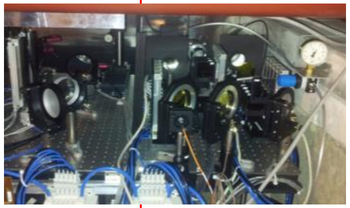
BI for Machine Protection

T. Lefevre on behalf of the people involved in BI and MPE groups

Outline

- Interlock BPMs (IP6)



- Abort Gap Monitoring
- Beam Current Change Monitor : dI/dt

Status of Interlock BPMs

- Hardware modifications during LS1 to improve the dynamic range of the monitors
  - New 50Ω terminated strip-line pick-ups and low-pass absorptive filters (suppressing signal reflections)

- New Firmware / FESA3 / expert GUI to improve the diagnostics
  - Increased Post-mortem buffer memory with beam positions of all bunches during the 154 last turns

- Improved long-term stability with BPM acquisition electronic in water-cooled racks

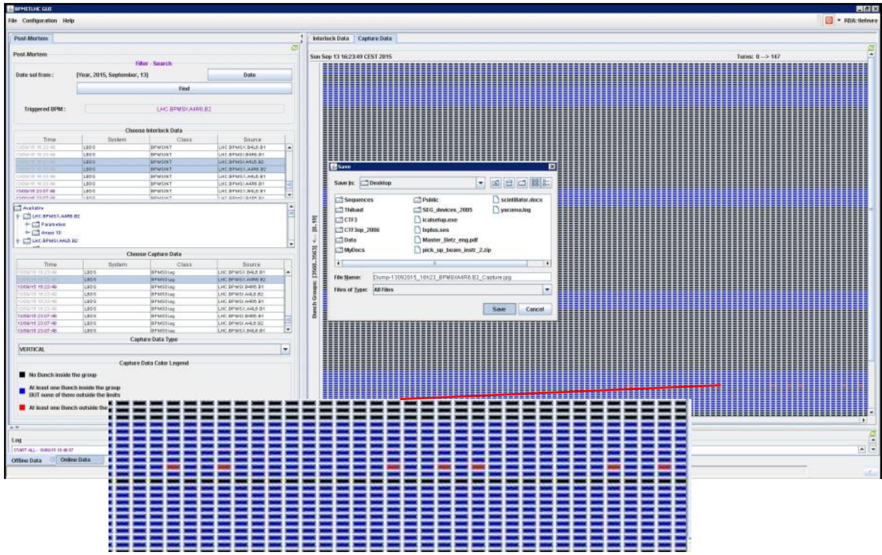
Interlock BPMs
New dynamic ranges

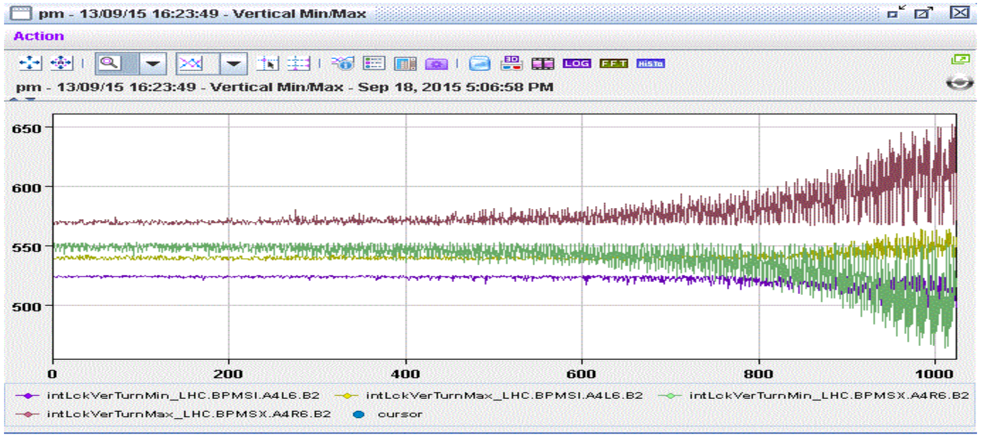
	Run 1	Run 2
High Sensitivity	1.5E9 – 3E10	1.5E9 - 1.3E11
Dynamic range improved by more than 10dB		
Low Sensitivity	*2E10 - >2E11*	*1.5E10 - >2E11*

This value is an Operational choice / compromise

Interlock BPMs Post-mortem data

- Storing the last 154 turns of all bunches (limited by on-board memory)
  - Can be used to see which bunches become unstable
- Storing min/max positions for the last 1024 turns
  - Can be used to measure rise time of instability





Interlock BPMs Issues in 2015

- Commissioning new firmware / FESA3
  - In collaboration with CO (Michel Arruat): Implementation in CPU encore driver of a programmable interrupt queuing routine

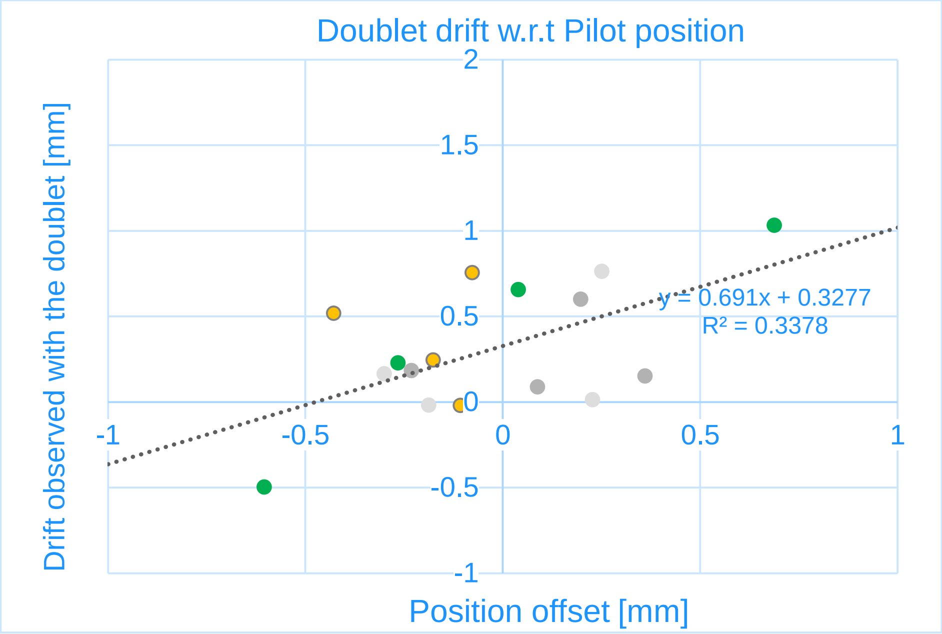
- 12 entries in the fault tracking system
  - 8 false dumps due to bunch intensities decreasing below 1.5E10 (It does not like ‘fat’ pilot)
  - 2 false dumps with doublets
  - 2 hardware issues:
    - *Integrator mezzanine replaced on BPMSI.B4L6.B2 (Surface building)*
    - *Faulty RF filter on BPMSX.A4R6.B1 (Tunnel)*

Interlock BPMS
Issues with Doublets (1/2)

- BPM electronics not designed to work with bunch spacing shorter than 25ns (worst case for 5ns !)
  - Orbit data with doublet is distorted (RMS at 700um)

Interlock BPMS
Issues with Doublets (2/2)

- BPM electronics not designed to work with bunch spacing shorter than 25ns (worst case for 5ns !)
  - B/B Offset and fluctuations up to 2 mm



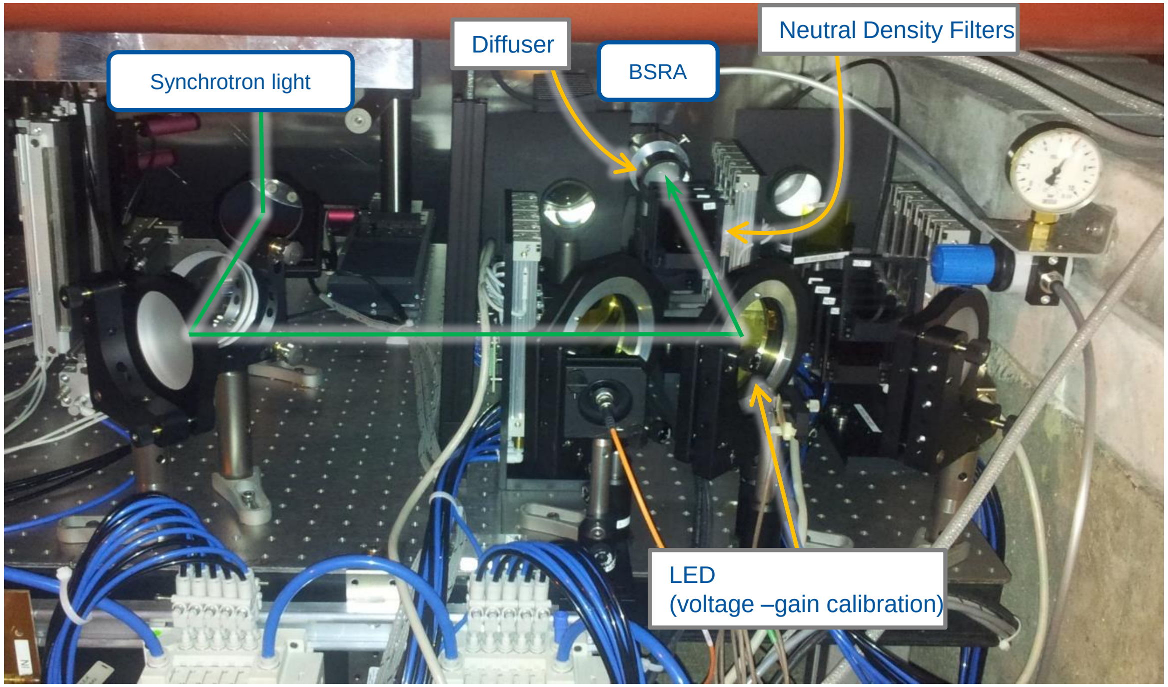
- No solution in the short term, apart from increasing the limit
  - Launched the development of a new B-b-B electronic read-out

Abort Gap monitoring
- BSRA -

Improving reliability: Optics

New optical line design (2015):

- New extraction mirror
- BSRA + LDM separated from imaging/interferometry lines
- New optics: larger aperture lens more tolerant to source angle changes



Improving reliability: Calibration checks

- As of October 2015: Voltage/Gain calibration check performed by the LHC sequencer before injection
  - Results published in BI LHC logbook. Acceptance threshold: +/- 30% (to be reviewed in 2016)

25/11/2015 04:25 DAY BI LHC

LHC SEQ: LHC.BSRA.US45.B1 calibration finished. Overall result: OK
a = -1.58698E-6 a_calc = -1.5515506709418148E-6 b = 0.0115021 b_calc = 0.011277224414357079

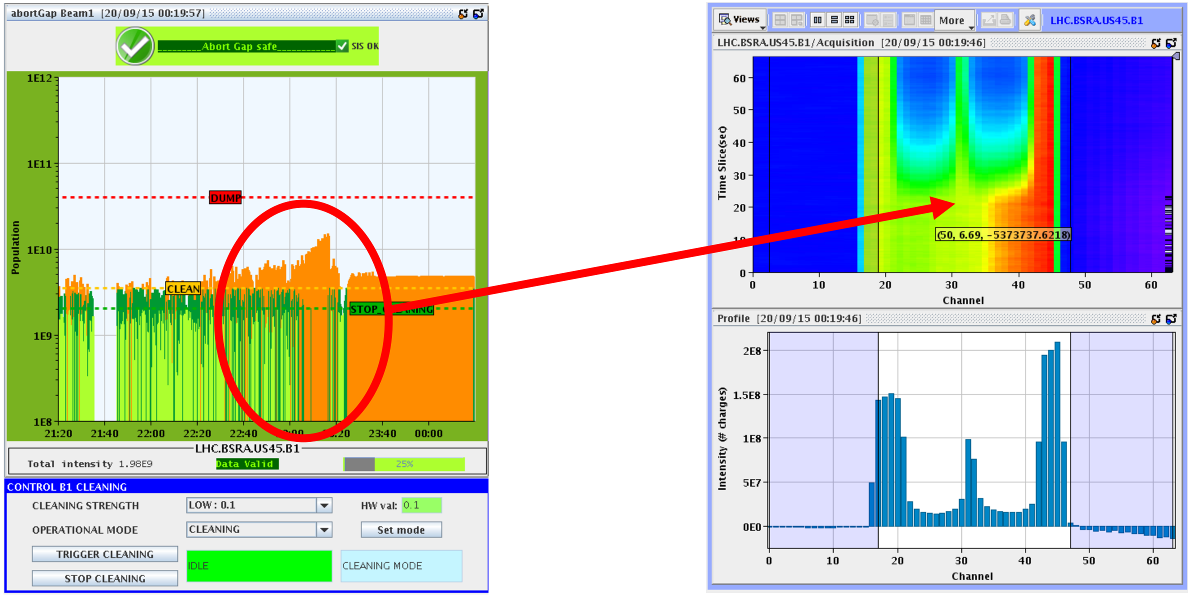
25/11/2015 04:28 DAY BI LHC

LHC SEQ: LHC.BSRA.US45.B2 calibration finished. Overall result: OK
a = -1.18416E-6 a_calc = -1.3814844641857338E-6 b = 0.00944717 b_calc = 0.010626167778696072

- To be implemented: Periodic checks using FBCT reading
  - Now less critical due to improved optical line and extraction mirror design

BSRA for Machine protection

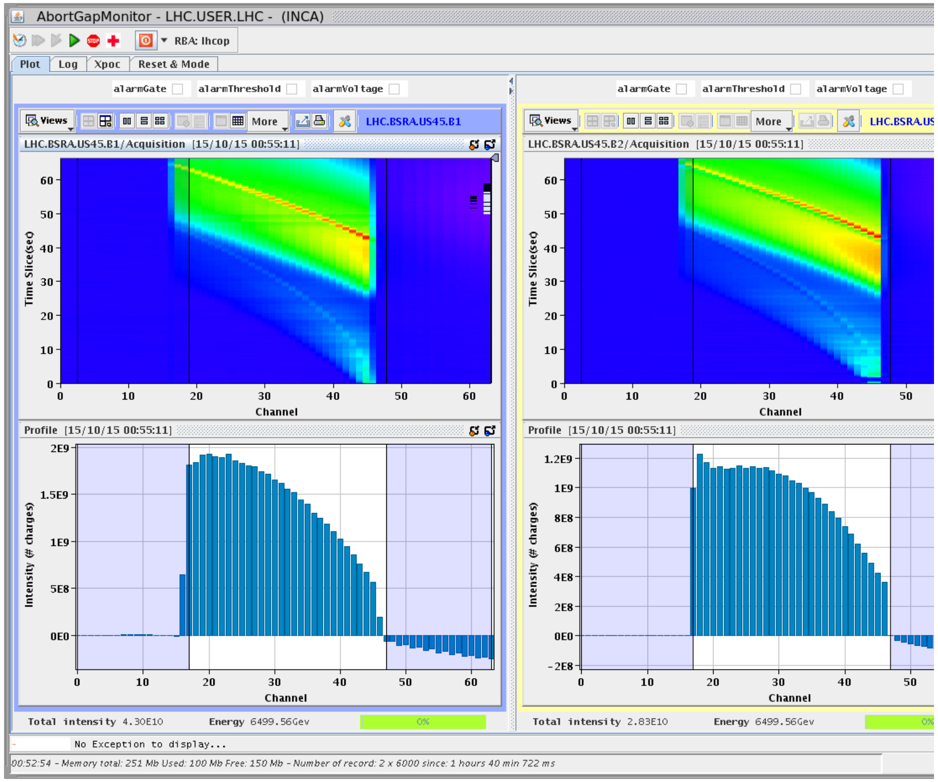
- Since start of Run2, new AG population threshold scheme
  - Two flags published by BSRA: AG cleaning (start-stop) and beam dump
  - AG cleaning now triggered by SIS based on BSRA reading. Tested in June 2015, now routinely used in operation



- Beam dump flag still not implemented in SIS so far.

Observation of Asynch. dump

Automatic recovery (1-2s) from PMT protection state was put in place so that Asynchronous beam dumps can be monitored automatically



14/10/15 Protons @ 6.5 TeV

BSRA performance: Sensitivity / Accuracy

Requirement (“*HIGH SENSITIVITY MEASUREMENT OF THE LONGITUDINAL DISTRIBUTION OF THE LHC BEAMS*”, LHC-B-ES-0005.00 rev 2.0):

- Min detectable AG population is $3x10^9$ (injection) and 10^8 (flat top)

	Required [p/100ns]	**Measured [p/100ns]**
Injection	< $4x10^9$	10^7 (typ)
Flat top	<$6x10^6$	$8x10^5$ (typ)

- Better than +/-50% absolute accuracy at flat top. B1 **35.4%**, B2 **(69.1%) – higher noise level – to be checked during YETS**

- Better than +/-5% absolute accuracy at injection **NOT POSSIBLE WITH PRESENT SYSTEM (is that needed ?)**

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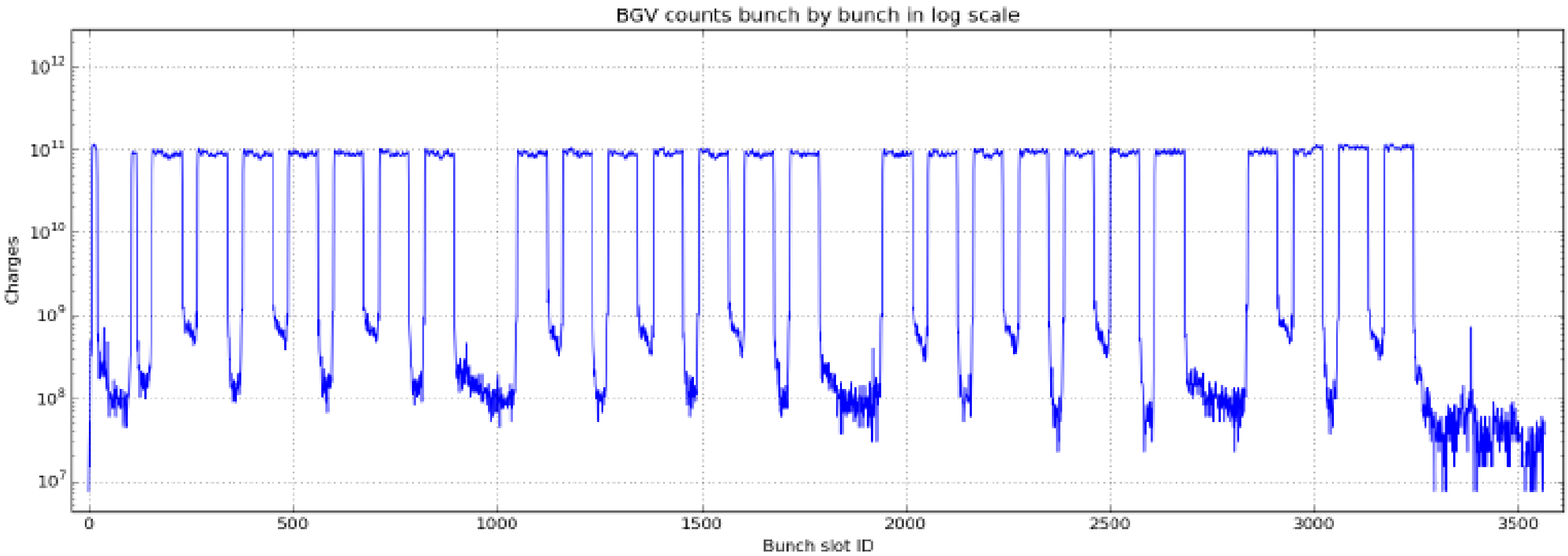
Alternatives for Abort gap monitoring

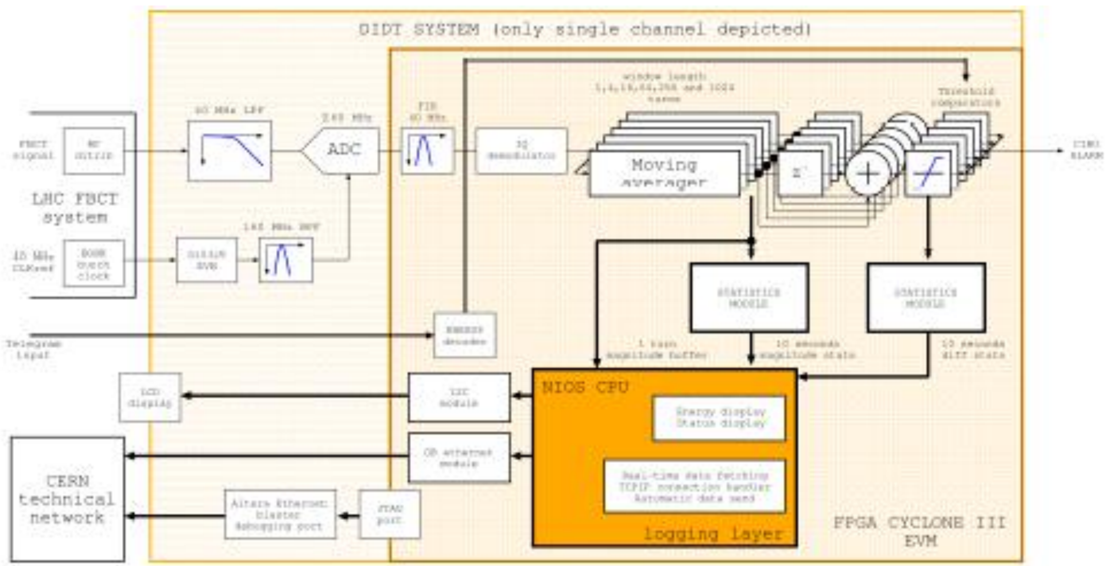
- Proposal to use Beam-gas interactions and Beam loss monitors
  - Tried with Diamond BLM but count rate is too low (physical size of diamond detectors)
  - Using the BGV ‘Trigger’ scintillators (coupled to SiPM) ?



Beam Current Change Monitor
- dI/dt -

BCCM system overview

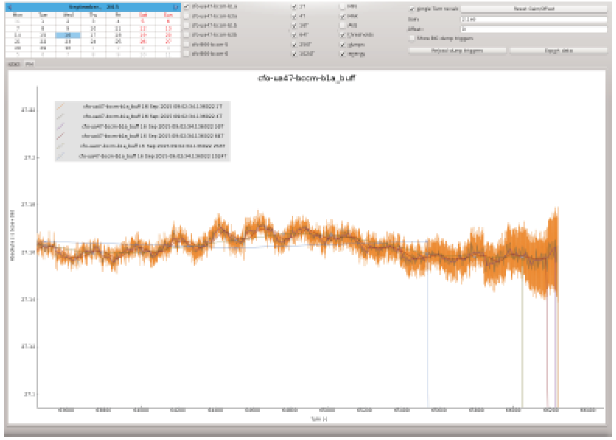
- 4 BCCM units installed in the LHC during the TS1 (on Syst. A & B)
  - Measuring the change in amplitude of the 40MHz component of beam intensity signals.
  - Calculating and publishing averaged changes over 1, 4, 16, 64, 256 and 1024 turns



  - Connected to BIC (but masked for most of the year)

BCCM in 2015 (1/2)

- Collecting data since TS1
- Mid June - set energy independent thresholds of 3e11 charges loss for all 4 installed systems
- 1st of September - operational BCCMs activated
- 16th of September – 2 false dumps
  - Caused by coherent transverse oscillations at injection with FBCTs being position dependent

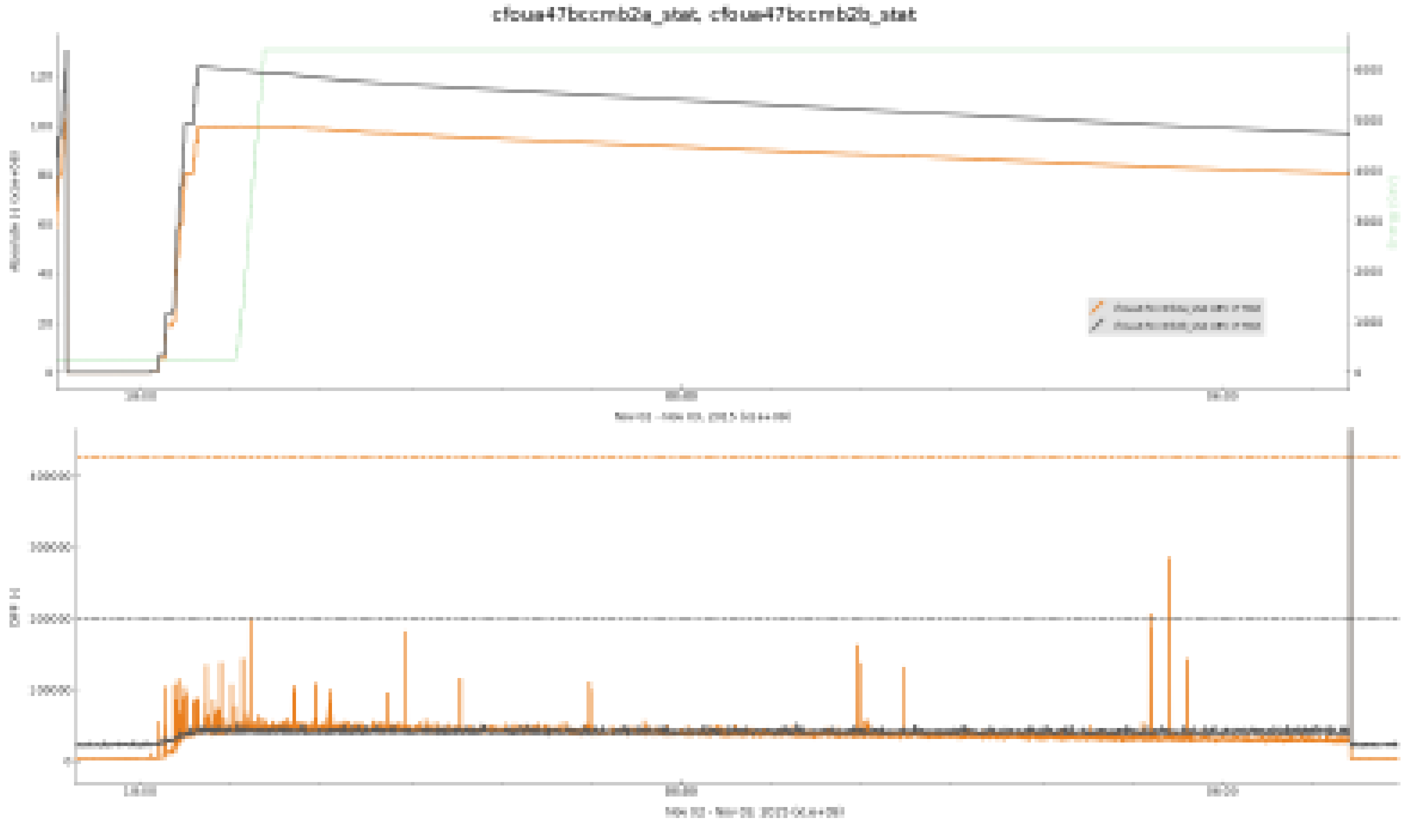


BCCM in 2015 (2/2)

- 9th of October – False dump
  - Operational BCCMs disabled
  - Understood later as a timing issue in the FPGA
- New firmware uploaded into operational systems on 30th October
- Investigations still on-going on the impact of a phase dependency in I/Q demodulation

BCCM in 2016
Reasons for Hope (1/2)

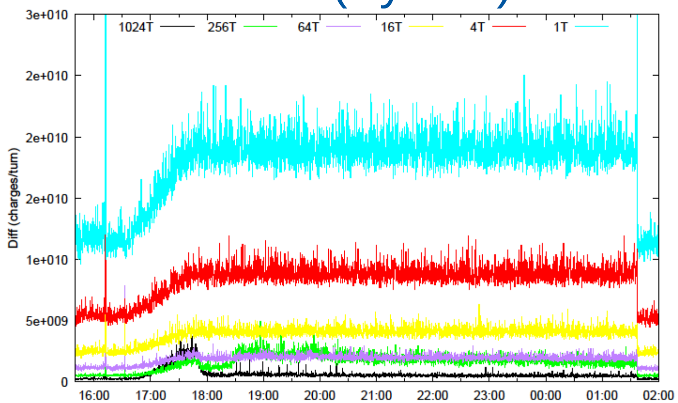
- Comparing the measurements with FBCT (orange) and BCTW (dark)



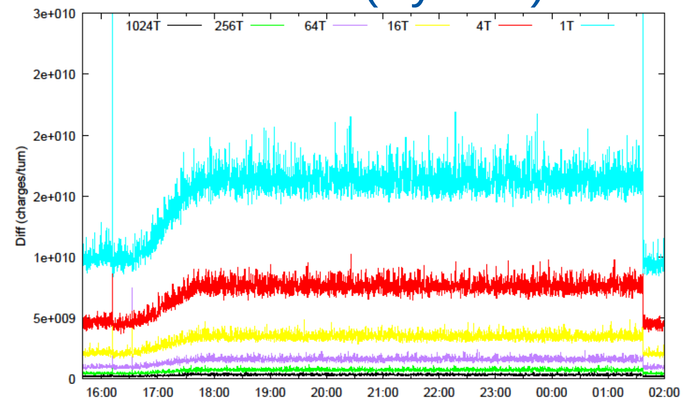
BCCM in 2016
Reasons for Hope (2/2)

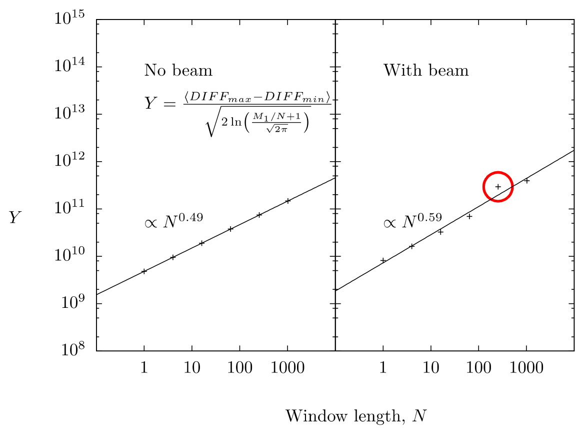
- Checking the RMS noise of the different averaging time windows

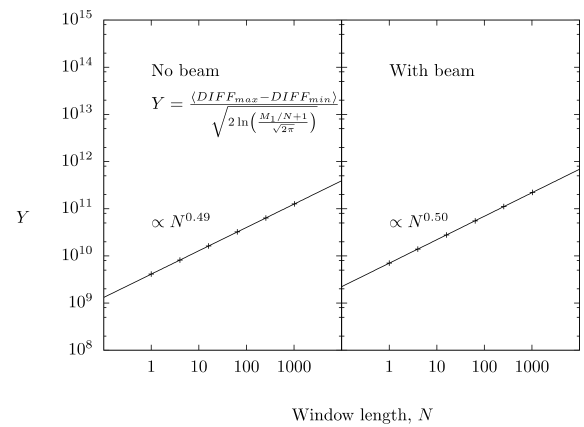
FBCT (Syst. A)



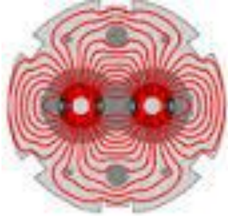
BCTW (Syst. B)







Conclusion



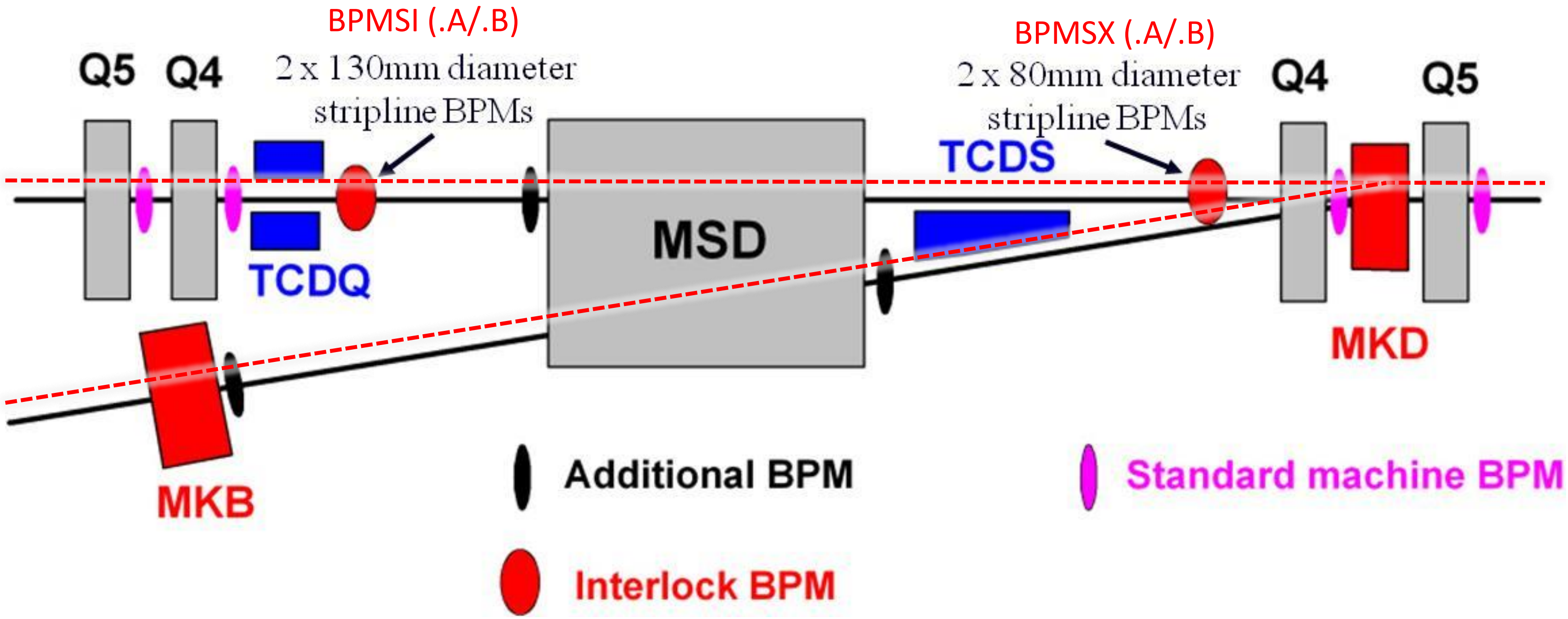
- Aiming for BCCM back in operation in 2016
  - New monitors to be installed during YETS
  - Still some hardware investigations to validate the system performance
  - Large amount of work to be put in the software (FESA & Expert GUI)
  - Hardware review during YETS to be planned

- Abort gap monitor
  - BSRA worked reliably, Systematic checks implemented & AGC used operationally
  - Do we need to unable the beam dump flag in SIS ?
  - Do we need a redundant monitor for abort gap ?

- Interlock BPMs
  - Working better than in 2012 with very few false dumps and only few unavoidable hardware failures
  - B-B data to be included in the Post mortem analysis
  - Need a new hardware development to cope with doublets

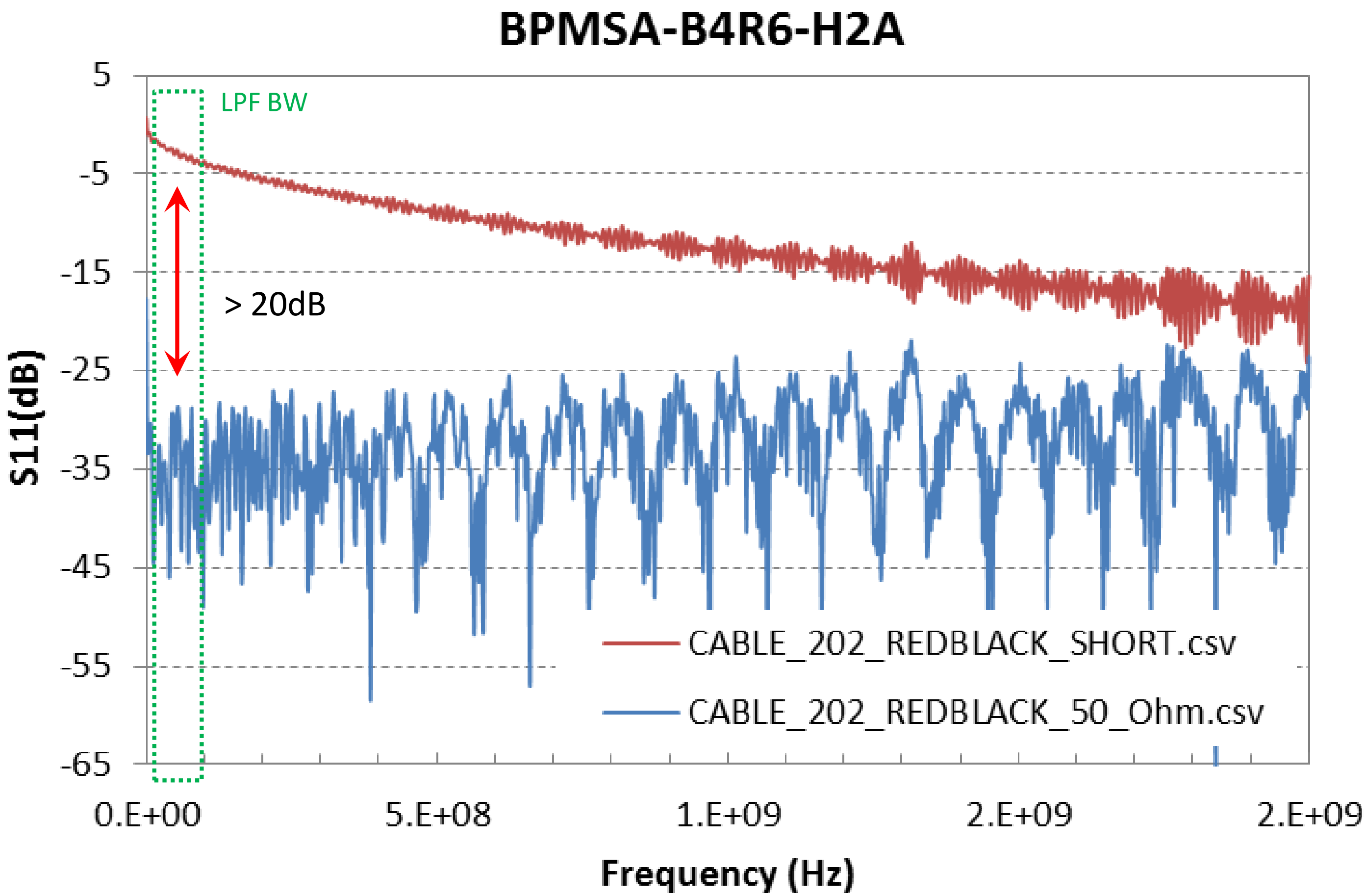
Spare Slides

Dump Channel



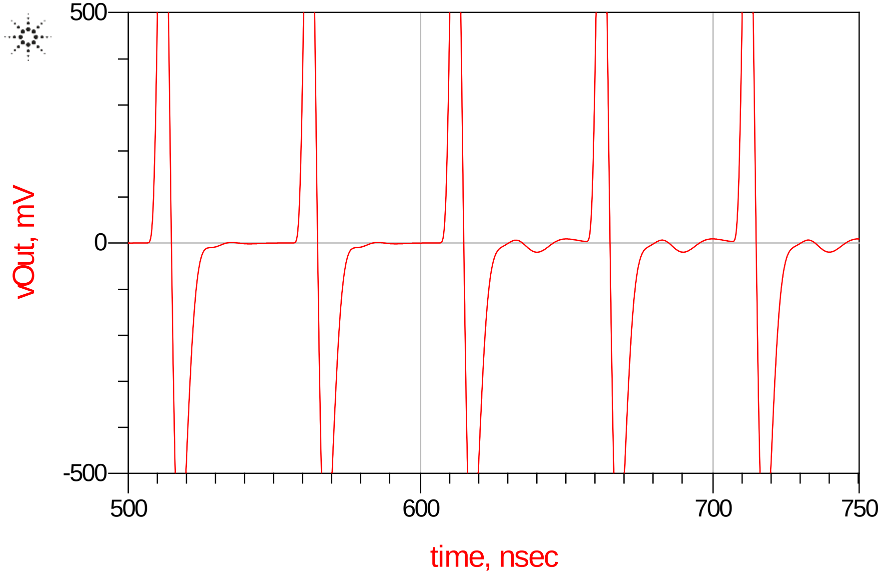
The main aim of these BPMs is to avoid large orbit offsets leading to high losses on the septum protection during a dump

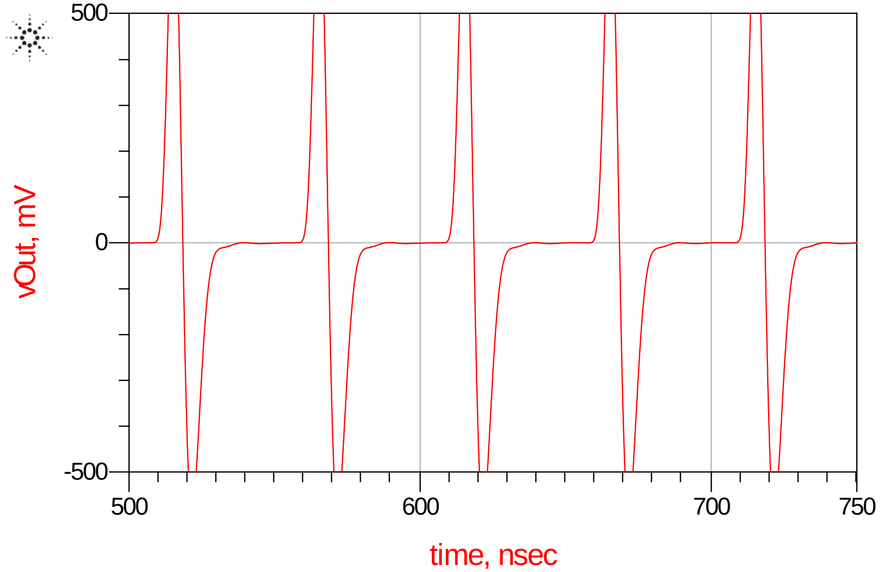
BPMs Reflections



More than a factor 10 improvement on the Pick-up

Reflections in time domain



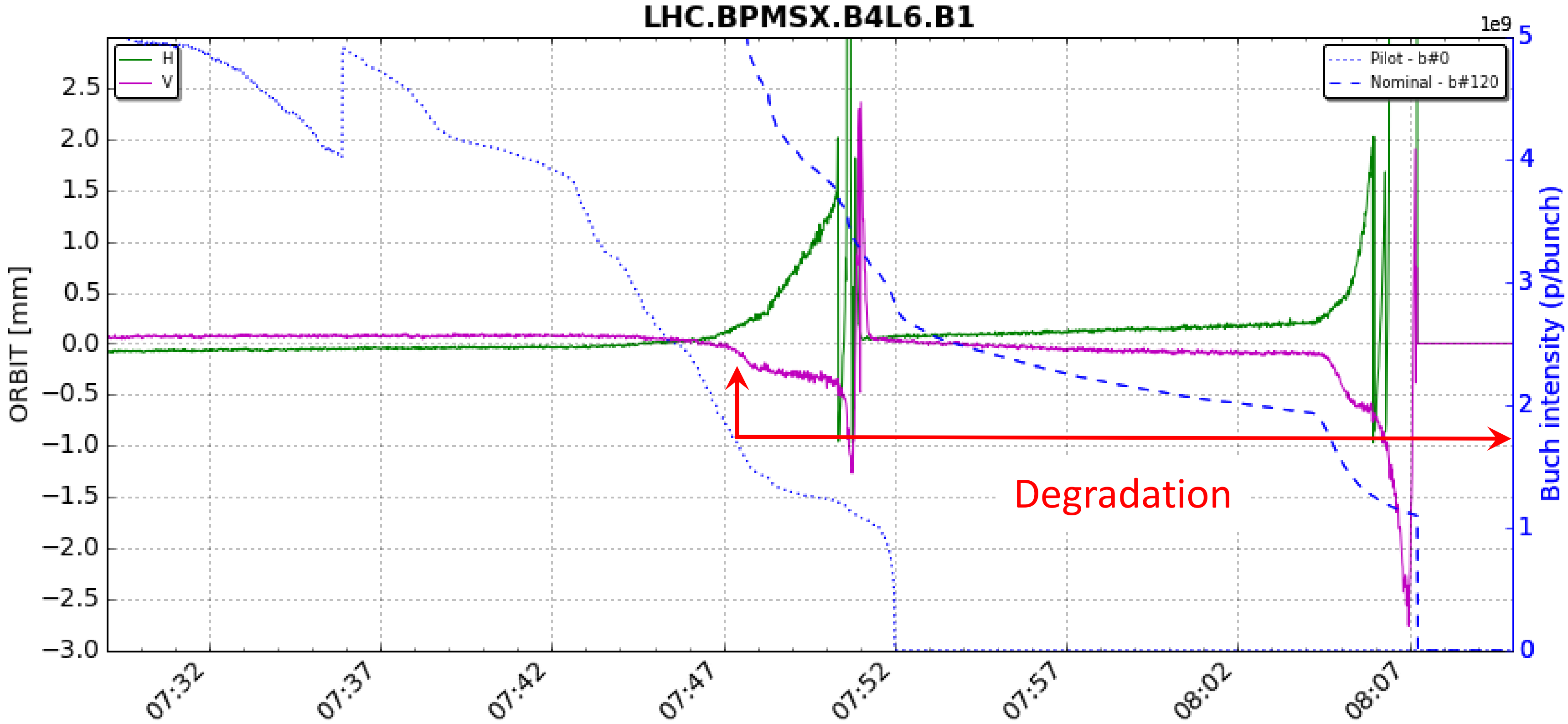


Shorted strip-lines reflections
Measurement: -27 dB
Simulation: -34 dB

Terminated strip-lines with LPF:
Simulations: <-46 dB

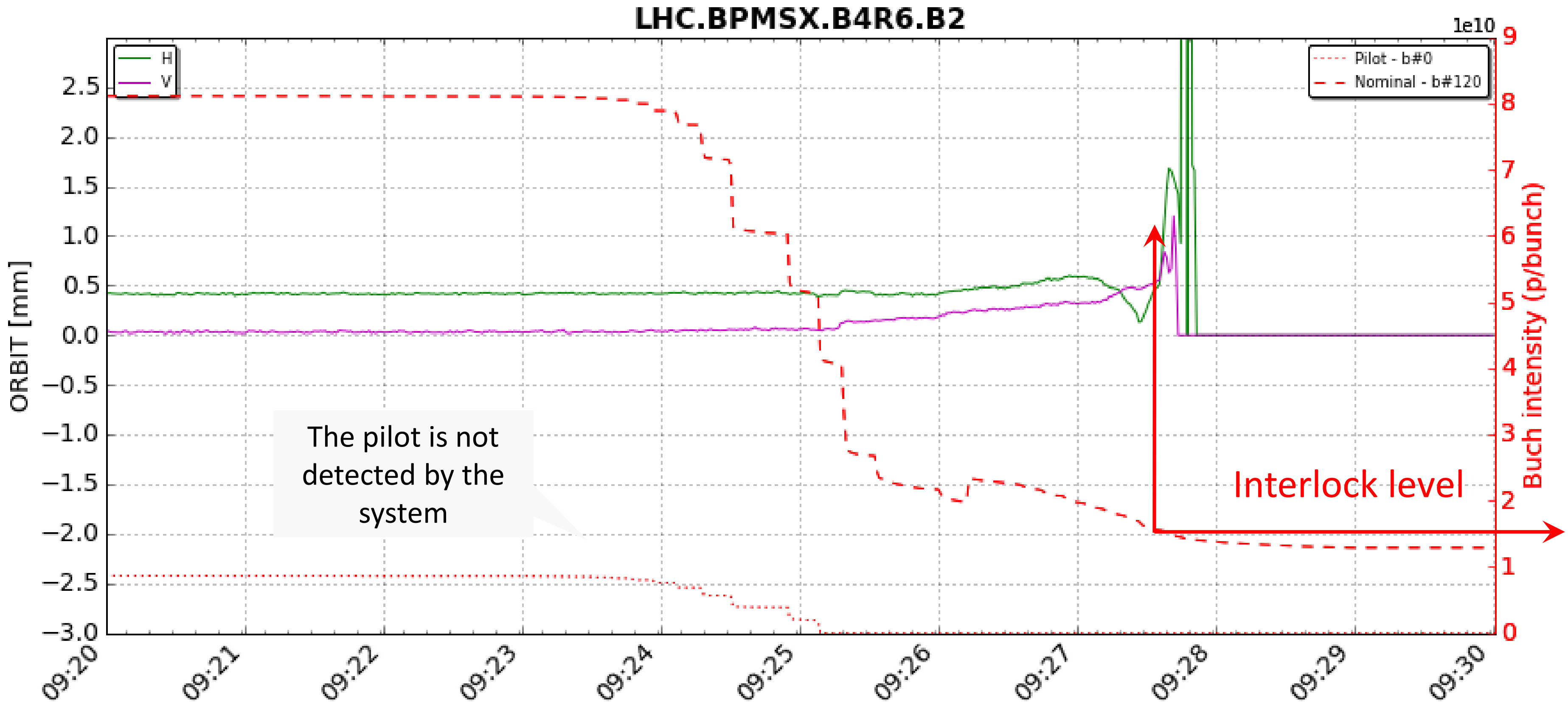
LHC IBPM Re-commissioning

Scrapping one Pilot and one Nominal in **High sensitivity** mode

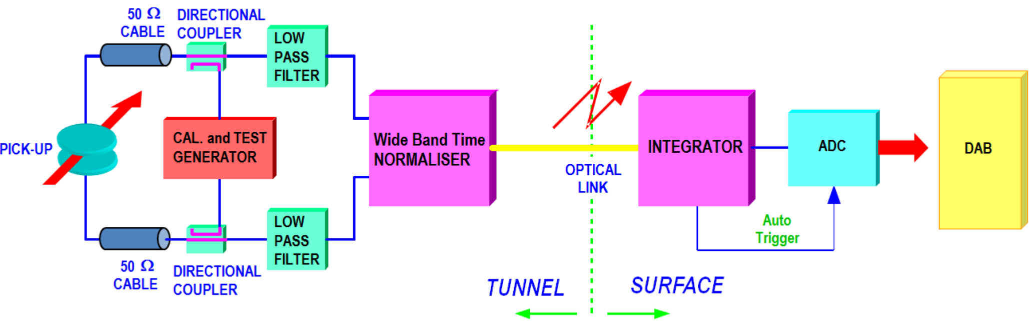


LHC IBPM Re-commissioning

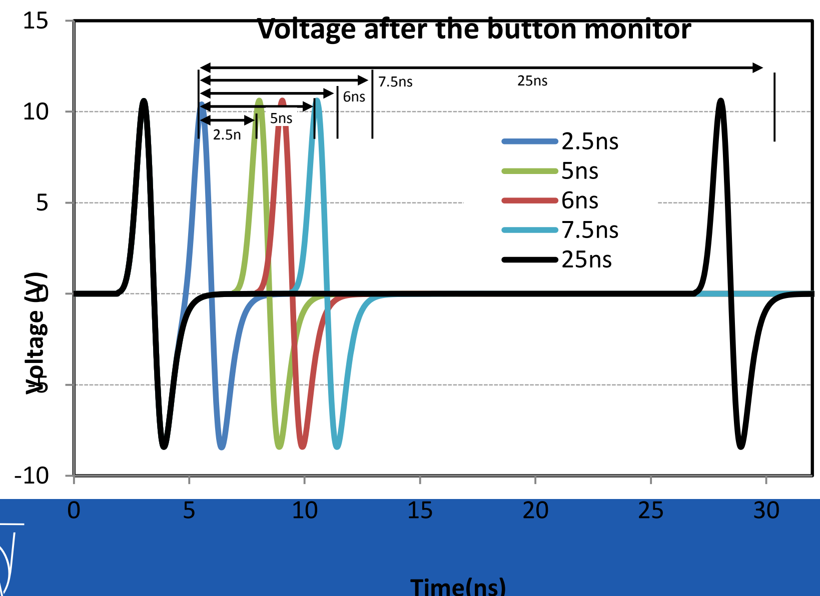
Scrapping one Pilot and one nominal in **low sensitivity** mode

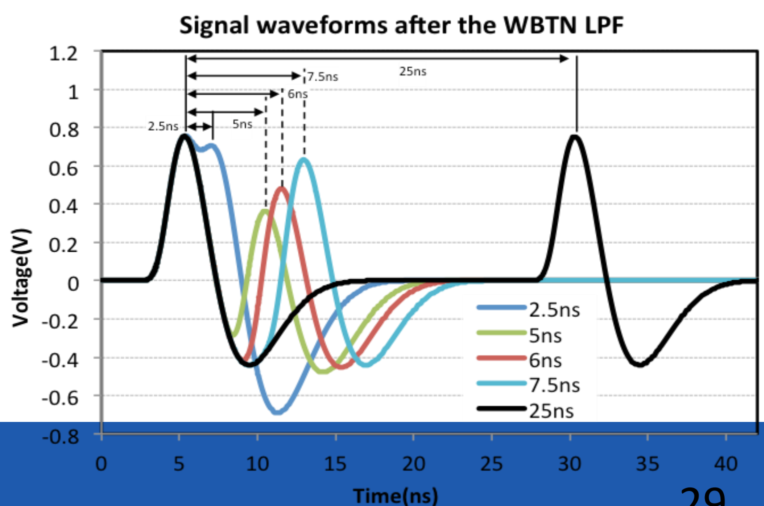


LHC BPM - WBTN



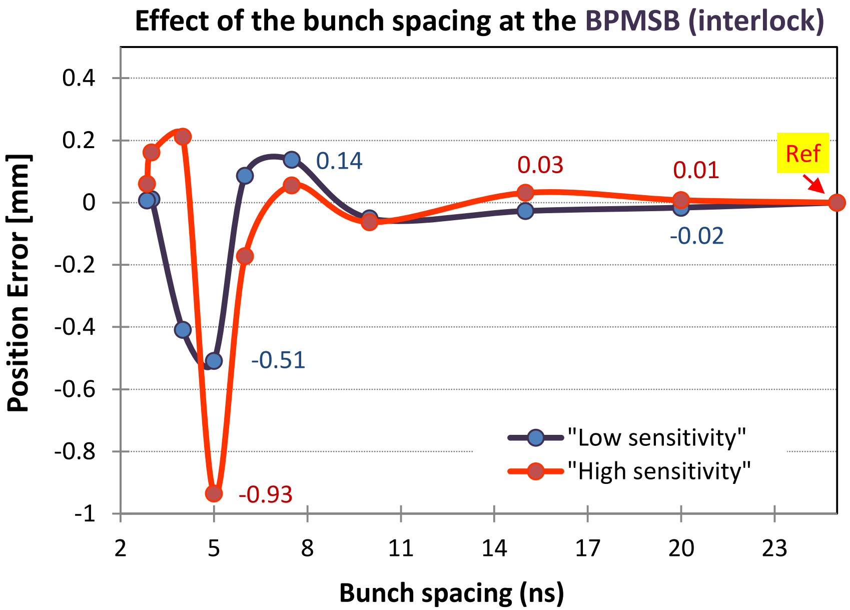
- Amplitude to Time conversion
- 70MHz LPF at the input of the electronic (bunch length independent)
- Depending on the bunch spacing , the signal will overlap in different ways.
- The system will provide a single measurement for bunches which are spaced by less than ~20ns.

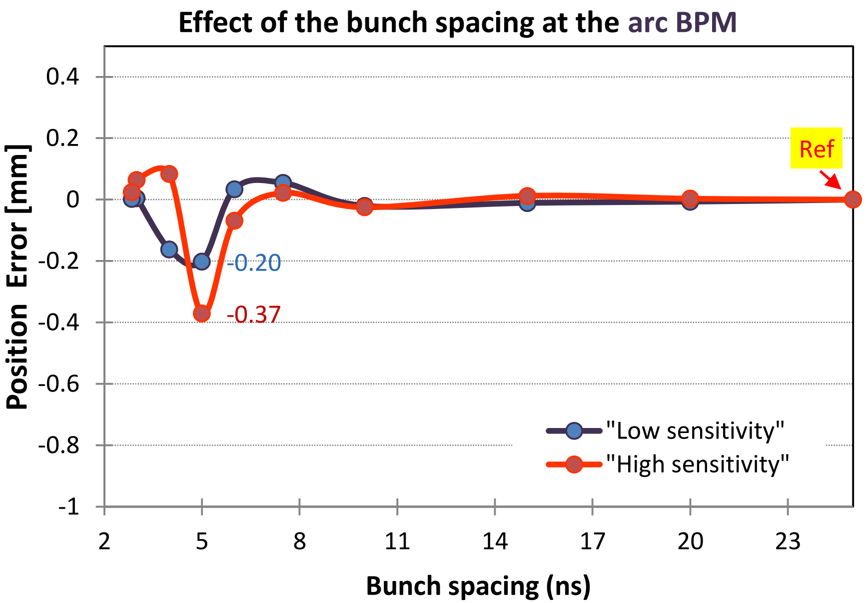




Scrubbing doublets

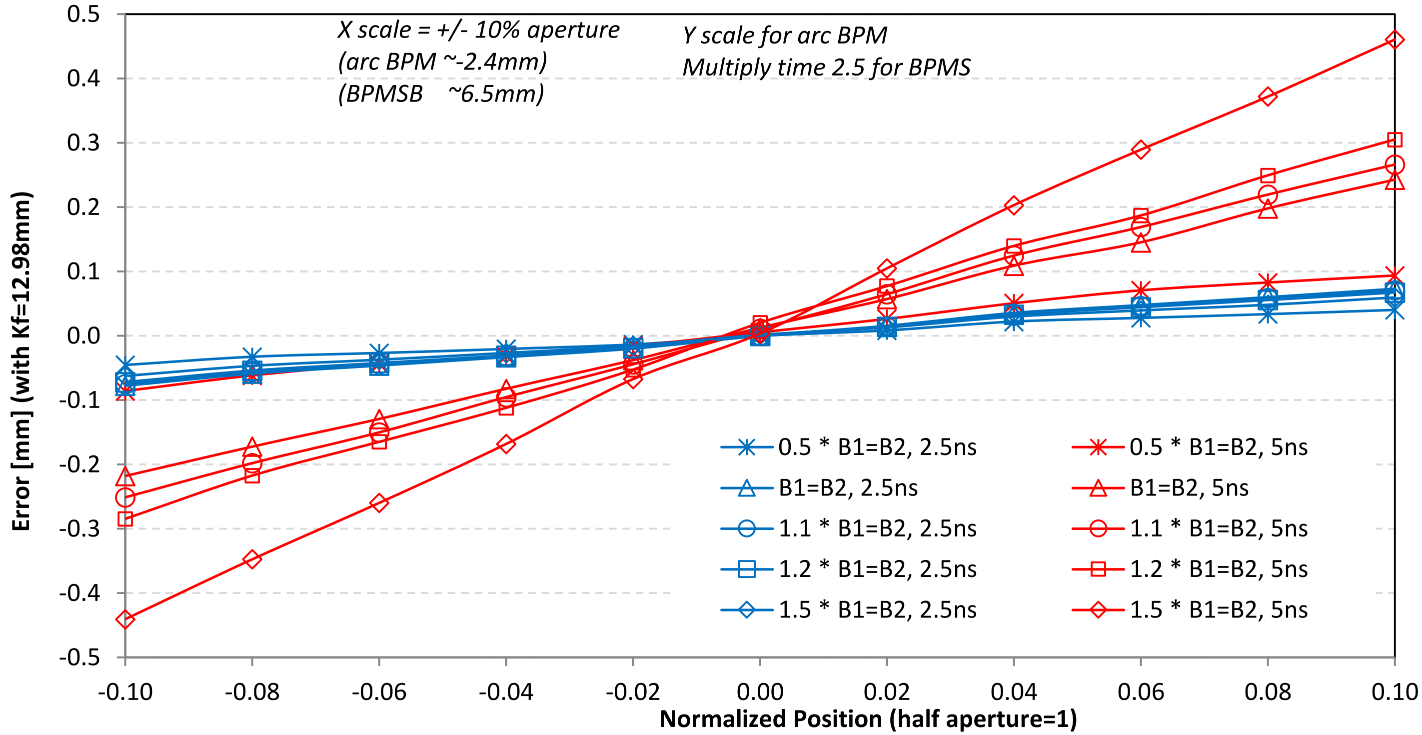
Beam “simulator” tests (beam signal replaced by pulse generator)
May be possible to test on SPS with beam





Doublets simulations 1

Bunch 1 and bunch 2 with same position



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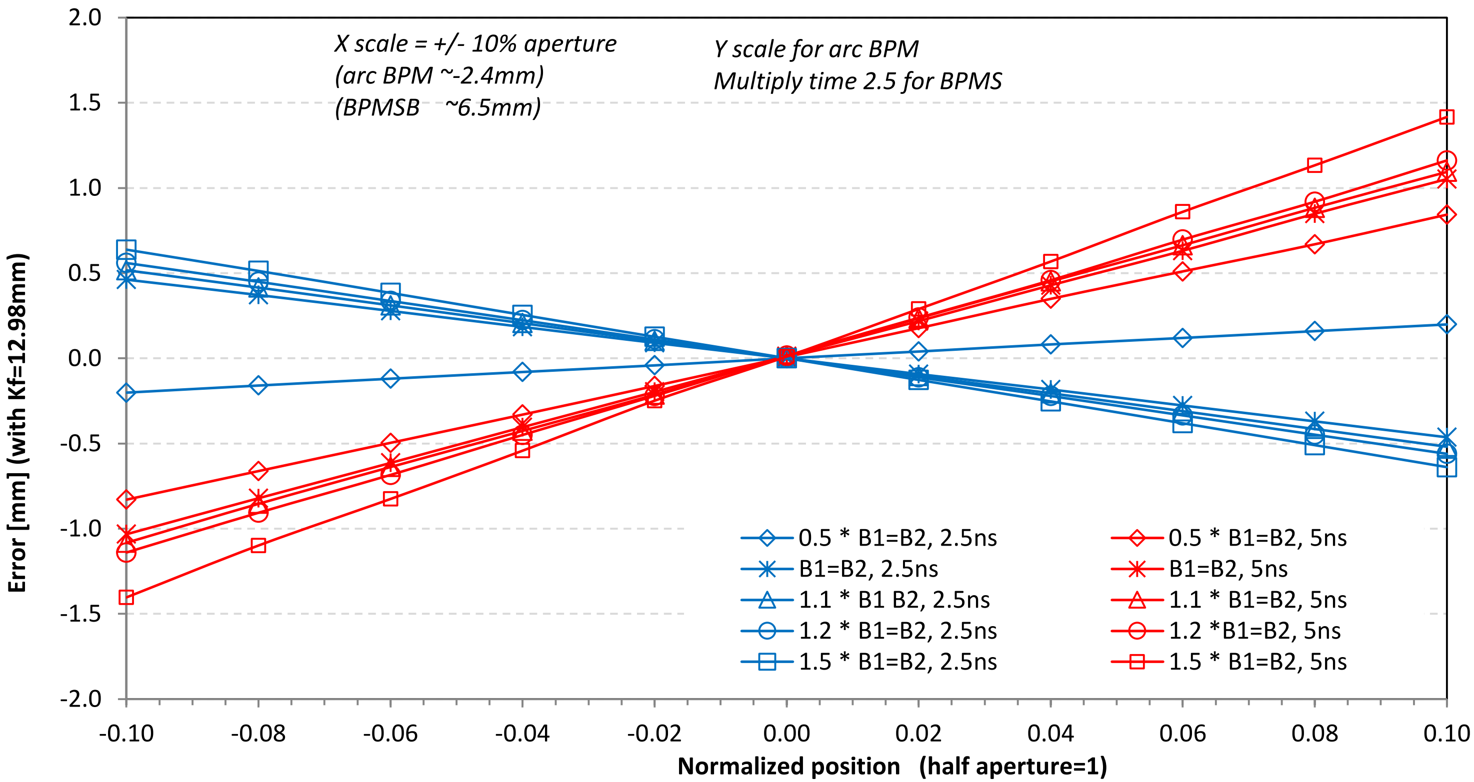
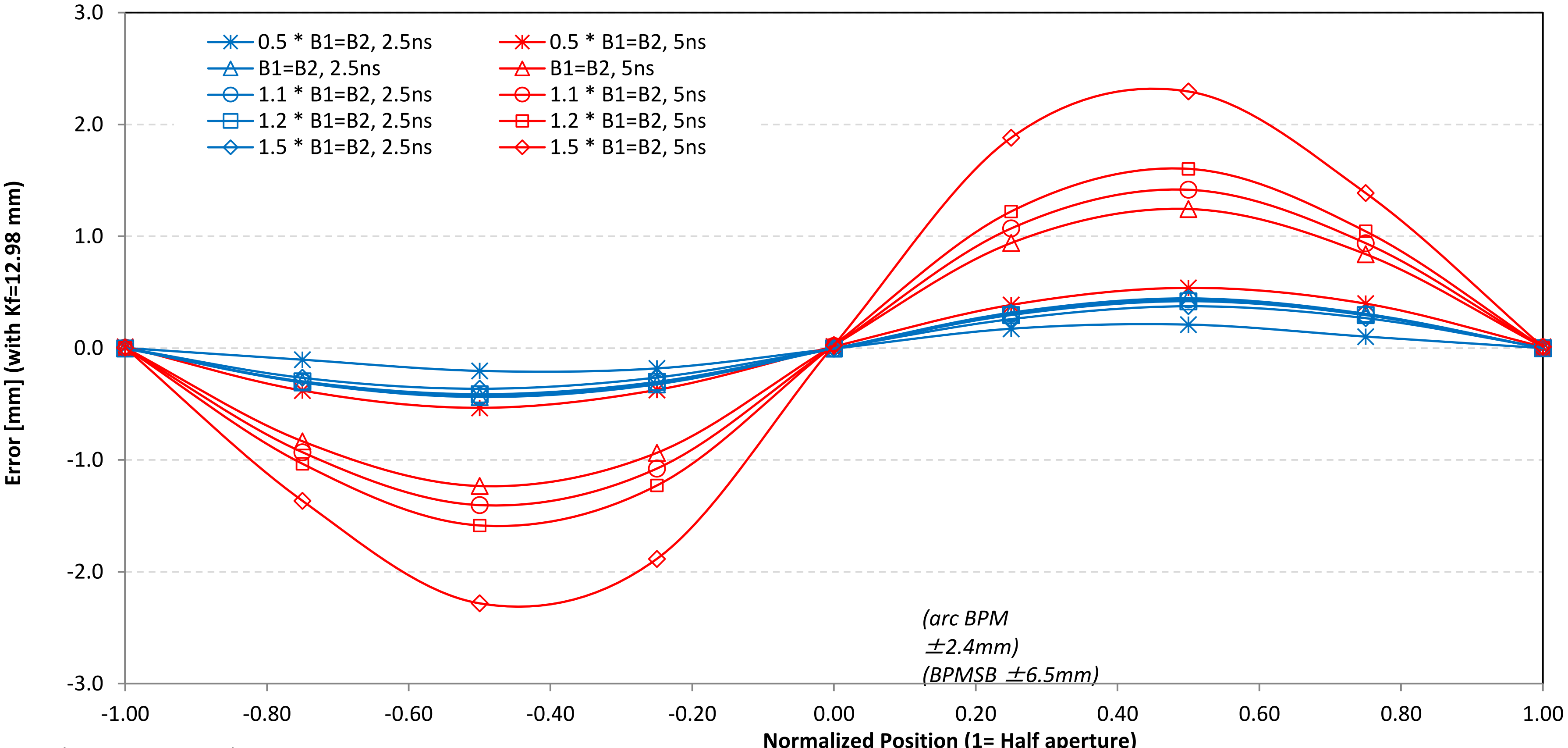
Doublets simulations 2

Bunch 2 always centred



Simulations with Pspice

- **Bunch 1 and 2 can have different intensities : ‘(Un)Balanced Doublet’**
- Normalizer model circuit and signals are “ideal”
- Realistic Bunch length

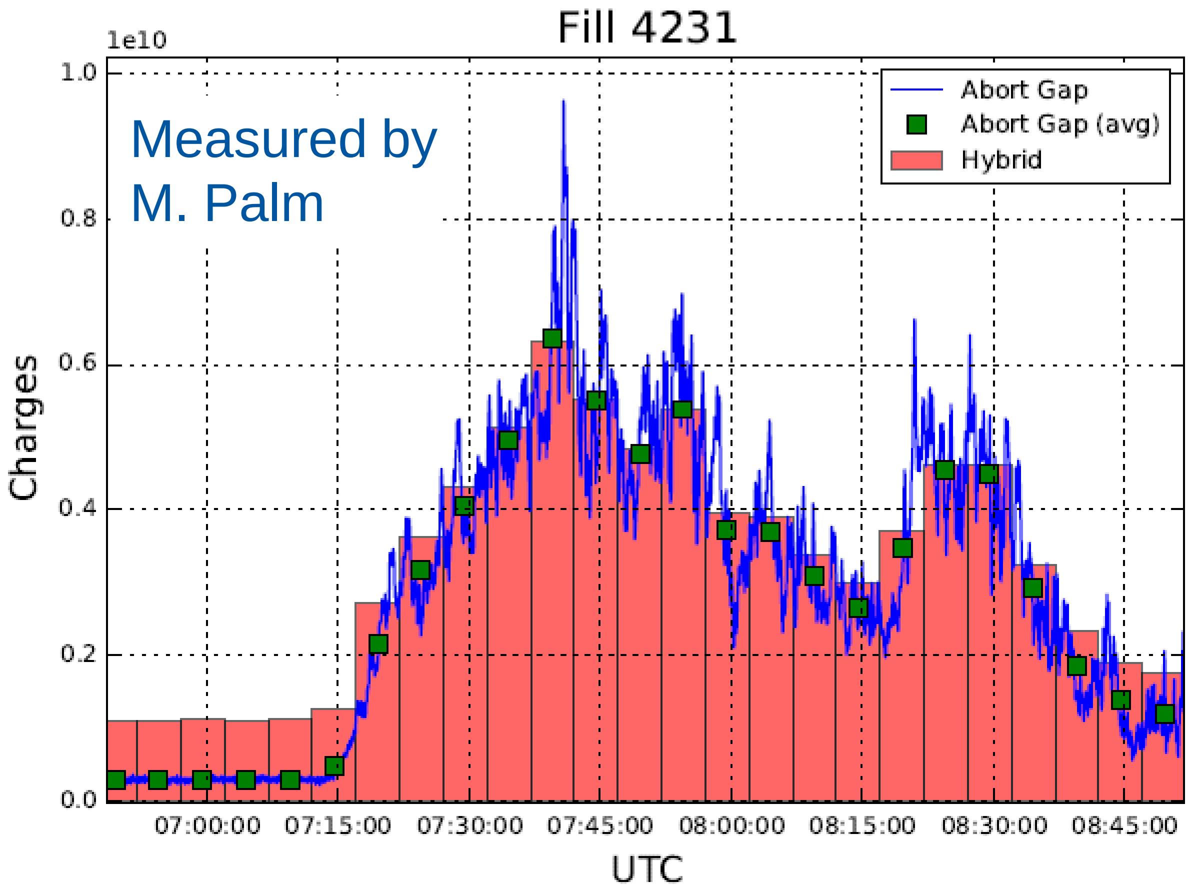


(arc BPM ~-24mm)
(BPMSB ~65mm)

Note : Half Aperture of arc BPM = 24mm
Half Aperture of BPMSB = 65 mm

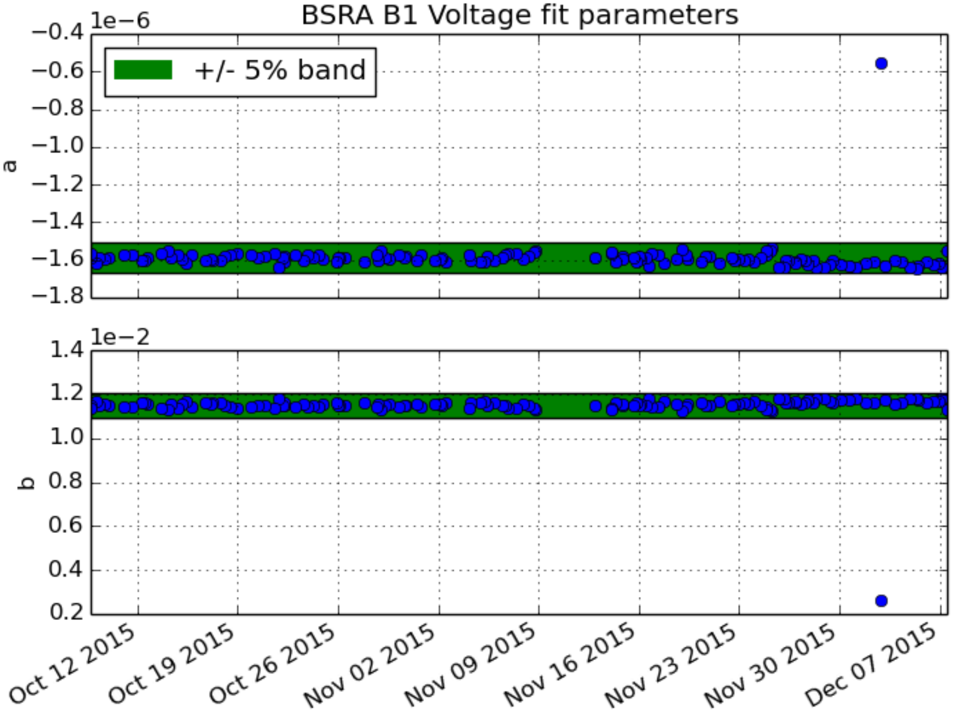
BSRA performance: B1 Accuracy

- A confirmation for B1: fill 4231, comparison with Longitudinal Density Monitor Hybrid PMA. Agreement within +/- 18%



BSRA performance: accuracy

- Better than +/-50% absolute accuracy at flat top. B1 **OK**, B2 **(69.1%)**
- Better than +/-5% absolute accuracy at injection **NOT POSSIBLE WITH PRESENT SYSTEM (needed?)**

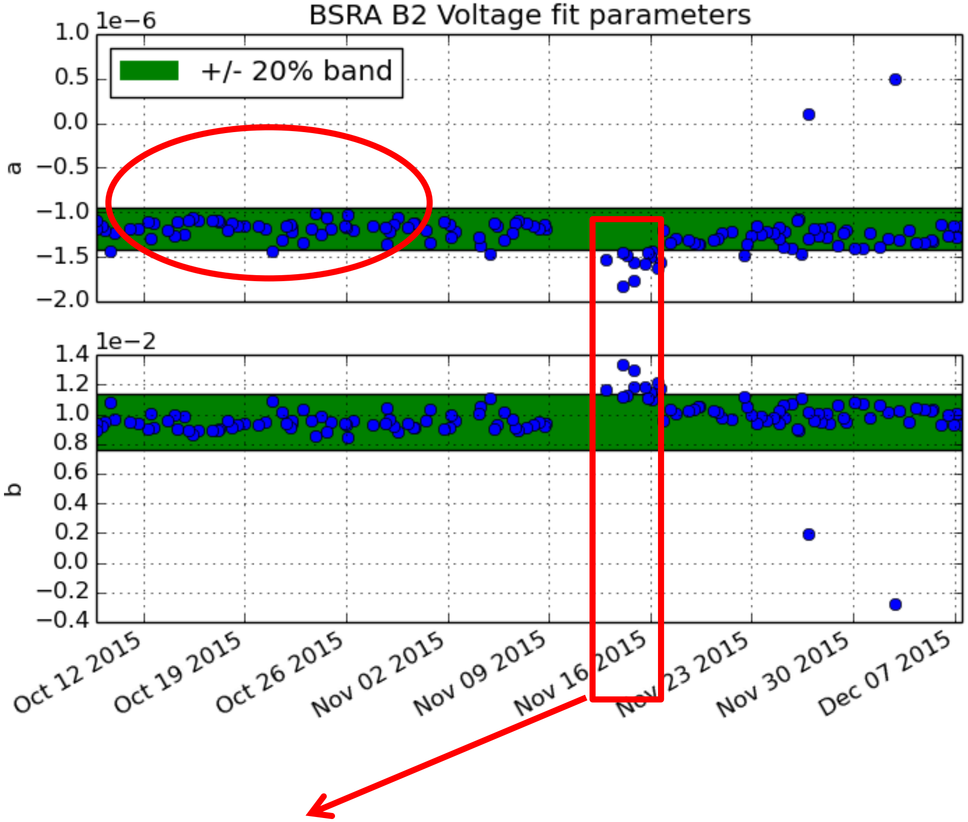


B1 Calculated accuracy at 6.5 TeV:

+/- 35.4 % OK

From voltage-gain calibration historical data (backup slides). B1 gain curve known with good precision.

BSRA performance: B2 accuracy



Outliers after technical stop

B2 Calculated accuracy at 6.5 TeV:

+/- 69.1 % NOT OK

Due to noisier gain curve. **However**: B1 and B2 signal have same noise amplitude. Gain noise might be due to low signal in calibration procedure.

...TO BE INVESITGATED DURING YETS 2015

Calculation of accuracy (backup)

From raw to calibrated data:

$$p \propto A \downarrow flt (E) / W(E) \; 1/10 \uparrow a$$
$$V \uparrow 2 + bV \;\; I$$

Where is the AG pop, the ND filters attenuation, the normalised photon emission per particle, the PMT voltage, gain curve fit parameters.

Predominant contribution to is error on parameters:

where , derived from historical gain curve fit data.