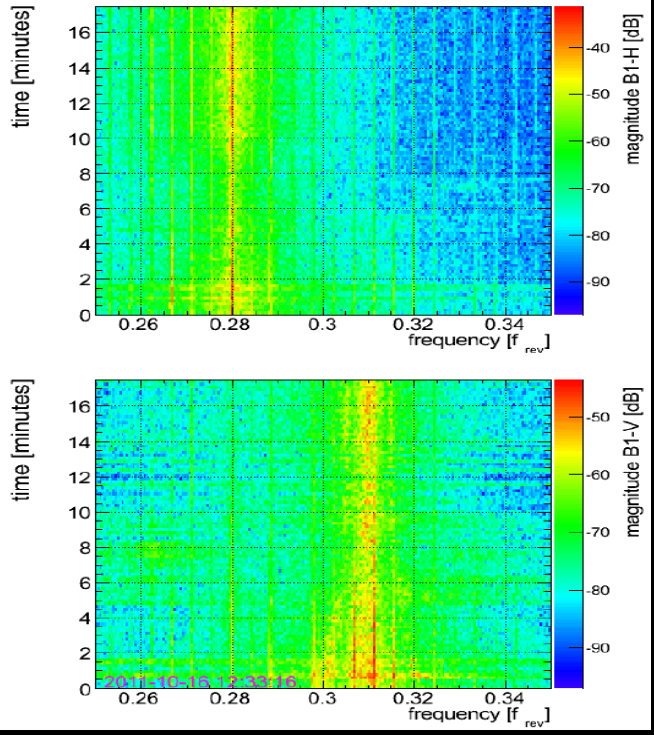
- Temperature Dependence
  - Mitigated to some extent by
    - Calibration before each fill
    - On-line corrections to each channel using measured temperature
  - Not expected to improve before installation of temperature controlled racks in LS1
    - Prototype racks currently under test
    - Achieved stability <1°C over 3 day period



Feedbacks

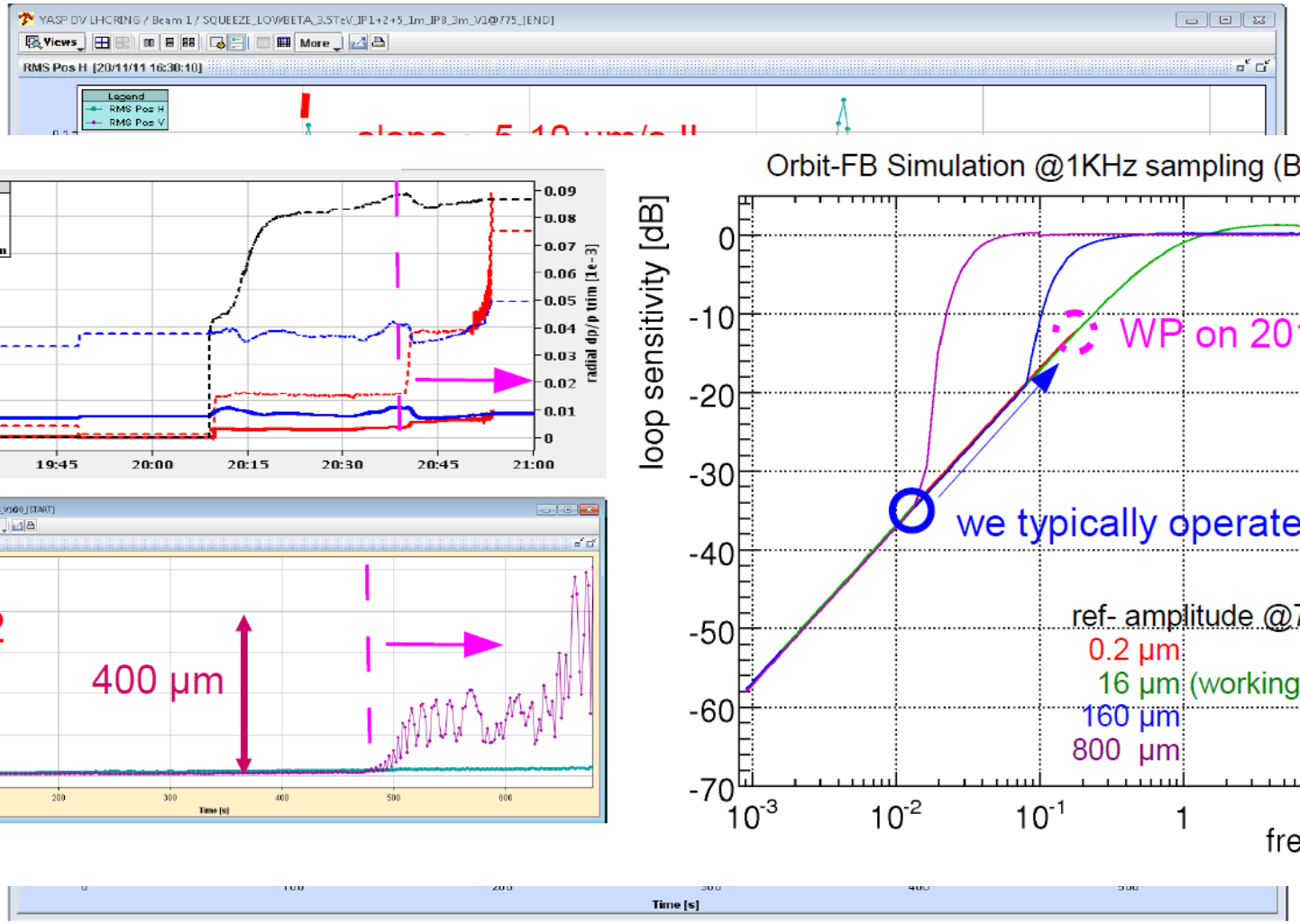
- OP-Feedback on Beam-Feedbacks (Evian'11):
  - “Feedbacks saved more fills than they dumped: we cannot live without them”
- 33 fills lost directly/indirectly due to FBs (25% of dumps during ramp & squeeze)
  - 5 fills lost due to FB specific instabilities or wrong references
  - 23 fills lost due QPS ↔ Tune-FB ↔ BBQ signal quality interdependence
- Required continuous post-fill performance monitoring and Q-tracker tuning
  - Performance during injection dominated by ADT-gain/feedback loop
  - Performance during squeeze limited by beam stability (factor 2 S/N) !

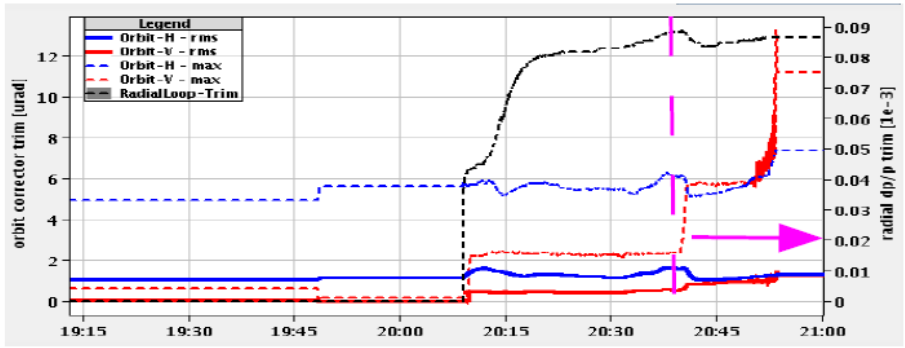


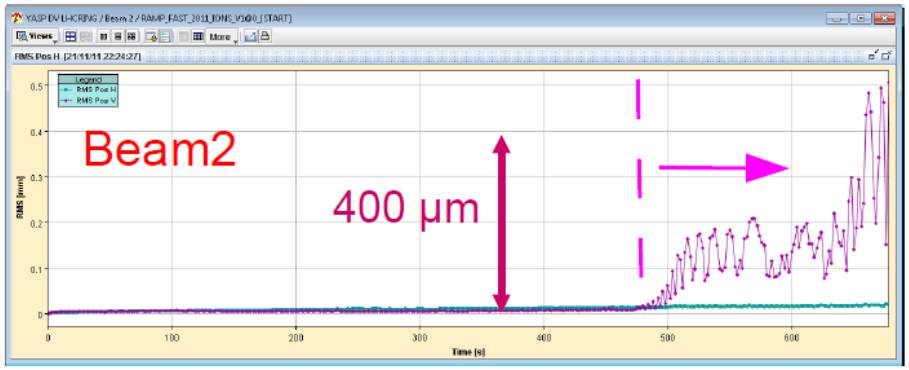


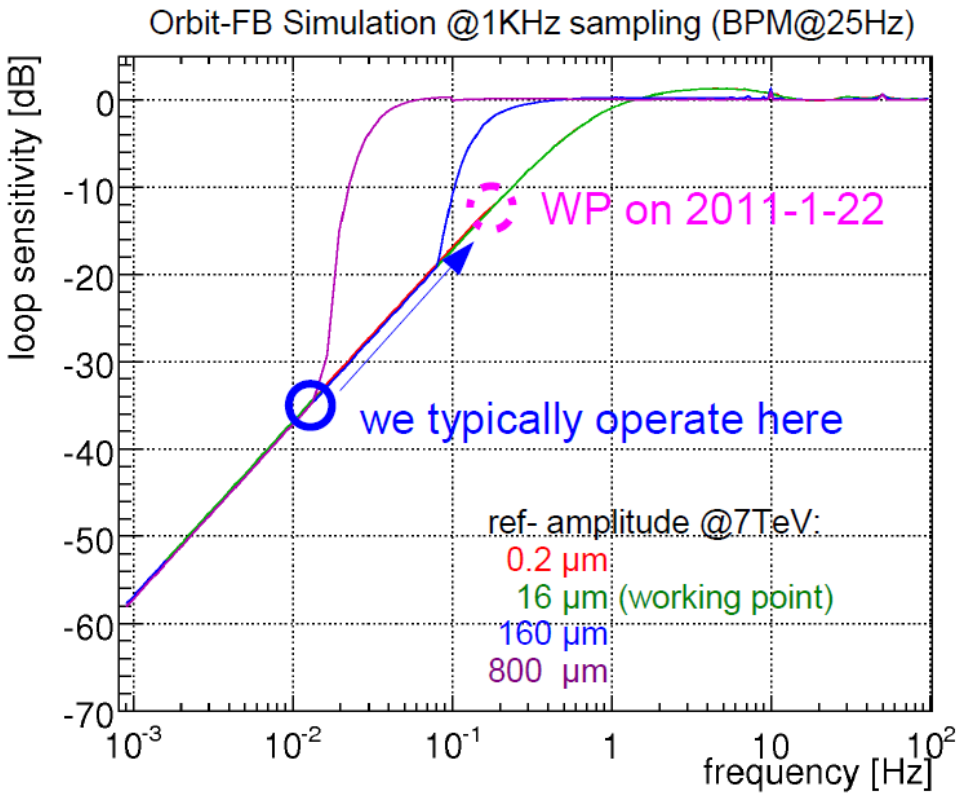
Feedbacks

- Test of orbit feedback with tenfold increase in closed loop bandwidth
  - Successfully controlled large orbit transients at matched points during squeeze
- But
  -









Feedbacks - Outlook

- Margin to improve, so aim at considerably reducing dumps in 2012
  - Increase threshold for RQT[F/D]s circuits to mask spurious QPS triggers
    - not a long-term sustainable solution
    - need to investigate more robust solution & fix problem at source for after LS1
  - BBQ HW optimisation to reduce saturation sensitivity
    - trade-off between available signal-to-noise performance
  - A very long list of controls integration and GUI improvements:
    - split Q/Q‘ diagnostic & acquisition chain according to use cases
    - more flexible, optimised settings for Tune-FB, |C-| & Q'-Meas.
    - deploy & commission Energy-FB
    - arbitrary user-controlled reference functions, ATS, BLM-based FB,…

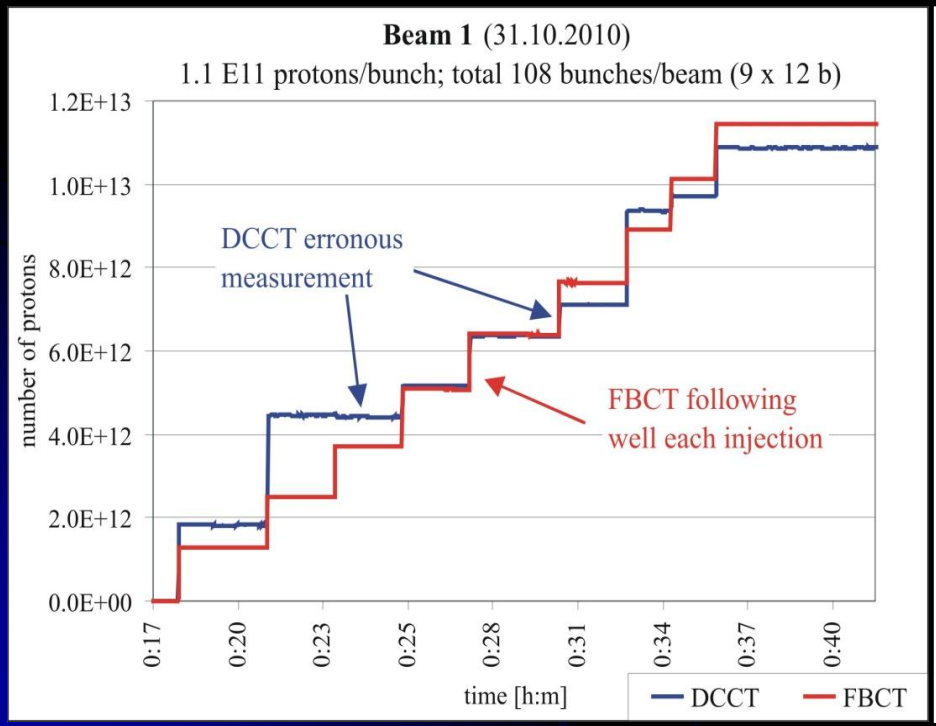
- Continued development & understanding required in 2012
  - Time for optimisation at each significant commissioning step
  - Tests of BPM & Q/Q’ effects & improvements with beam

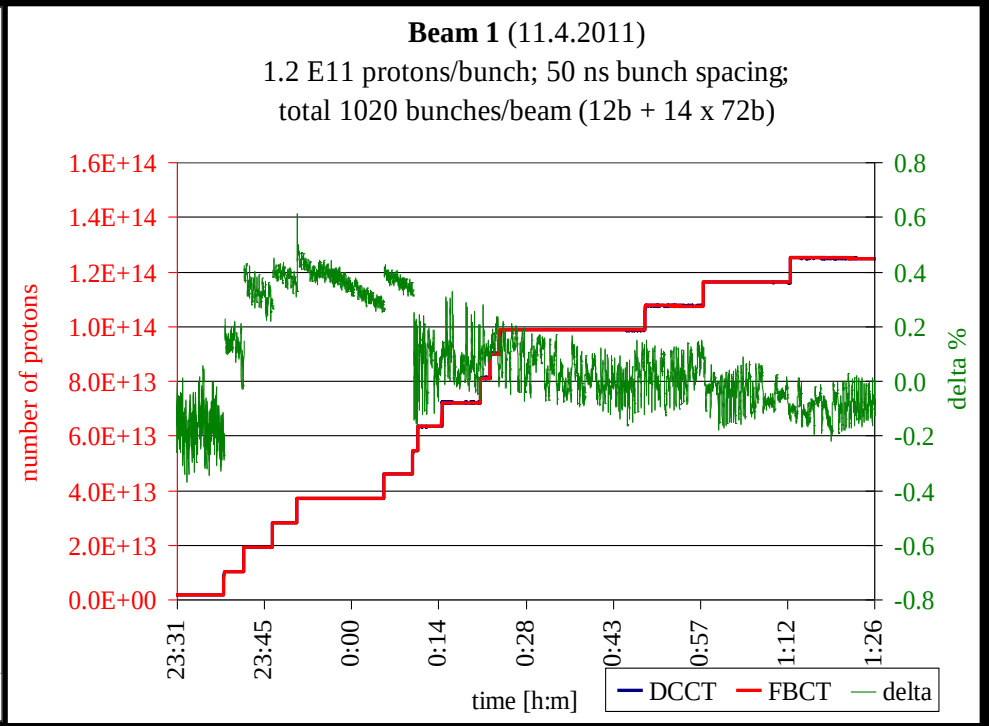
- Performance in 2012
  - Apart from fewer dumps, OP should expect similar performance as 2011
  - Testing of various BPM, ADT and BBQ-based diagnostics will be ongoing
    - Any novel or considerably improved systems can only be deployed after LS1

BCT Systems

Addressing BCT Error Sources

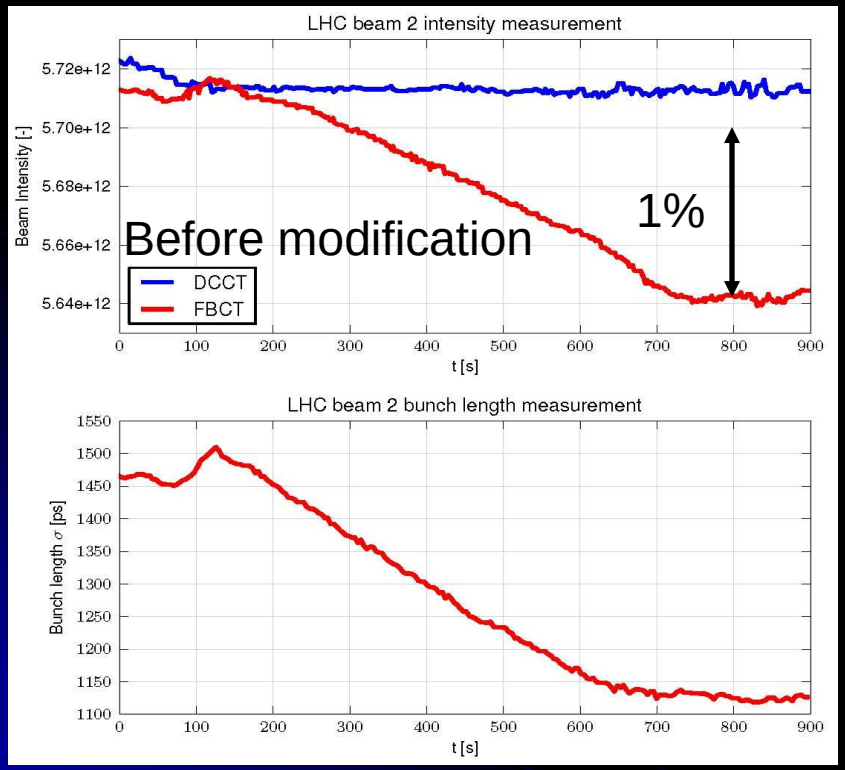
- Bunch by bunch intensity important for absolute luminosity calibration
  - BCT errors a major contribution to the final precision in 2010
    - estimated 3% absolute accuracy of bunch population measurement
  - Triggered fruitful collaboration between BI Group & LHC Experiments
    - Pushed LHC Beam Current Transformer performance to its limits
    - Well beyond requirements for normal operation
- Bunch pattern dependence & saturation of the DCCT
  - Modified DCCT feedback loop, wall-current bypass & front-end amplifiers
  - Uncertainty in the absolute DCCT calibration now at the < 0.3% level

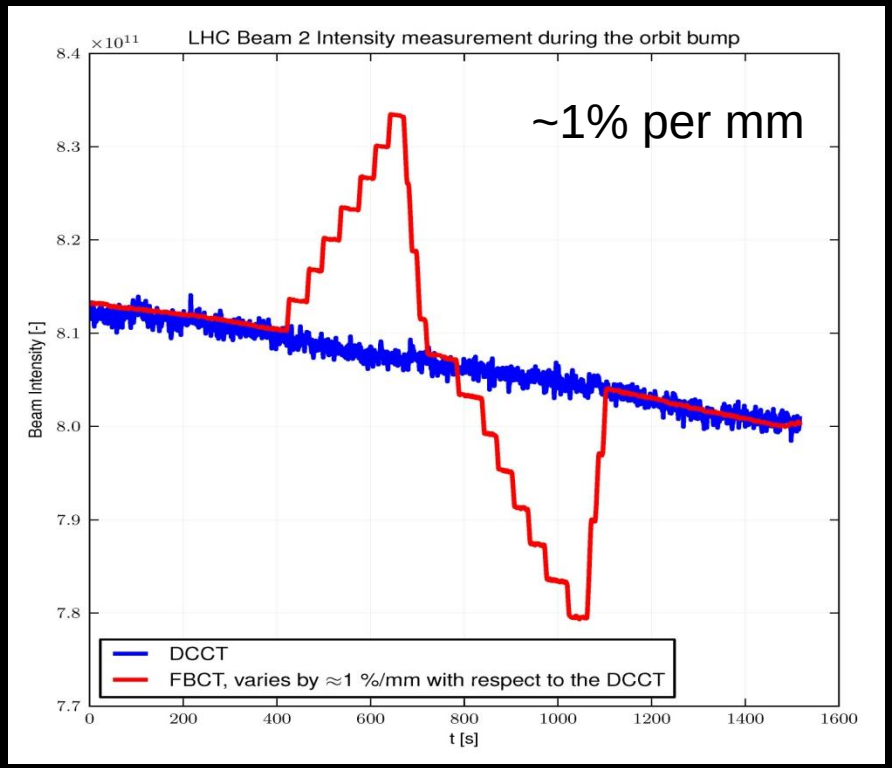




Addressing BCT Error Sources

- Bunch length dependence of the fast BCT
  - Mitigated with 70MHz LP filters (now <0.3%) - still allows bunch-by-bunch measurement
- Bunch position dependence of the fast BCTs
  - At 1% per mm this effect was not at all expected
    - Found to come from commercial toroid used - new monitor under development
  - Fortunately orbit is kept sufficiently stable & limits effect to well below 1%
- 2012
  - Test new toroid (ICT) & aim to complete testing of dI/dt electronics

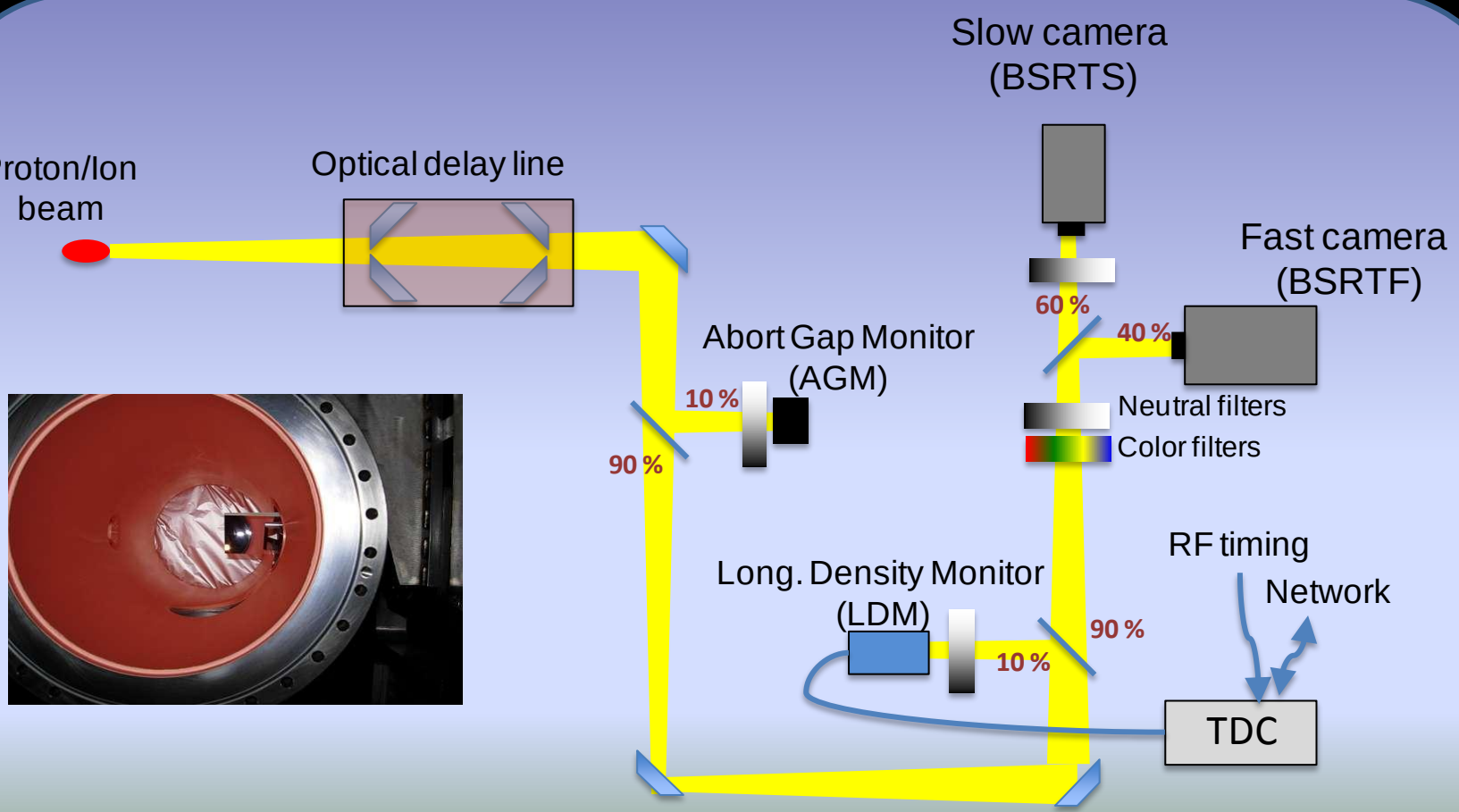




Synchrotron Light Systems

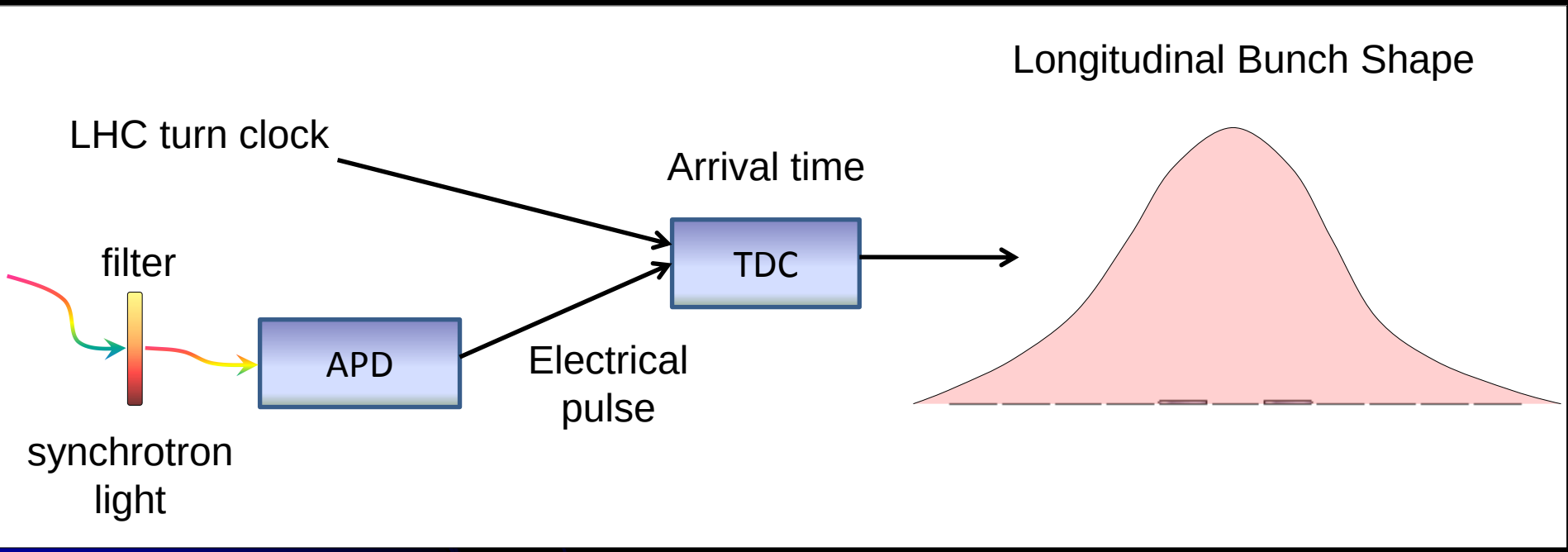
Synchrotron Light Diagnostics

- Longitudinal Density Monitor
- Abort Gap Monitor
- Synchrotron Light Cameras

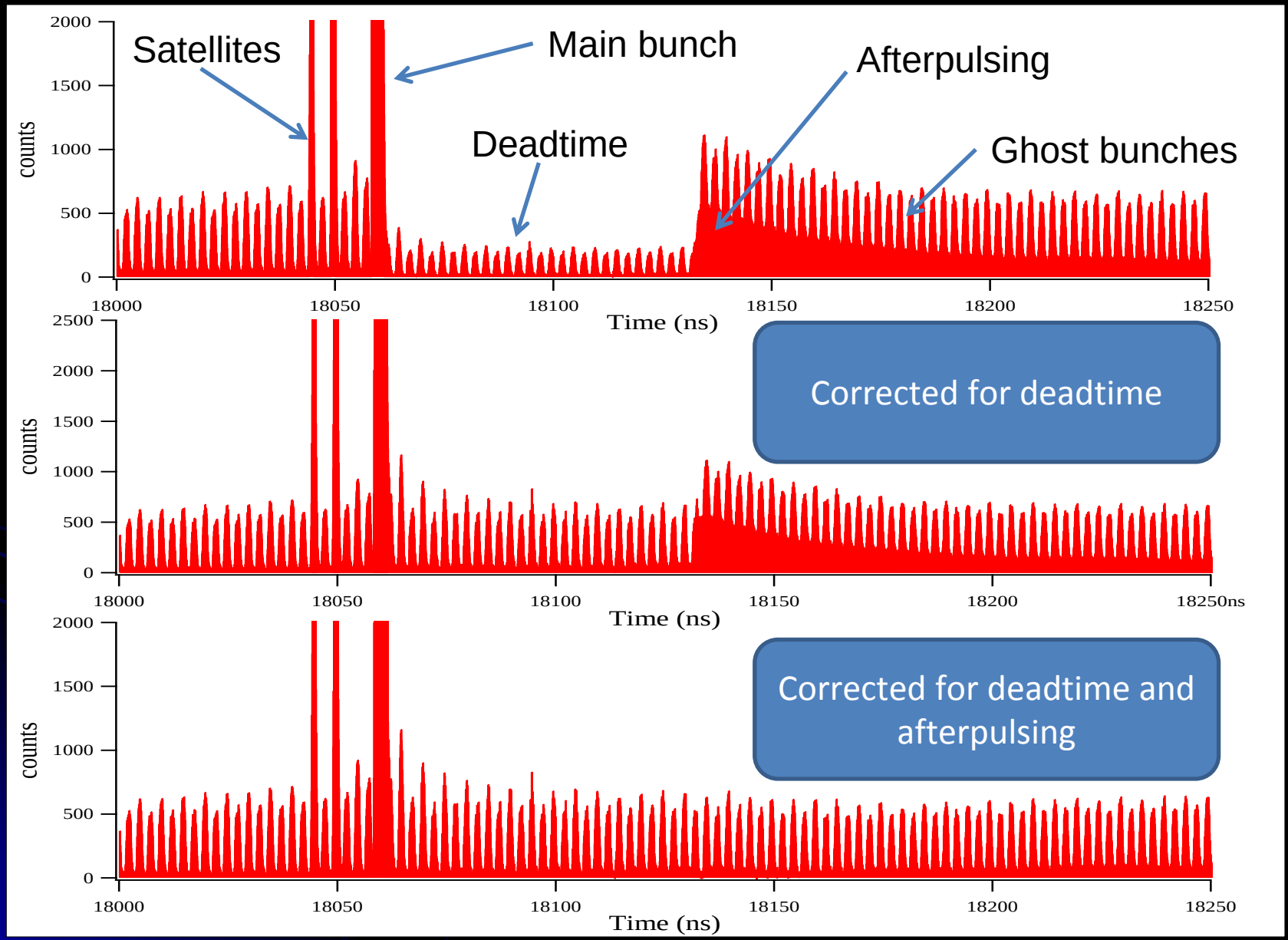


Longitudinal Density Monitor (LDM)

- Aims:
  - Profile of the whole LHC ring with 50ps resolution
  - High dynamic range for ghost charge measurement
- Method:
  - Single photon counting with synchrotron light
    - Avalanche photodiode detector
    - 50ps resolution TDC

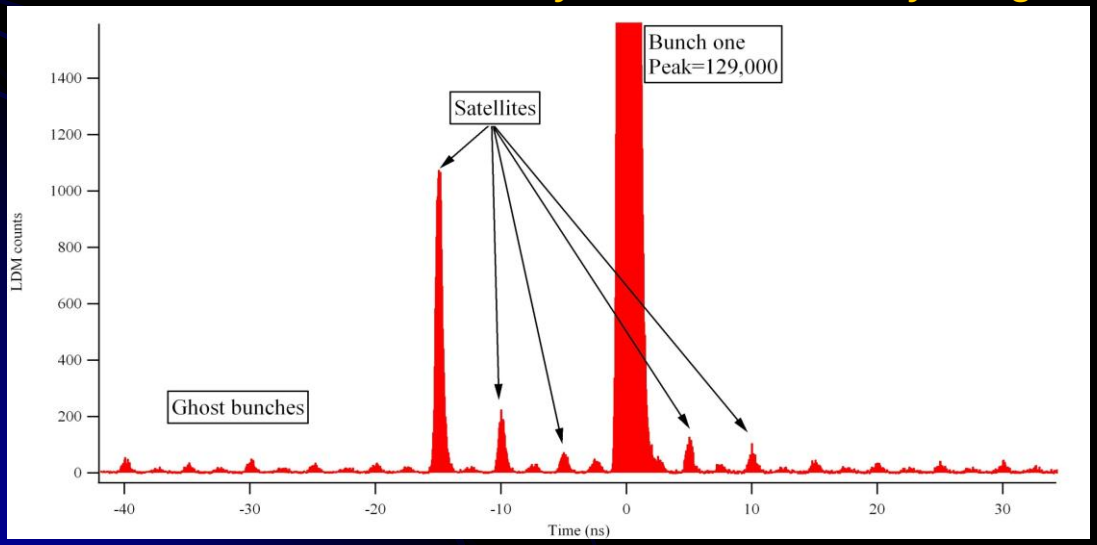


LDM On-Line Correction



LDM Performance

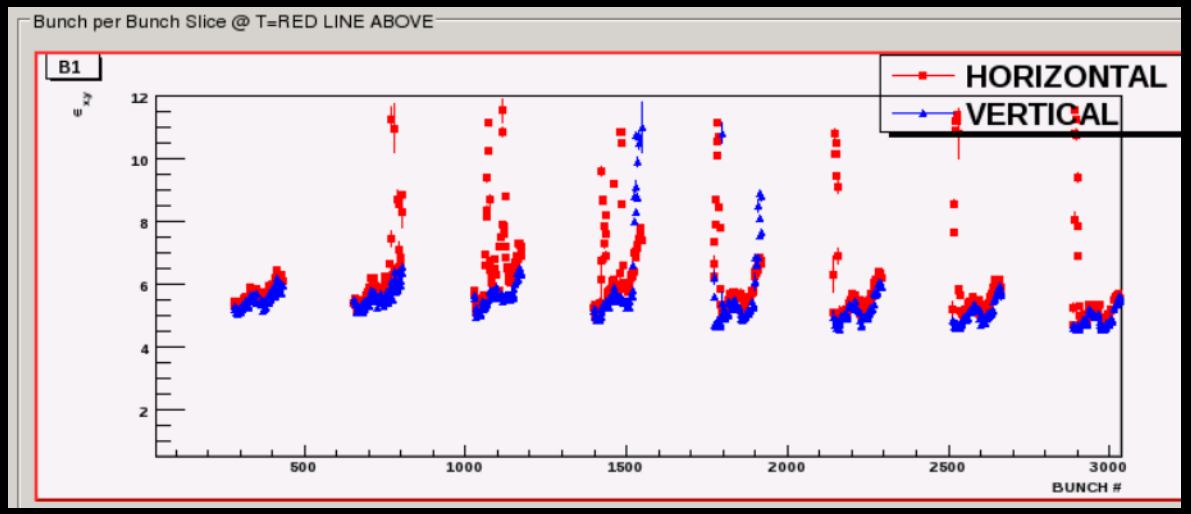
- Achievements:
  - Dynamic range of up to 10^5 with integration time of a few minutes
- Used for:
  - Checks for injector optimisation
    - Detection of large satellite populations
  - Optimisation of LHC RF
  - Verifying satellite populations during van de Meer scans
    - To quantify error in cross calibration of fast BCT with DCCT
- 2012
  - Finalize software for fully automatic running & improved display
  - Adapt optical system to eliminate dependence on transverse bunch size
  - Perform detailed study of LDM accuracy for ghost and satellite populations



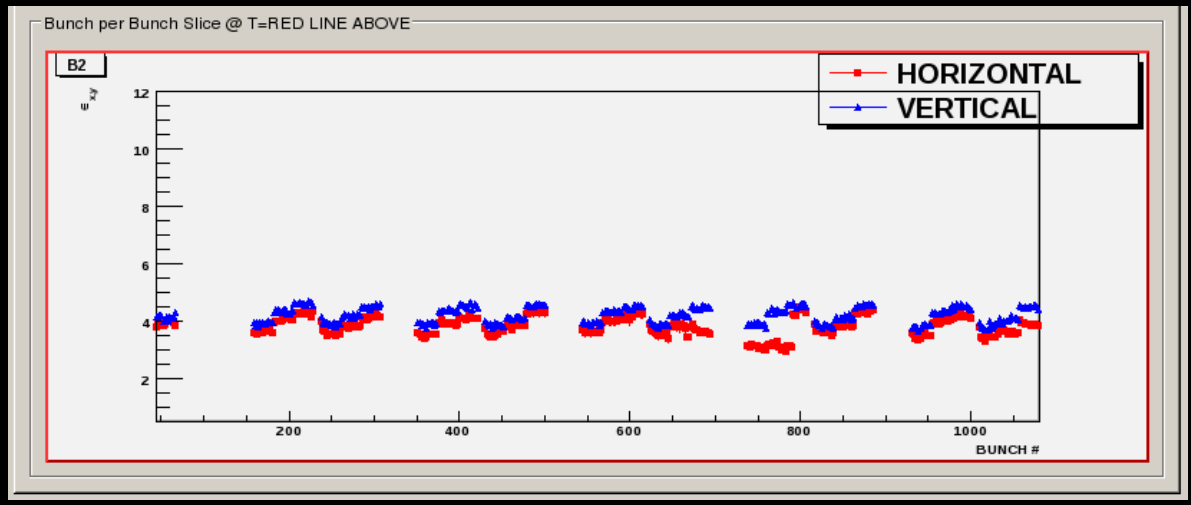
Lead ions at 3.5 Z TeV
10 min integration

Synchrotron Light Cameras (BSRT)

- In 2011 implemented gated mode
  - Allows profile of single bunch to be captured in a few seconds
- Operational uses
  - Identify instabilities leading to emittance growth
  - Verify correct injection parameters from injectors
- Limitations
  - Time required to scan over all bunches
    - 10 times faster readout being investigated



804 bunches – with strong electron cloud activity



after some time of vacuum chamber scrubbing

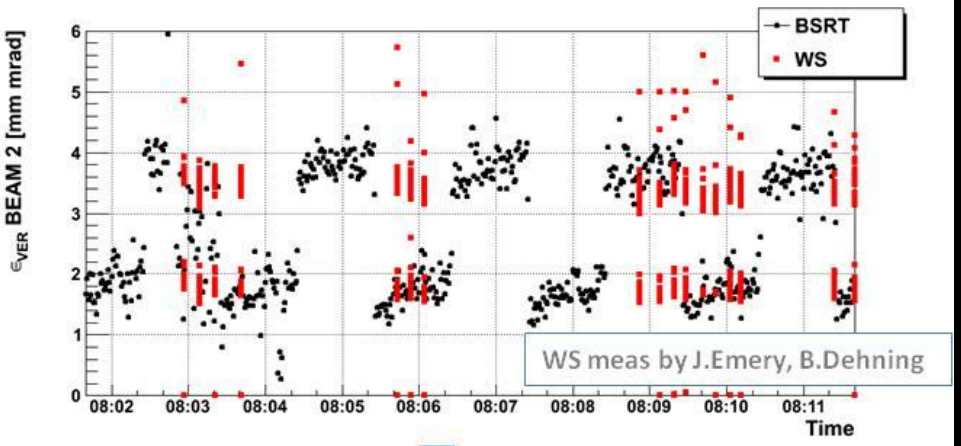
BSRT Accuracy & Calibration

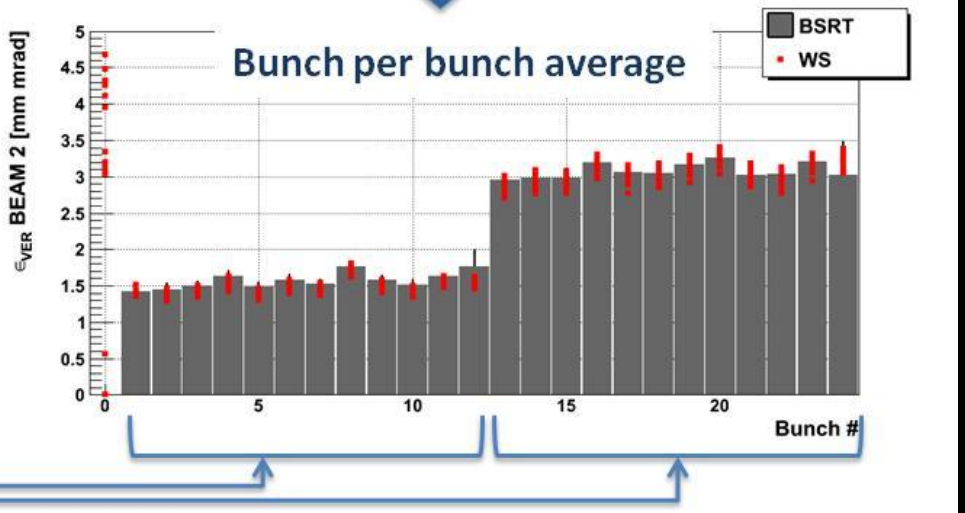
- Large correction factors required (as in many synchrotron light systems)
  - Up to 900μm on 1-1.5mm (injection) : 300μm on 300μm (3.5TeV) sigma beam
- OK for given setting (camera position, color filter) & nominal bunches, emittance

$$\sigma^2_{meas} = (MAG \cdot \sigma_{beam})^2 + \sigma^2_{PSF}$$

σ_{PSF}:
- Diffraction
- Depth of field
- Extended source
- Camera resolution

Beam 2 Vertical 450 GeV
- 12 'small' emittance bunches
- 12 'large' emittance bunches



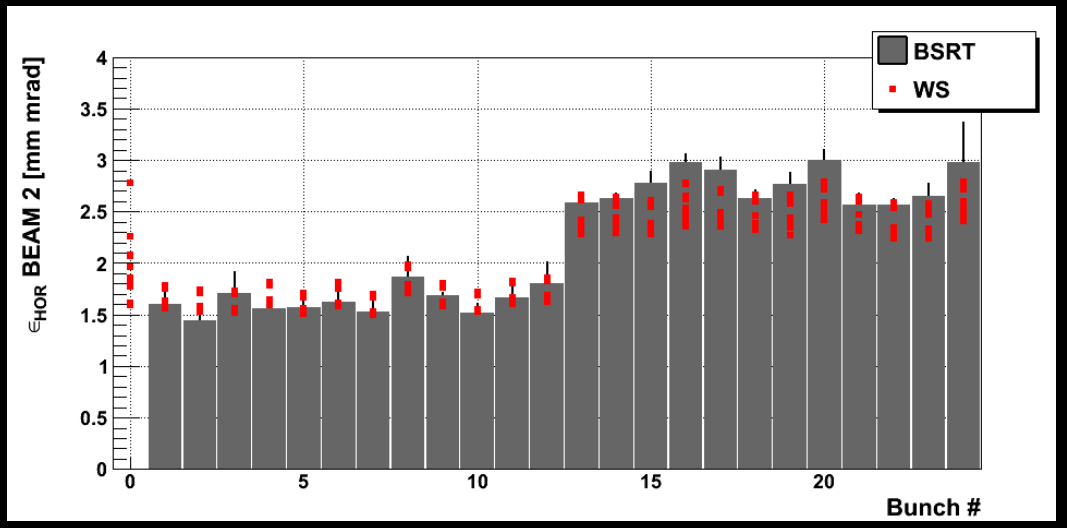


CONCLUSION
- WS – BSRT b-to-b agreement ~ 1%
- Obtained during special MD period (BI experts optimization)

BSRT – Limitations & Actions

Not so Good - B2 H @ 3.5 TeV

- Single correction factor doesn't work for both small & big bunches
- Indicates scaling factor in addition to correction in quadrature
  - Confirmed by correction factor vs beta function correlation



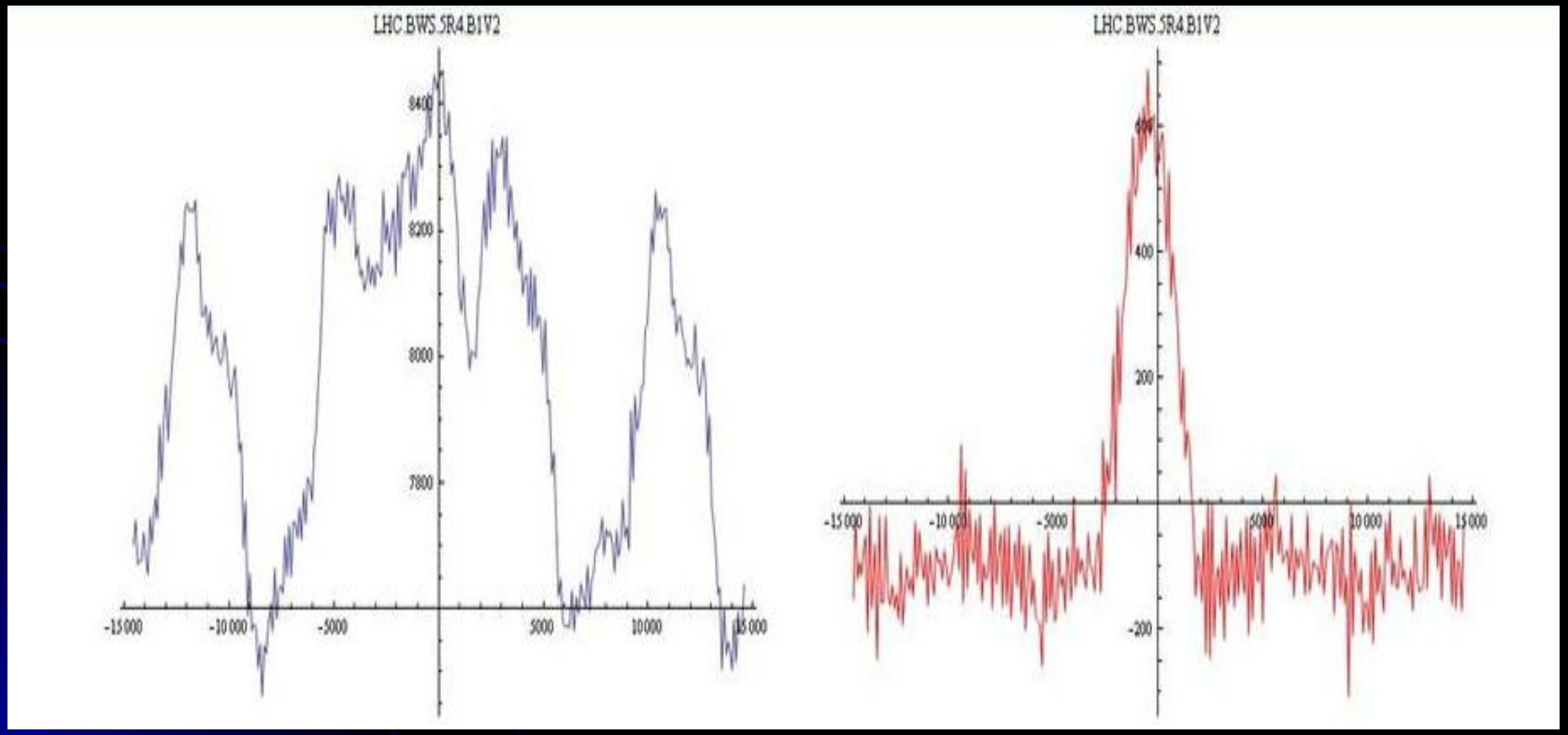
Actions 2012:

- Publish corrected sigmas within error of ±10% at injection & top energy
- Understand sources of errors
  - Analyze in detail data from last MD & perform new MDs to
    - Determine magnification at 450 and 3500 GeV via closed orbit bumps
    - Verify that with such magnifications correction factors work for all bunch sizes
  - Still have to completely exclude any dependence on intensifier gain
- Verify the steering of the optical line
  - Additional camera installed to look at where the light hits the extraction mirror
- Move front-end software to new LINUX PC
  - Allows quicker processing to acquire bunch by bunch profiles a factor 10 faster

Wire Scanners

Wire Scanners

- Noise on B1 signal
  - Source investigated during several technical stops – not identified
- Solution:
  - Acquire signal in abort gap
  - Subtract this baseline from the bunch signal
  - Tested in MD3 & successfully applied for subsequent operation



Wire Scanners

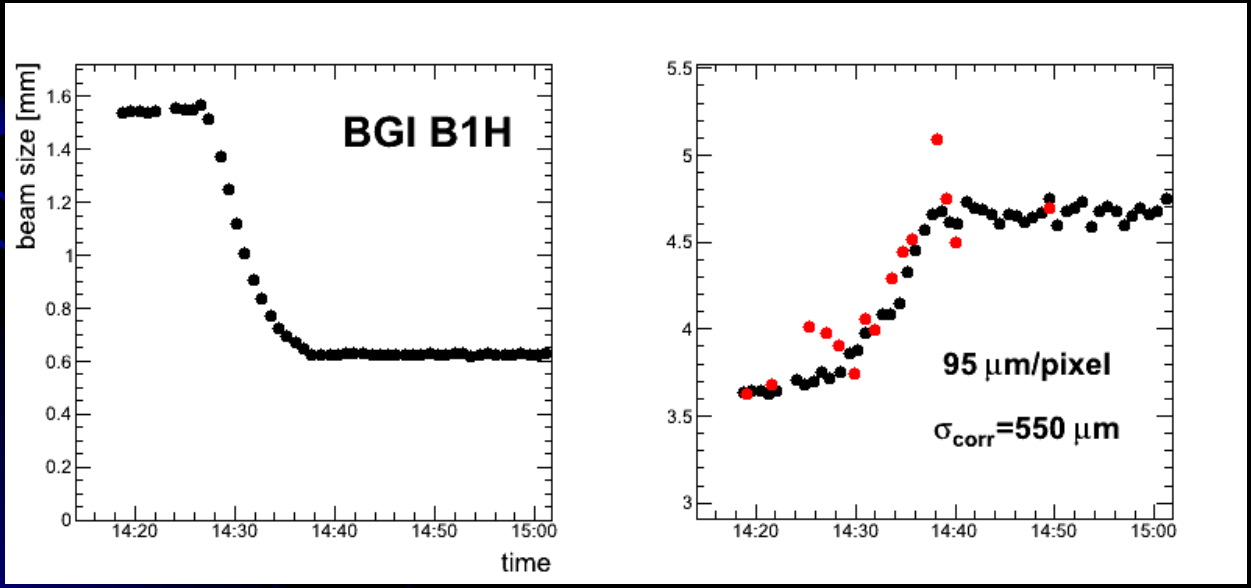
- Vital for X-calibration of other beam size measurement devices
  - Only possible with low intensity beam (Quench & wire breakage limits)

Studies Performed in 2011

- Consistency Checks
  - Comparison of turn vs bunch mode:
    - Both modes gave same beam size to within 2%
- Bunch by bunch cross talk measurements:
  - 25ns $\Rightarrow$ residual signal from 1 bunch to the next ~8%
  - 50ns $\Rightarrow$ residual signal from 1 bunch to the next ~2.5%
- Ease of use
  - Finding optimal PM gain & filter settings not straightforward
    - Particularly important during ramp measurements
    - 2011 MDs used to check system linearity
- Main goals for 2012:
  - Automatic PM gain & filter settings to fit beam parameters
  - Automatic scans at intervals throughout injection, ramp & squeeze
    - When beam conditions allow

Rest Gas Ionisation Monitor (BGI)

- Development throughout 2011
  - Integration of camera gain & gate control
  - Integration of gas injection control (now controlled by OP application)
- Issues in 2011
  - Image intensifiers (MCPs) deteriorate & gain becomes non-uniform
    - Procedure to correct this effect deployed in front-end server
    - MCPs exchanged during this winter Technical Stop
      - Only possible for one beam due to issues with leak tightness
- Accuracy of calculated emittance
  - Similar to the BSRT the obtained emittance does not always agree with WS
  - Needs further study – both simulations & MDs - in 2012



Other Systems in 1 Sentence

- Abort Gap
  - Used for monitoring – needs work to make it robust
- Schottky
  - Works well for ions – issues with coherent signals with protons
- Head-Tail
  - Operational – added automatic instability trigger
- Wall Current Monitor
  - Work on-going to improve overall frequency response of system
- Diamond Beam Loss Detectors
  - Installed in collimation and injection regions allowing losses to be distinguished on a bunch by bunch basis
- BTV Screens
  - Recent issues found with RF fingers – 5 of 6 not OK (1 repaired)
    - Should only be used if absolutely necessary in 2012 (disabled)

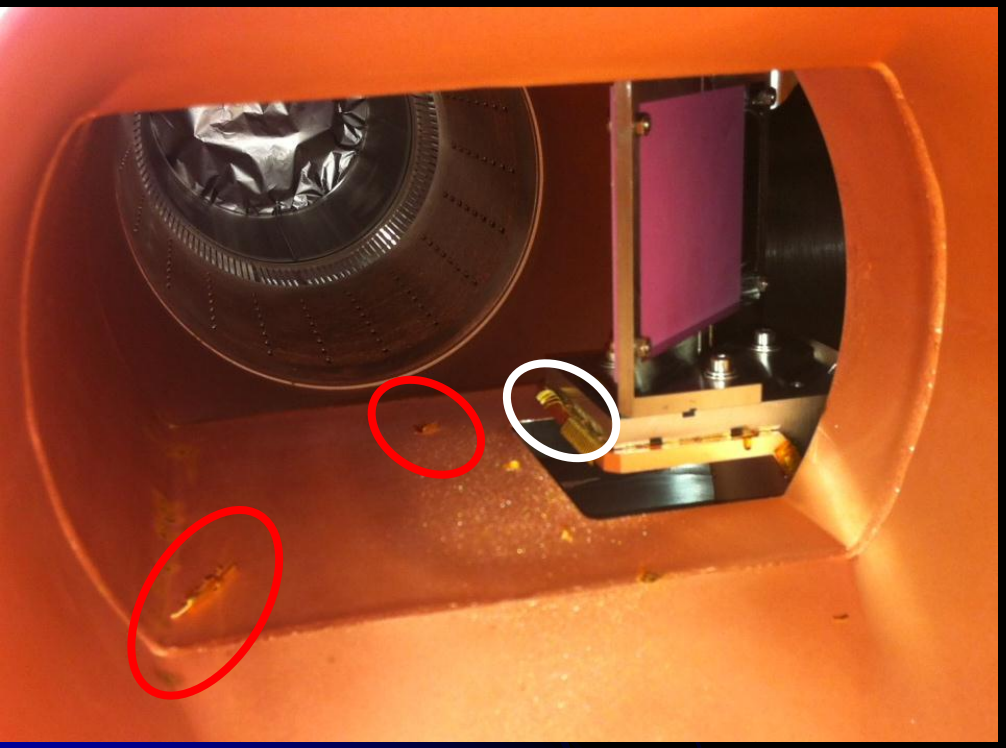
Conclusions

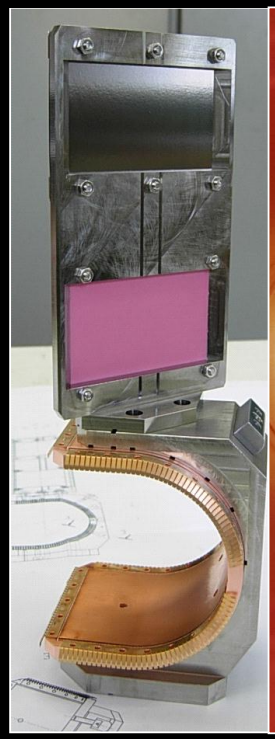
- Overall a very good performance of BI systems in 2011
  - MD time vital
    - for a better understanding of these systems
    - to test improvements before making them operational

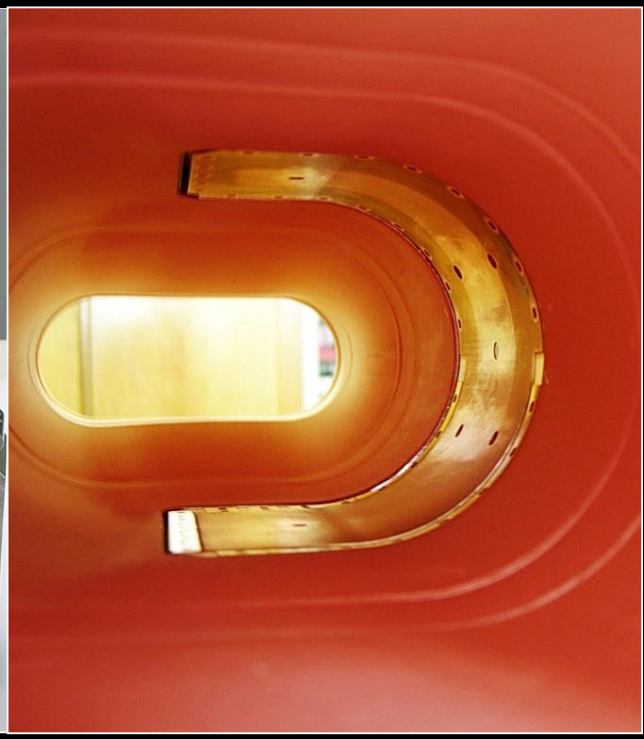
- Main Objectives for 2012
  - BPM
    - Make the LSS BPMs more reliable
  - BCT
    - Finalise dI/dt electronics
  - LDM
    - Should be fully automatic with improved fixed display
  - Wire scanner
    - Introduce automatic gain & filter settings
  - BSRT
    - Achieve 10 times faster bunch-by-bunch measurement
  - BGI
    - Provide independent continuous emittance measurement

BTV Situation

- Observation
  - Broken RF contacts on dummy chamber
    - 4 of 6 now seen to suffer from this
  - X-rays will be performed to check aperture
    - Also check BTVSI/BTVM design







BTV Situation

- Why?
  - Subsequent movement in tunnel did not show any obvious mechanical misalignment issue
  - Initial checks on contacts does not indicate loss of elasticity
  - Surface analysis on contacts underway to try determine cause
- BTVST.A4R8 repaired, but not enough time or spare parts to repair remaining 4 affected monitors (Pt 2, 6, 8)
- Proposal
  - Lock BTVs in their “circulating beam” configuration
    - No images possible
    - No major impact for injection/extraction if no issues found (Brennan)
      - Can still decide to use BTVs if necessary
      - Carries a small risk of inducing an aperture restriction or vacuum leak
- To check
  - Can missing RF fingers lead to impedance issues?
  - Spares situation – ensure necessary spares available ASAP