# Status of Tune and Orbit Measurements and Correction, Testing Strategy

M. ANDERSEN, G. BAUD, M. BETZ, C. BOCCARD, A. BOCCARDI,
E. CALVO, J. FULLERTON, M. GASIOR, S. JACKSON, L. JENSEN, R. JONES,
**T. LEFEVRE**, J. OLEXA, J.J. SAVIOZ, R. STEINHAGEN, M. WENDT, J. WENNINGER

# OUTLINE

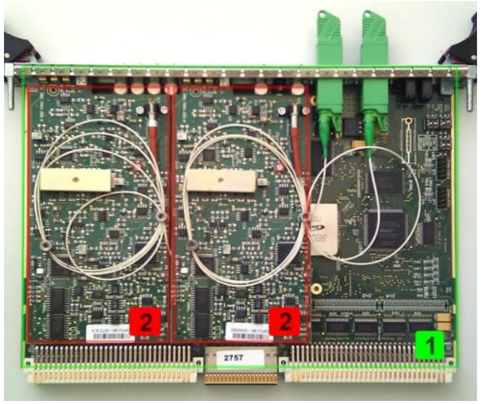
- Status of Beam Position Monitor
  - Hardware and software upgrades
  - Implementation of DOROS
- Status of Tune monitors
  - Tune monitoring systems for post LS1 operation
  - Overhaul of Schottky monitors
- Status of Feedback systems
  - Hardware and software modifications
- Conclusions

*HT and Instability monitors not covered in this talk (see daniel’s talk) !!*

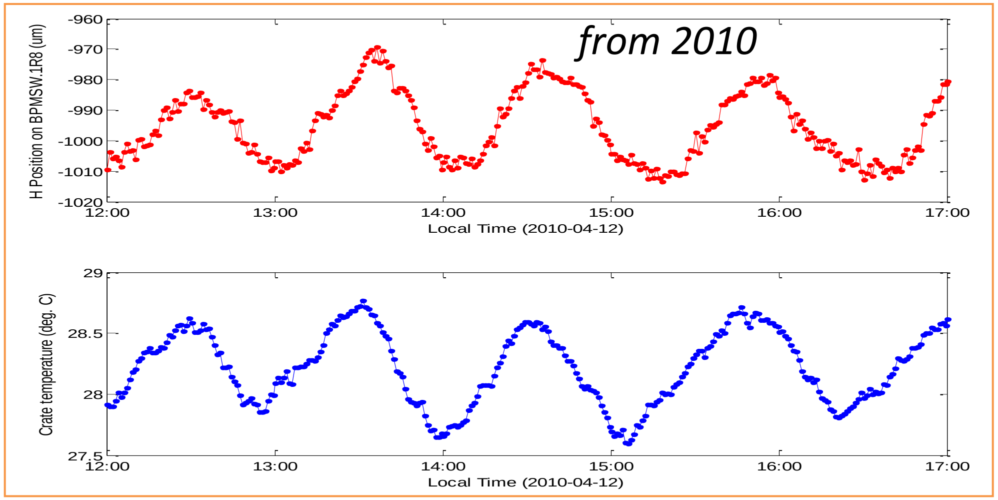
# BPM – Standard WBTN

- The WBTN resolution in Orbit mode measured ~few µm

- *Suffered from long-term drift in position due to temperature variation in VME integrator mezzanine*




VME based Digital Acquisition Board and WBTN Mezzanine Cards

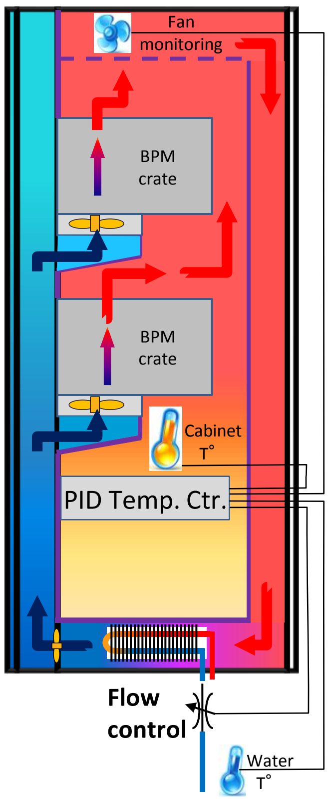


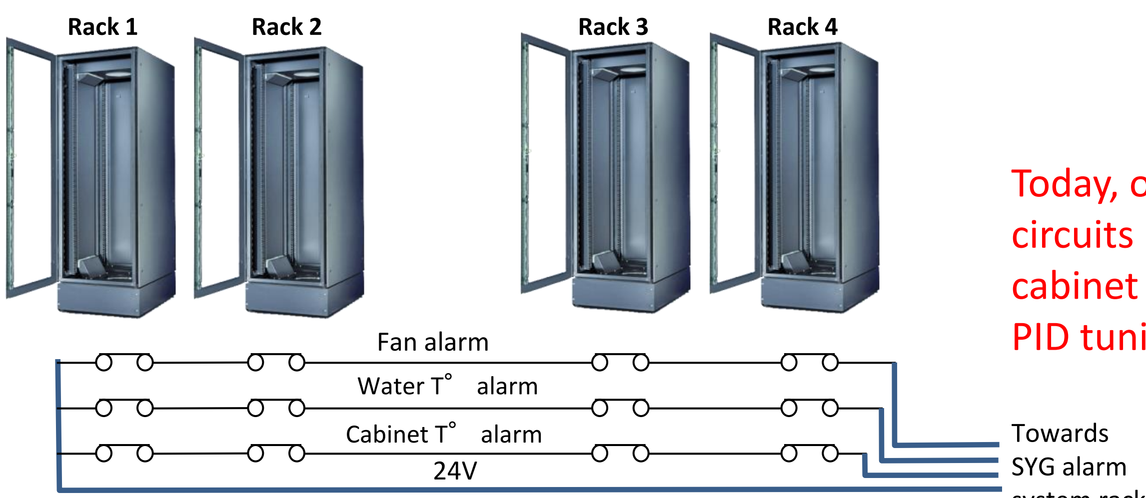

- *Installation of Water cooled racks (48) completed by the end of April (10 months of installation)*

# BPM – Water cooled racks

## Thermalized Racks (BPM & BLM) consist of:

- A temperature controller module that regulates the cool water flow depending or the cabinet temperature and monitors the status of the alarms.
- 3 Alarms (per IP) have been implemented will be sent to TIM at the CCC :
  - Inlet water temperature, status of Rack fan , Cabinet temperature
- if the last alarm (T° inside the cabinet) exceeds a safety level, the rack doors will open automatically
- Alarms consist in NC (normally closed) switches connected via daisy chain
- No direct connection to BIS foreseen for the moment !

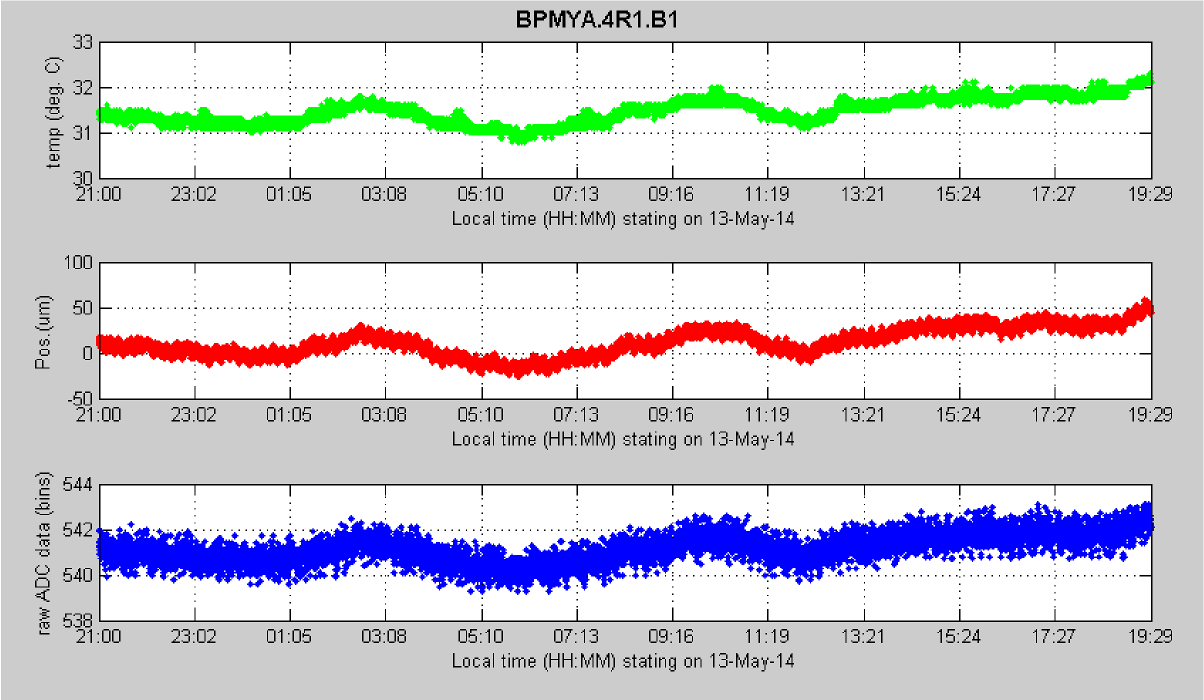



Today, only SR1 and SR6 have the water circuits "in service". Currently studying the cabinet temperature stability. Water flow and PID tuning optimization is being assessed

# BPM – Water cooled racks

- One example of the evolution of temperature variations and BPM reading over one day (13th May 2014) – using calibration signals



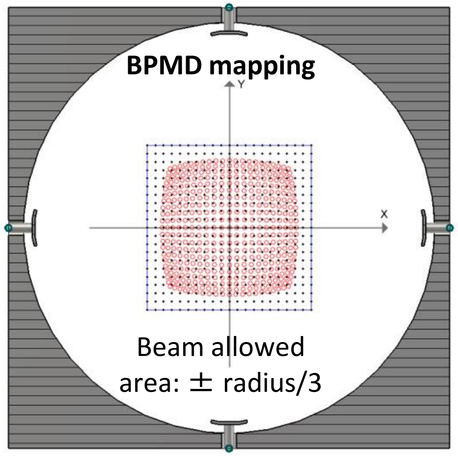

- Water-cooled racks will keep the temperature variations within 1° C peak to peak over 22h (compared to 10° C without the rack)

- Tp correction algorithm to be used to correct further the observed drift
  - *RMS noise measured to be between 2-5um depending on the channels (possibly hitting the stability of our calibration source)*

# BPMs during LS1

- Hardware Modifications:
  - 2 new BPMs installed in IR4 close to BGI
  - Few BPMs modified, repaired, displaced (roman pots)
    - 50Ω terminated strip-lines for ALFA, mechanical modifications to improve alignment, NEG coating, ..
  - Survey campaign
    - Verify position of 'usual' suspect BPMs, i.e. BPMD..
    - Difficulty to align precisely BPMs @Q1
  - Replacing VME crate's CPUs (MEN A20) – *involving Firmware upgrades*

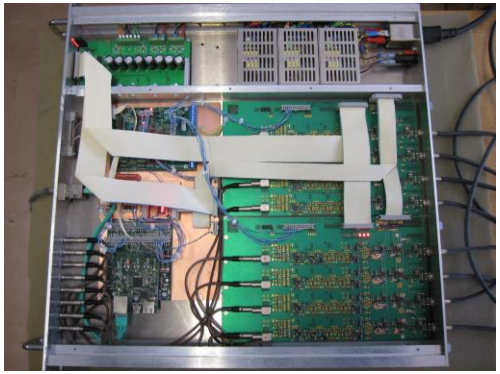
- Software modifications:
  - BPM non-linearity corrections using a 2-D cross-term polynomial
    - Reducing the maximum error from 6mm to 100um with an average error < 30um

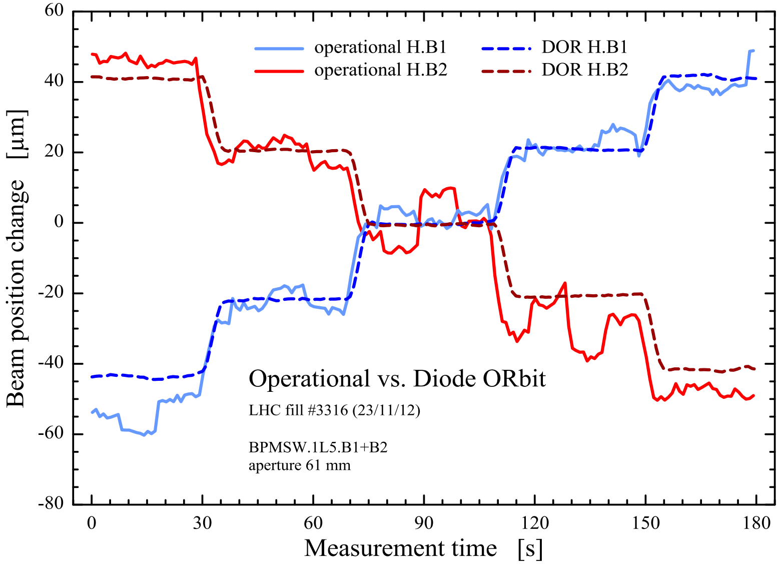


# BPM with DOROS

- DOROS developed to process BPM signals with <um resolution
  - It is optimised for
    - position resolution, absolute accuracy of centred beam, robustness and simplicity
  - It assumes:
    - bunch-by-bunch is not needed, required bandwidth is in the Hz range
    - larger beam offsets (> 1 mm) not measured with high precision (< 1 µm)

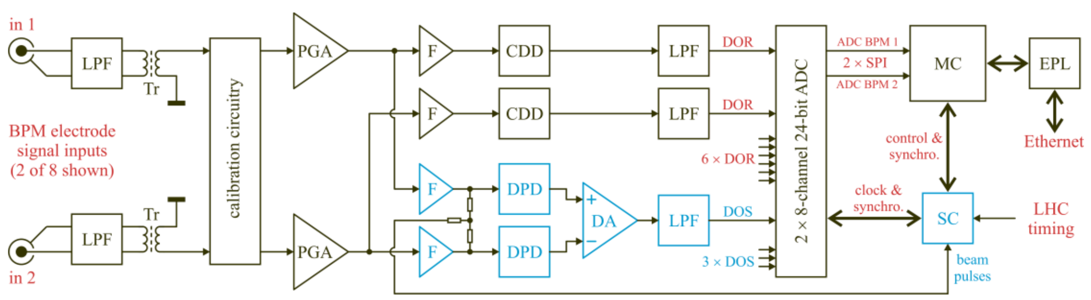
- Prototyped for Collimators BPMs, Demonstrated sub-micrometre resolution at SPS and LHC





# BPM with DOROS

- Analogue signal conditioning of each BPM electrodes (including beam calibration)
- Diode ORbit (DOR) as a high resolution position measurement
- Diode OScillation (DOS) ≈ BBQ on each BPM
  - *OS needs a synchronous timing (BST - turn clock)*
  - *Possibly 10 less sensitive than BBQ systems : Synchronous detection at two selectable frequencies, assumes beam excitation hopefully only at the 10 micrometre level – using ADT or AC dipole*
- Digitalisation using 24-bit ADCs sampling at $f_{rev}$ *(BST turn clock or local clock)*
- FPGA real-time data processing
  - Allowing measurement of local betatron coupling and betatron phase advance
  - Data serialisation and transmission using UDP frames



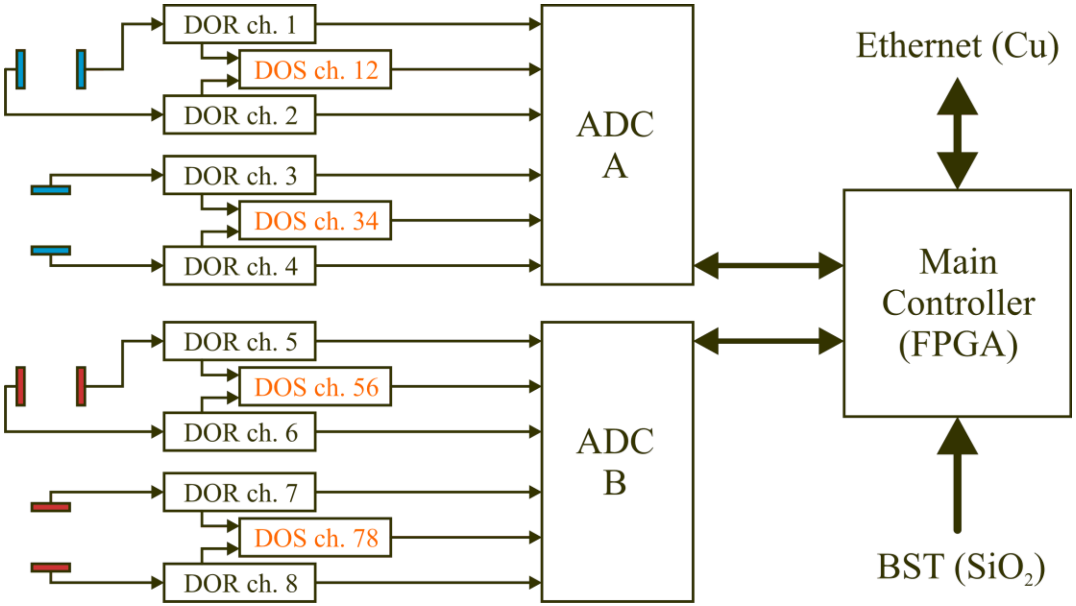

LPF = Low Pass Filter
PGA = Programmable Gain Amplifier
F = Follower

CDD = Compensated Diode Detector
DPD = Diode Peak Detector
DA = Differential Amplifier

MC = Main Controller
SC = Synchronisation Circuitry
EPL = Ethernet Physical Layer

# BPM with DOROS

- The essence of one DOROS unit:
  - Standalone Architecture using 1U 19” boxes (no VME, no operating system)
  - 8 orbit ADC channels, 4 oscillation ADC channels
    - 2 collimators with 4 buttons each
    - 2 regular 4-electrode BPMs
  - Ethernet (UDP) data transmission implemented on FPGA

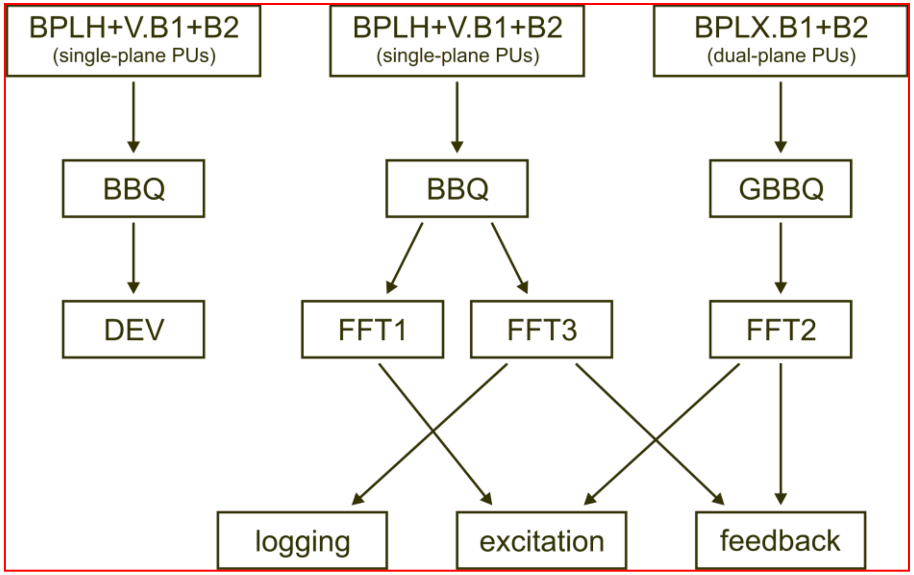


# DOROS post LS1

- DOROS will be installed on
  - New TCTP and TCSP collimators (x18)
  - In parallel to standard BPM electronics
    - Q1 strip-line BPMs in IP1,2,5 & 8 (x8)
    - Q7 strip-line BPMs in IP1 (x4) for coupling measurements
    - TOTEM's button BPMs (x8) in IP5
    - *May be few add. channels - on-going discussions between OP-ABP-BI*
- Operation with DOROS in 2015
  - Evaluate the system performance
    - In terms of Resolution, Accuracy, Stability, …. (sensitivity to cross-talks between the two beams in directional strip-line)
    - Develop its software and operational procedures, i.e. calibration, gain adjustment, BST synchronisation for oscillation, etc….
  - Prepare next phase and upgrade
    - Possibly deploying up to Q7
    - …

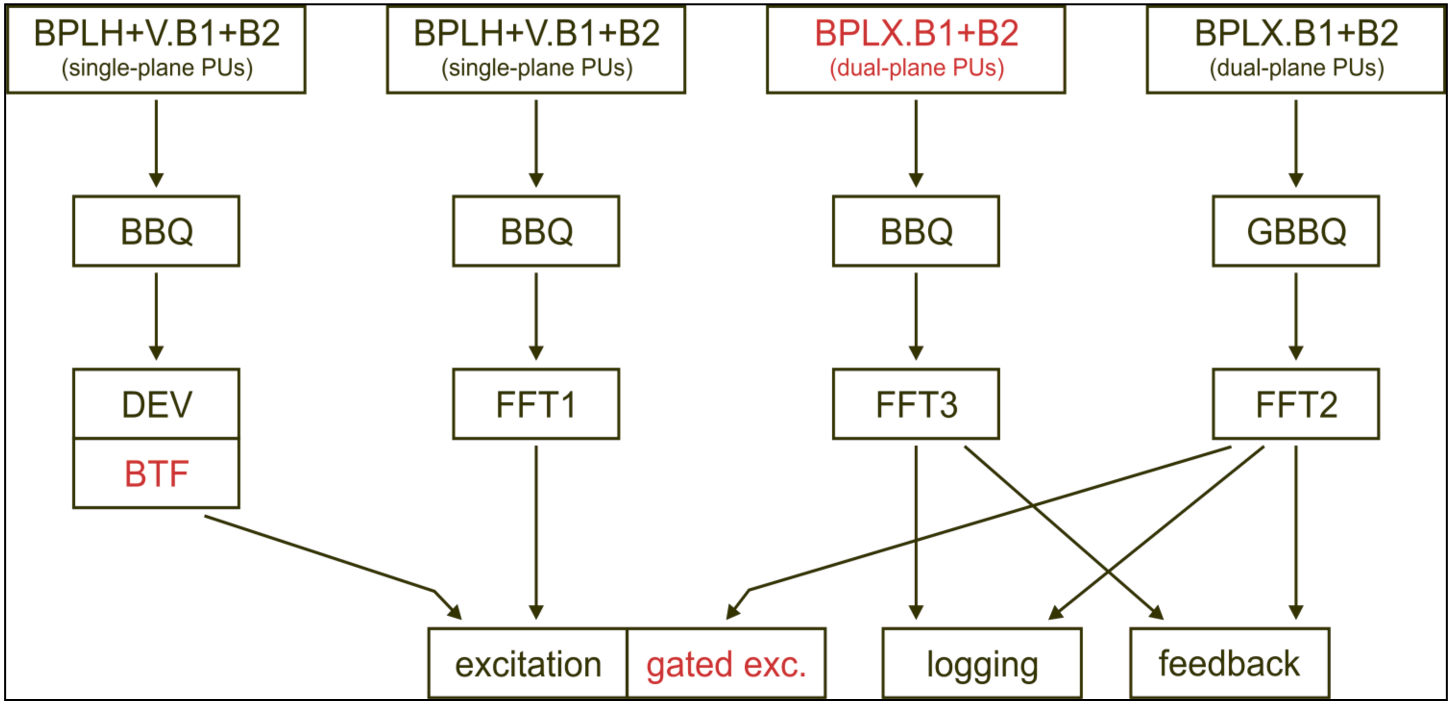
# TUNE Systems in 2012

- 3 sets of pick-ups for each beam
  - Single or dual plane pick-ups
    - Single plane pick-ups not optimum for coupling measurement because @ different locations




- Used by 4 independent acquisition systems:
  - FFT1- "On demand" system used to perform measurements requiring changes in the acquisition settings and beam excitation, like chromaticity measurement
  - FFT2-"Continuous gated BBQ" and FFT3-"Continuous BBQ" systems used for feedback and continuous measurements of tune and coupling
    - The feedback functionality implies that the acquisition settings are fixed
    - Continuous system sees all bunches – e.g. observing beam instability
  - DEV: Development system used for beam studies and kept as a hot spare

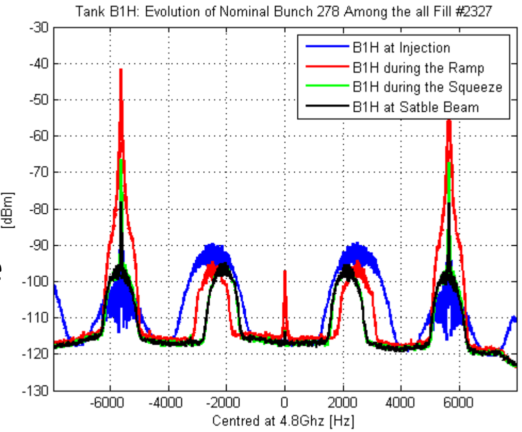
# TUNE Systems in 2015

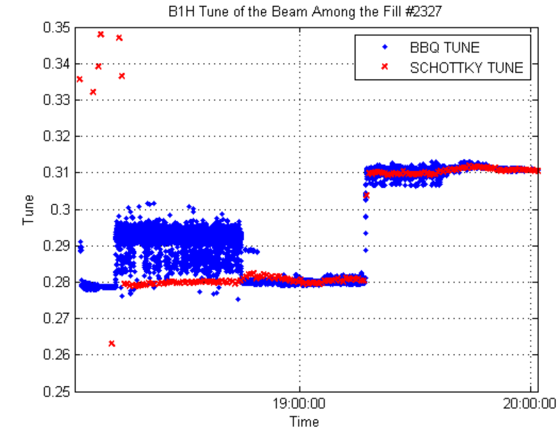



- 2 new dual-plane BPLX pickups – one for each beam (optimize functionalities)
  - Better coupling measurements with both continuous (BBQ & GBBQ) systems
  - New "gated excitation" option to excite only the bunches (typically 6) seen by the BBQ if the natural beam excitation does not provide an acceptable S/N ratio
- New Beam Transfer Function (BTF) measurement (derived from the PLL)
  - It will be first deployed as a MD tool on the DEV system

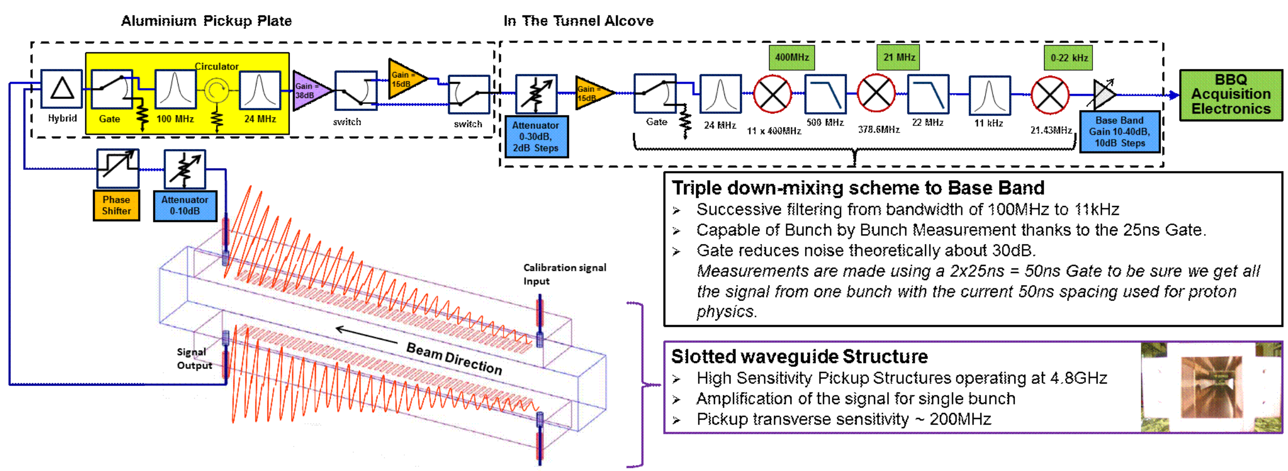
# Schottky Monitors pre LS1

- $Pb^{82+}$ ion run 2011
  - Stable, high level Schottky signals on all ion fills for B1H, B1V and B2H.
  - Reliable single bunch measurements for the tune, and possible also for the chromaticity



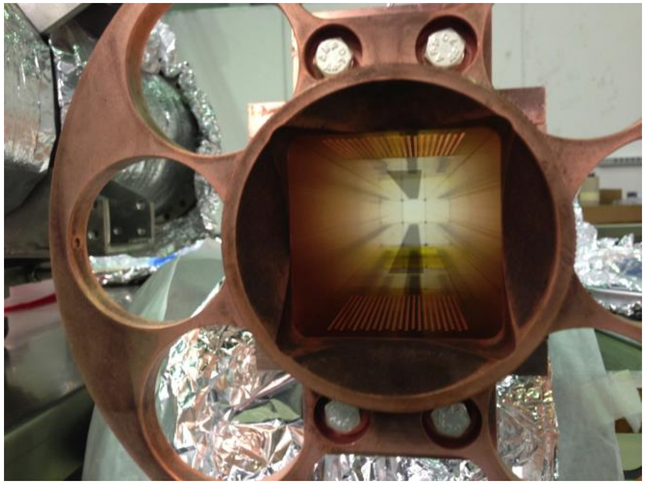

- Proton run in 2012
  - Still acceptable Schottky signals, single and multi-bunch at injection and top, but only on B1H.
  - Large coherent signals saturate and destroy pre-amps
  - Missing controls to balance electrode signals, and to change the operational frequency
  - Promising modification of the B2V gating topology
    - Significant reduction of the coherent signal peaks, however, no increase of the Schottky signal levels.

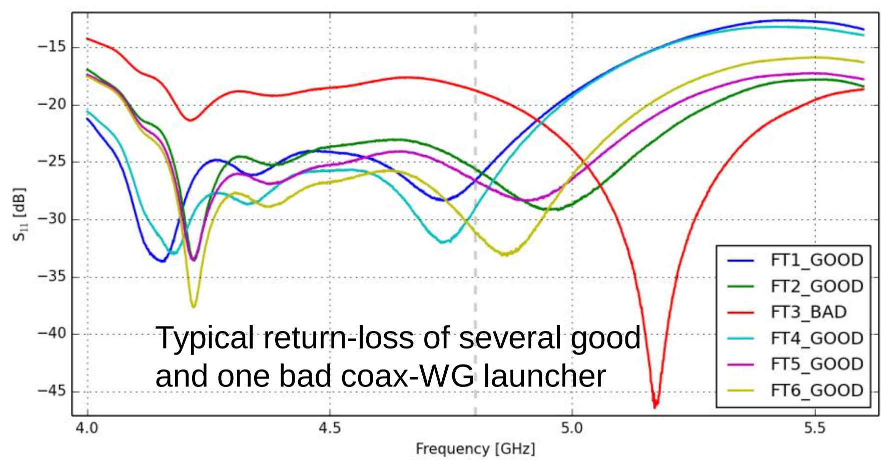



*Analogue Processing Chain describing the modified pickup plate with the addition of a gate and a 24 MHz filter (elements highlighted in yellow).*

# New LHC Schottky Pick-up’s

- All 4 LHC Schottky pickup’s have been renewed, and are (almost) ready for re-installation
  - New waveguides made out of copper, to keep the thermal expansion matched to the slotted CuBe coupling foils
    - This avoids a warping of the foils after the bake-out procedure
    - Canted coil-springs are used to guarantee a good RF contact between the individual parts of the sandwich construction
  - New coaxial-to-waveguide launcher design with improved return-loss to minimize reflections and standing waves
    - ~20…25 dB return loss in the range 4.6…5.0 GHz





# LHC Schottky: Next steps

- Improvements on the RF front-end – Still experimental!
  We will not modify all Schottky electronics for the LHC restart
  - Implementation of fast, high isolation gate switches
    - Based on a KEK design
    - Will be located in front of the amplifiers to allow narrow band operation
  - Tunable operation frequency in the 4.6…5.0 GHz range
    - Allows to find a “sweet spot” for the operation and minimize the coherent signals
    - Requires tunable 1st LO and new narrowband input BP filter (YIG)
  - Add control electronics for all attenuators and phase shifters
    - This allows to balance the electrode signals,
      i.e. to minimize the coherent, common mode signal background
- Modifications in the control software
  - Adapt control software to the hardware modifications
    - Extend remote controls to all attenuators and phase shifters
  - Overhaul of the Java user application software
    - Separate low-level control software from the user interface

# FEEDBACK – Hardware

- From 6 (in 2012) to 4 new (in 2015) machines
  - ‘Test’ Machines (x2) will not be replaced
  - New Gen8 machines will replace old G5s
    - Gen8 24 thread 32GB versus G5 4 thread 12GB
  - Operational Controller and Service Unit
    - Will start with exactly pre-LS1 configuration (SLC5, 32bit)
    - Running pre-LS1 versions of OFC and OFSU with minimum changes
  - 2 ‘dev’ machines – for testing
    - Will start with SLC6 64 bit
    - Running the next versions of the OFC and OFSU
- New hardware in CCR to be installed soon to forward orbit trigger to OFC
  - Hardware ready (Raspberry Pi)
  - Software currently being made – ready before start-up

# FEEDBACK – Software (1/3)

- Operational Machines for start-up
  - Updates for Power converter changes
    - Adapt the feedback to the new QPS threshold
  - Data from collimation (DOROS) pick-ups will be accepted and processed in the OFC loop
  - Changes to Optics data injection in OFSU
  - OFSU will remain in FESA2 !

# FEEDBACK – Software (2/3)

- Development Machines
  - All changes as per operational machines
  - OFC will run in 64 bit mode (already compiled)
    - Also investigate introduction of CTR timing to the controller meaning the OFSU is less critical to operations
  - We will investigate splitting OFSU to 2 new FESA 3 classes
    - One for the OFSU proxy
    - One for the OFSU optics 1 settings handling
    - We might even break down further
  - We will investigate the impact of running the OFSU and OFC on the same machine
    - This way we can exploit the increase in thread performance
    - No more private 2$^{nd}$ ethernet link

# FEEDBACK – Software (3/3)

- Introduction of new ‘Dev’ changes
  - During ‘quiet’ periods to avoid (minimize) disruptions to operation
    - OFC will be subtly switched hopefully without any impact on operations
    - OFSU is more difficult…
      - We will kill the ‘operational’ FESA 2 OFSU, then startup our new FESA 3 versions for testing
      - Possibly certain OFSU functionality will be unavailable during this period

      e.g. no optics management if we are testing the new OFSU proxy only
  - We expect that the structural changes will become operational after a few months of testing
  - The elimination of the *tinterlink* (private ethernet link) will come later in 2015

# CONCLUSIONS (1/2)

- Improvements on Beam Position Monitors
  - Thermalized racks for better stability and reproducibility (aims at <10um)
    - Watch out the new alarms !
  - Make use of the synchronous orbit mode for common region BPMs
    - Limiting the cross-talk between the two beams – need MD's time for validation
  - Implement better correction of non-linearities for better accuracy
- Implementation of DOROS for high-resolution orbit and betatron phase advance and coupling measurements
  - New system to be put in operation
    - Start with commissioning of collimator BPMs
    - Make use of the high-resolution orbit measurements for Q1 a.s.a.p
    - Assess the overall system performance
  - Possibly deploy it further by end 2015 and 2016

# CONCLUSIONS (2/2)

- Tune systems
  - New pick-ups for better coupling measurements on continuous systems
  - New gated excitation (BI and RF damper) to improve further the gated BBQ
  - BTF as a development tool
  - Keep an eye on the performance of the tune monitoring system based on transverse Damper pick-ups (see Daniel's talk)
  - Strong hope to improve the Schottky monitors and use them with Protons for
    - Monitoring Chromaticity at Injection and Flat top
    - B/B tune measurements during MD's
  - New expert GUI's for Tune and Schottky monitors to include all functionalities
- Feedback systems
  - Will profit from the upgrades of Tune and BPM monitoring systems
  - Starting with new machines running an 'old' version of OFC/OFSU and moving towards FESA 3 and improved versions of OFC and OFSU ....

# Thanks to

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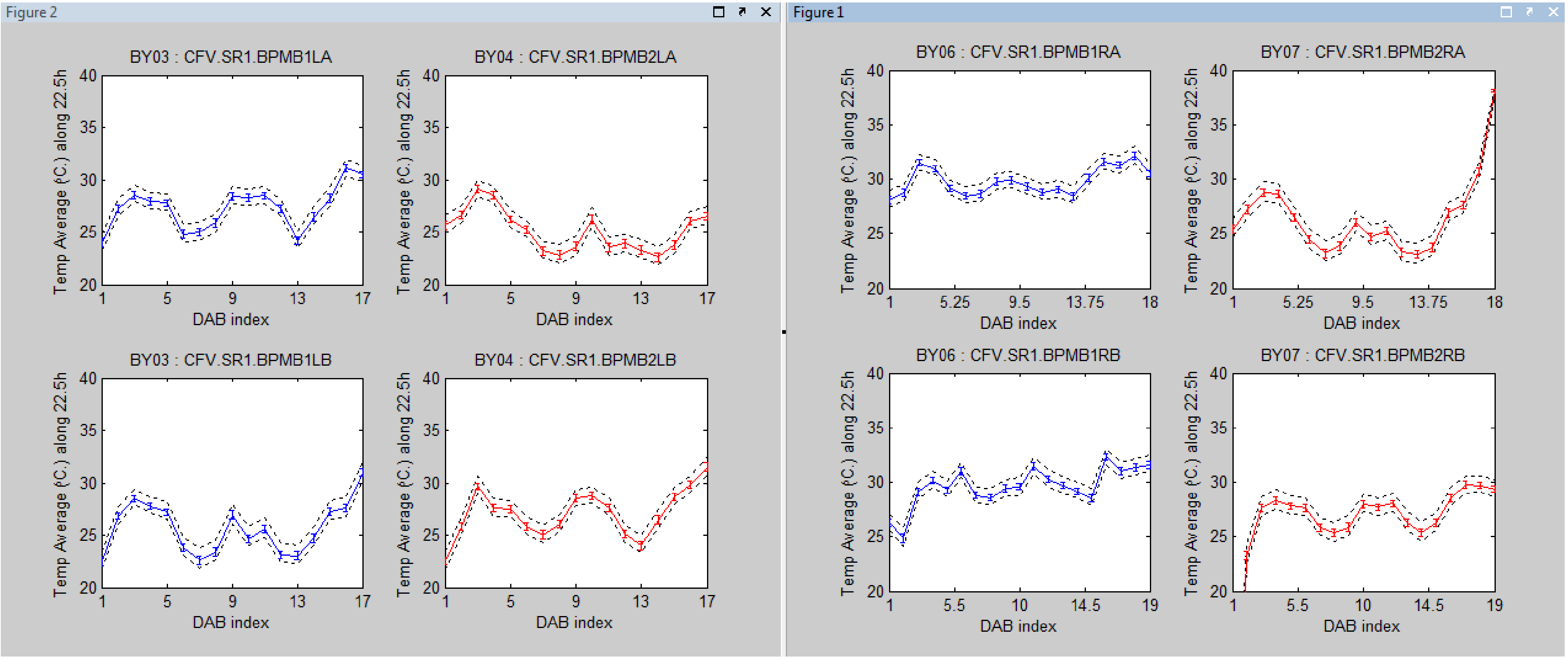
# BPM – Water cooled racks

- 4 racks/Octant, equipped with 2-3 VME crates
- each crates filled up with up to 18 DABs



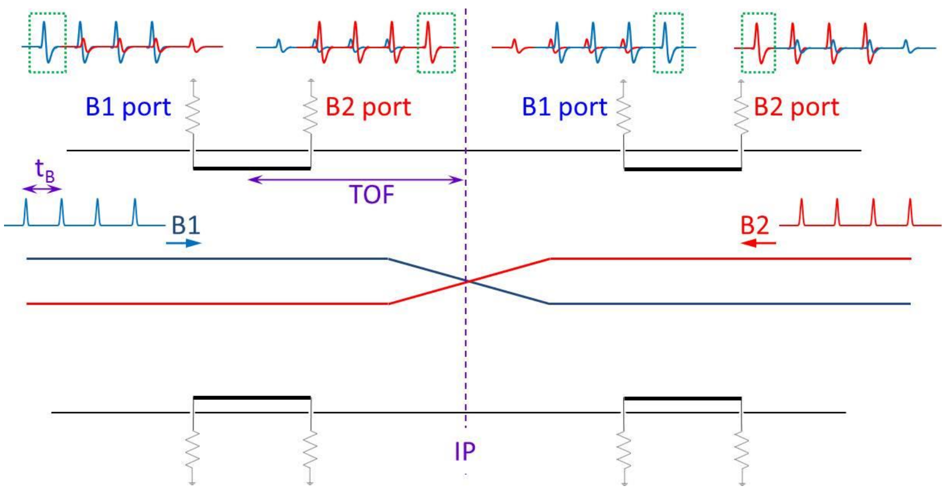
# Orbit resolution in LSS

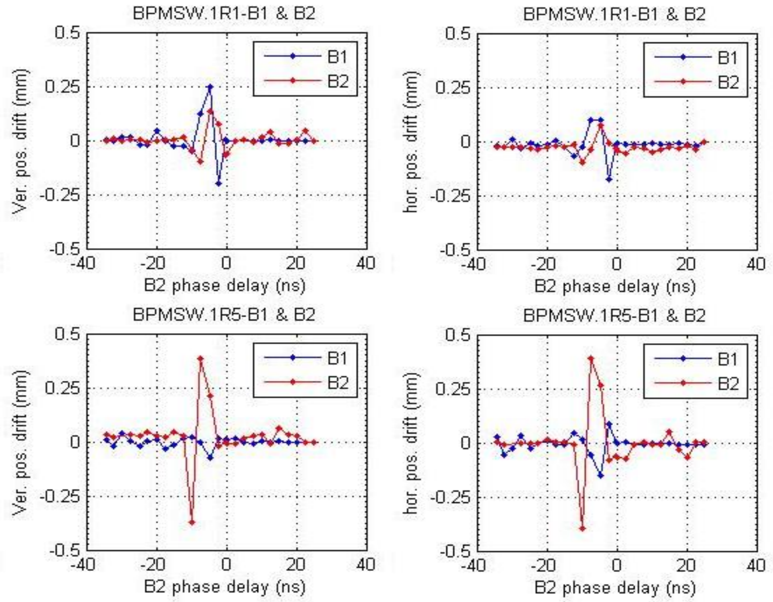
Subject: Cross-talk between both beams in insertion BPMs (stripline).

Solution: Use synchronous mode with orbit calculated from single bunch which has no long range collision close to BPM location. Firmware deployed since January 2011.

Action 2012:

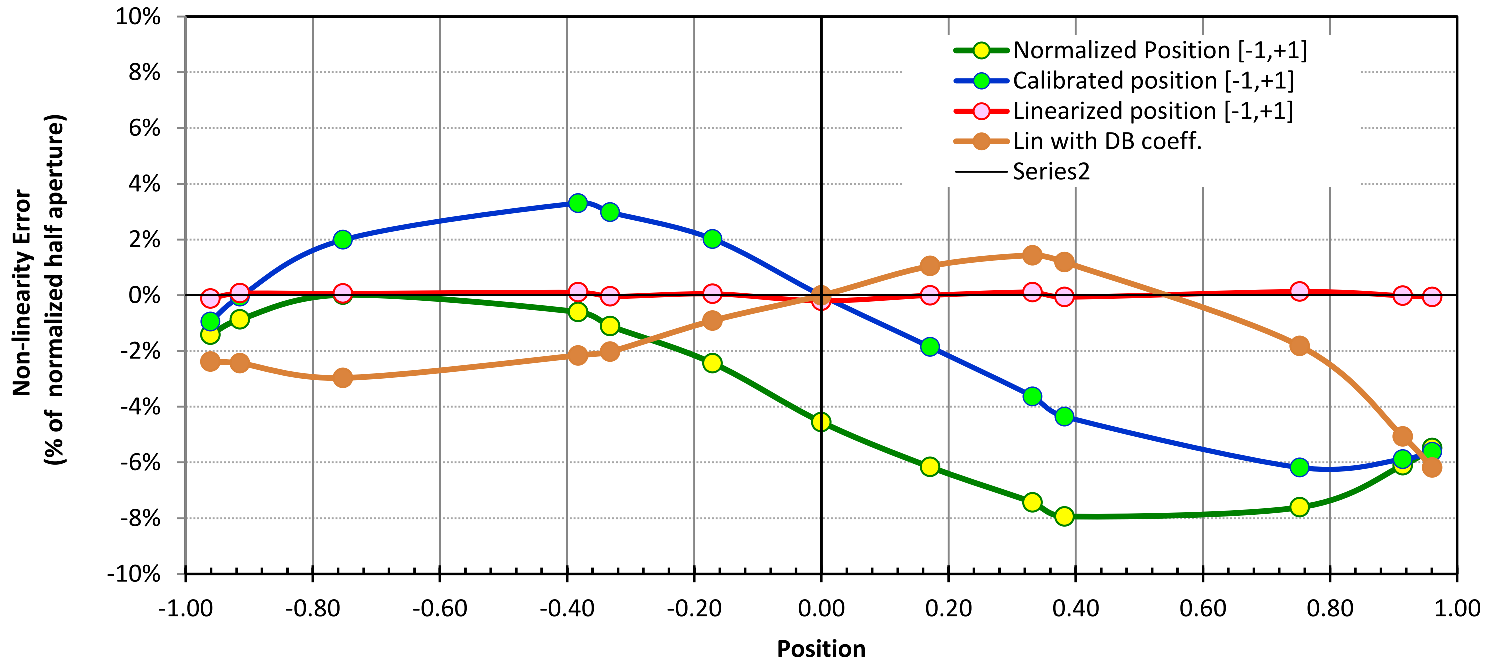
- Mask needs to be configured for each BPM and dynamically as filling progresses
- There is a (OP) person working on an application to do this automatically.



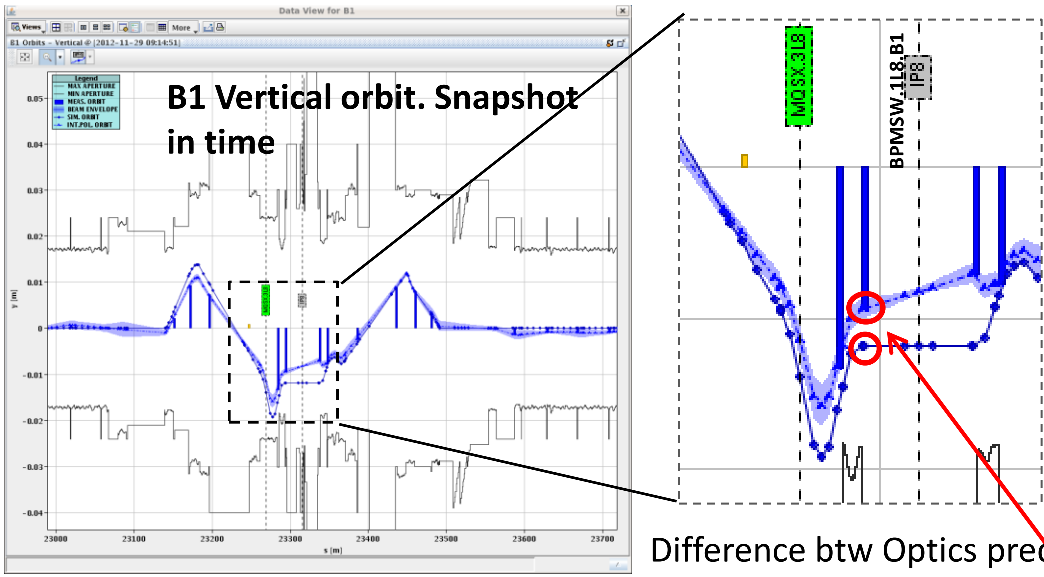
# BPM – non-linearity corrections

- *Issue with 10-20% scaling error in LSS's stripline BPMs*
  - Normaliser non-linearity and error in test-bench using BPM simulator
  - Check with fixed attenuator – found >8% error in worst case



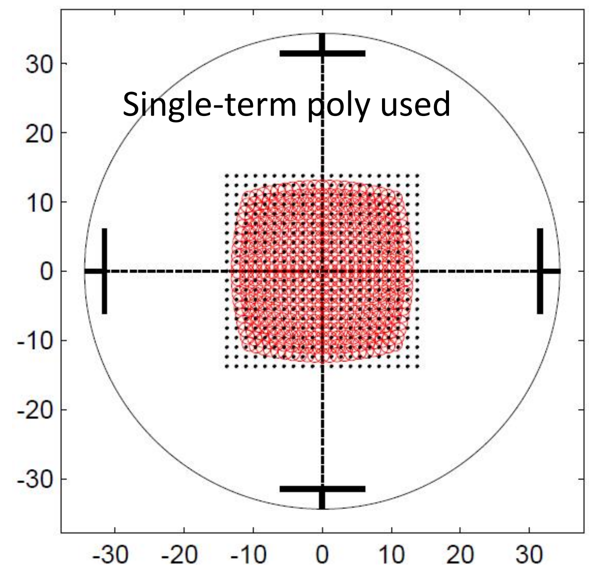

- *Limitation due to limited directivity of stripline BPM in common vacuum chambers : (Cross talk between both beams)*
  - *Mitigation using Synchronous Orbit Mode and selecting appropriate bunch – Tested in MD's on one BPM– To be deployed…(contributions from OP)*

# Beam Position Monitors: BI MD4 IR8 scan (29 Nov. 2012)



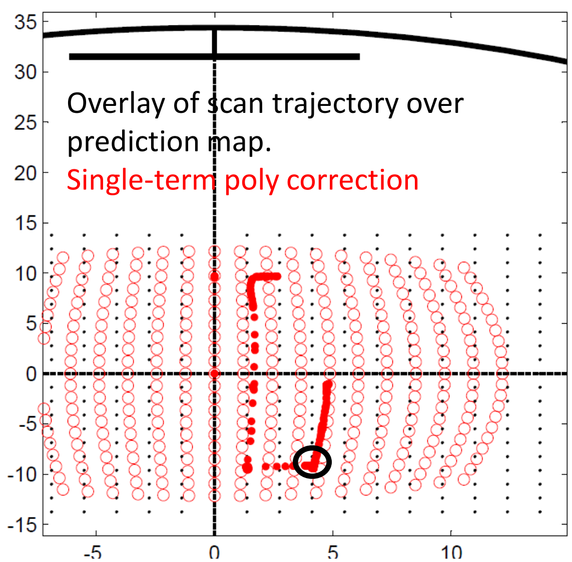

Difference btw Optics prediction and BPM measurement: **~2mm**

BPMSW 68.8mm

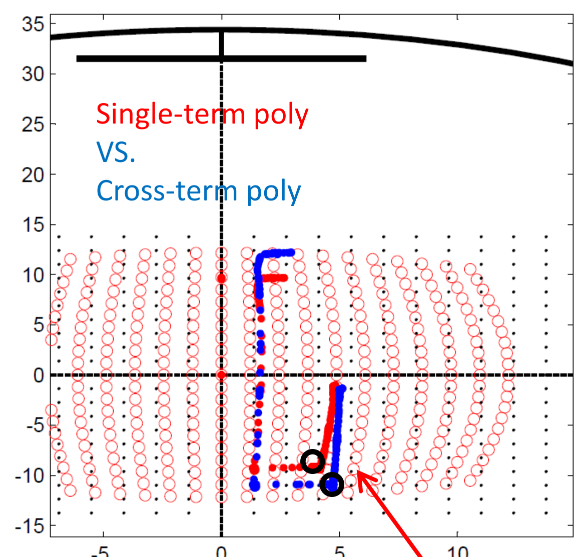



**EM Model: prediction map**

BPMSW 68.8mm

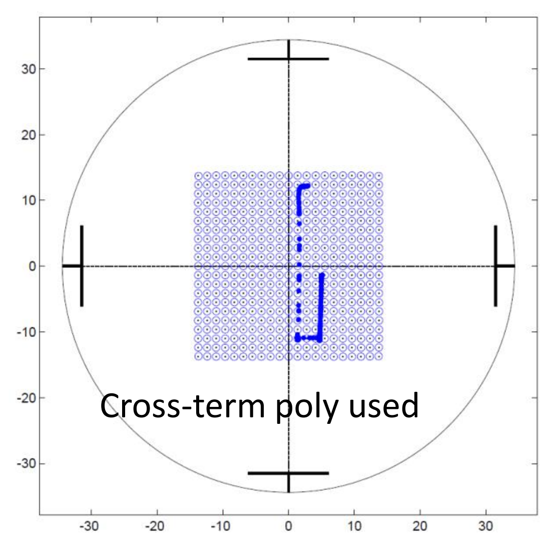



BPMSW 68.8mm

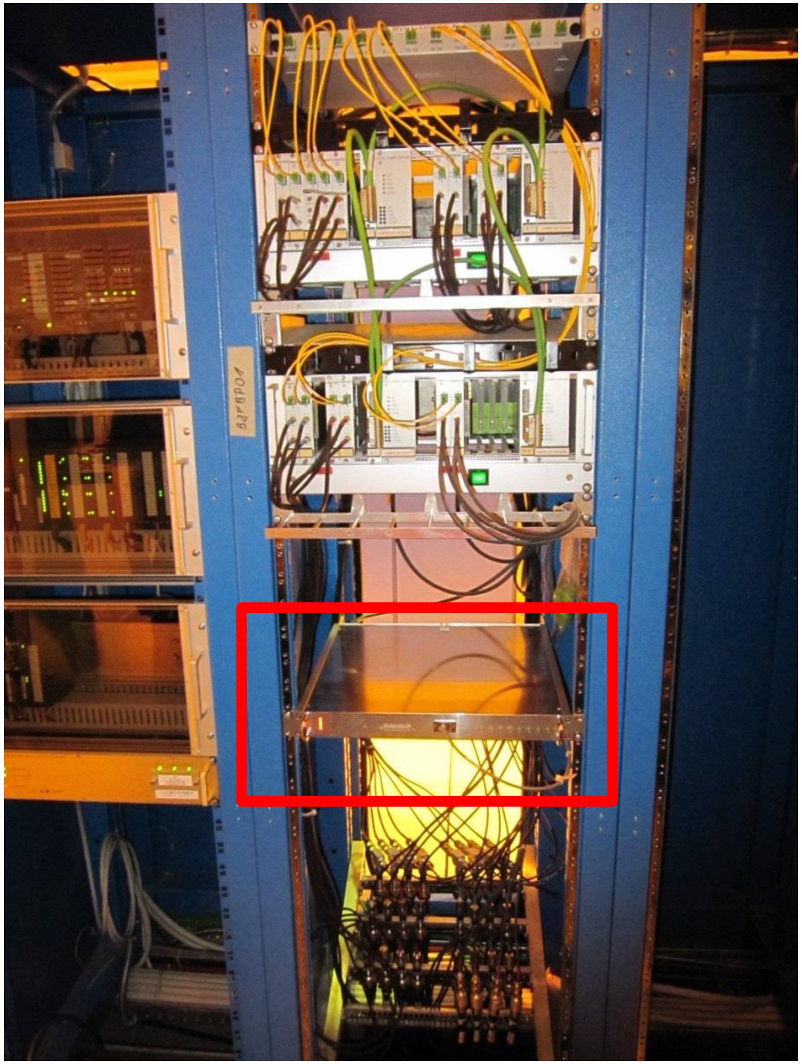



Difference between positions: **~1.8mm**

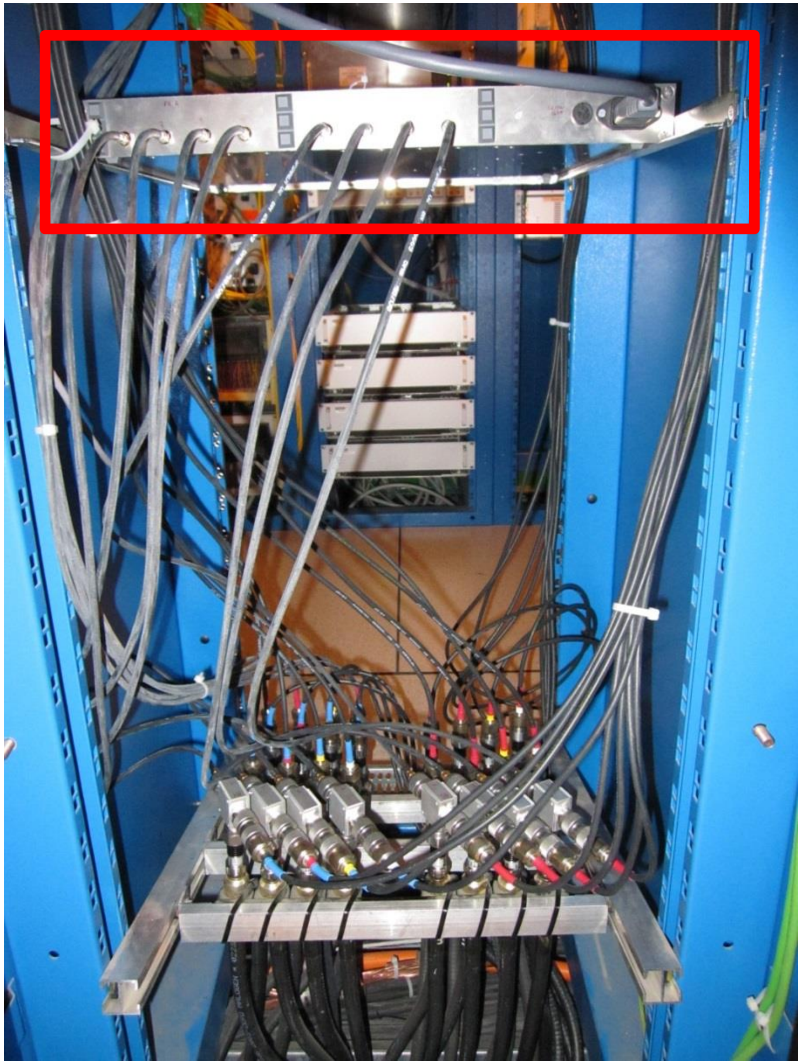
BPMSW 61/68.8mm



# DOROS prototype installation on 2 BPMs at PT5



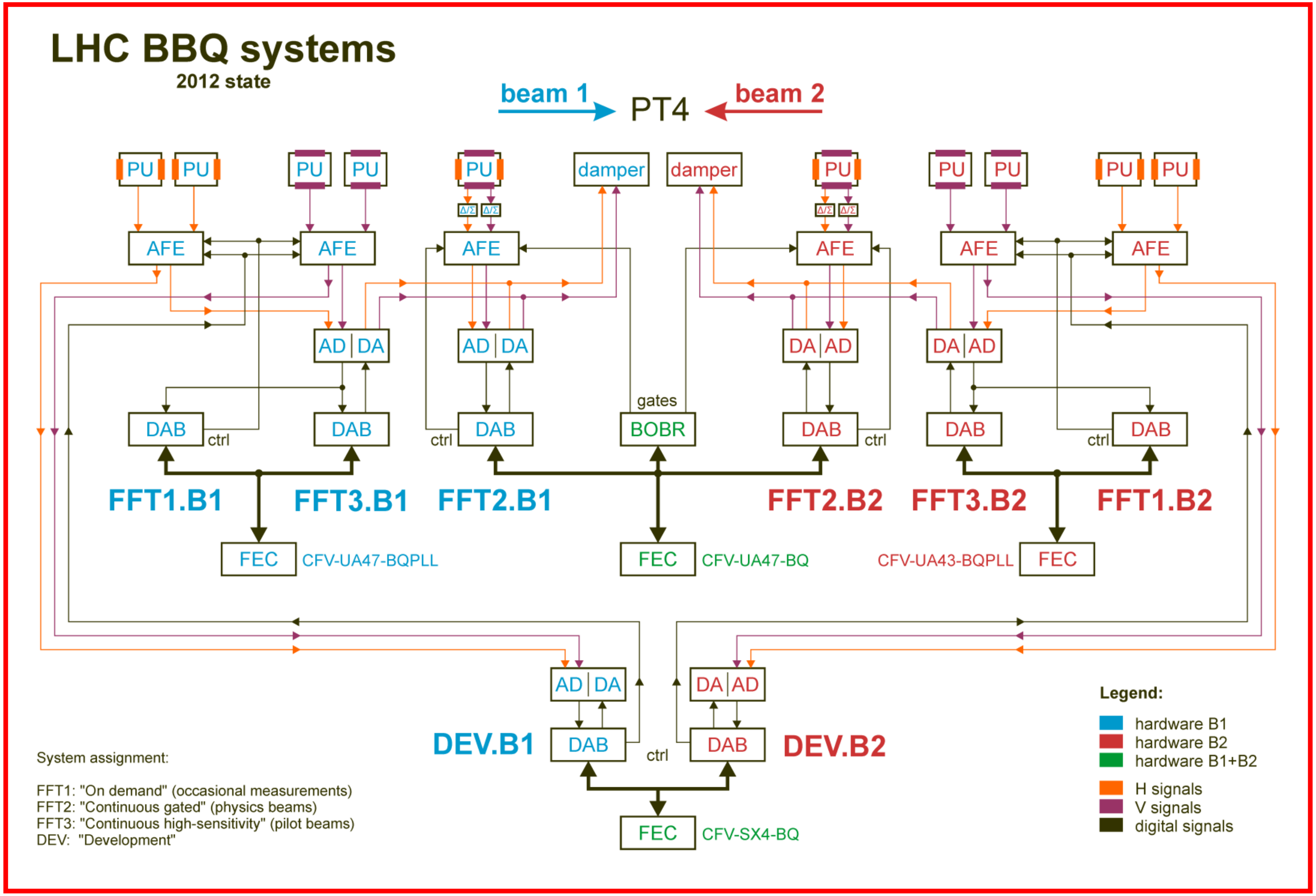
- One DOROS front-end is a 1U 19” box
- It has 8 beam inputs, one Ethernet socket and two optical sockets for BST B1 and B2



- Signals from BPM electrodes are divided into two paths with passive splitters
- One part goes to the standard electronics and the second to a DOROS input

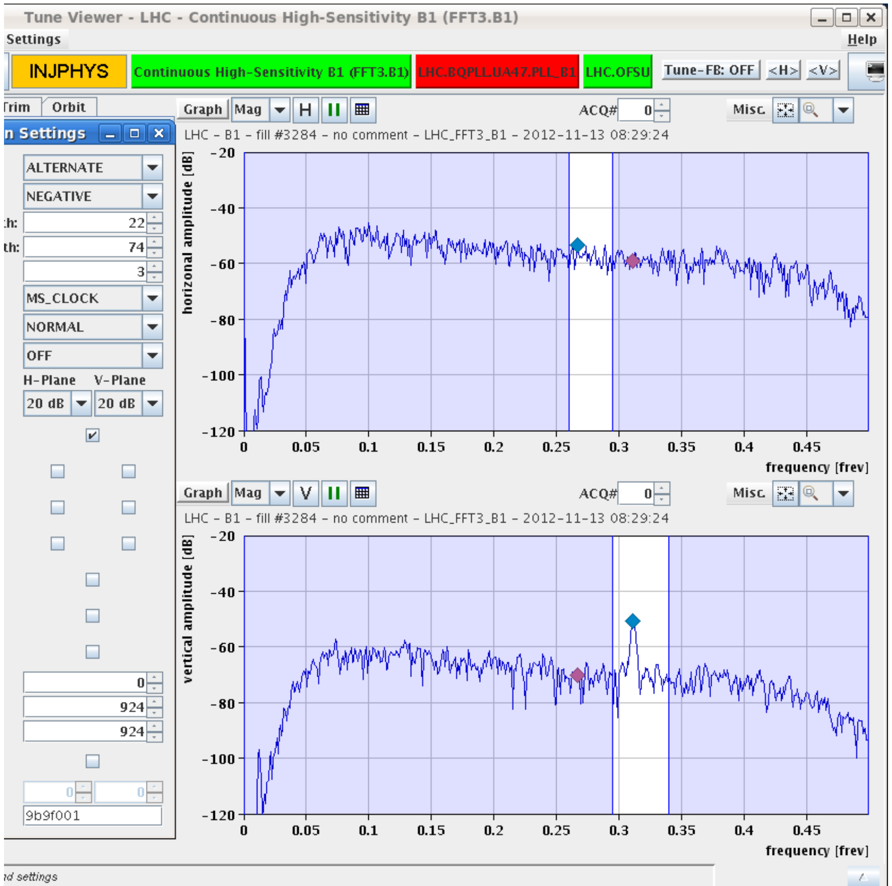
# TUNE Systems

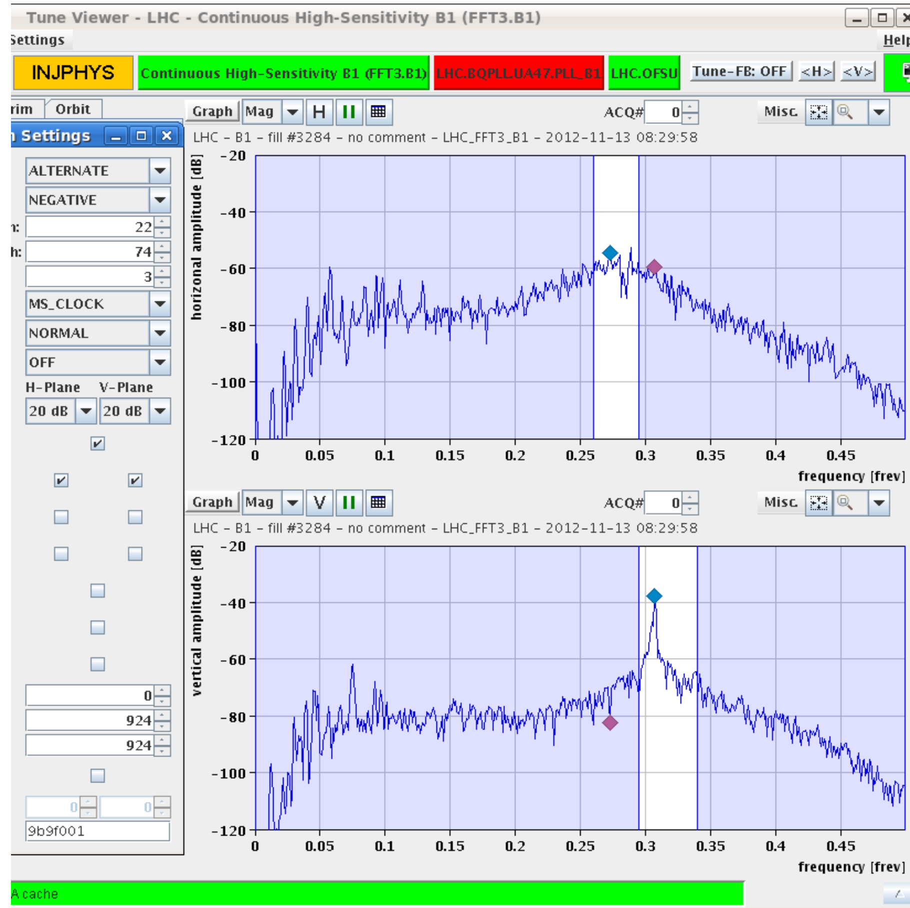
## System hardware settings optimized for different beam configurations



# TUNE

Settings of BBQ FE for different beam conditions



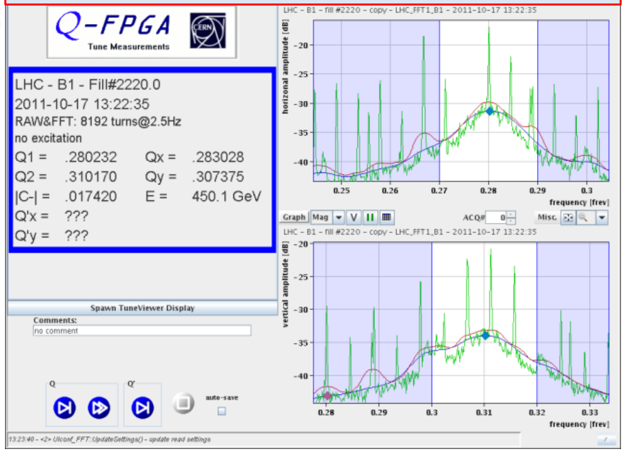

Need to be put in operation through sequencer to use full BBQ capabilities

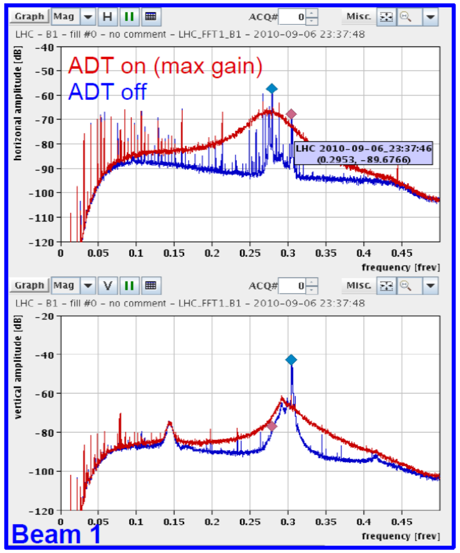
# TUNE with FB

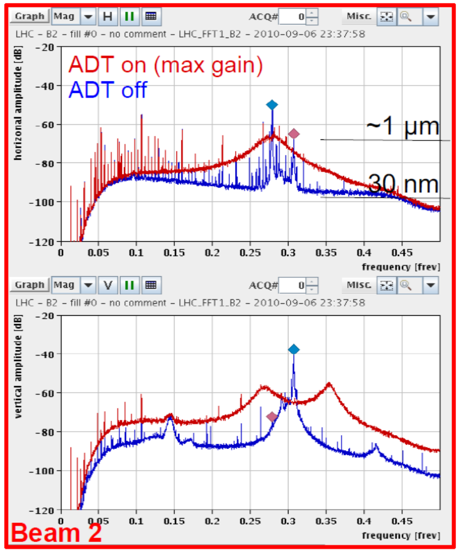
## Main ‘issues’ with the LHC Tune system during last years

- *Tune FB triggering QPS (too fast voltage change) due to poor Q peak quality*
- Pending request for b/b tune measurements
- Low S/N ratio for certain beam conditions
  - Damper system operated at high gain
  - Large octupole currents and chromaticity

*The peak finding challenge*



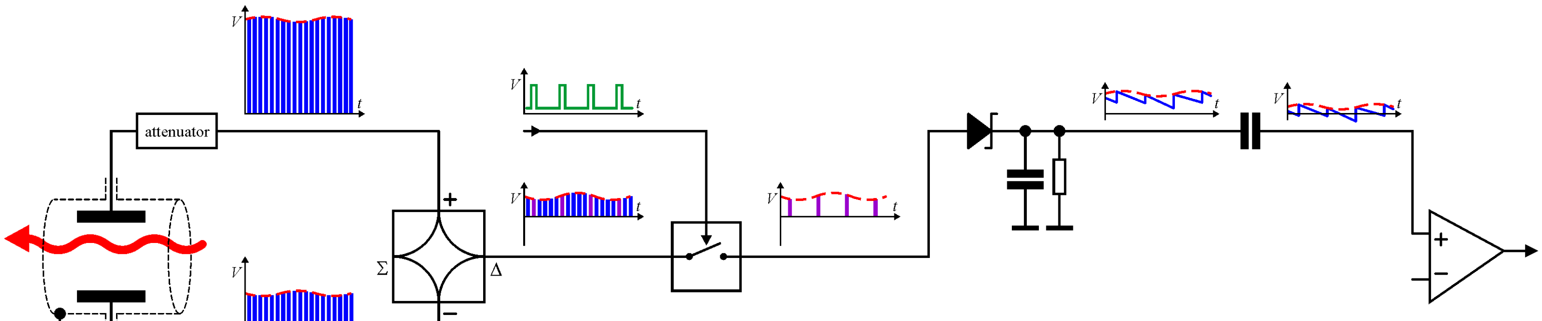



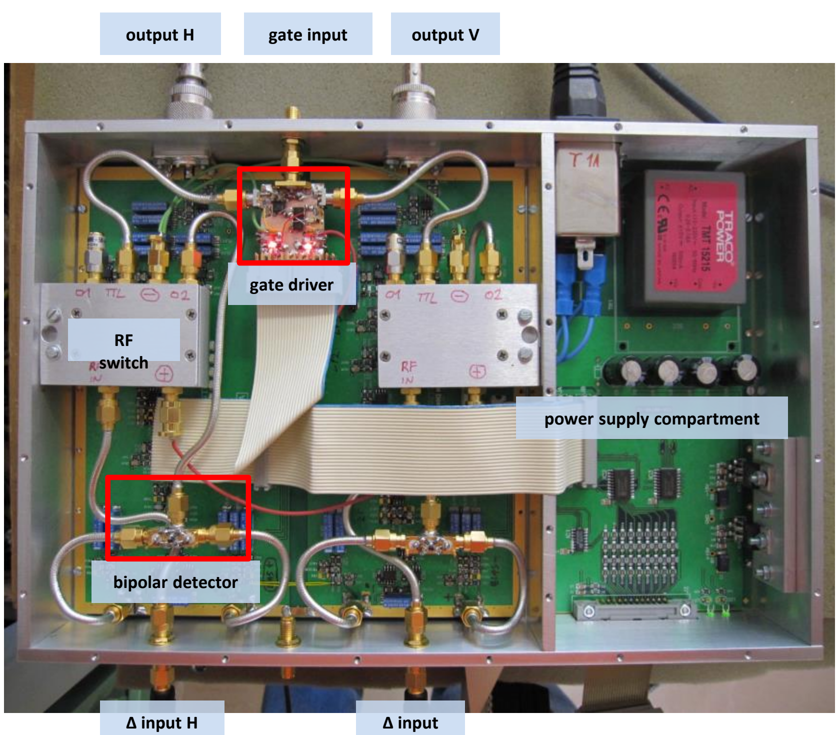

### Solved by Gated BBQ system

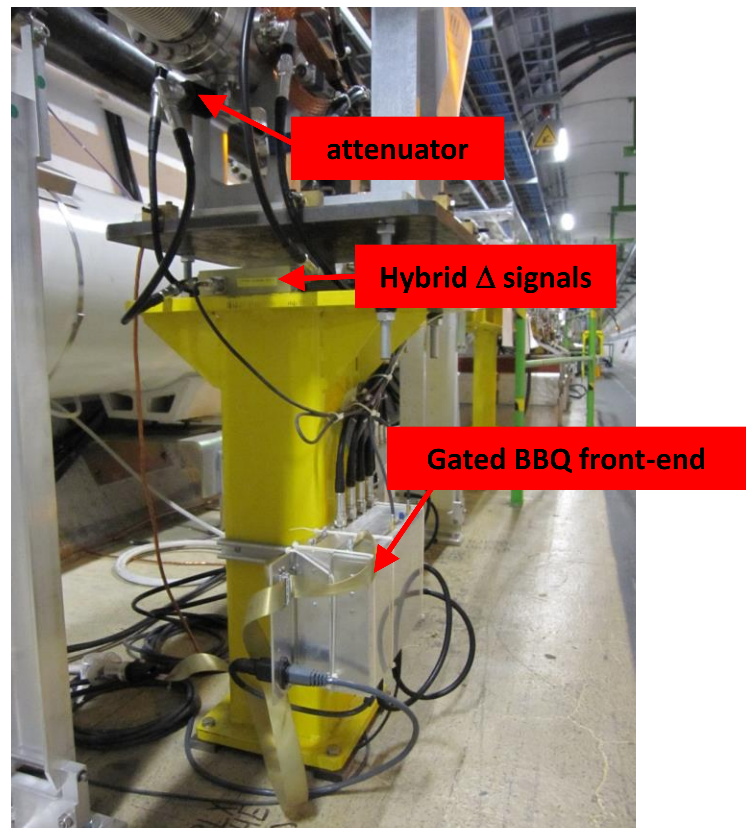
- Gating on bunches for which the damper operates at lower gain
- Long development resulting in first prototype tested in summer 2012
- Operational in 2012 with basic functionality

# GATED TUNE

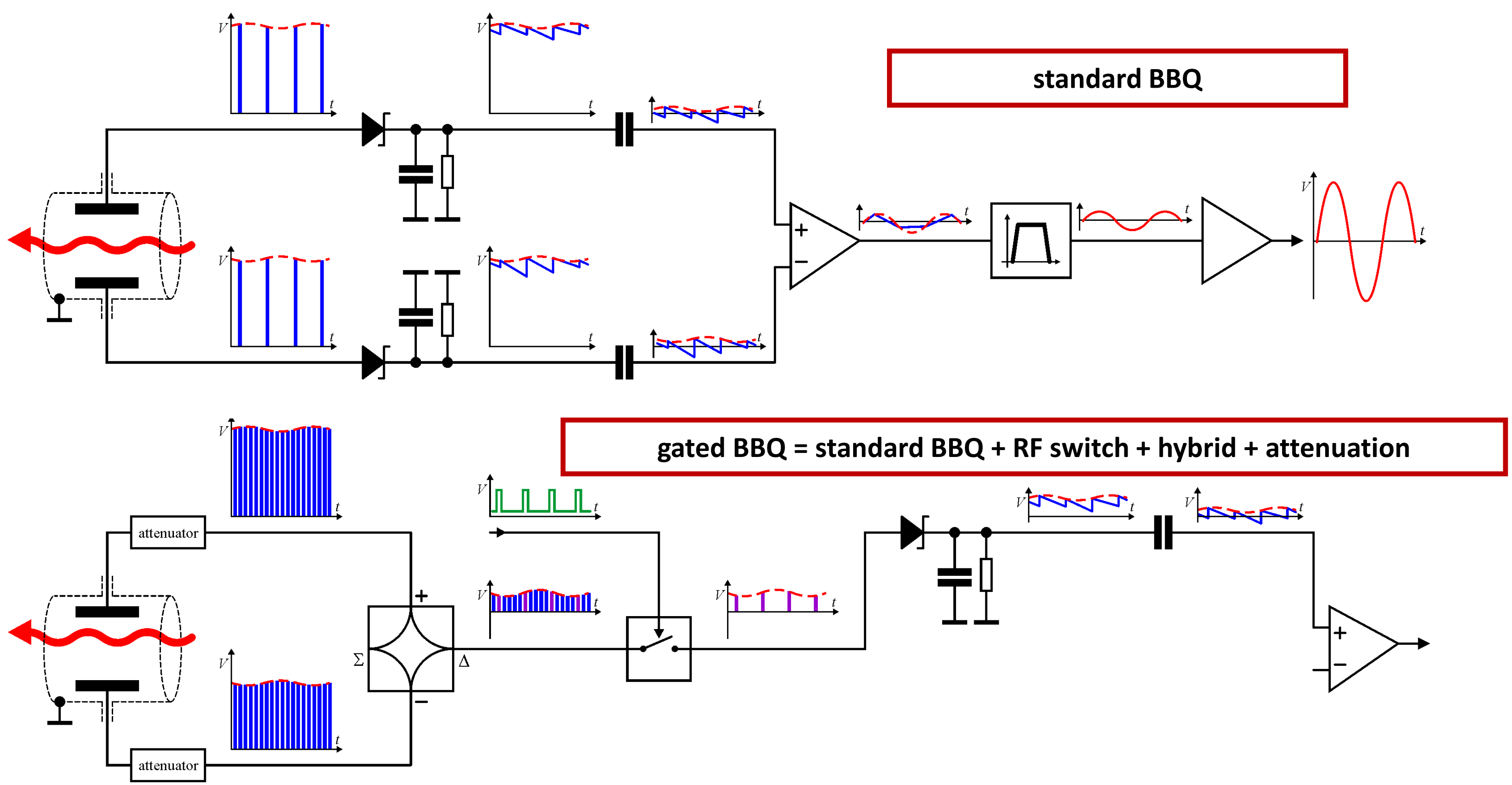



gated BBQ = standard BBQ + RF switch + hybrid + attenuation



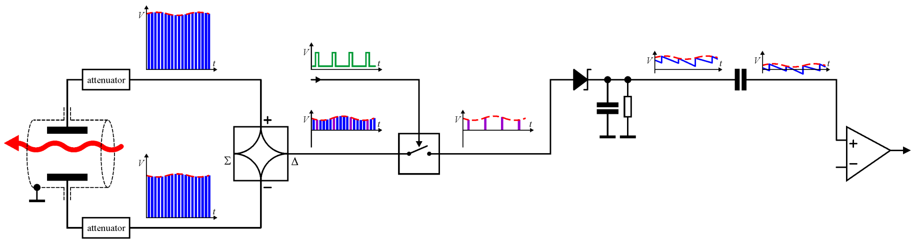



# GATED TUNE

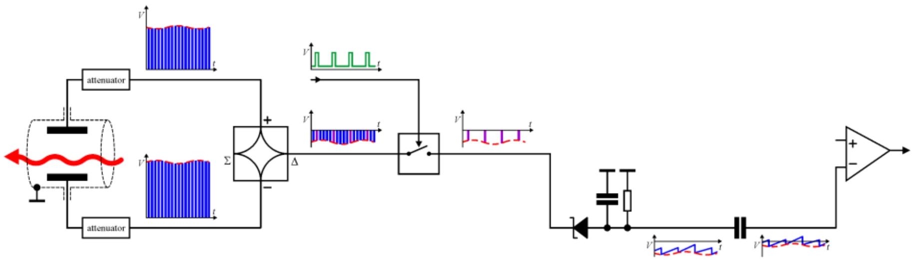



- The RF switch can accept some ≈ 30 Vpp, so smaller amplitudes needed (the standard BBQ handles ≈ 500 Vpp straight form the PU electrodes).
  - An RF 180º hybrid used to subtract the pick-up electrode signals to decrease the signal level at the input of the RF switch.
  - The hybrid cannot take the whole electrode signal power (>10 W). 10 dB attenuators are used, causing a sensitivity loss w.r.t. the regular BBQ.
- Sensitivity of the gated BBQ is decreased less than the attenuation, as the gated BBQ detector has only one diode, while the standard detector has 6 diodes to deal with the high electrode signal amplitude.
- The gated BBQ operates as the standard BBQ with one bunch (or a few bunches) in the machine .
  The whole acquisition chain and its software is the same.
- The above scheme started to be studied only in 2012, as a result of difficulties with the previous development based on a floating gate, which did not require signal attenuation. The current scheme with a series RF switch works only due to the fact that an RF switch was found, accepting signals with sufficiently high amplitudes, which are well above its data sheet spec.

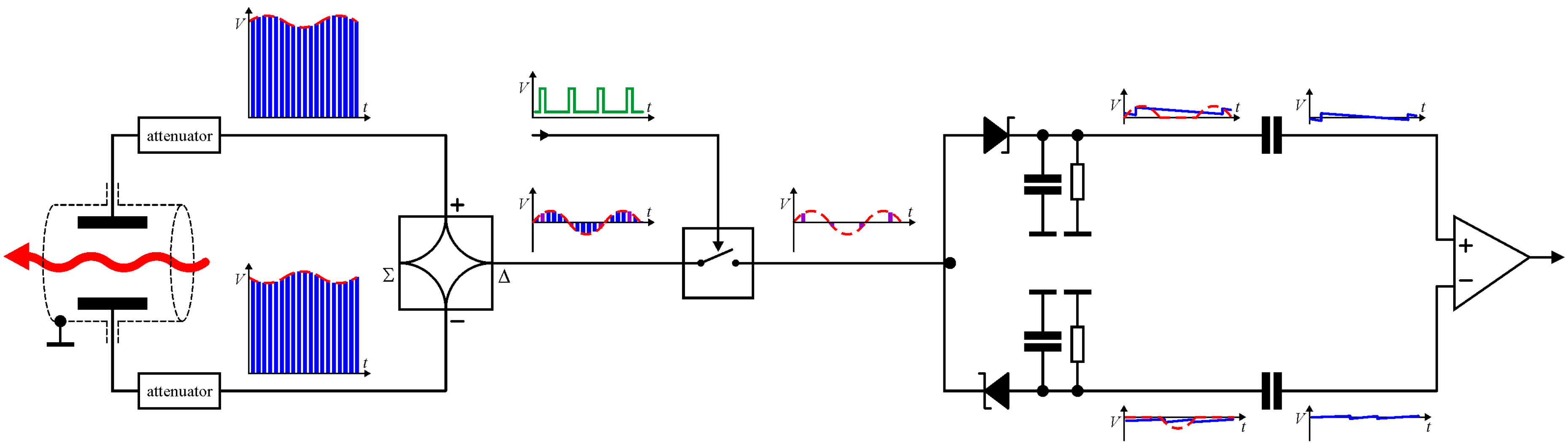
# GATED TUNE




**operation with positive beam offsets**

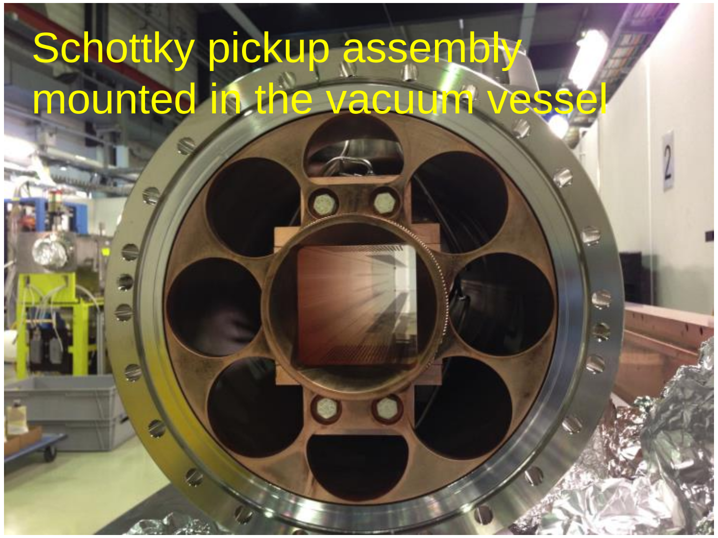


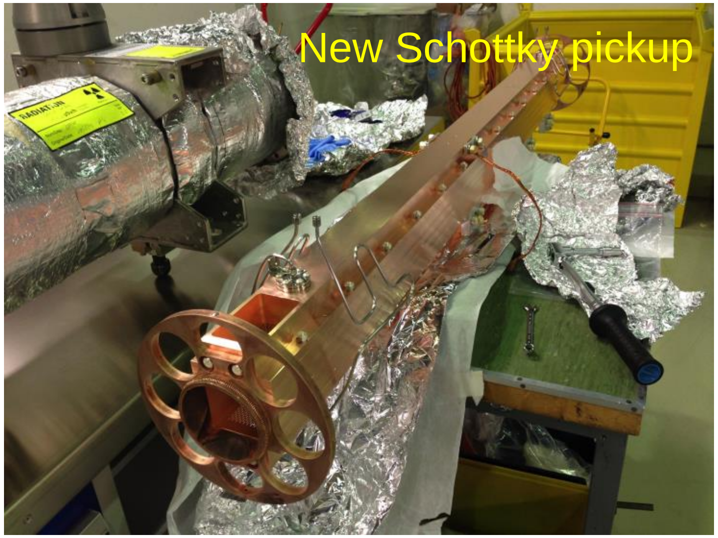

**operation with negative beam offsets**



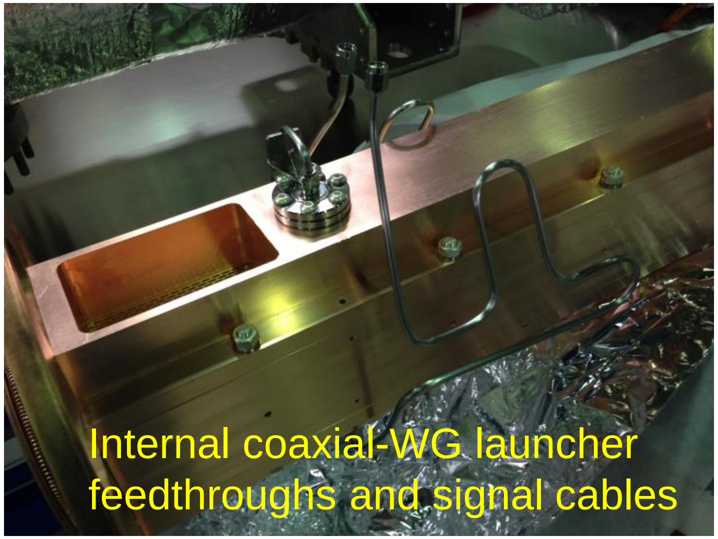

**the implemented configuration: for operation with bipolar beam signals**

# New LHC Schottky Pick-up's

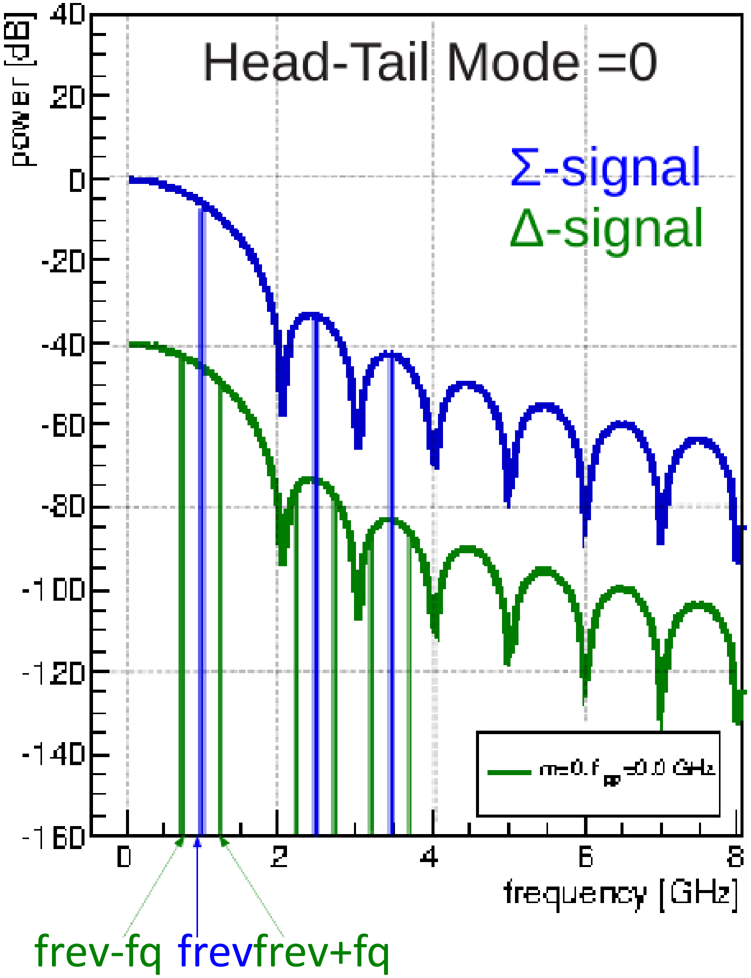


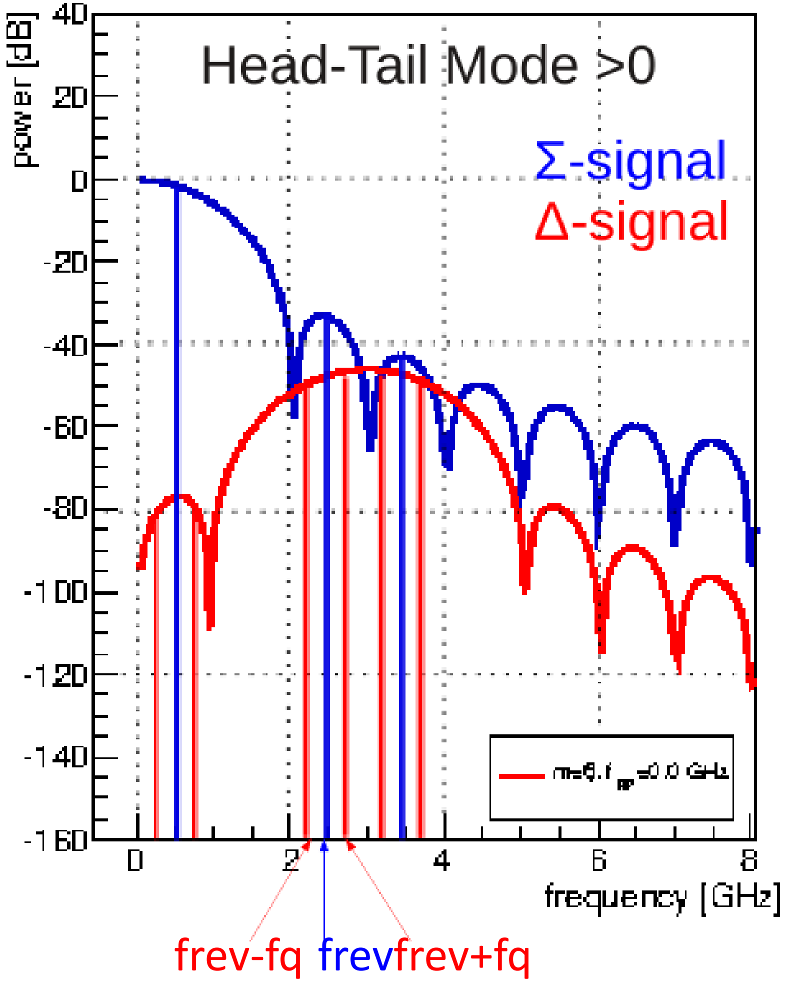







# MONITORING INSTABILITIES

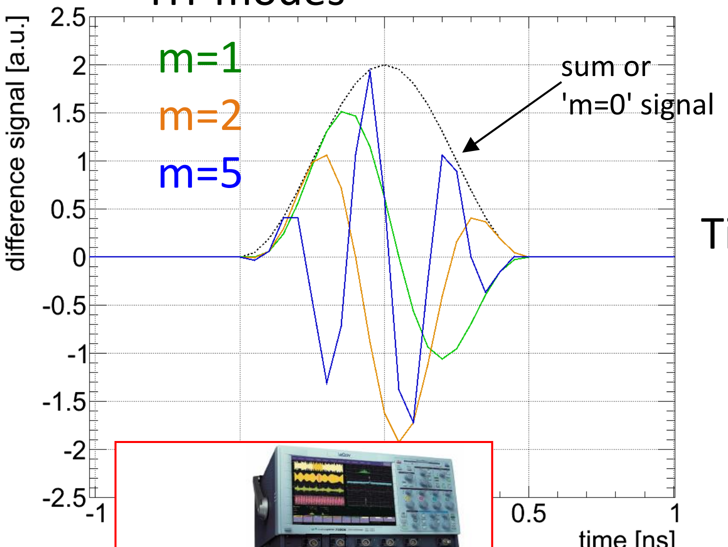


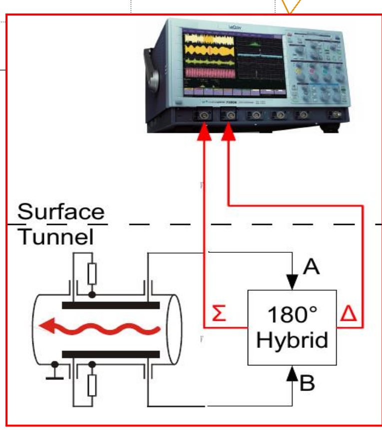



# MONITORING INSTABILITIES

- Observation of instabilities in 2012 relied mainly on BBQ spectra and ADT activity (see daniel's talk)
- LHC head tail monitors using fast sampling oscilloscopes limited to the detection of 100um oscillation amplitudes and limited in memory

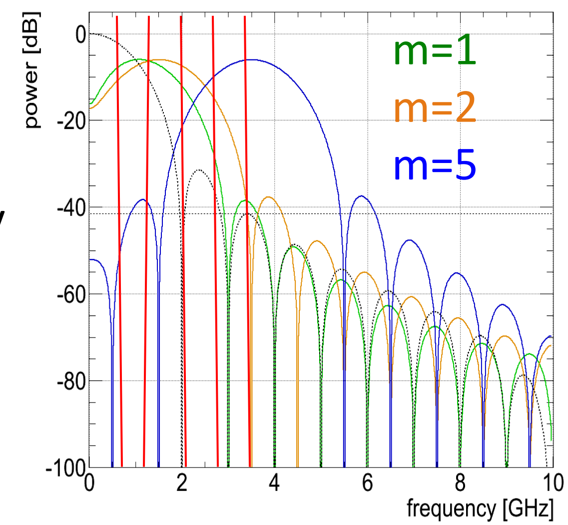
HT modes




Time ⟷ Frequency

Channel index 0 1 2 3 4 5 ...

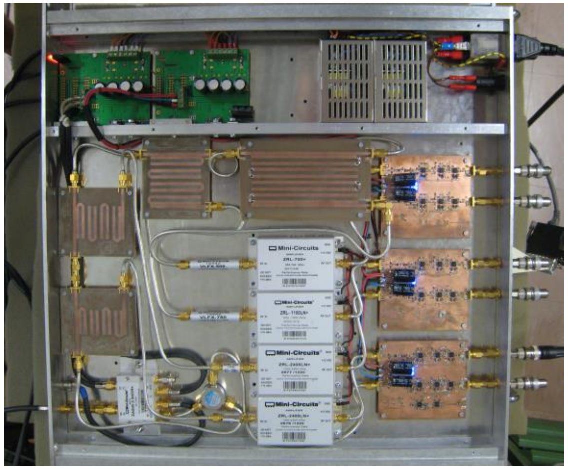



Development of high senstivity frequency domain detection system based on bandpass filters and diodes

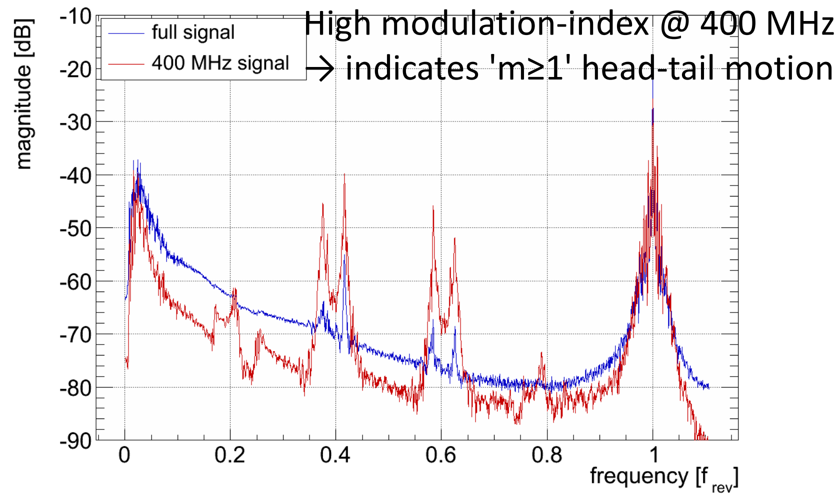
# MONITORING INSTABILITIES

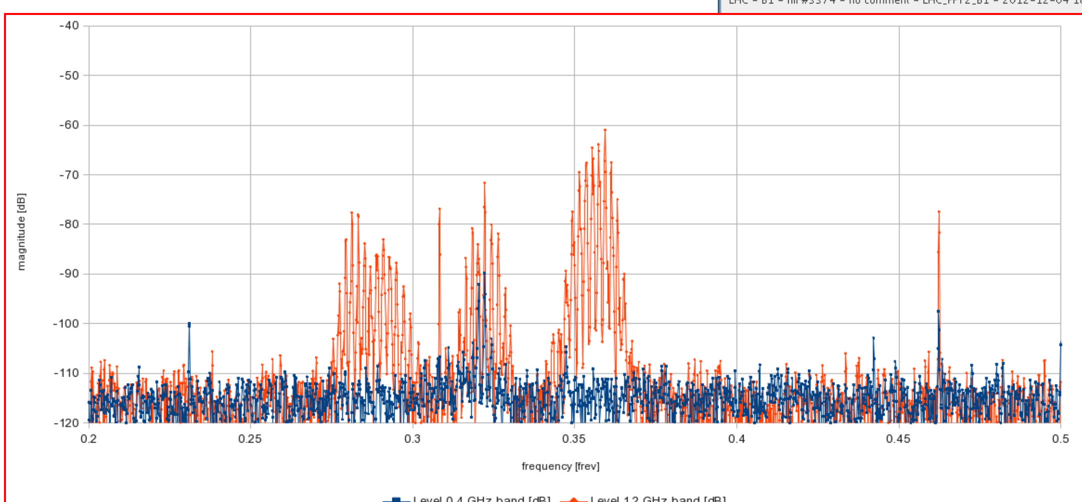
Prototype tested on SPS in Summer 2012 ; Installed shortly after on LHC

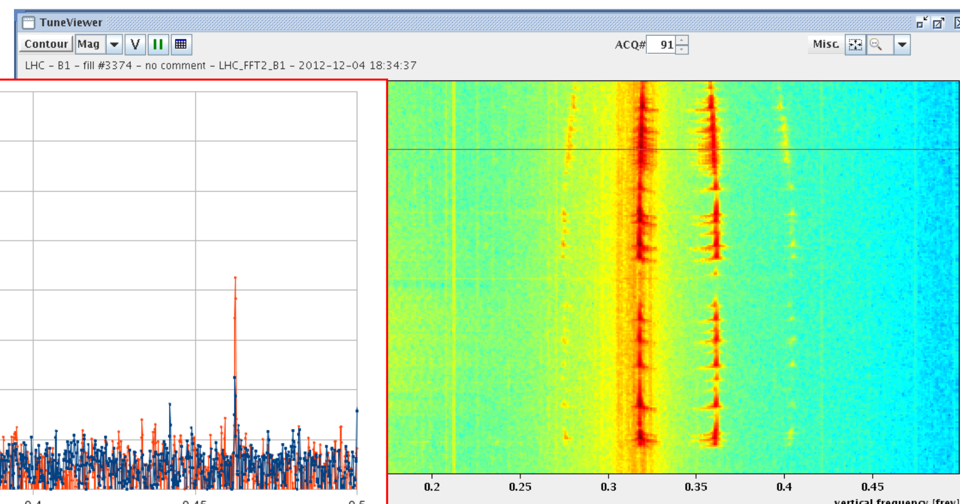
Input
Δ-Signal



Output
0.4 GHz
0.8 GHz
1.2 GHz
1.6 GHz
full-range



# MONITORING INSTABILITIES

*Proposal for LS1 – more for discussion !*

- Put the ‘Multi Band Instability Monitor’ in operation with several functionalities
  - Providing observation system for beam oscillation in several frequency bands with high resolution (<100nm) (to be discussed how many channels and which frequency bands)
  - Generate an appropriate ’instability Trigger’ (software or hardware) for
    - Head-Tail oscilloscope for intra-bunch oscillations (100um)
    - Damper pick-up (400MHz) for B/B measurement @ 1um resolution
  - Possibility to use a set of high-frequency tickler (BQK) to excite and measure the growth/damping time of specific  instability modes

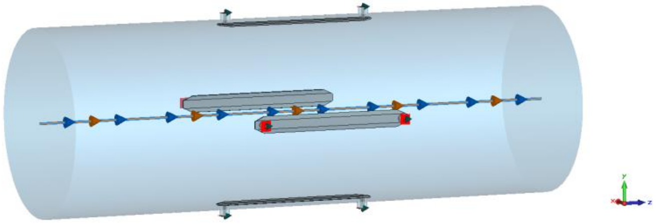
- Upgrades the HT oscilloscopes with fast digitizers providing more memory (not budgeted yet)

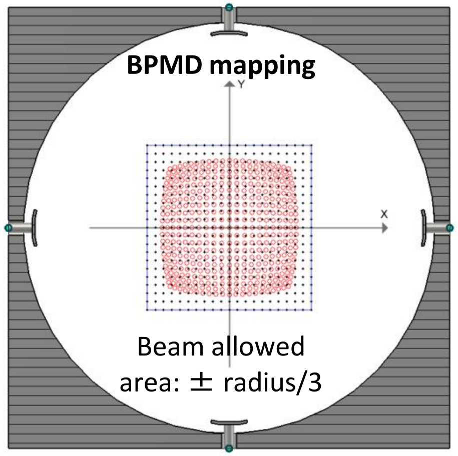

Guzik’s GSA & ADC 6000series
- 4 (2,1) channels @ 4 (6.5, 13) GHz
- 16 (32) GB samplig buffer (1.6s of beam data)
- Online FGPA processing: FFT & DFT

# BPM – non-linearity corrections

*Especially for IR bumps and Dump line BPMs*

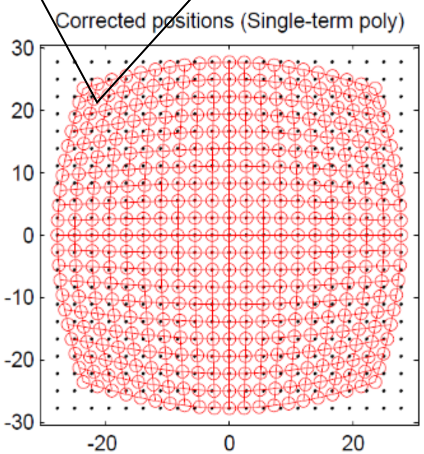
**BPMD:**
130mm diameter strip-line LHC BPM in front of the Dump transfer line



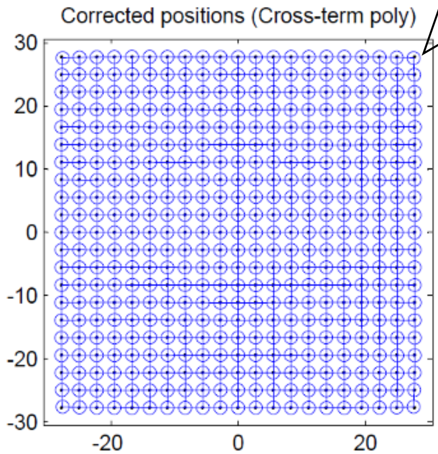



Existing non-linearity correction can be improved by using a 2-D cross-term polynomial

**Average error in beam allowed area: 1.1 mm**
**Max error for on-diag beam: 6mm!**




**Max error for on-diag beam: < 100 um**




**Average error in beam allowed area: 30 um**