Elettra Sincrotrone Trieste

Integration of a pilot-tone based BPM system within the global orbit feedback environment of Elettra

G. Brajnik, S. Bassanese, G. Cautero, S. Cleva, R. De Monte

Elettra – Sincrotrone Trieste

Outline

- Introduction
- Pilot tone compensation
- eBPM prototype at Elettra
- Characterization and Performances
- Integration and results with beam

Introduction

- Goal of the project is the development of a innovative BPM system for electron storage rings (Elettra, Elettra 2.0) based on pilot tone compensation

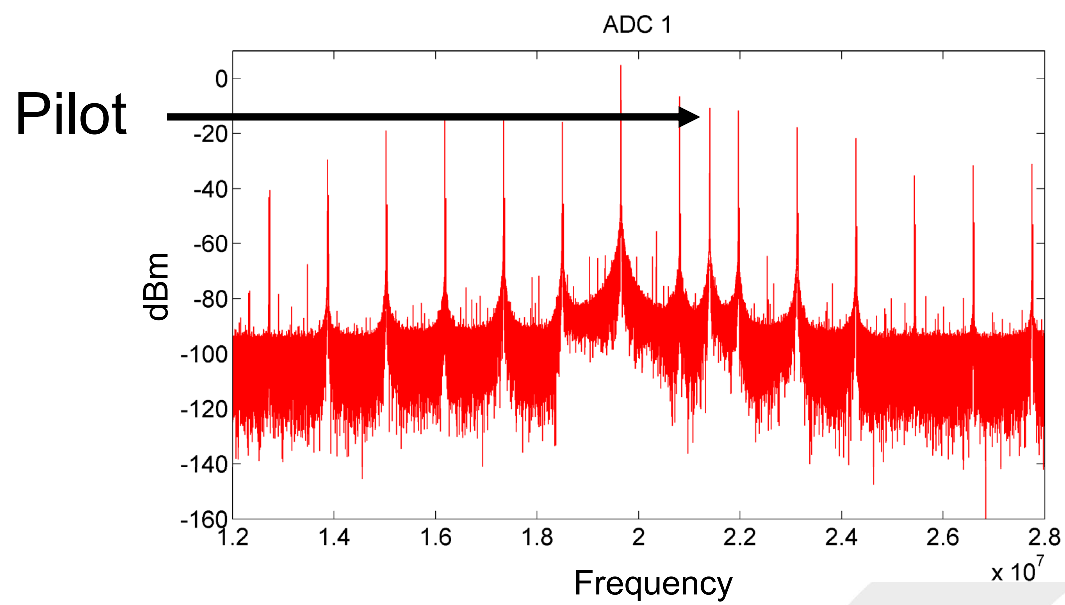
- Specifications:
  - Sub-micron resolution @ 10 kHz
  - Long-term stability better than 2 µm in 24 hours
  - Compensation of thermal drifts, channel variations, cables response

- Modular system:
  - Analog RF front end
  - FPGA-based digitiser
  - Computation unit for control systems (Tango, Epics)

Pilot tone: proposed implementation by Elettra

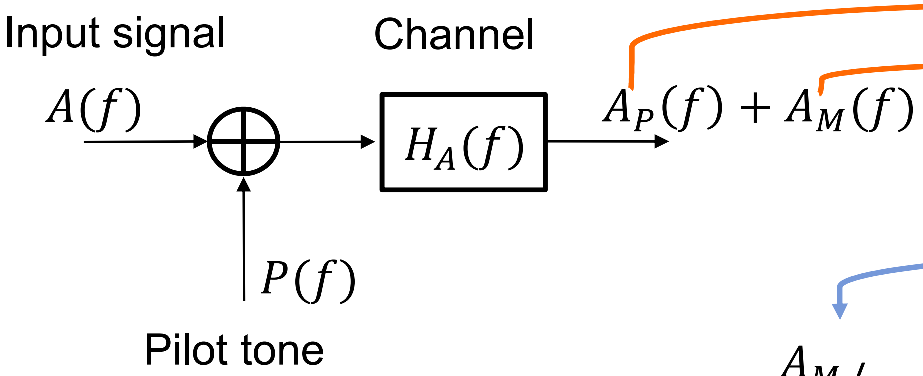
- A fixed sinusoidal tone is added to the original signal coming from the beam;
- The 4 channels use the same tone as reference;
- The pilot tone frequency has to fall near the carrier one without interfering with the latter;

Typical spectrum of a eBPM button plus the pilot tone



Compensation technique

Hypothesis: every channel variation affects in the same way both the carrier and the pilot



$$A_P(f) = H_A(f) \cdot P(f)$$

$$A_M(f) = H_A(f) \cdot A(f)$$

$$A(f) = \frac{A_M(f)}{A_P(f)} \cdot P(f)$$

$$x = K_x \cdot \frac{{}^{A_M}/_{A_P} - {}^{B_M}/_{B_P} - {}^{C_M}/_{C_P} + {}^{D_M}/_{D_P}}{{}^{A_M}/_{A_P} + {}^{B_M}/_{B_P} + {}^{C_M}/_{C_P} + {}^{D_M}/_{D_P}}$$

Compensated position in classical Difference-over-Sum (DoS) equation

Advantages in beam diagnostics

- Compensation of cables
  - Possible when the tone is injected near to the pick-ups
- No need for thermoregulation
  - Thermal drifts are the same for carrier and pilot
- Reduced current dependence
  - Pilot can be also used as a “dithering” with low beam currents
- The pilot position returns a diagnostic of the system status
  - Hardware faults can be identified

- References:

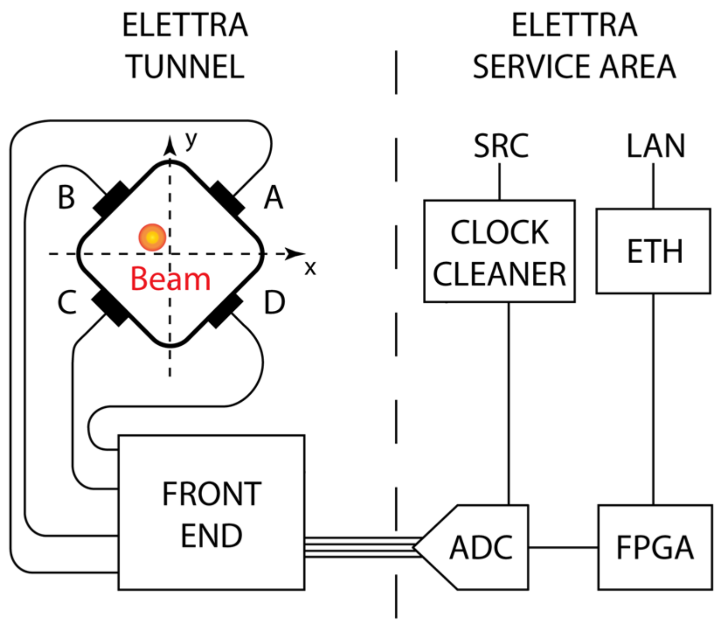
- G. Brajnik, et al., “A novel electron-BPM front end with sub-micron resolution based on pilot-tone compensation: test results with beam.”, IBIC'16.

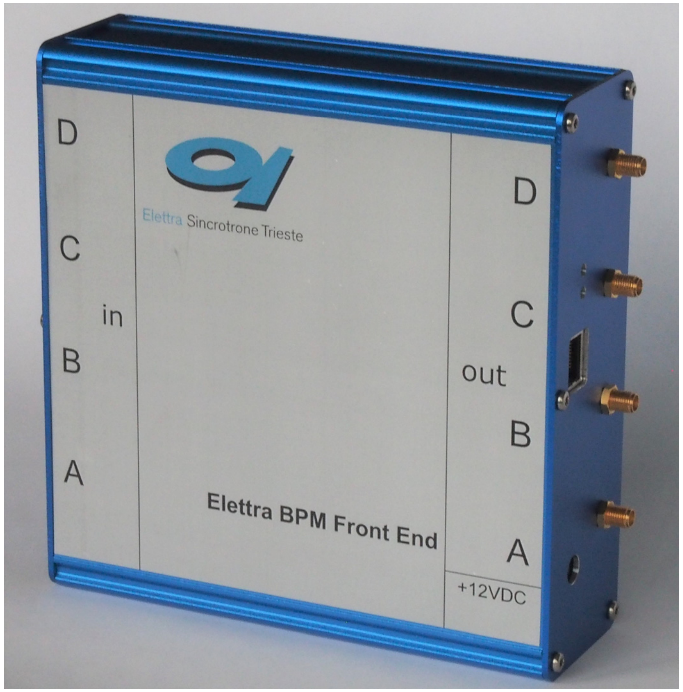
- G. Brajnik et al., “Reducing current dependence in position measurements of BPM-systems by using pilot tone: quasi-constant power approach.”, IBIC’17.

- R. De Monte et al., “Integration of a novel BPM system within the global orbit feedback environment of Elettra.”, DEELS’18.

eBPM with Pilot tone at Elettra

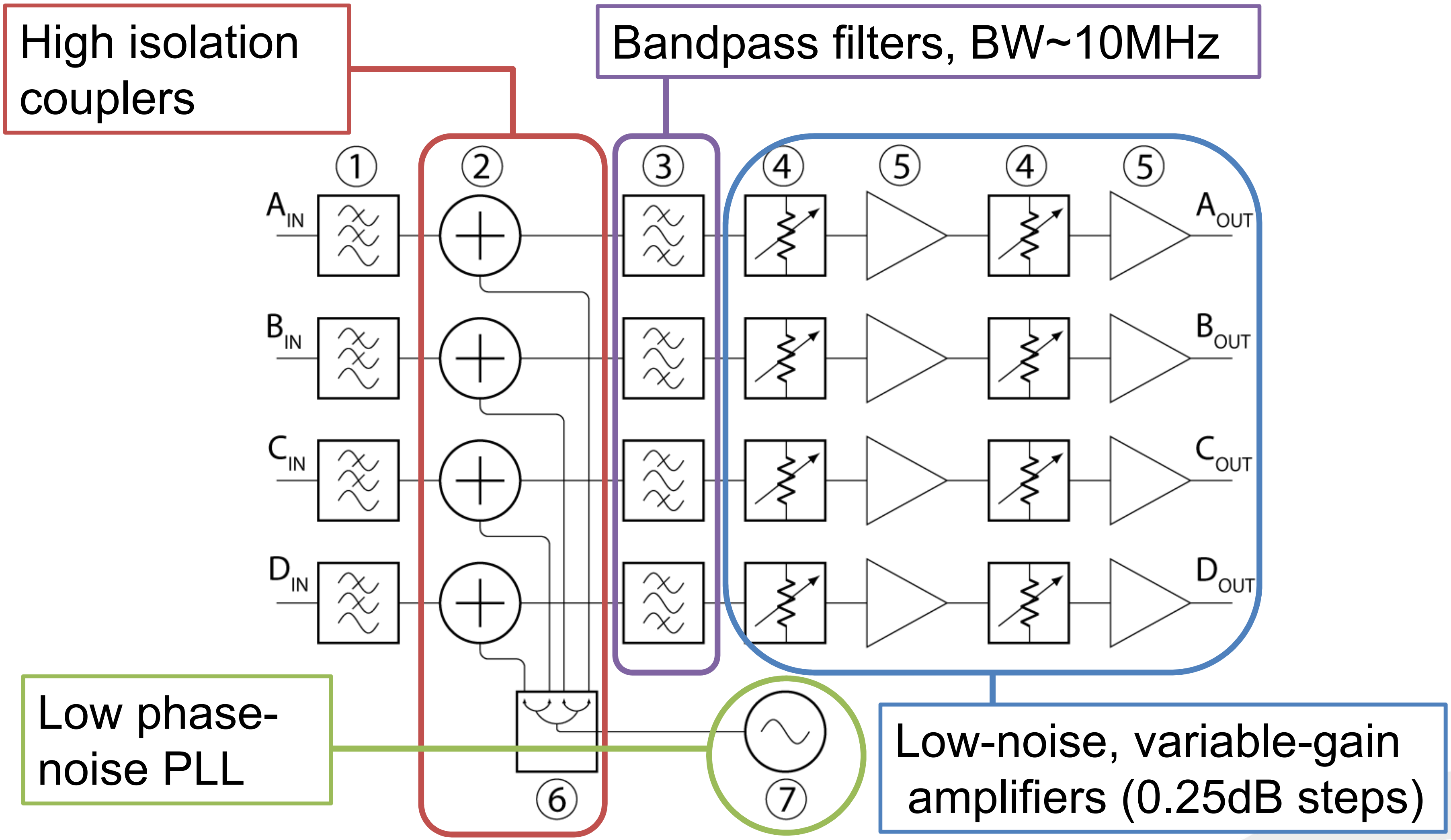
- Modular approach:
  - Analog front end in machine tunnel
  - Digitiser in service area



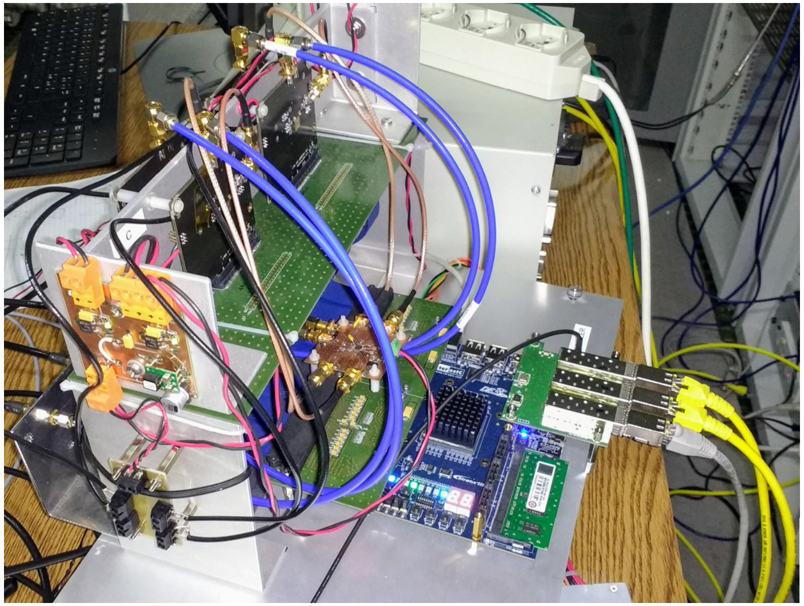


- Analog front end
  - Low noise figure
  - Generation and injection of pilot tone
  - Variable gain
  - Ethernet controlled / PoE capable

Front end block diagram



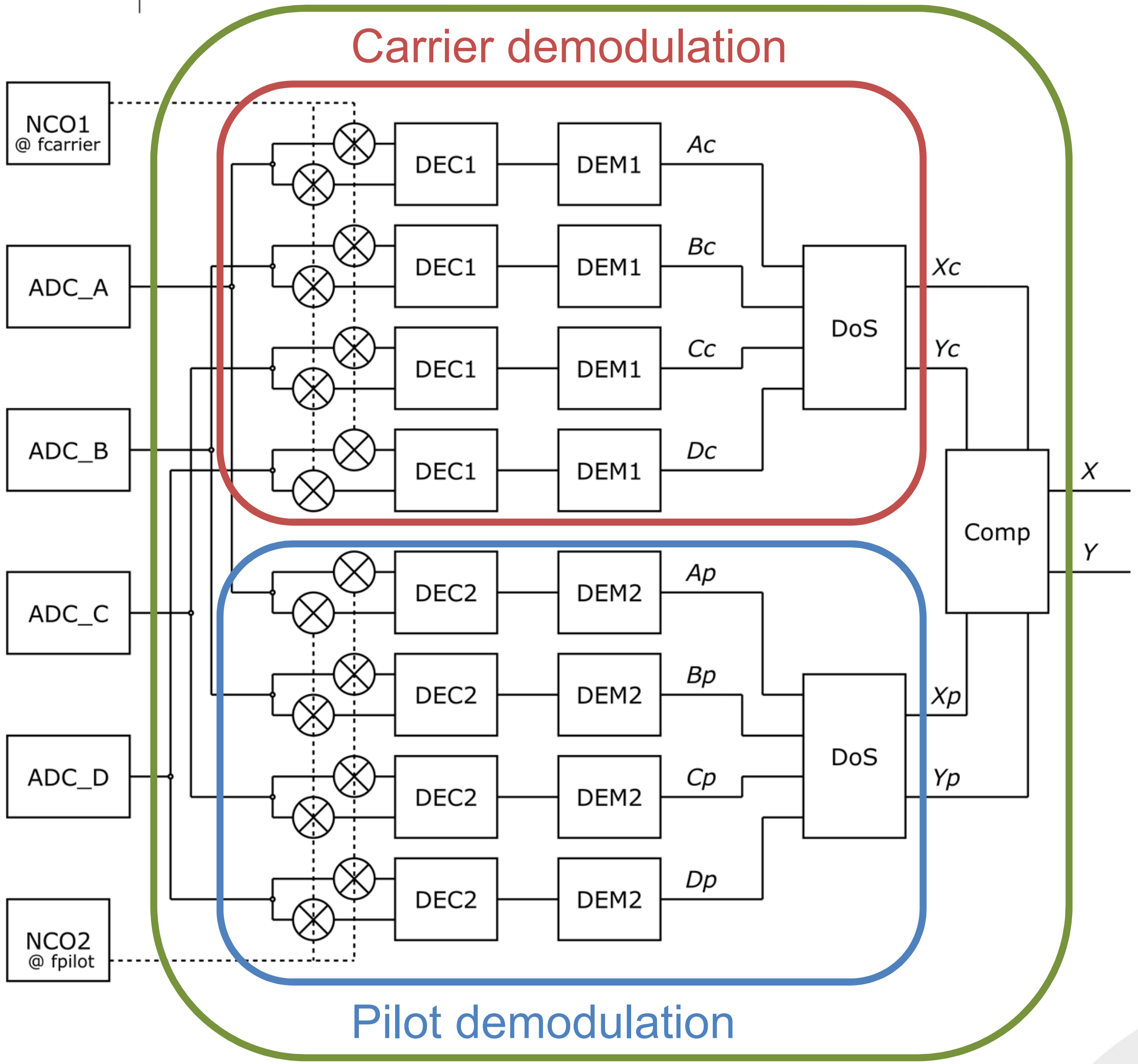
eBPM with Pilot tone at Elettra



- Digitiser
  - High speed ADCs (160 MS/s, 16bit) working in undersampling
  - Double digital receiver in FPGA (Altera Stratix III)
  - Continuous and parallel demodulation of both carrier and pilot
  - Compensation on GOF data (Global Orbit Feedback, 10 kHz)
  - SFP communication with Gigabit Ethernet

FPGA block diagram

Parallel data processing

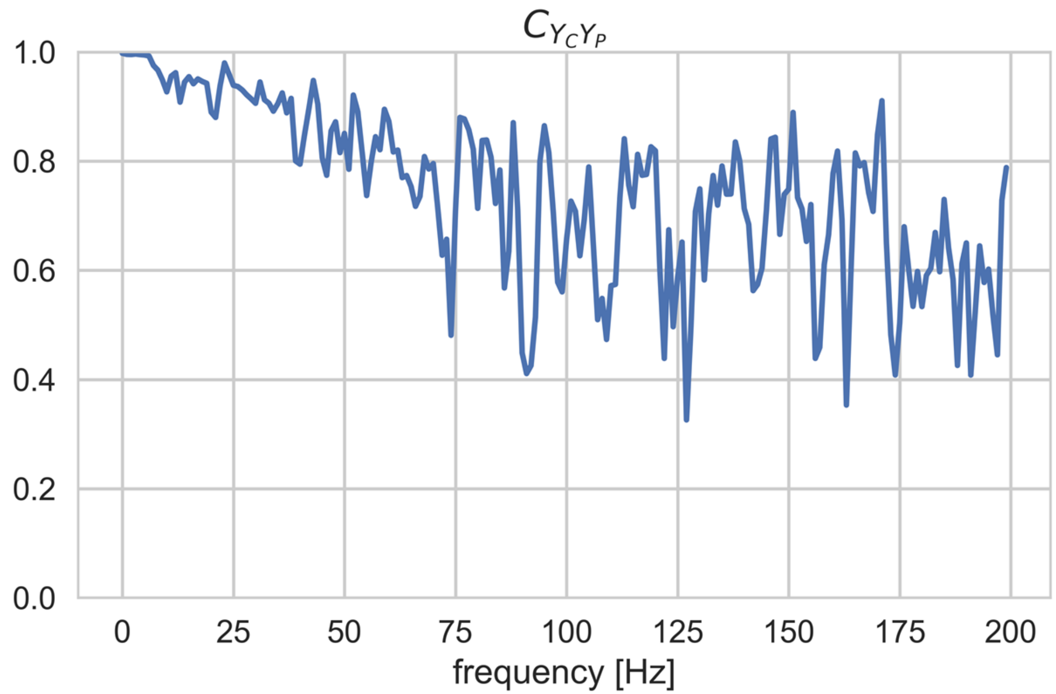


Spectral coherence

Definition:

$$C_{Y_C Y_P}(f) = \frac{\left|G_{Y_C Y_P}\right|^2}{G_{Y_C Y_C}(f) G_{Y_P Y_P}(f)}$$

It is a measure of the correlation between carrier and pilot positions



Verify the hypothesis stated in slide 6: *every channel variation affects in the same way both the carrier and the pilot*

Good coherence up to 50/70 Hz: useful for «slow» compensation

Elettra Sincrotrone Trieste

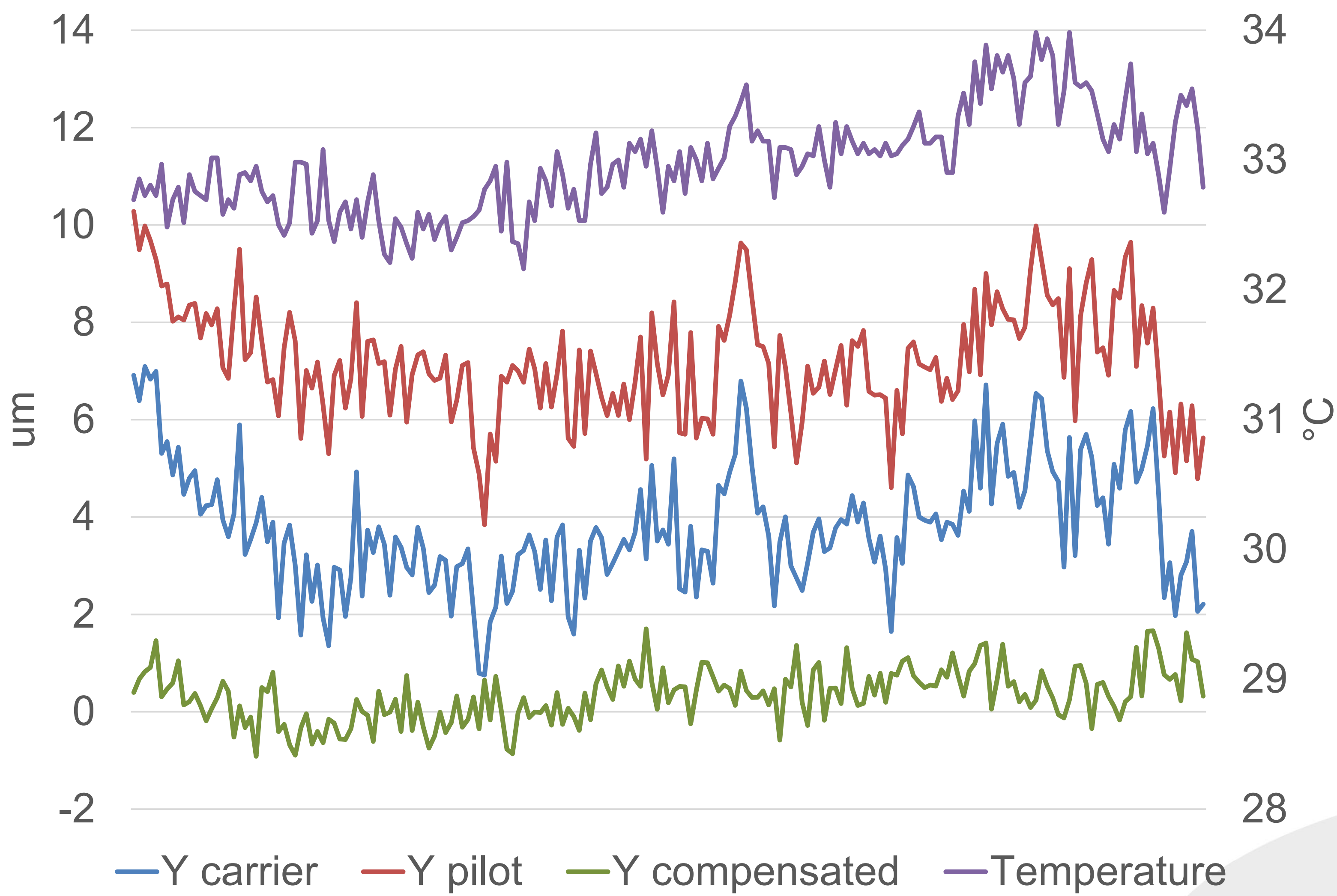
Performances

- Setup scheme for reference measurements:
  - RF generator that emulates the beam plus a 4-way splitter
  - RF frequency = 499.654 MHz
  - Pilot frequency = 502.051 MHz

- Performances with K=20 mm, ADC @ 80% FS:
  - With a RF generator directly at ADCs input: 50 nm sd @ 10 kHz
  - Real conditions (Elettra beam + front end + cables) with 300mA and 2 GeV: ~180 nm sd @ 10 kHz

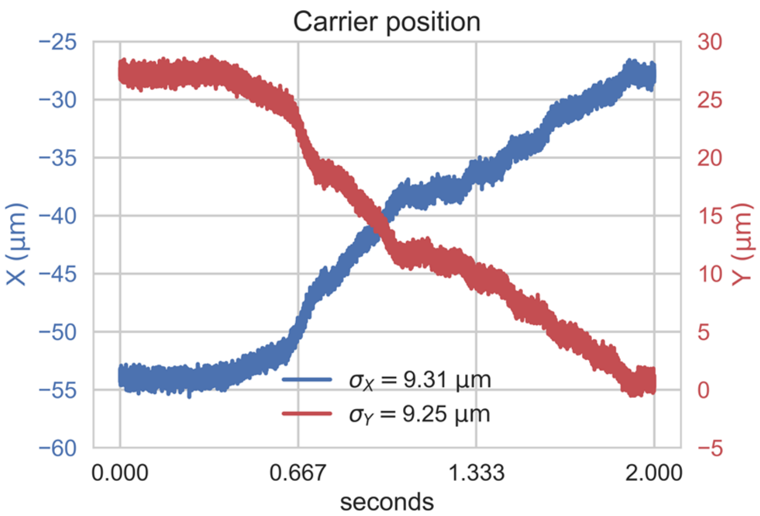
- Compensation of temperature changes and cables: improvement at least of a factor of 4 on position drift

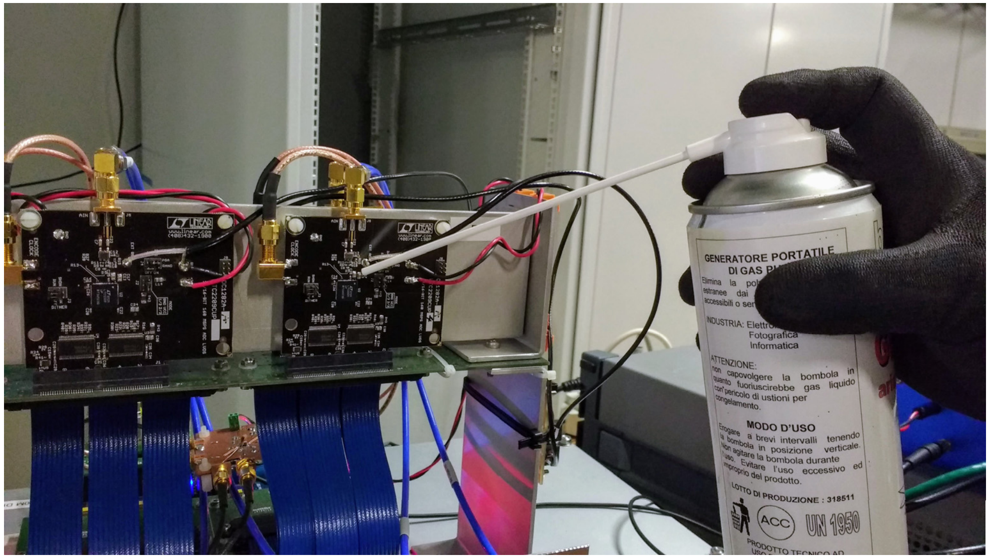
Temperature compensation

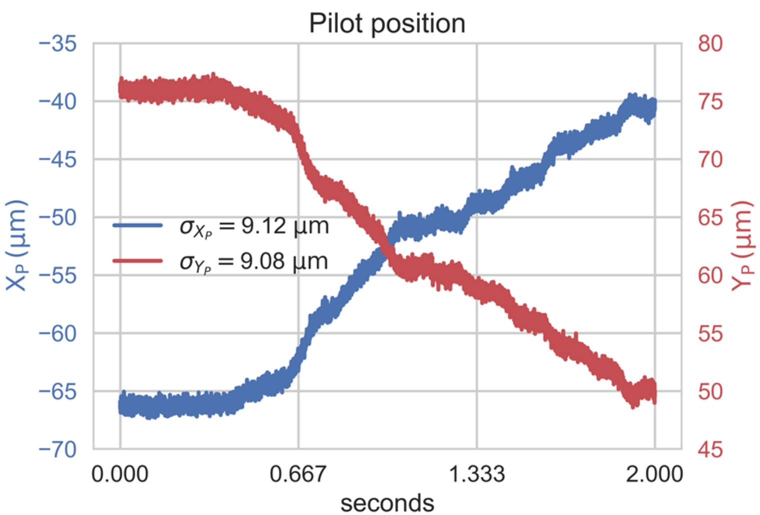


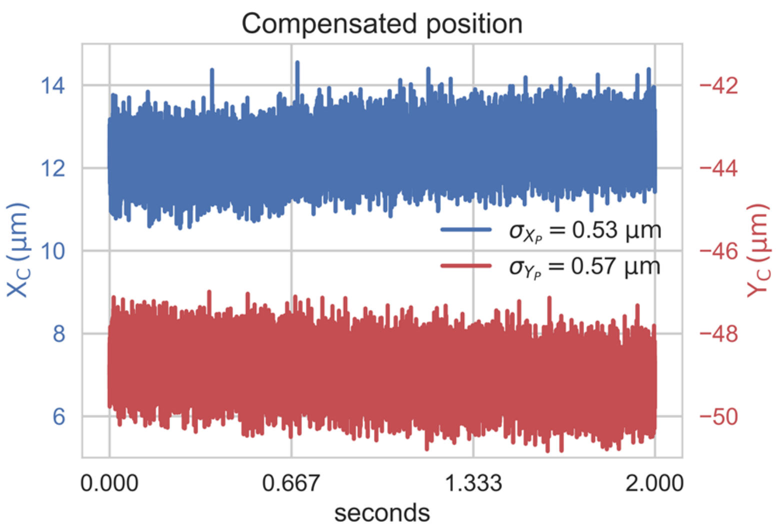
Elettra Sincrotrone Trieste

Change in ADC temperature – ch. D

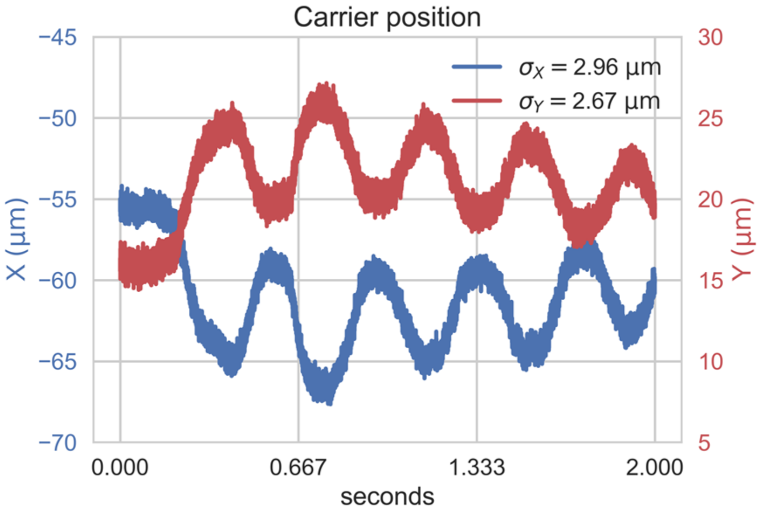


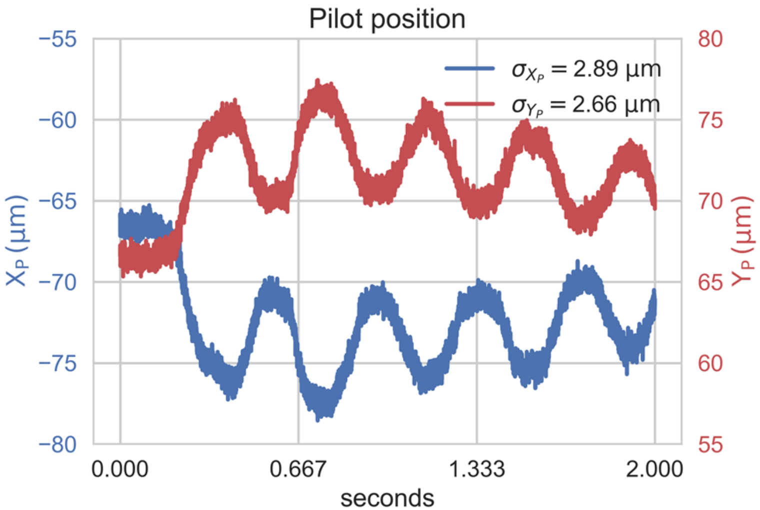




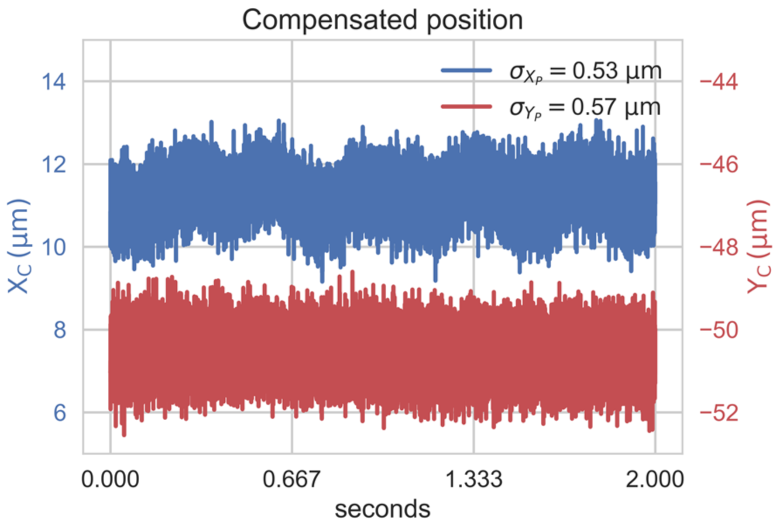


Wobbling of cables – ch. D





Residual oscillations



Integration in Elettra environment

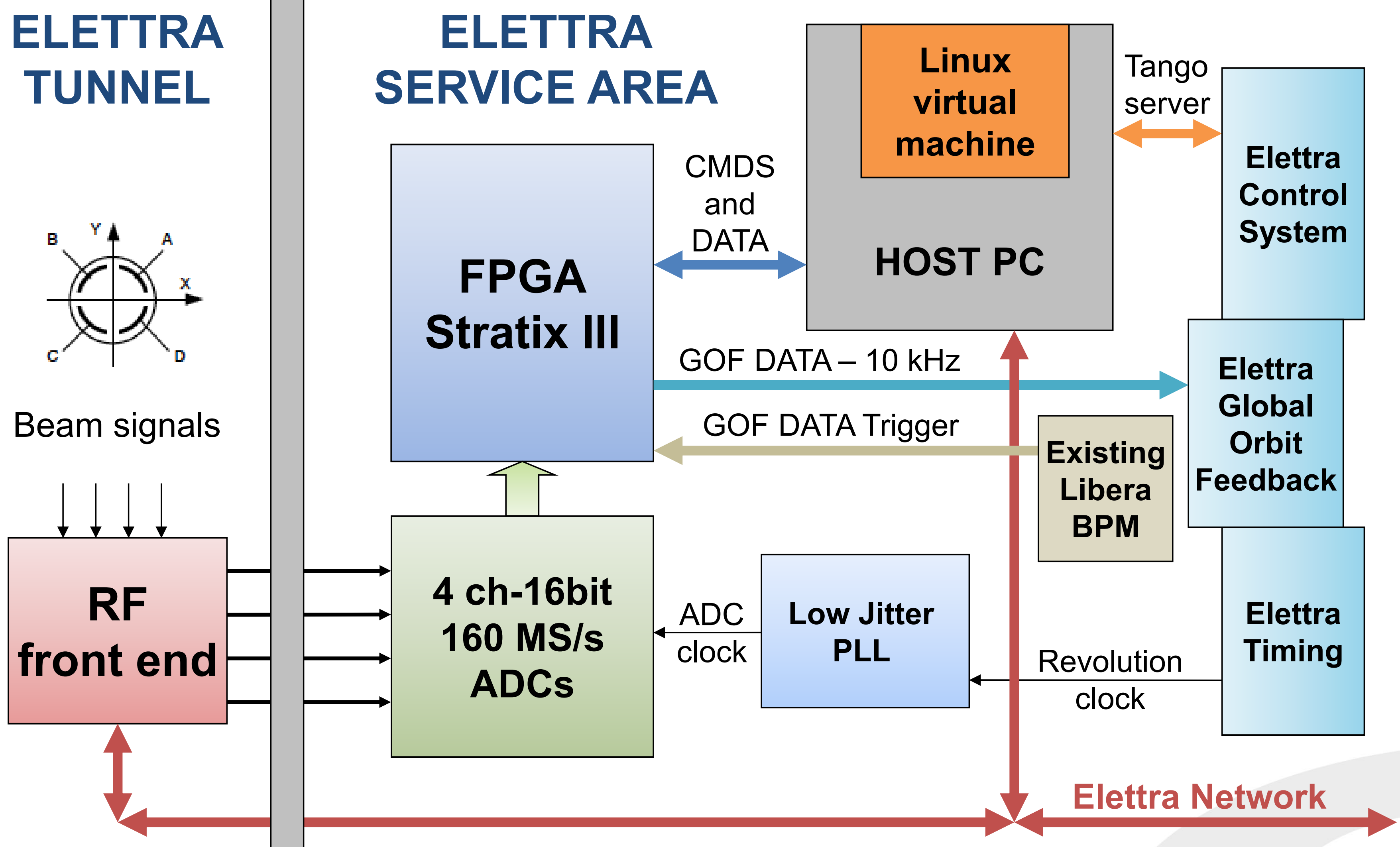
- Complete replacement of a Libera Electron unit:

  - Connection to machine revolution clock (**SRC**), 1.156 MHz
    - Both ADC clock and FPGA processing are synchronous to SRC

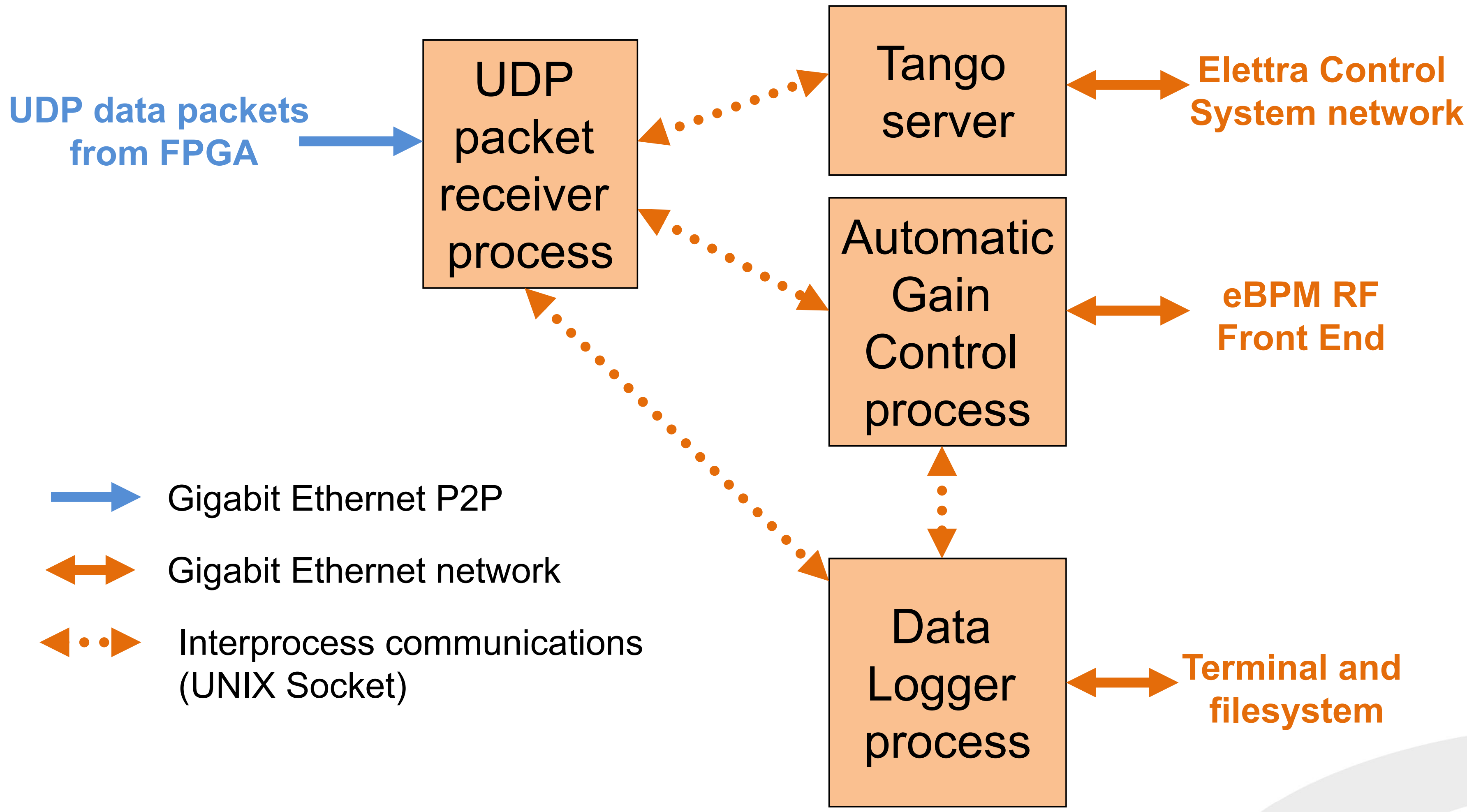
  - Gigabit Ethernet link to Global Orbit Feedback (**GOF**)
    - Due to a different internal processing, there is a difference of 0.02 Hz between 10 kHz data from the Libera and the prototype: solved using the replaced unit as a trigger

  - Second Ethernet link for Tango Server/housekeeping
    - A porting of the standard Tango BPM server was installed on a Linux VM that communicates with the prototype, calculating slow data and handling AGC/pilot amplitude

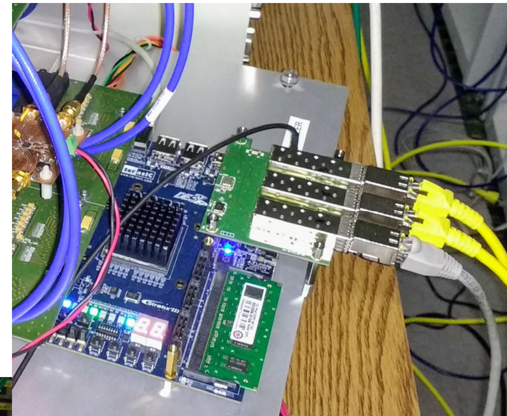
Complete block diagram



Linux VM: data path and process structure

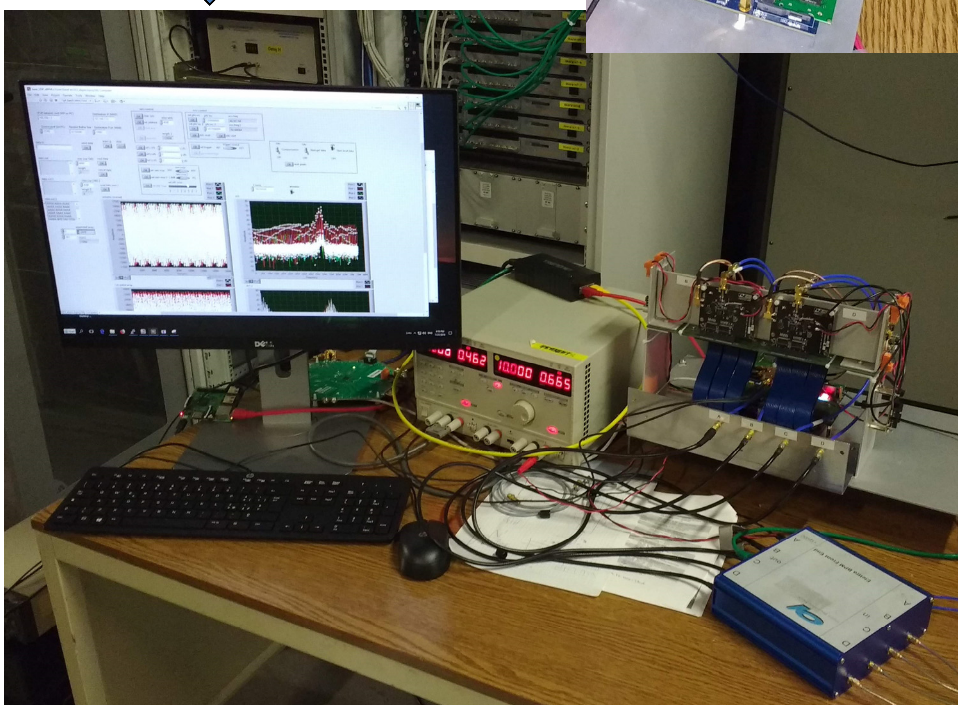


Overall system in Elettra Service Area

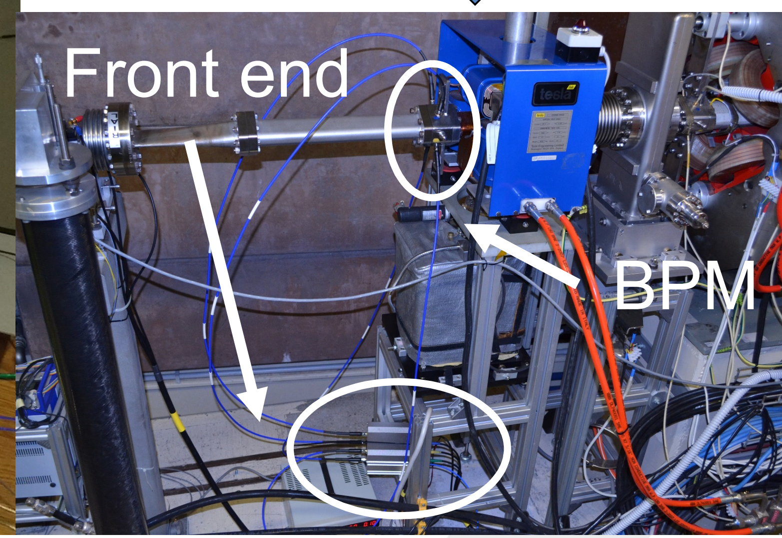


FPGA and
Gigabit Ethernet
detail

Elettra Service Area



Elettra Tunnel



Data logger output: 300 mA, 2.0 GeV

Elettra Sincrotrone Trieste

```
Started 18-2-2018 22:7:18 logging to file GofON_1min_mean60_quat.xlt  Now 3 loglines  18-2-2018 22:10:21

Va  =   43065835.4              RMS     21599.18
Vb  =   51906701.7              RMS     27025.16
Vc  =   55702573.9              RMS     25403.22
Vd  =   46934320.0              RMS     29354.82
Sum =  197609431.1              RMS     14998.18
Q   =      -7236.0              RMS       691.59
Xum =      -1754.591  RMS         10.09
Yum =       -754.764  RMS          1.55

PVa   =   53451318.7   RMS      1755.58
PVb   =   54265351.1   RMS      1741.43
PVc   =   53870777.4   RMS      1690.61
PVd   =   53693140.5   RMS      1715.98
PSum =  215280587.7   RMS      5948.55
PQ    =     -58206.8   RMS       184.56
PXum =         -90.701         RMS       0.18
PYum =          13.807         RMS       0.18

Compensated Xum =    -1663.890   TangoXum   =     -771.690        Xoffset=  892.200
Compensated Yum =     -768.571   TangoYum   =      119.429        Yoffset=  888.000

att A  0=    4   1= 94
att B  0=    4   1= 94
att C  0=    4   1= 94
att D  0=    4   1= 94
att Pil   12      freq=502435897
Pil out1    4     out2=     9
TEMP abcdl:   405         407     401     385     412
```

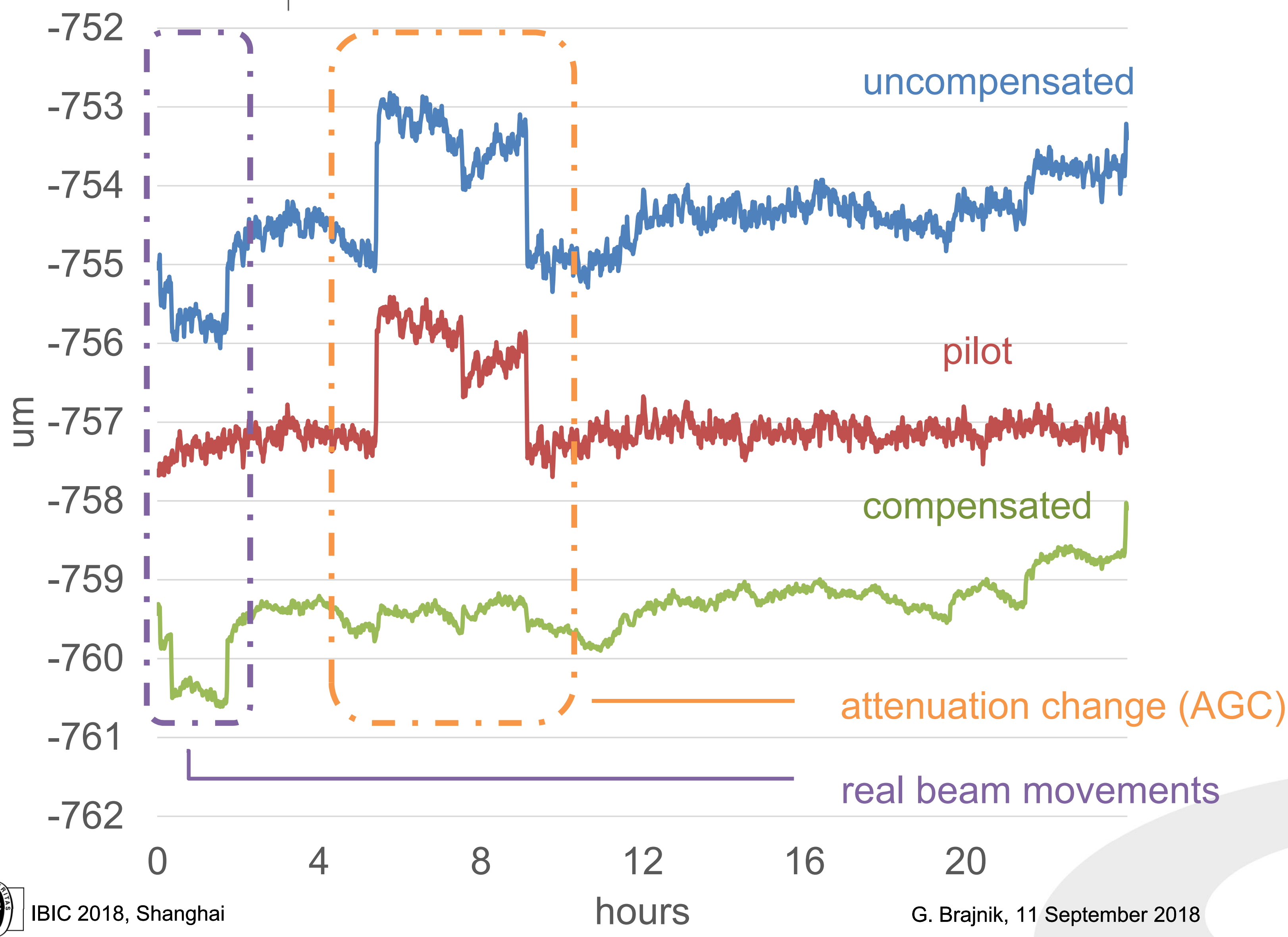
Beam parameters

Pilot parameters

Quality of measure

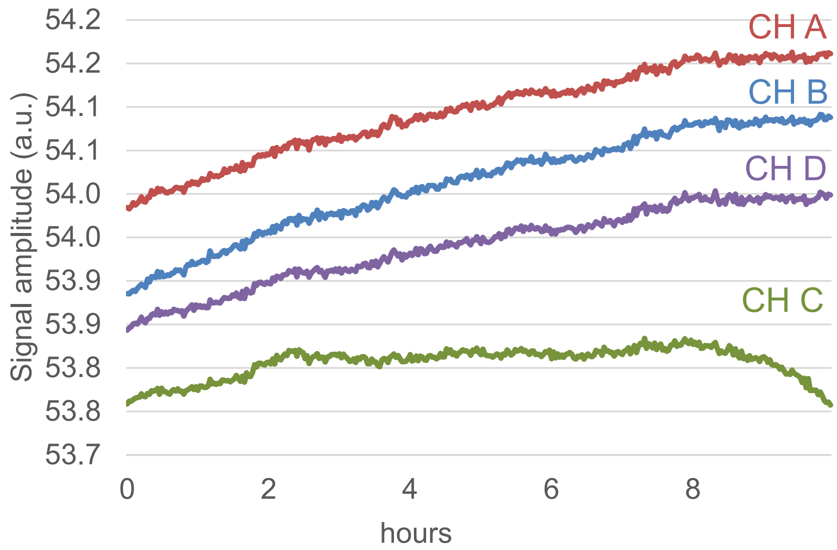
Front end parameters

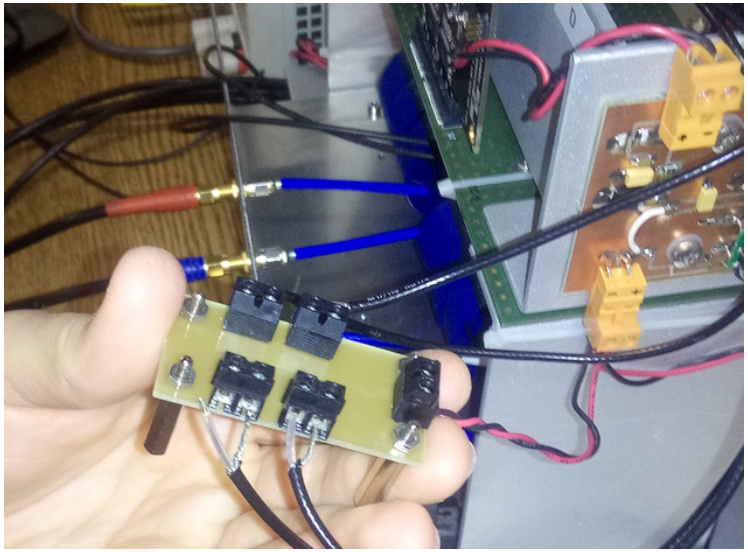
Beam Y-position in a 24-hours time window



Self-diagnosis using pilot

Having a well-known pilot signal can help in detecting hardware problems.
Here is an example of "strange" behaviour during an 8-hour acquisition: channel C demodulated amplitude was different from the others.





The common reference voltage for the ADCs had a broken contact: so ADC C was using the internal reference voltage rather than the common external one, causing the unexpected drift.

Conclusions

- A prototype of a new eBPM using “pilot tone” has been successfully tested on Elettra machine during **dedicated and user shifts** with no issues:
  - **Resolution better than 200nm @10 kHz**
  - **Long-term stability better than 500nm in 12 hours**
  - **Active compensation of temperature, cables and channels differences; on-line diagnostic is possible**

- Further developments:
  - Frequency-hopping pilot to better estimate the channel response
  - Different filtering for pilot tone (narrow bandwidth)

- Coupling of Elettra front end with I-Tech’s Libera Spark
  - **See poster TUPB13 and I-Tech booth for a live demo**

Thank you!

www.elettra.eu