Diode ORbit and OScillation (DOROS) System

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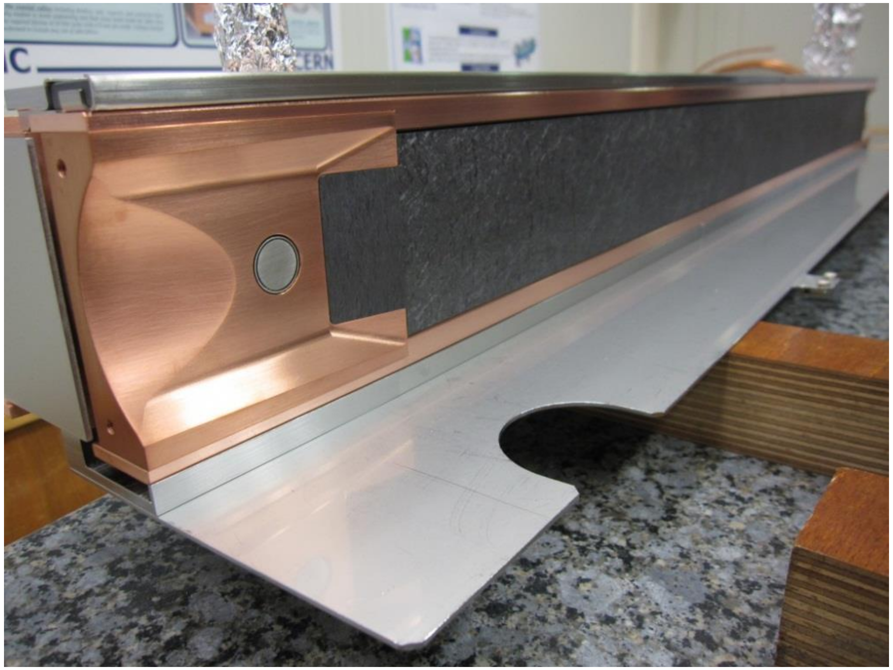
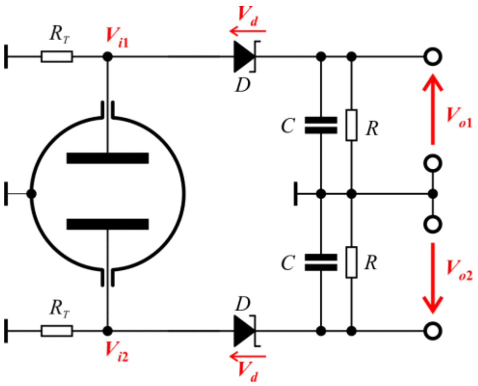
Collimator BPMs



- Each jaw end motorised independently
- Beam centring required on each collimator end
- Four button BPMs, one on each extremity of each jaw
- Requirements for the collimator BPM electronics:
  - resolution in the 1 µm range
  - beam centring accuracy in the 10 µm range
- Slow orbit measurement sufficient, 1000-turn averages acceptable
- Bunch-by-bunch not needed

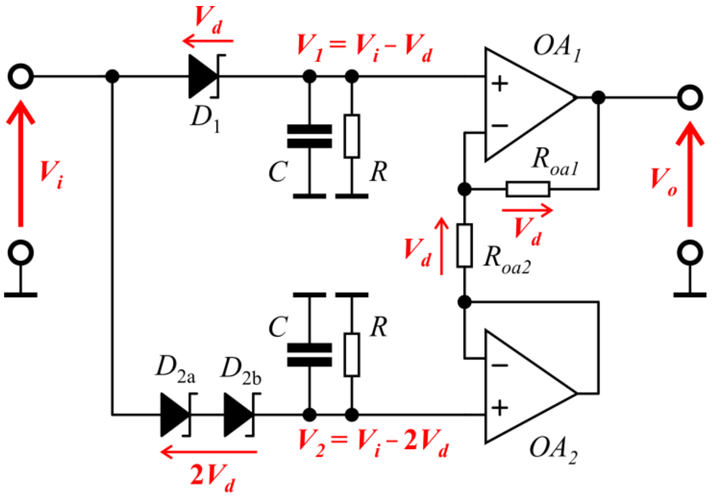
The new idea: compensated diode detectors

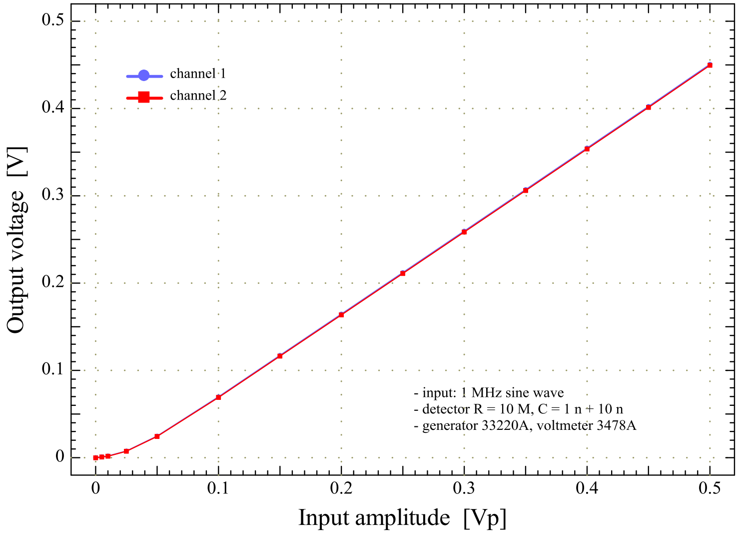
- Very good experience with diode detectors for tune measurement (BBQ systems):
  - simple conversion of nanosecond beam pulses into slowly varying DC signals;
  - sub-micrometre resolution possible with standard button and stripline BPM;
  - very simple and robust.
- Standard diode detectors not precise enough for orbit measurement (diode forward voltage, its temperature dependency)
- New scheme for orbit measurement: compensated diode detectors



$$\text{ideal}: \quad p_{12} = c_{12} \frac{V_{i1} - V_{i2}}{V_{i1} + V_{i2}}$$

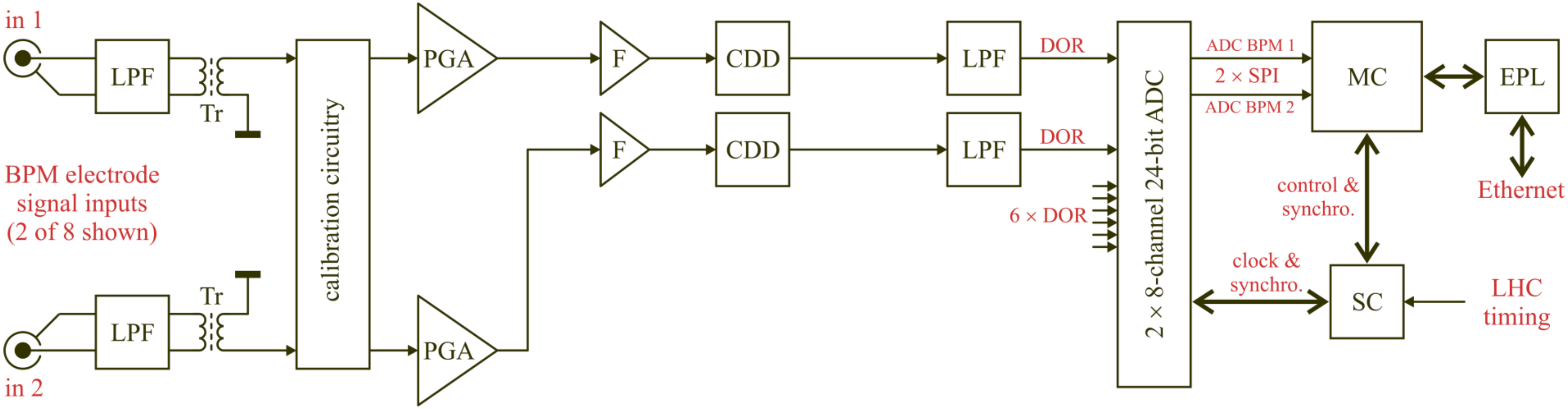
$$\text{real}: \quad p_{12} = c_{12} \frac{V_{o1} - V_{o2}}{V_{o1} + V_{o2}} = c_{12} \frac{V_{i1} - V_{i2}}{V_{i1} + V_{i2} - 2V_d}$$





- input: 1 MHz sine wave
- detector R = 10 M, C = 1 n + 10 n
- generator 33220A, voltmeter 3478A

Diode ORbit (DOR)



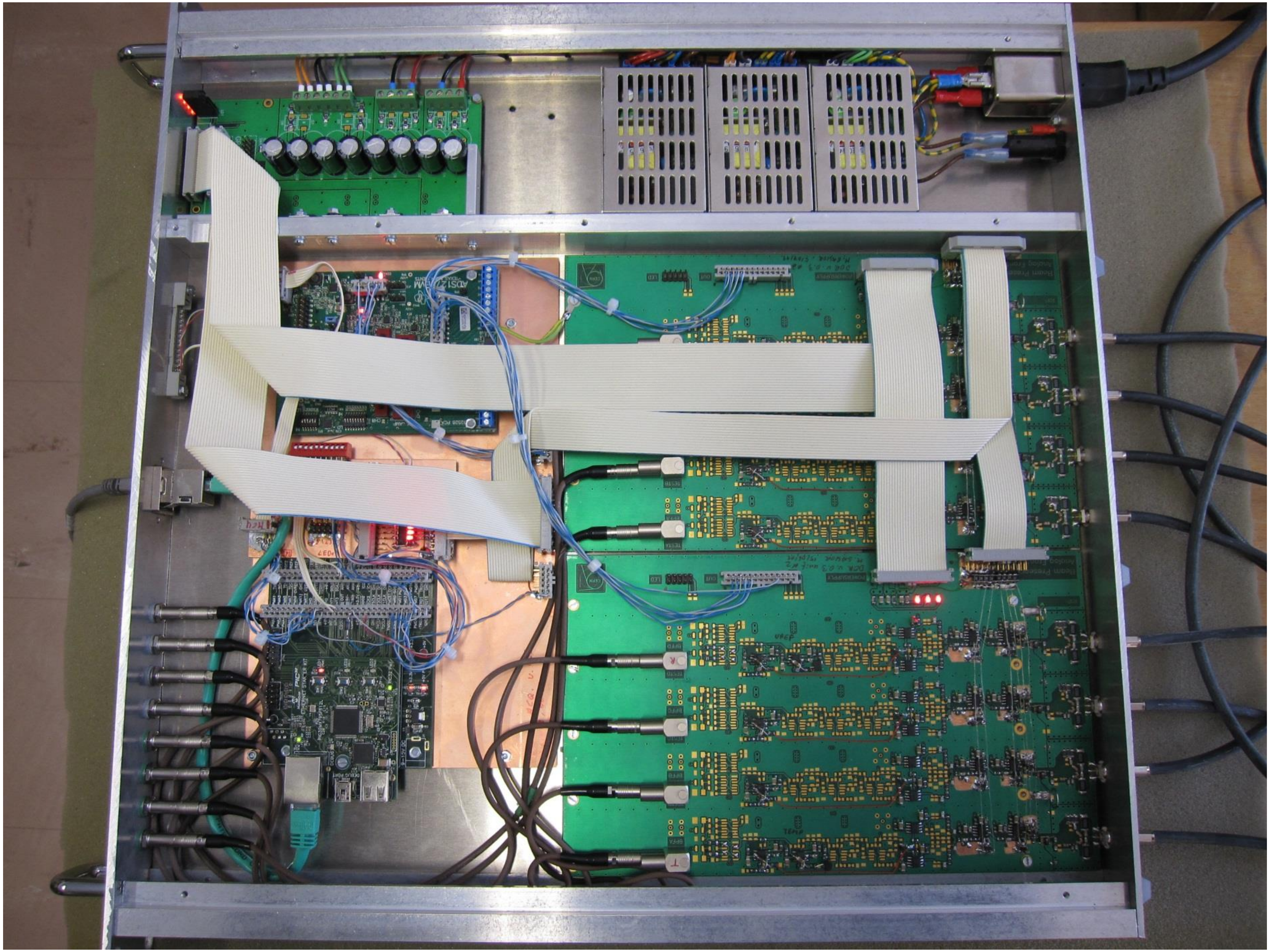
LPF = Low Pass Filter
PGA = Programmable Gain Amplifier

F = Follower
CDD = Compensated Diode Detector

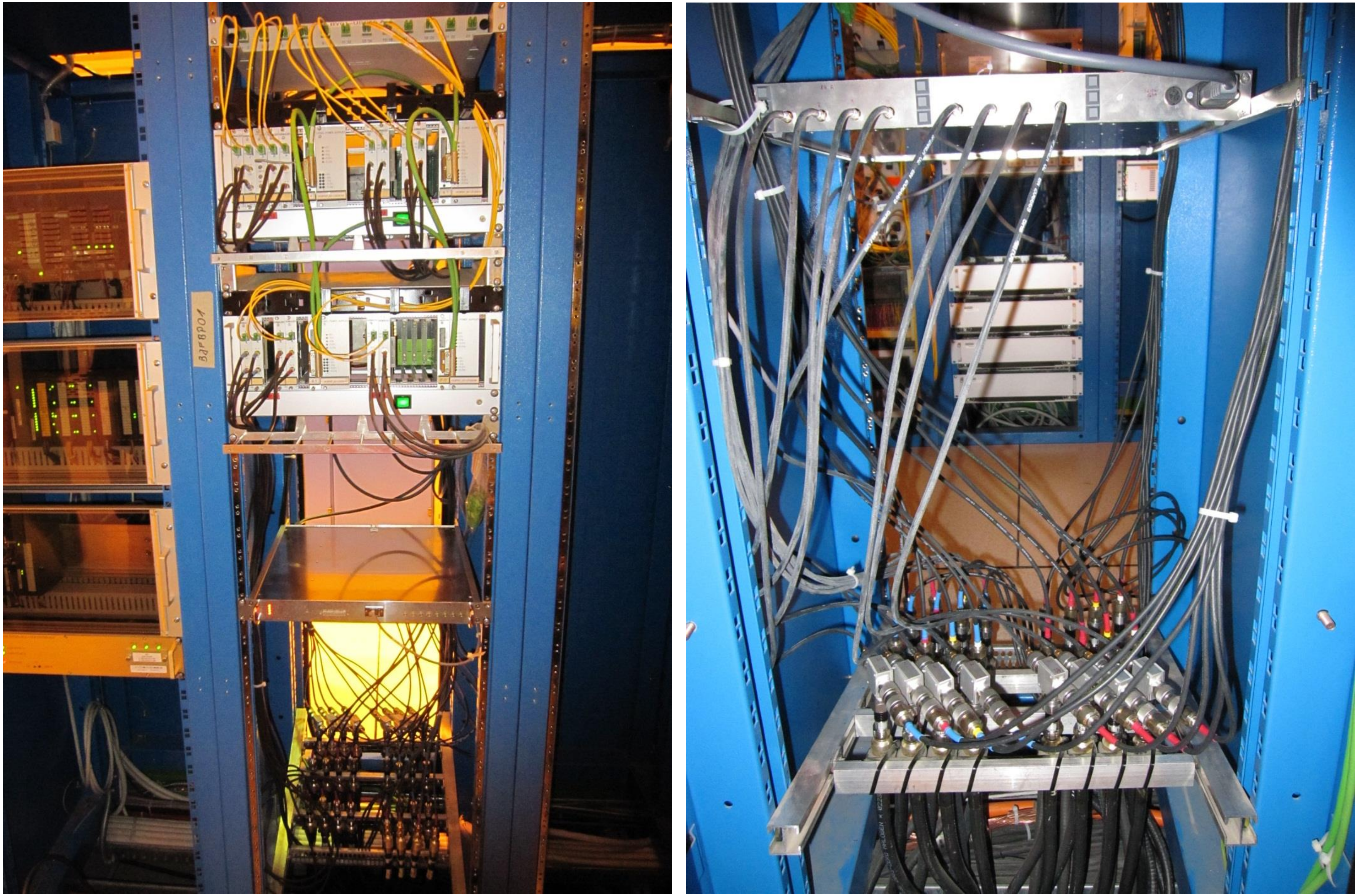
MC = Main Controller
SC = Synchronisation Circuitry
EPL = Ethernet Physical Layer

- The most important part: Compensated Diode Detectors (CDD)
- Initially designed for very precise beam centring,
  only later considered as a candidate for the LHC orbit measurement with regular BPMs
- One processing and one ADC channel per BPM electrode
- Beam position fully evaluated in the digital domain
- 24-bit ADCs sampling at f_{rev} and averaged down to the standard 25 Hz, compatible with the current BPM system, UDP transmission
- One DOR unit is for two collimators or two regular BPMs (8 channels for 4 planes)
- Data throughput: 4 electrodes × 32-bit samples × 25 Hz = 400 bytes per second per BPM

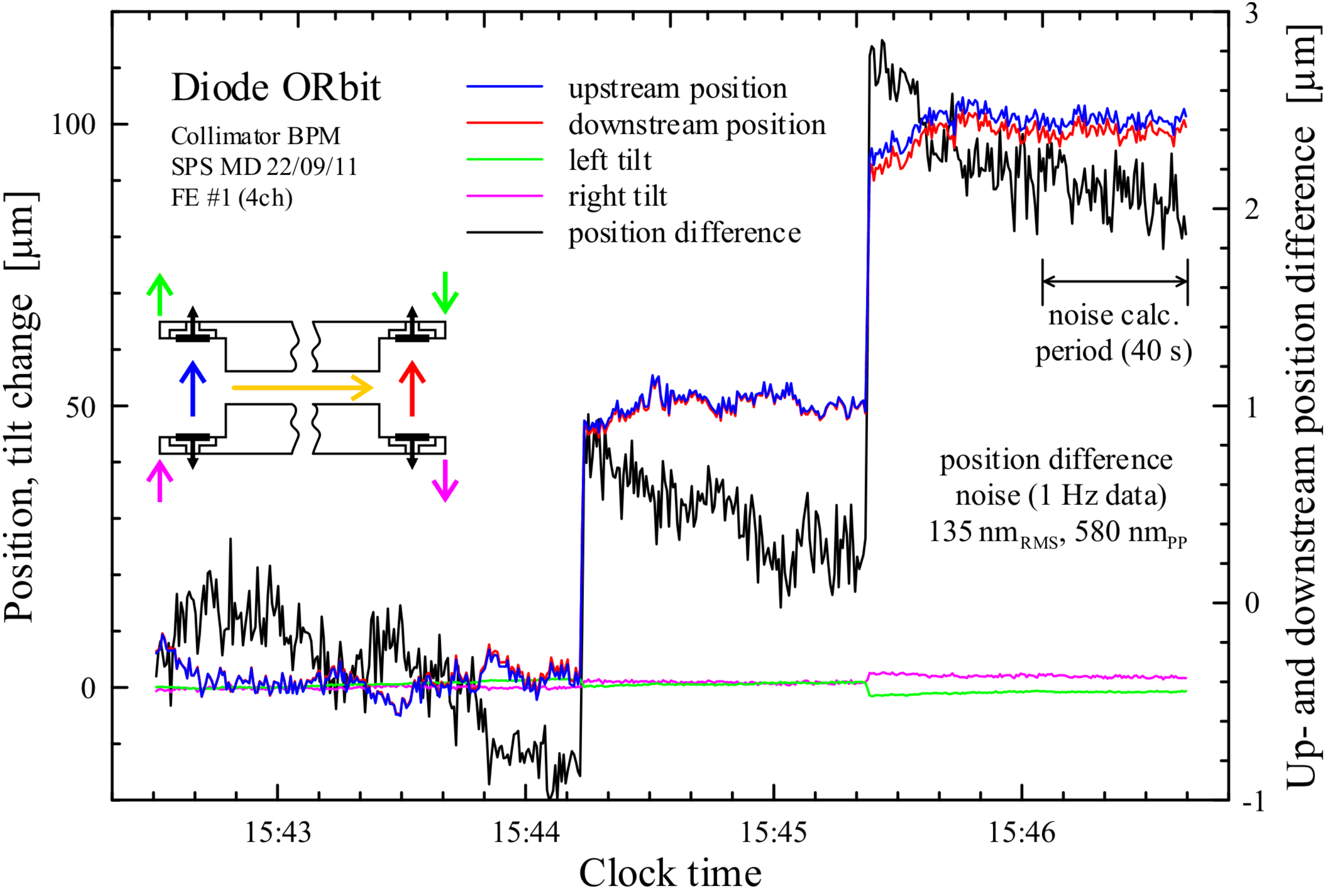
DOR front-end prototype



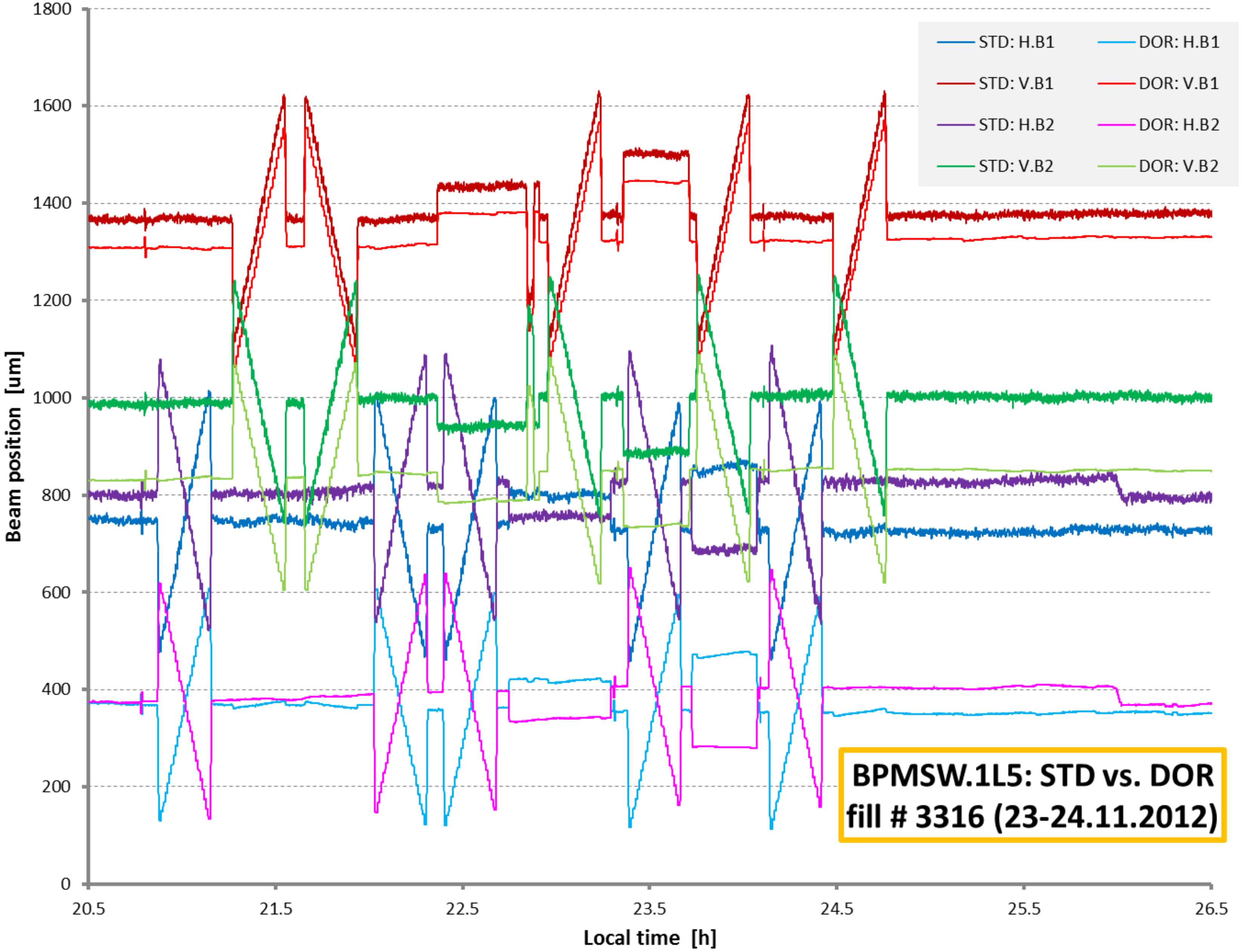
DOR FE prototype installation on 2 BPMs in PT5



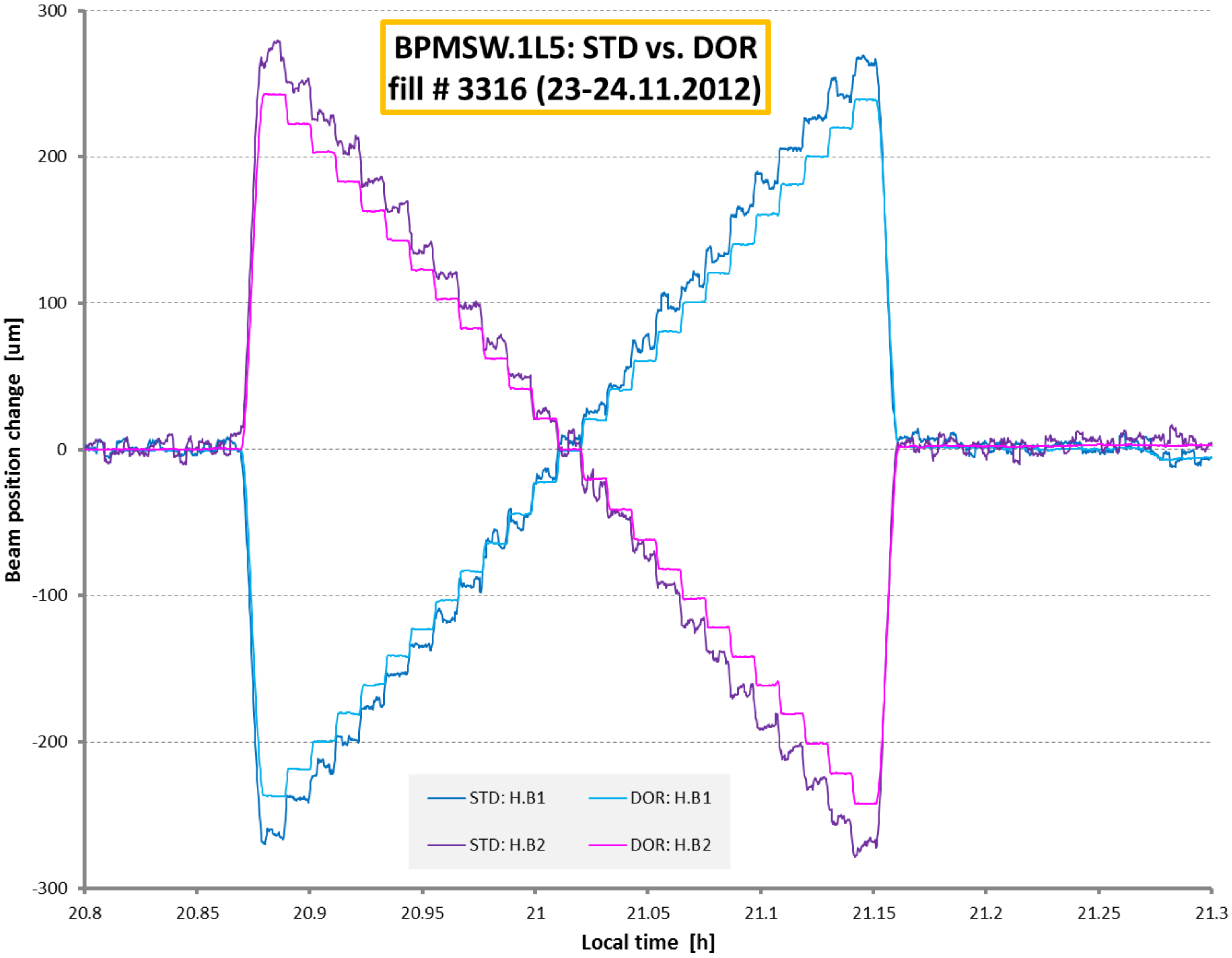
DOR results with the collimator BPMs (SPS coasting beam)



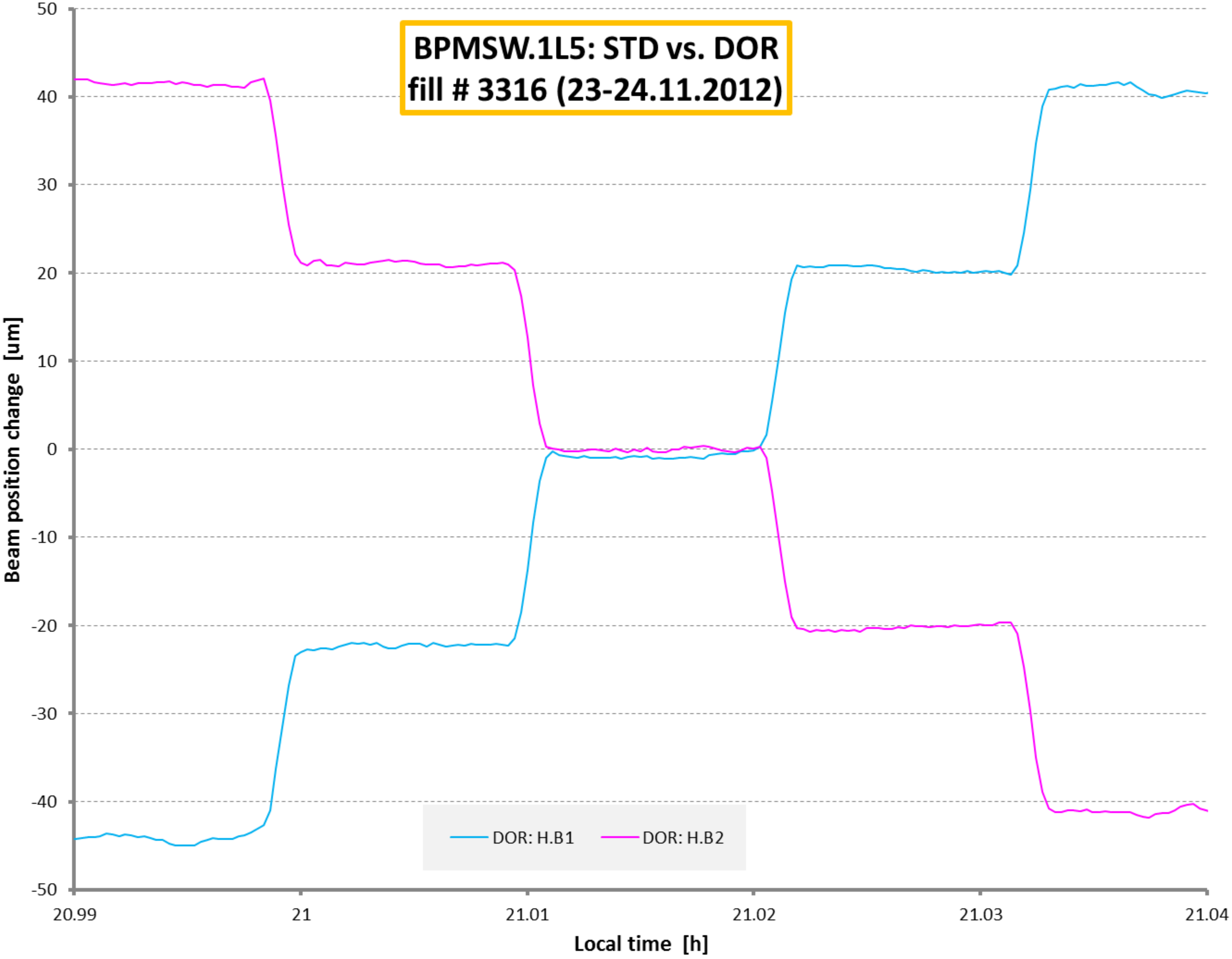
BPMSW.1L5: Standard vs. DOR during fill #3316



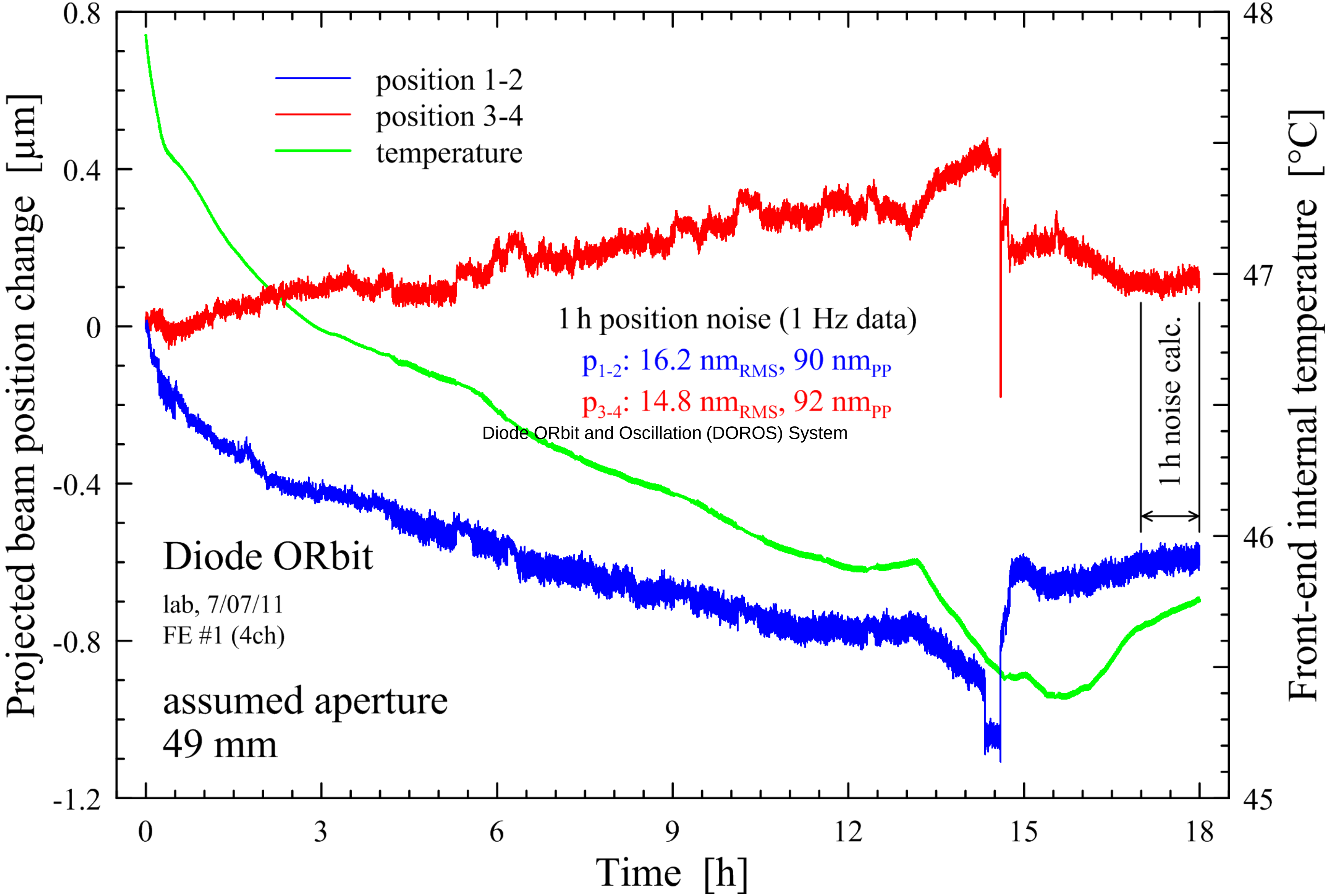
BPMSW.1L5: Standard vs. DOR during fill #3316



BPMSW.1L5: Diode ORbit during fill #3316



Diode ORbit: stability measurement in the lab



DOR vs. standard BPM electronics

- **Optimisation:**
  Standard: universal, bunch-by-bunch.
  DOR: orbits only, (sort of) bunch average.

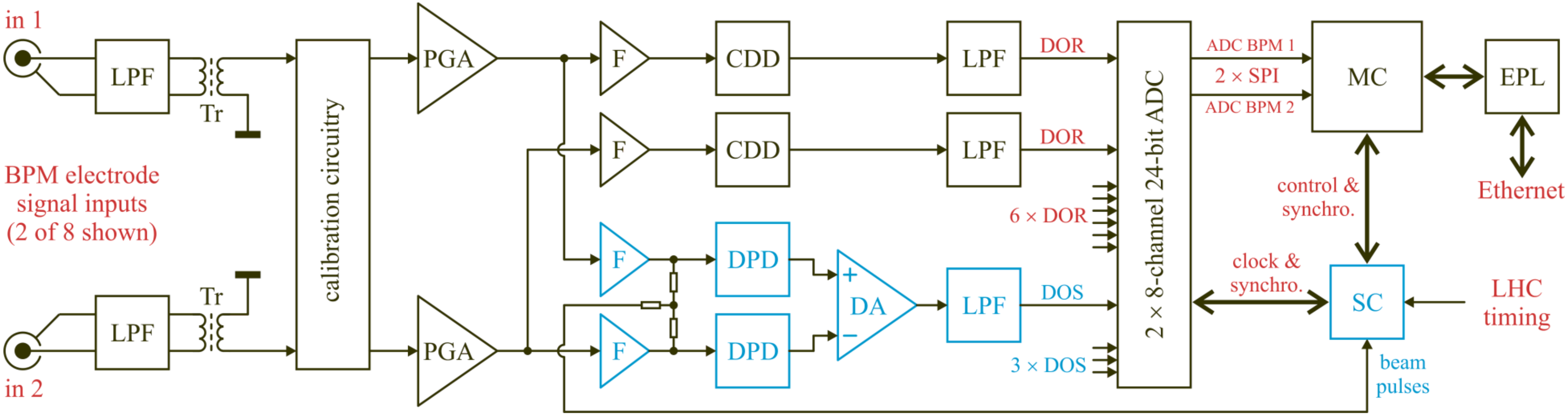
- **Amplitude and time resolution:**
  Standard: 12-bit ADCs sampling at 40 MHz.
  DOR: 24-bit ADCs sampling at f_{rev}, samples averaged down to 25 Hz.

- **Gain switching:**
  Standard: two gains (high and low).
  DOR: Many gains to maintain a fairly constant amplitude at the compensated diode detectors.
  The first prototype had 5 dB gain steps, the final will have 1 dB.

- **Calibration:**
  Standard: simulated beam pulses.
  DOR: simulated beam pulses with variable filling pattern and amplitude and calibration with beam signals
  (e.g. swapping electrode signals on two DOR channels,
  two DOR channels connected to the same BPM electrode) .

- **Architecture:**
  Standard: modular, VME.
  DOR: standalone unit with Ethernet UDP data transmission, modular inside the DOROS unit.

DOR + OScillation (DOROS)



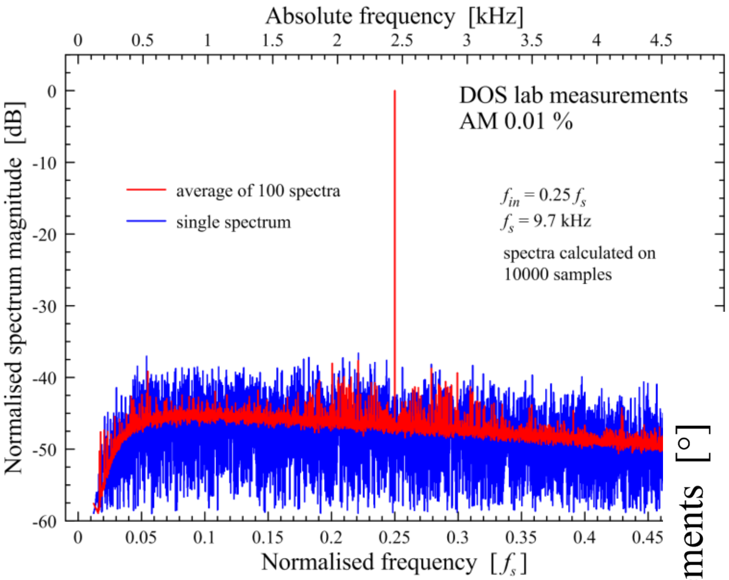
LPF = Low Pass Filter
PGA = Programmable Gain Amplifier
F = Follower

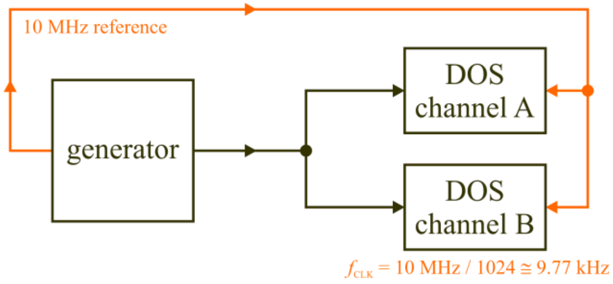
CDD = Compensated Diode Detector
DPD = Diode Peak Detector
DA = Differential Amplifier

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

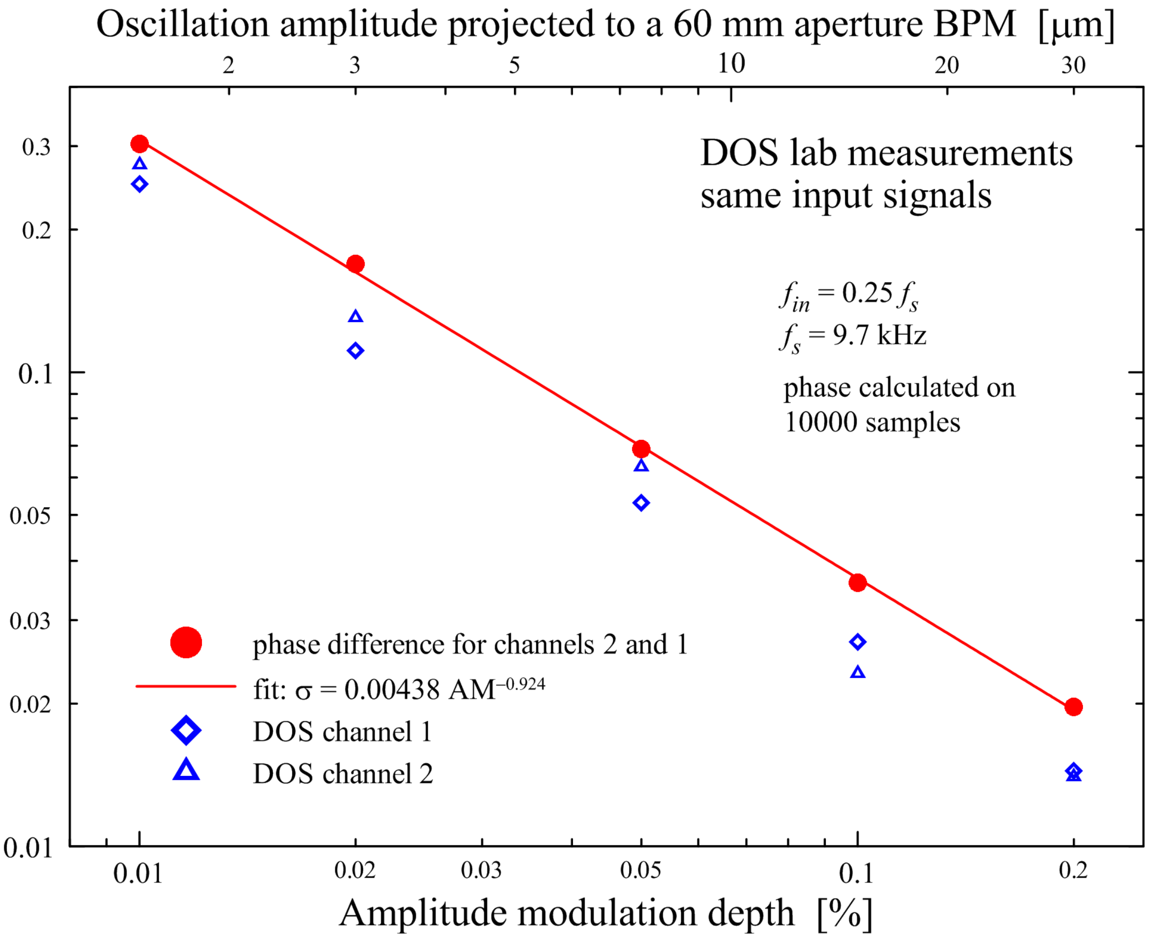
- DOS ≈ BBQ on each BPM for phase advance measurement.
  The idea demonstrated by Ralph Steinhagen in the SPS in 2008 (see CERN-ATS-2009-031).
- BPM + part of analogue processing + data transmission shared with the DOR
- Largest overhead w.r.t. the DOR part is the beam synchronous timing (BST), which DOR does not need
- 24-bit ADCs sampling at f_{rev}, real-time phase calculation, results at 25 Hz compatible with the orbit system, sent together in common UDP frames
- Each DOS unit measures the phase advance w.r.t. a common reference derived from the BST
- Real-time phase calculation at two frequencies (H+V) for coupling measurement
- One DOROS FE = 4 orbits + 4 phases (typically H+V.B1 + H+V.B2)

DOS lab measurements





More on DOS in CERN-ATS-2013-038:
Prototype system for phase advance measurements
of LHC small beam oscillations

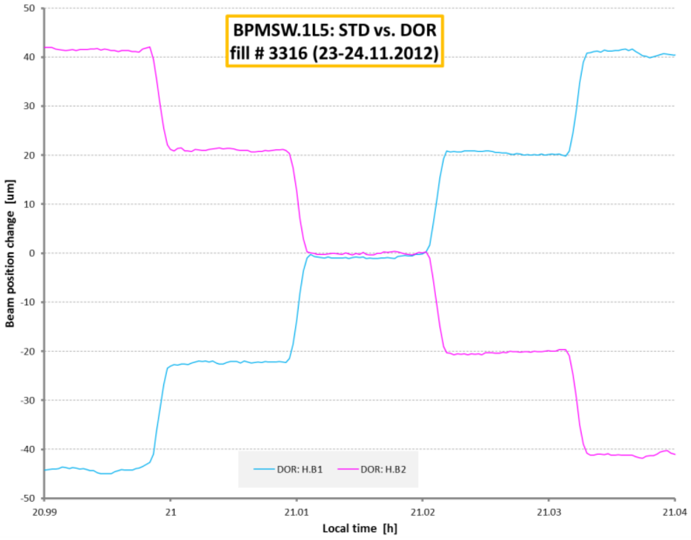


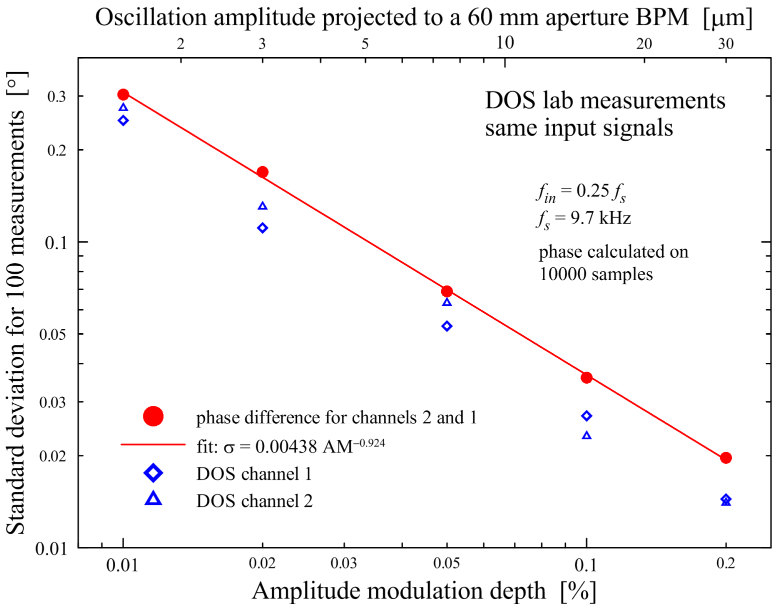
DOS vs. BBQ

- **Optimisation:**
  BBQ: frequency measurement with very small beam oscillations
  DOS: phase advance measurement in a sub-system "glued" to the diode orbit system
- **Amplitude sensitivity:**
  DOS is a "slave" sub-system added to the DOR "master", optimised for orbit measurement, while the BBQ is an "independent" system optimised for beam oscillation sensitivity. Therefore, DOS will be less sensitive than the BBQ. Probably part of the "sensitivity loss" can be compensated by longer phase advance measurement, which for the tune typically are not possible.
- **Synchronisation:**
  All DOS units will be synchronised to a common phase reference from the beam synchronous timing; BBQ system units are synchronised to a common frequency reference (f_{rev}) with an arbitrary phase and therefore are not optimised at all for phase advance measurement.
- **Excitation:**
  BBQ can operate with residual "natural" beam oscillations, while DOS will require proper beam excitation, hopefully in the 10 µm range. This is caused not only by the smaller DOS sensitivity, but also by the "explosive" nature of the natural beam oscillations.
- **Analogue filtering:**
  BBQ has very heavy analogue filtering (6th order Chebychev + f_{rev} notch filters), introducing large phase shift, likely to change from one unit to another. DOS will have only simple analogue filters and the "heavy filtering" will be done in the digital domain, assuring very good symmetry between the DOS units.
- **Data rate:**
  BBQ delivers data at f_{rev} allowing observation of the full beam spectrum. DOS will deliver data at the regular orbit feedback rate (25 Hz) with real-time phase advance calculation in the DOS unit. In the normal mode DOS will deliver data only at the two beam excitation frequencies. Only in the test/full mode DOS will provide turn-by-turn data for development purposes.

Summary

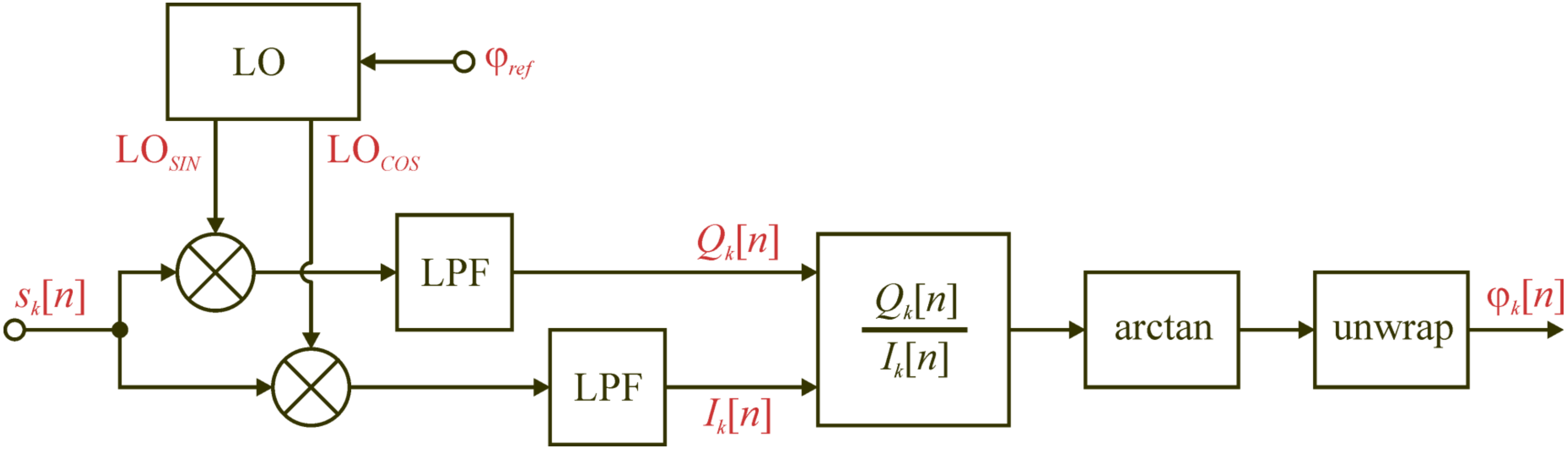
- The new DOROS system should allow beam orbit measurement with sub-micrometre resolution and micrometre long term stability
- DOROS will allow proper phase advance and coupling measurement, hopefully with beam excitation at the 10 µm level
- For the start-up the DOROS will be installed as the only electronics on:
    - Collimator BPMs (some 16 collimators)
    - New BPMs in point 4 dedicated for BGIs (4 BPMs)
- DOROS will be installed installed in parallel to the regular BPM electronics:
    - First BPM before each experiment (4 experiments x 2 beams x 2 sides = 16 BPMs and 8 DOROS FEs)
    - ???
- The above locations will be used to:
    - Evaluate the DOROS system, especially its long term stability
    - Optimise its hardware and software



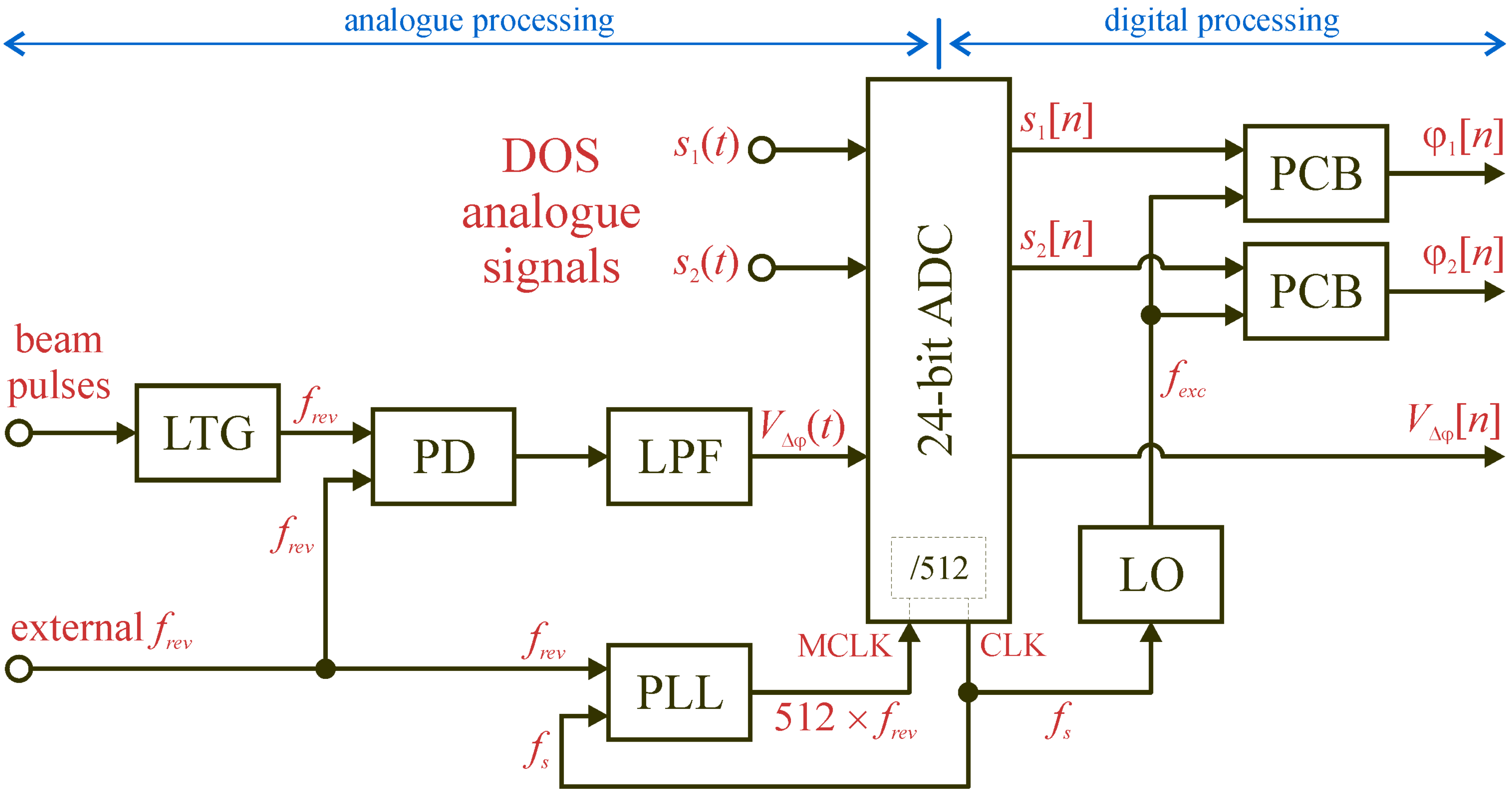


Spare slides

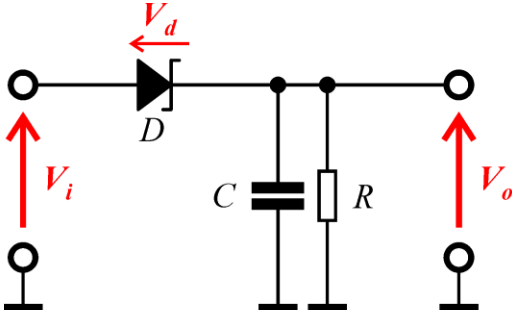
DOS phase calculation

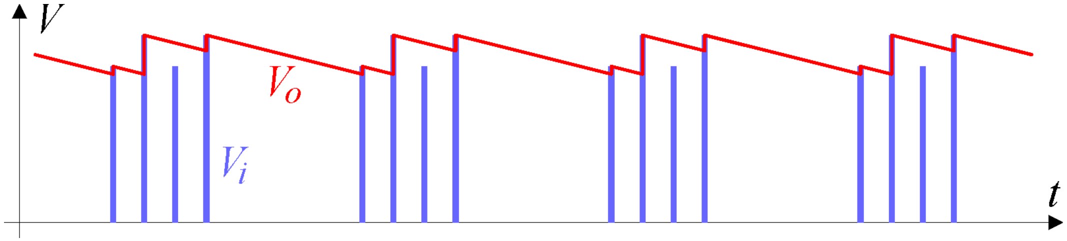


DOS synchronisation

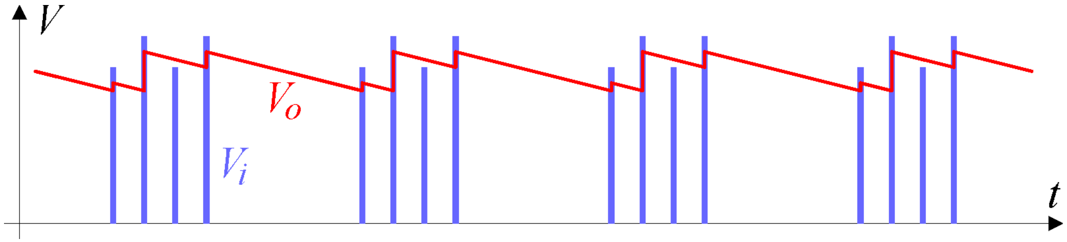


Diode detectors: modes of operation

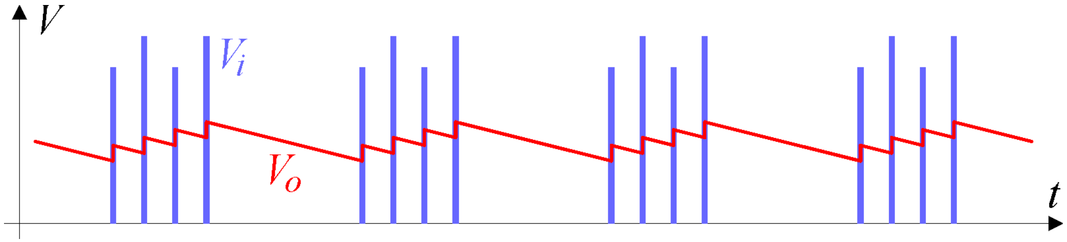




Input (V_i) and output (V_o) voltages of a peak detector with an ideal diode

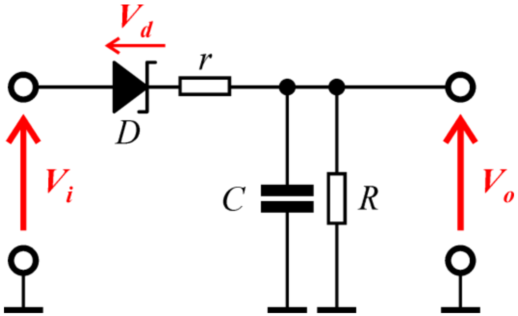


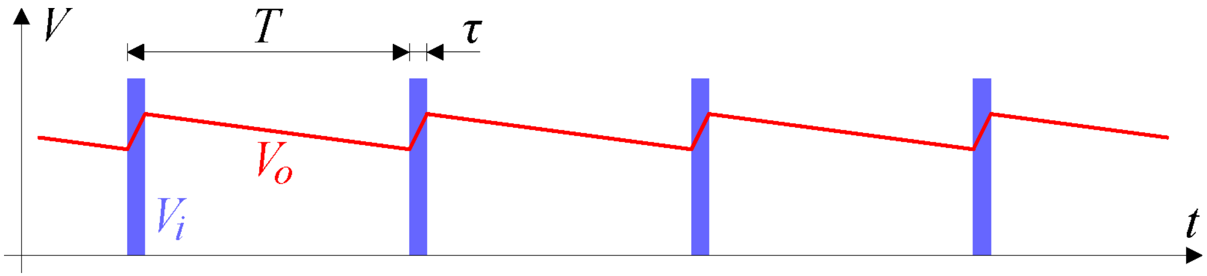
Input (V_i) and output (V_o) voltages of a peak detector with a real diode



Input (V_i) and output (V_o) voltages of an average-value detector

Peak detector with a (more) realistic diode





Charge balance equation for the following assumptions:

- a simple diode model with a **constant** forward voltage V_d and a **constant** series resistance *r.*
- constant charging and discharging current, i.e. output voltage changes are small w.r.t. the input voltage.

$$\frac{V_o}{R}T = \frac{V_i - V_o - V_d}{r}\tau$$

$$\frac{V_o}{V_i - V_d} = \frac{1}{1 + \frac{r}{R}\cdot\frac{T}{\tau}}$$

A numerical example: LHC, one bunch.

For LHC $\tau \approx 1$ ns and $T \approx 89$ µs, so for $V_o \approx V_i$ one requires R/r > T/τ.
Therefore, for $r \approx 100\,\Omega$, $R > 8.9$ MΩ.

- $V_i >> V_d$
- *n* bunches

$$\frac{V_o}{V_i} = \frac{1}{1 + \frac{r}{R}\cdot\frac{T}{n\tau}}$$

- For large T to τ rations peak detectors require large R values and a high input impedance amplifier, typically a JFET-input operational amplifier.
- The slowest capacitor discharge is limited by the reverse leakage current of the diode (in the order of 100 nA for RF Schottky diodes).