Status of optics measurements

Part 1: Technicalities

Piotr Skowronski &
Ana Garcia-Tabares Valdivieso &
OMC

Ring optics measurements techniques

- Turn – by – Turn (TbT) analysis
  - Excite the beam with a kicker or AC Dipole (ACD) to provoke betatron oscillations
  - At each BPM use FFT to calculate phase of the tune line
  - **Assuming** the model is correct between consecutive BPMs, calculate beta function
  - Advantage:
    - **Independent of BPM calibration**

- Orbit Response Matrix (ORM)
  - Change orbit with each of the orbit correctors and observe the orbit change
  - Find model correction that reproduce the data
    - The most famous algorithm is LOCO
  - Use the corrected model to get beta function
  - Disadvantages:
    - **Dependent on BPM calibration**
    - **Can not distinguish unambiguously between different errors, f.g. orbit corrector strength from BPM calibration, tilt of BPMs from tilt of magnets**

Ring optics measurements techniques

- TbT is the preferred method

- However, ORM can also give good results **IF**
  - BPM calibrations are well controlled
  - Machine is well understood and certain types of errors can be excluded
    - Alignment
    - Quality of magnetic fields

Ring optics measurements techniques

- Nota Bene, our experience from ESRF
  - Phys. Rev. Accel. Beams **20**, 082802

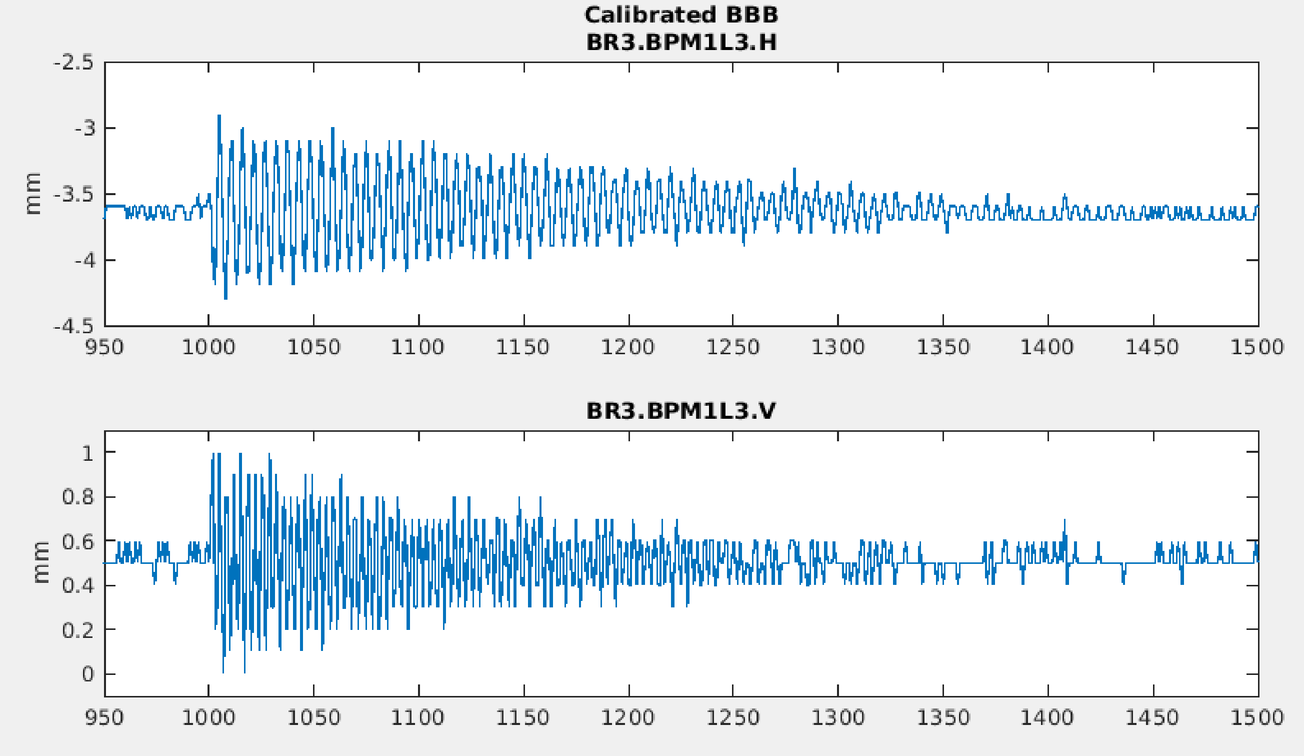
    "*Improving the precision of linear optics measurements based on turn-by-turn beam position monitor data after a pulsed excitation in lepton storage rings*"
    - https://journals.aps.org/prab/abstract/10.1103/PhysRevAccelBeams.20.082802

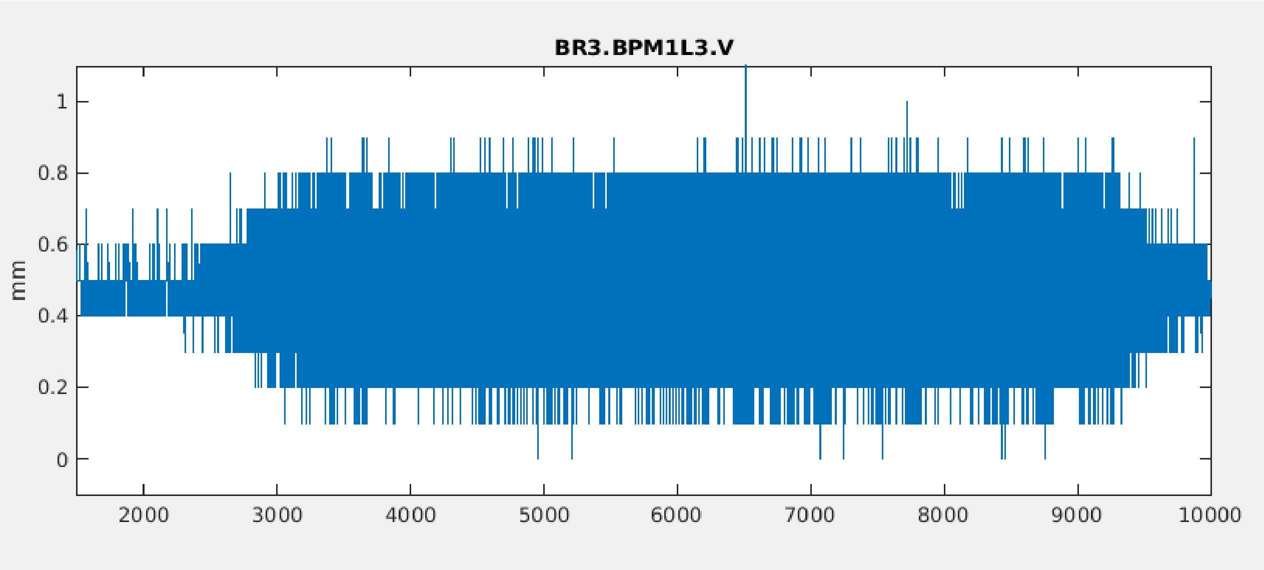
shows that combining the 2 methods gives the best result

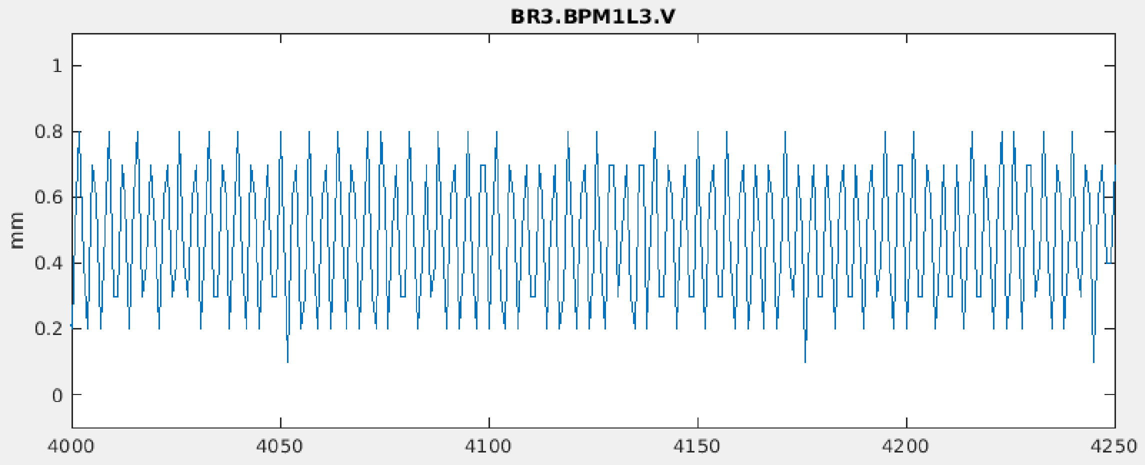
- Include TbT result (f.g. phase advance) in " the ORM model" production
- Use "the ORM model" to calculate beta from phase advance
  - In case of optics errors "the ORM model" is more accurate than the nominal one

TbT measurements

- **Excite the beam with**
  - A kicker
    - Needs a small chromas, otherwise decoherence is fast and the oscillations quickly disappear
  - An AC Dipole





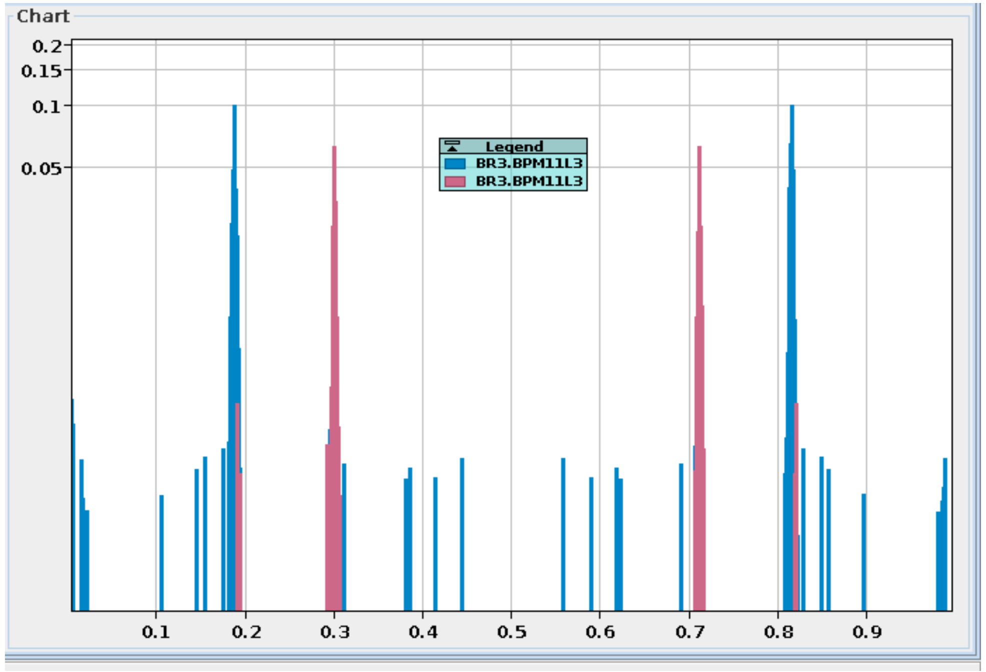


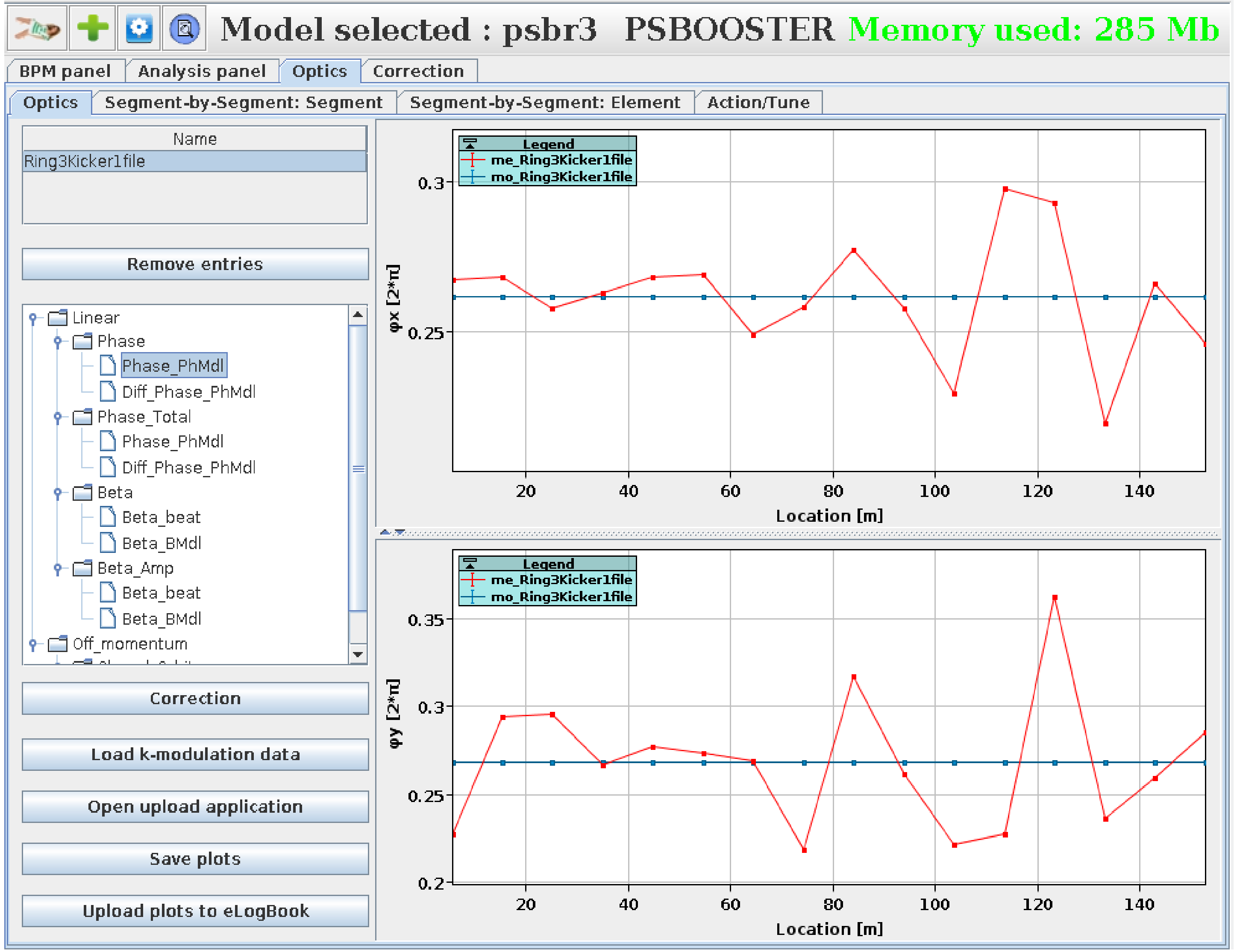
TbT measurements

- Clean the data with SVD
  - Remove noise by keeping only modes common to all the BPMs
- Remove BPMs
  - With no signal
  - Too much noise
  - Reconstructed tune too far away from average value
  - etc.

TbT measurements

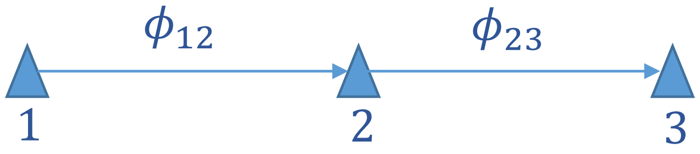
- For each BPM do FFT, **get phase** of the tune line
  - It is direct, model independent, measurement
  - It is used to correct the observed phase beating

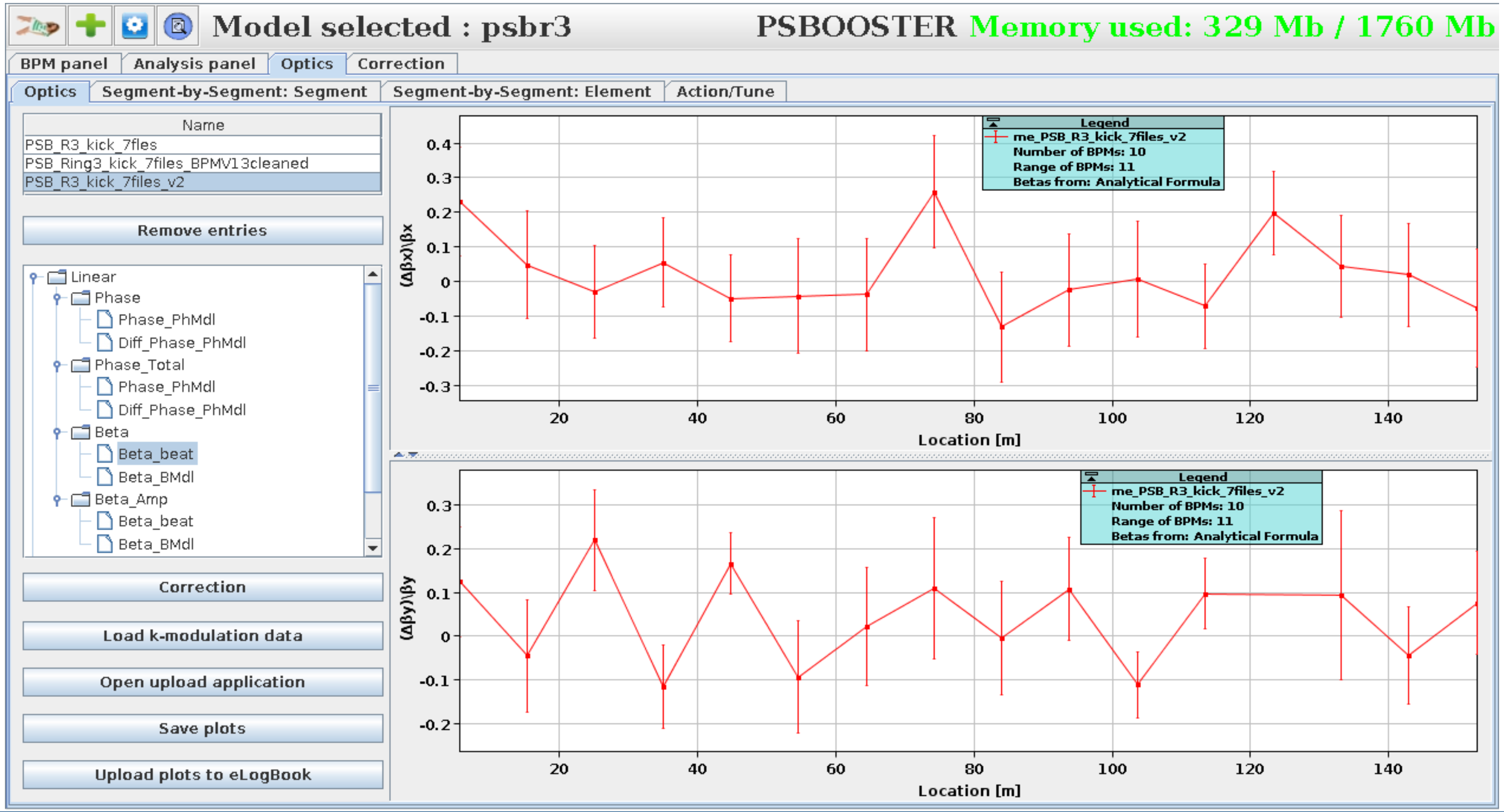




TbT measurements

- Beta function is calculated using phase of consecutive 3-BPMs
- $\beta_{2me} = \beta_{2mo} \dfrac{cot\phi_{12me} + cot\phi_{23me}}{cot\phi_{12mo} + cot\phi_{23mo}}$





Beta measurement – why error bar so big ?

- There are multiple factors entering the beta error
  1. Error of the phase measurement
     - Amplitude of the kick
     - Limited number of turns due to non-zero chromaticity
  2. Uncertainty of the model (magnetic field error), currently we assume
     - QFO dK1 = 0.0002
     - QDE dK1 = 0.0001
  3. Phase advance between the BPMs, in PSB it is close to 90°

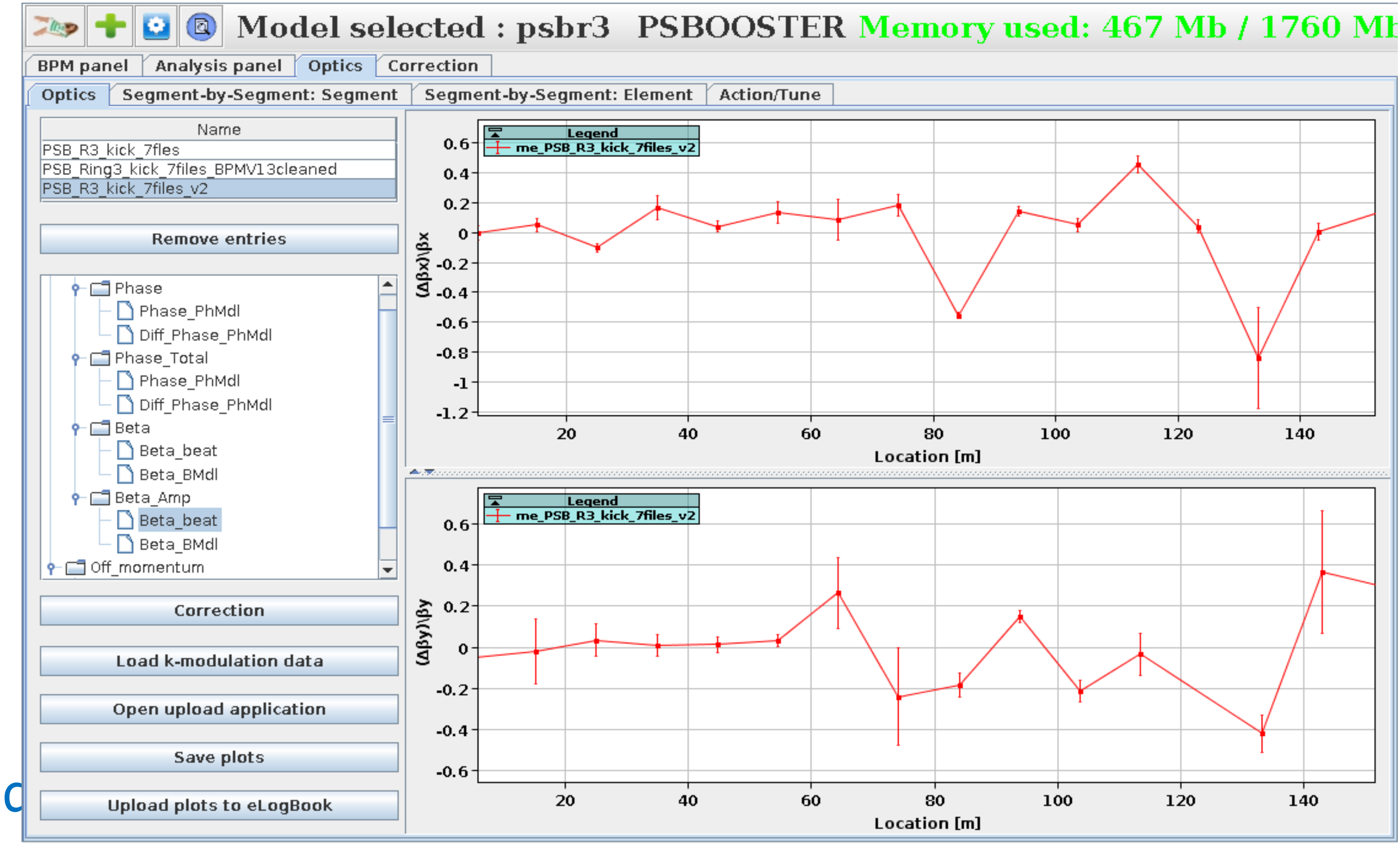
$$\beta_{2me} = \beta_{2mo} \frac{cot\phi_{12me} + cot\phi_{23me}}{cot\phi_{12mo} + cot\phi_{23mo}} = \beta_{2mo} \frac{cot90^\circ + cot90^\circ}{cot90^\circ + cot90^\circ} = \beta_{2mo} \frac{0+0}{0+0}$$

     - Normally we take the following BPM, but in PSB it has phase advance 90°+ 90°

- The way out: beta from amplitude

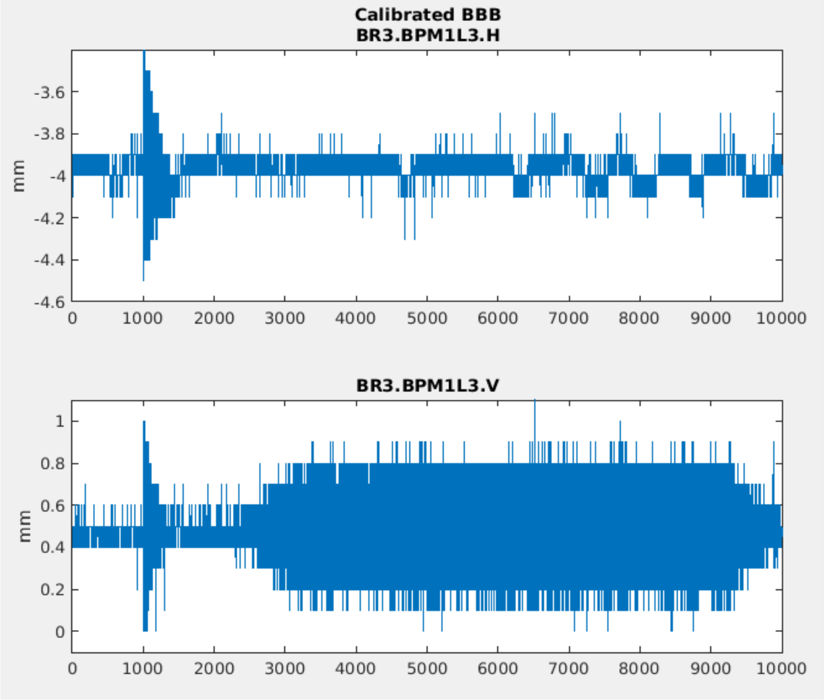
Beta from amplitude

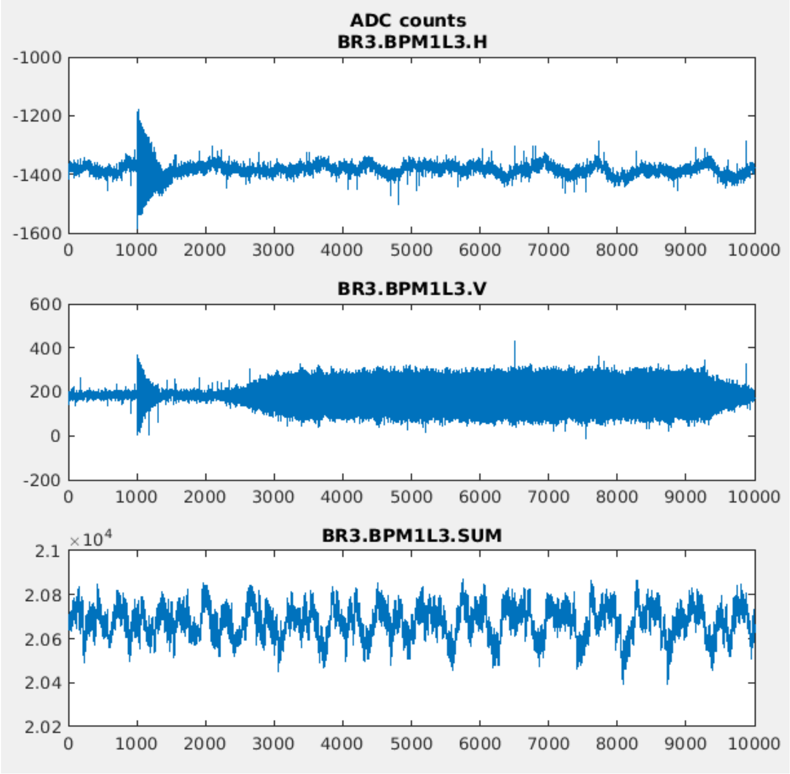
- If BPMs are precisely calibrated then amplitude of the oscillation can be used to calculate beta
  - Emittance is estimated as the value minimizing the beating
- How to get good calibration?
  - Measure beta beating at different working point where beta from phase is precise
- Therefore our request to **measure with tune plus or minus one unit** to obtain good BPM calibration
  - Can be also some other special optics moving phase ad

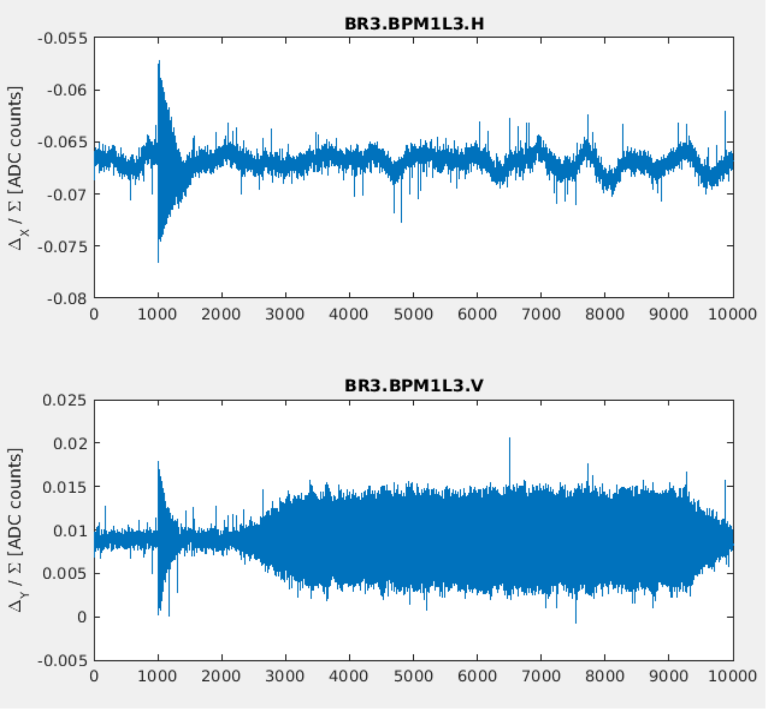


BPM granularity

- Standard readout of BPMs has granularity if 0.1 mm
- Stephane Bard Pedersen exposed for us the raw ADC counts in the FESA class
- **BIG THANKS!!!**



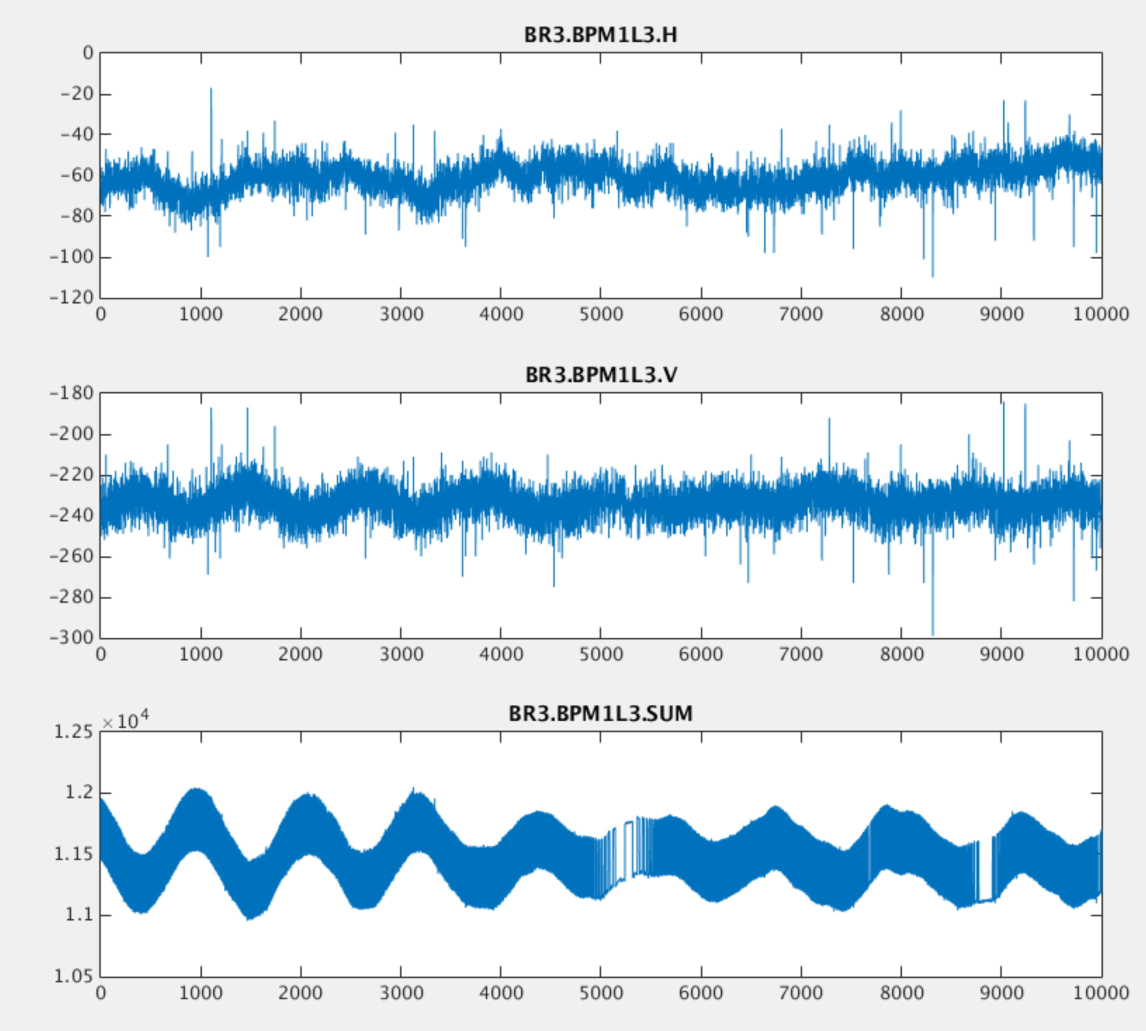




- We use average of Σ (sum) instead of point by point Δ/Σ to get rid of eventual ringing in Σ, that occurs quite often

Raw BPM signals quality

- Sometimes the sum ringing is really bad
- BTW
  - Position is transferred as 16 bit integer
  - It means it has range
    ±32768 * 0.1 mm = ± 3.27 m
  - If granularity was 0.01 mm then
    the range would be ± 32.7 cm

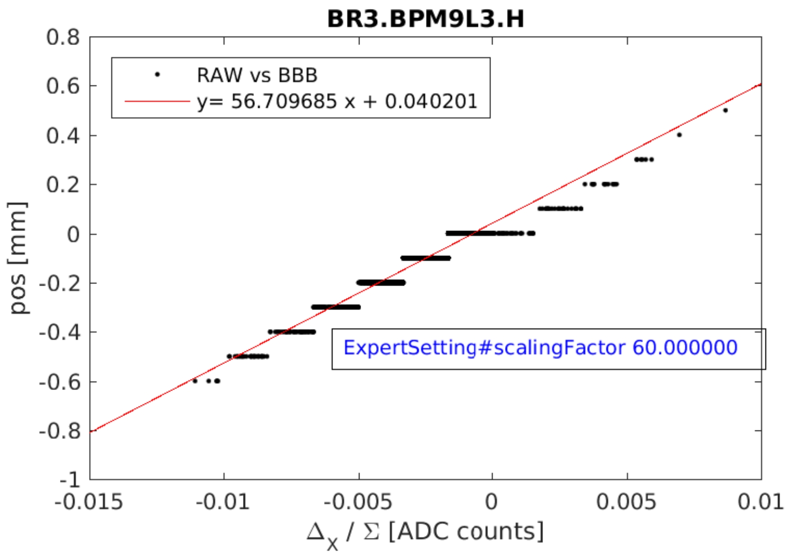


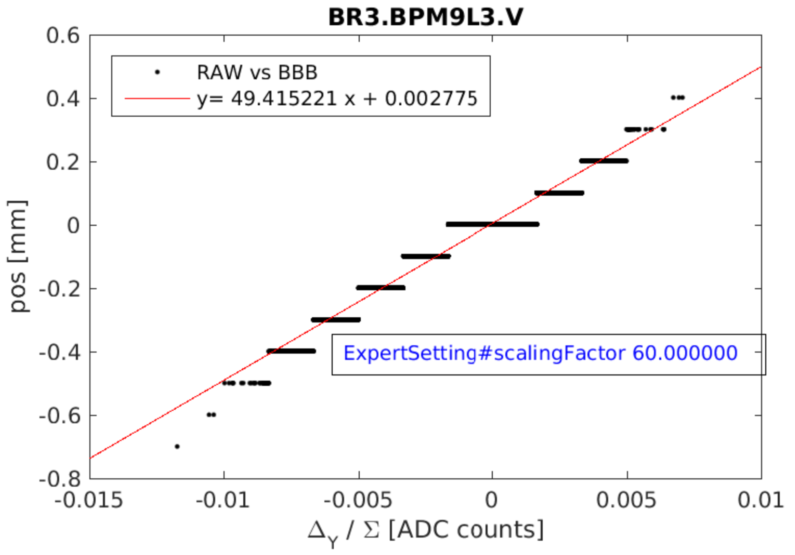
Empiric position calibration

- There are several constants involved in the transformation of the raw signals to position, and the exact equation is not documented

- Therefore we find empirically the effective calibration constants by fitting a line to correlation plot between Δ/Σ and PositionBBB

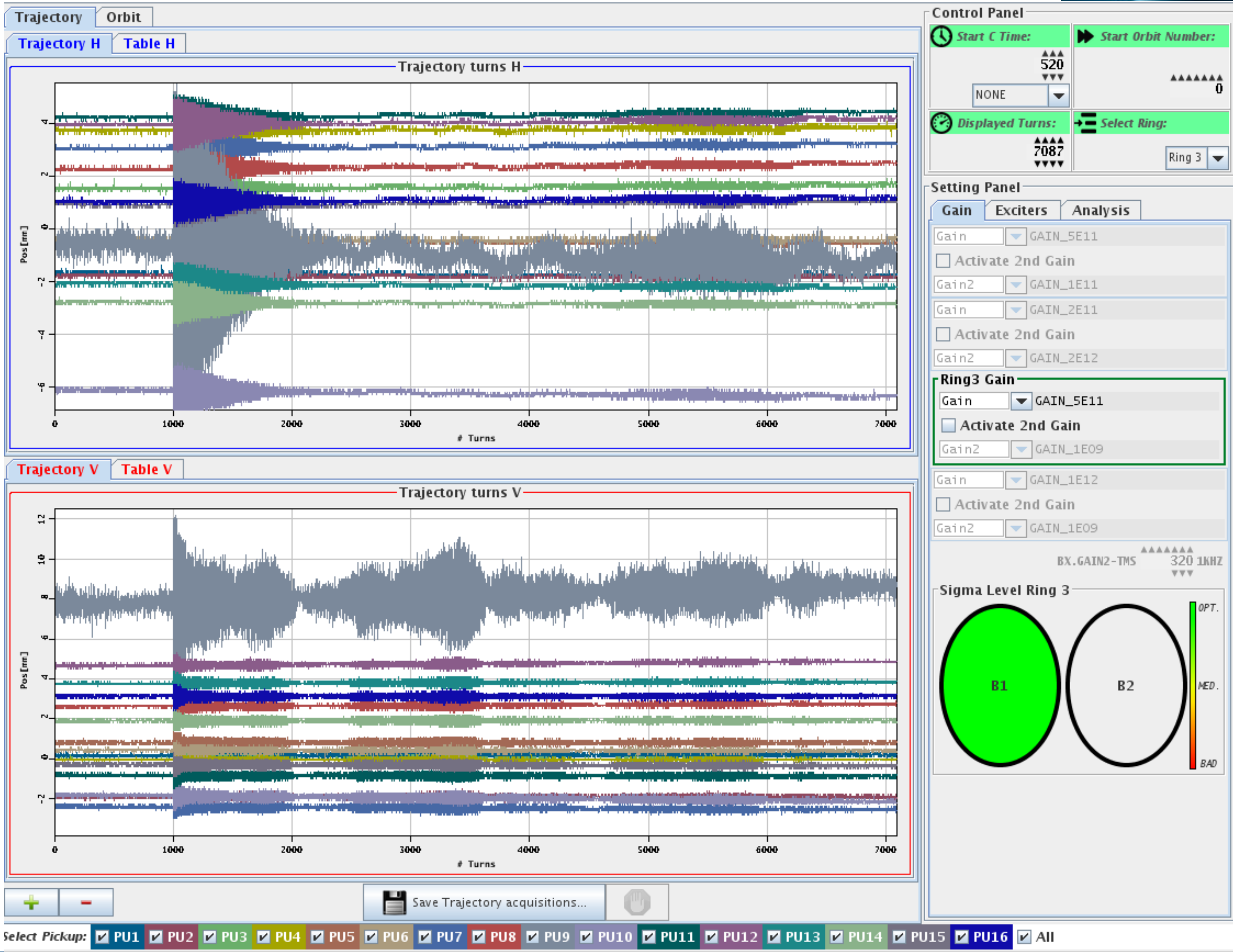
- Nota bene, PositionBBB is biased
  - by -0.05 mm for positive values
  - by +0.05 mm for negative values





Beam intensity

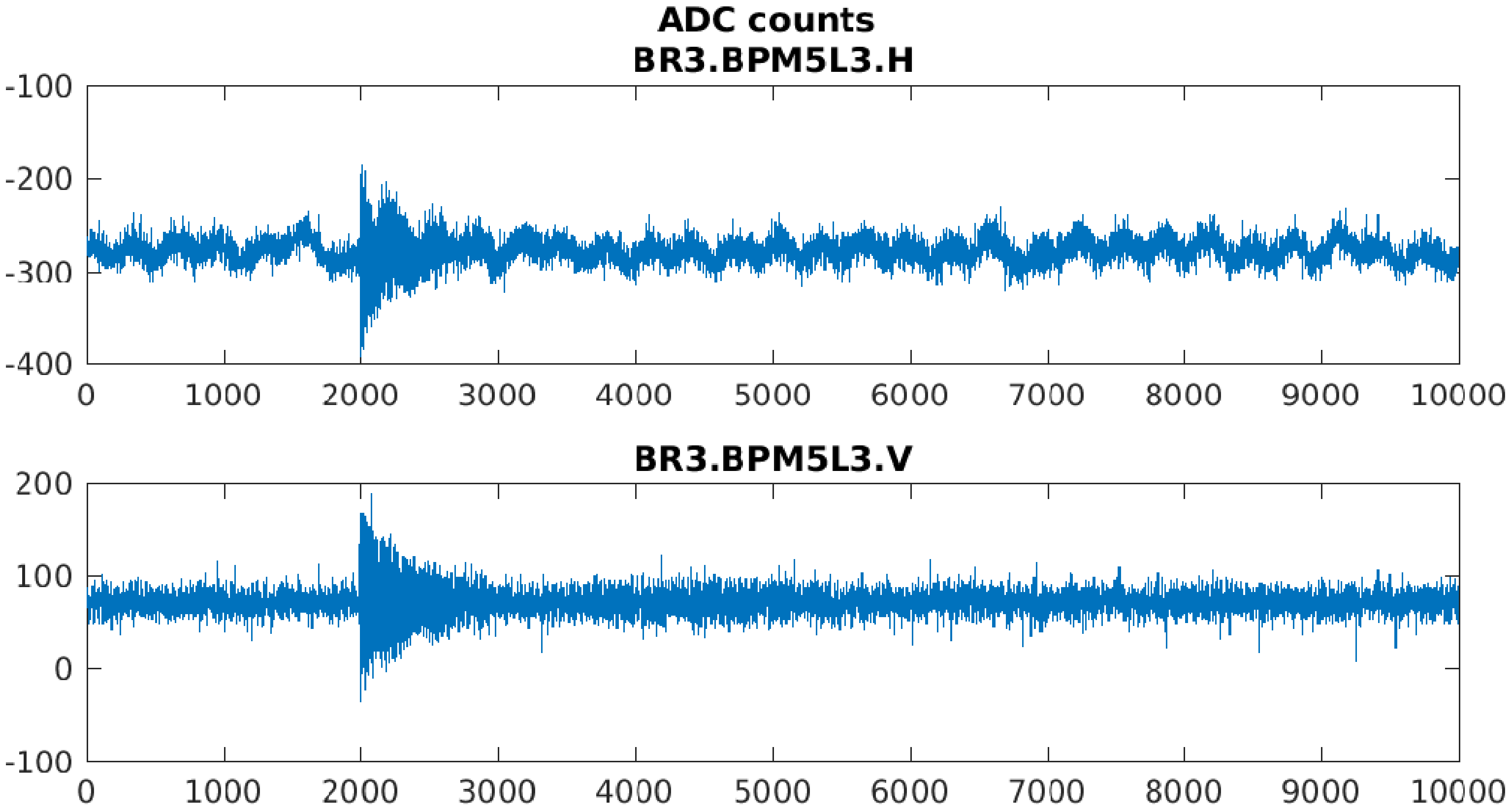
- When rings are full
  the beam response is strange
  - Non regular decay
  - Almost same amplitude oscillations re-appearing again
    - In horizontal after 2k turns of calm



Beam intensity

- When rings are full
  the beam response is strange
  - Non regular decay
  - Almost same amplitude oscillations re-appearing again
    - In horizontal after 2k turns of calm

- When intensity is reduced
  the beam response
  looks as expected



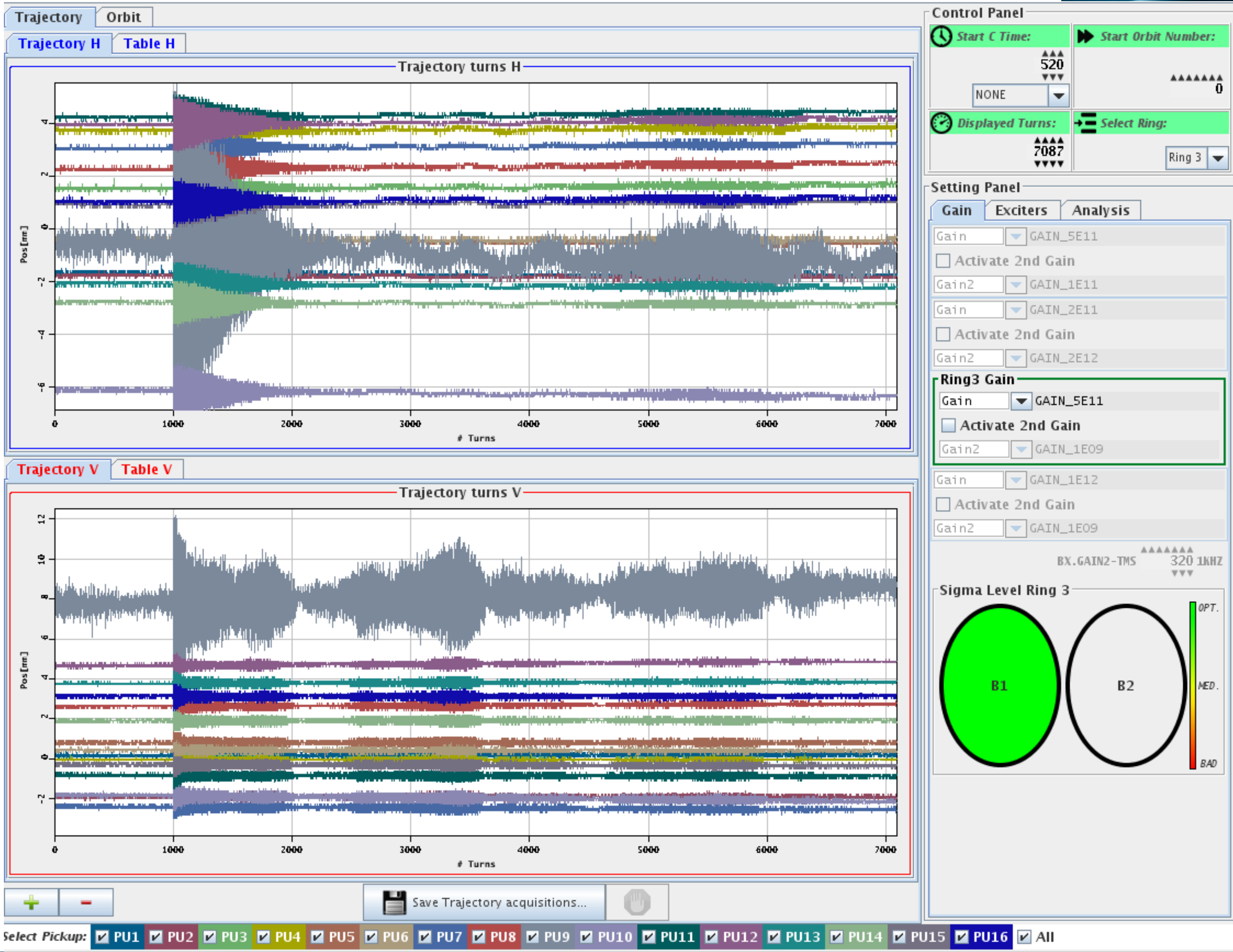
Beam intensity

- When rings are full
  the beam response is strange
  - Non regular decay
  - Almost same amplitude oscillations re-appearing again
    - In horizontal after 2k turns of calm

- When intensity is reduced
  the beam response
  looks as expected

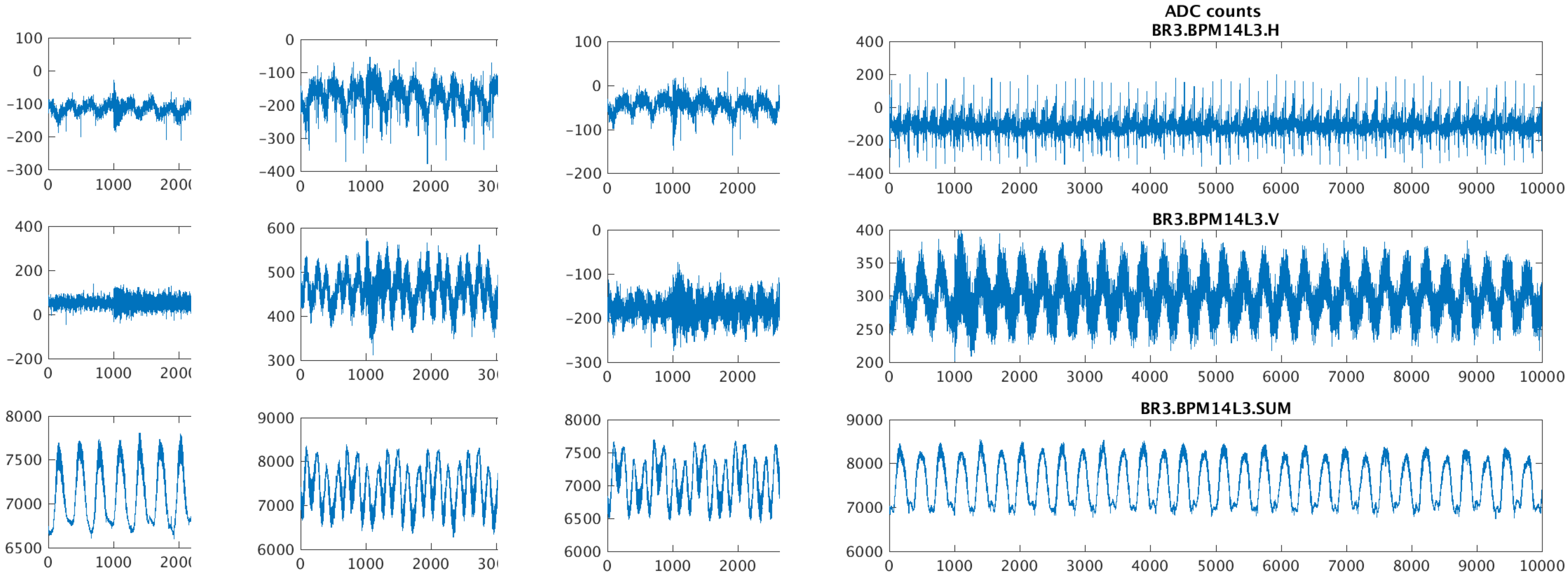
- The response is rather driven by
  - a collective effect
  - or some feed-back response

- Therefore preference to measure the optics at very low intensity, however …



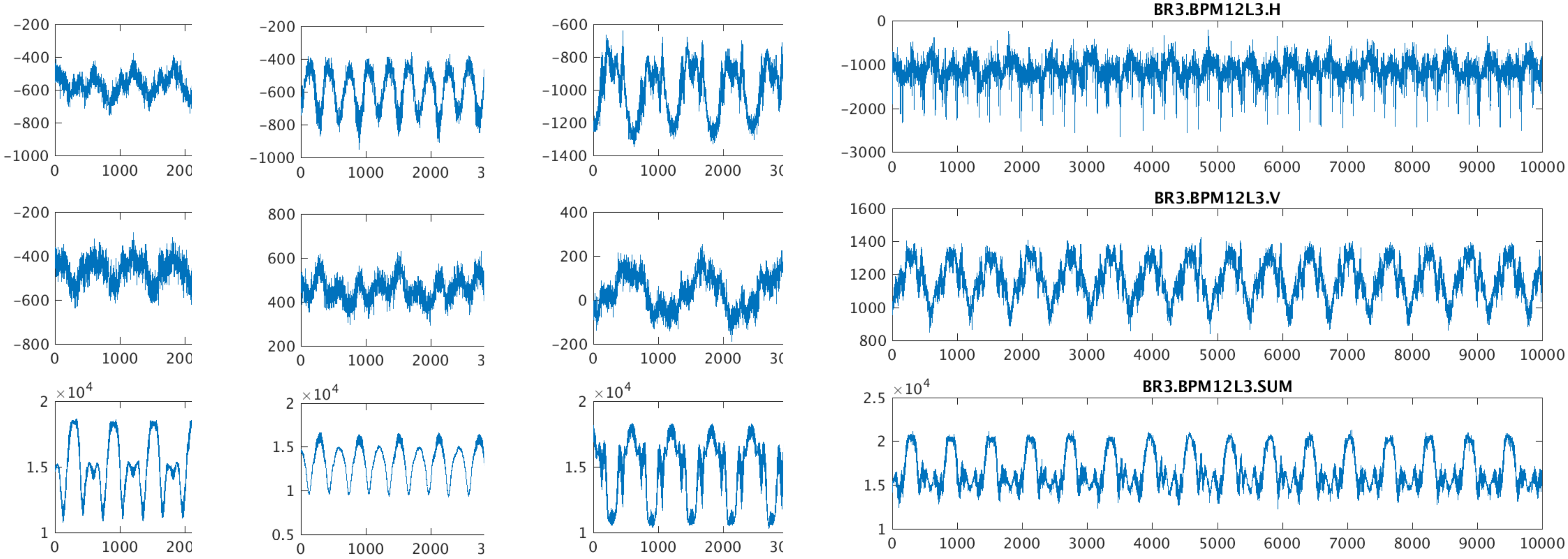
BPM signals at low intensity

- Using intensities at the levels of 0.1 turns (as in setting of the operation display) corresponds to BPM gain around 1e10
  - But than the readout looks like this



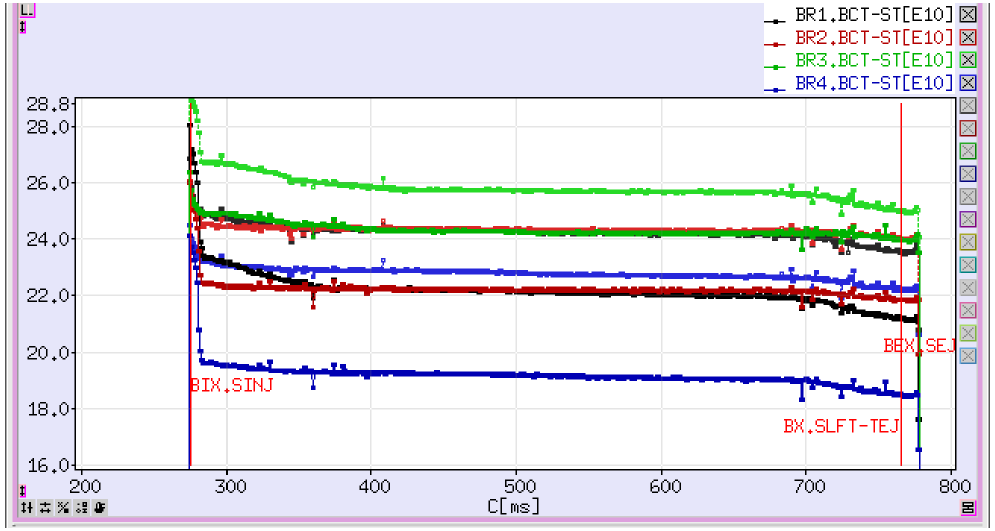
BPM signals at low intensity

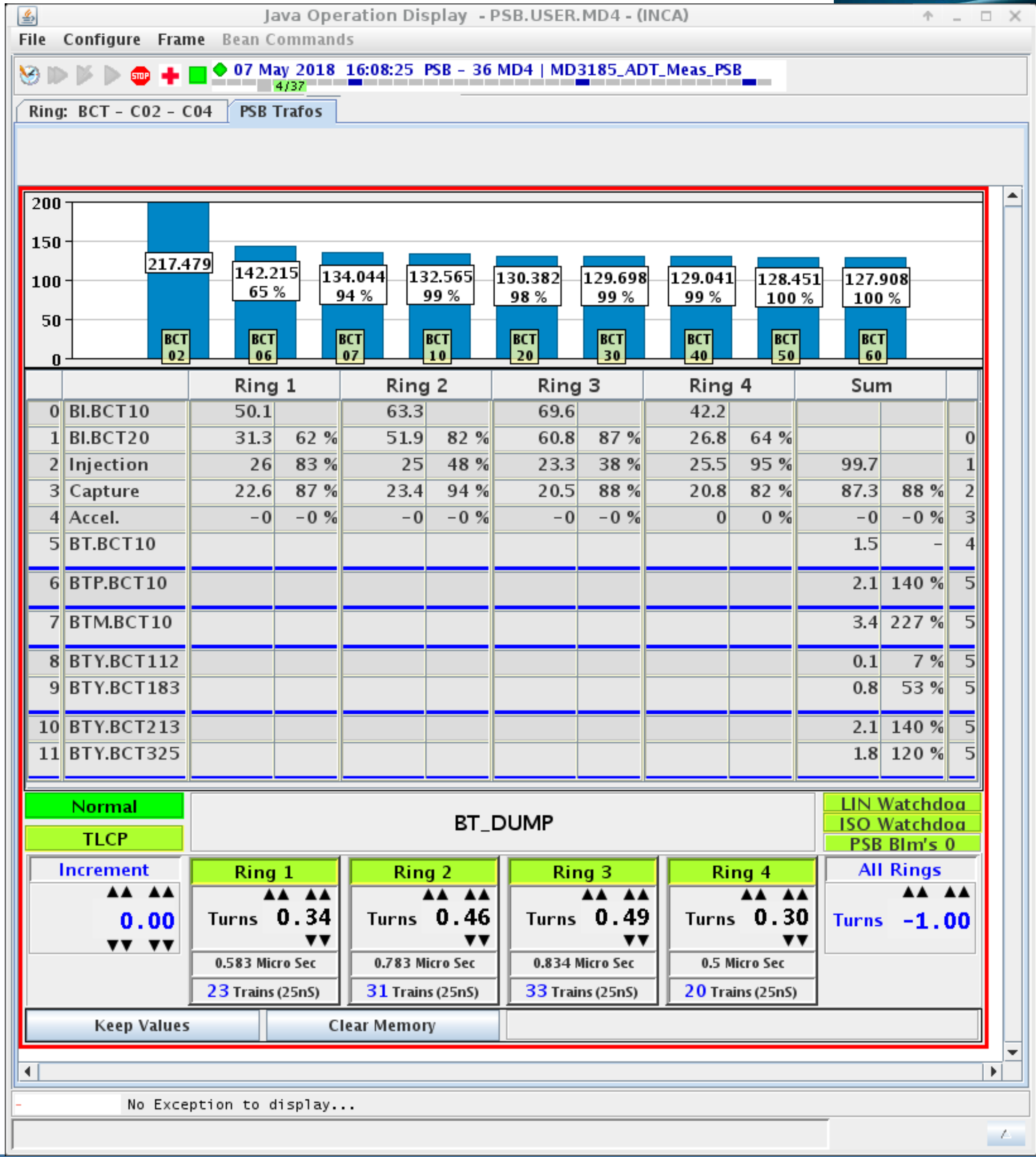
- Intensity 0.04 and gain 1e09



Need to find compromise intensity

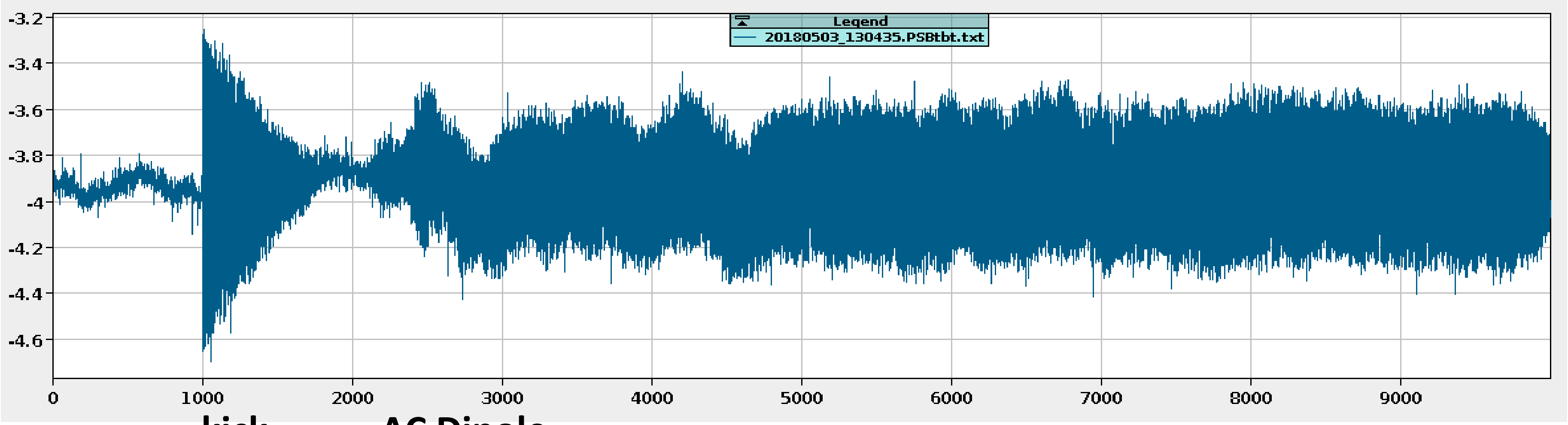
- We measure at 0.5 in ring 3, and adjust other rings to have more or less similar intensity as measured by BCTs
  - Is BCT reading calibrated?



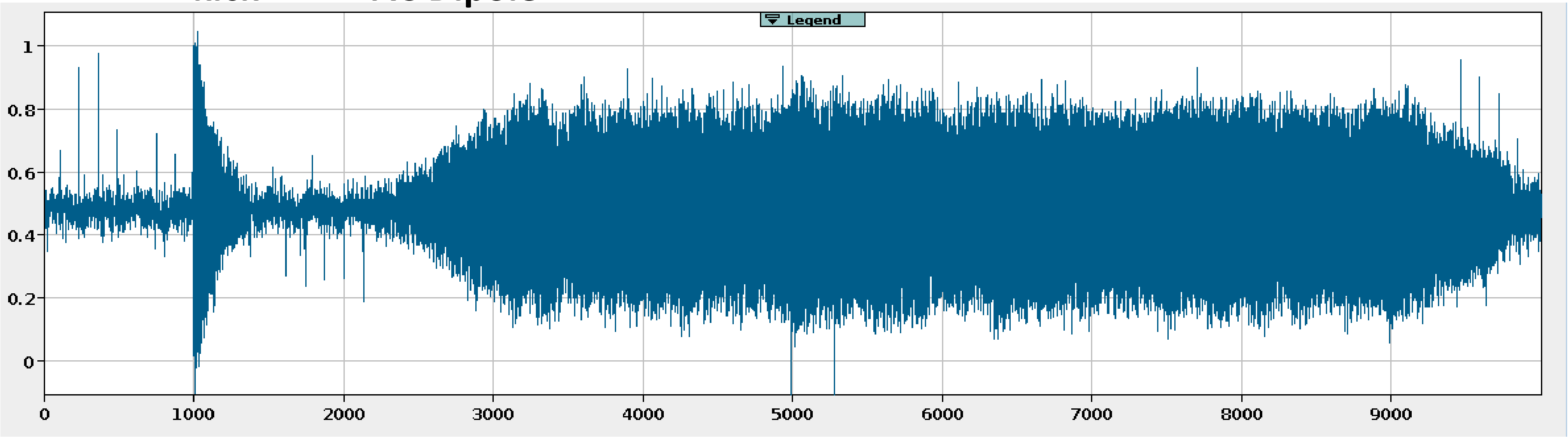


AC Dipole

- At this intensity the response to the AC Dipole also looked more as expected

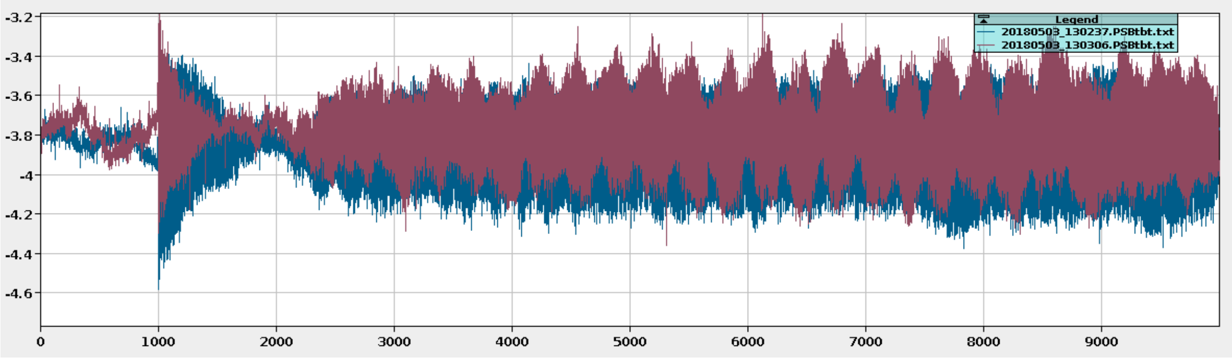


kick AC Dipole

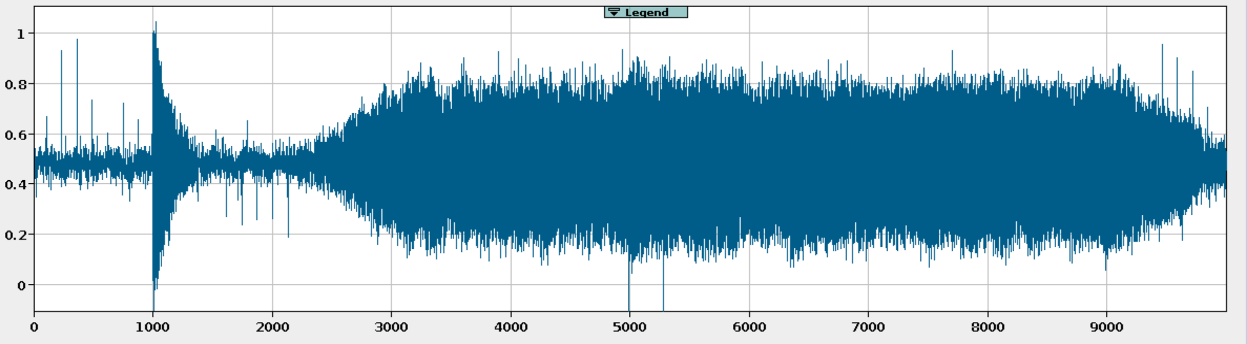


AC Dipole

- The measurements in the vertical plane were very good
  - Achieved decent amplitudes (1mm) with the ACD frequency 0.04 away from tune
  - The beam responses were steady having same envelope as the drive signal
- In the horizontal plane only one electrode was connected and had to approach with the ACD frequency towards tune to 0.02
  - Measurements were not as good



Horizontal

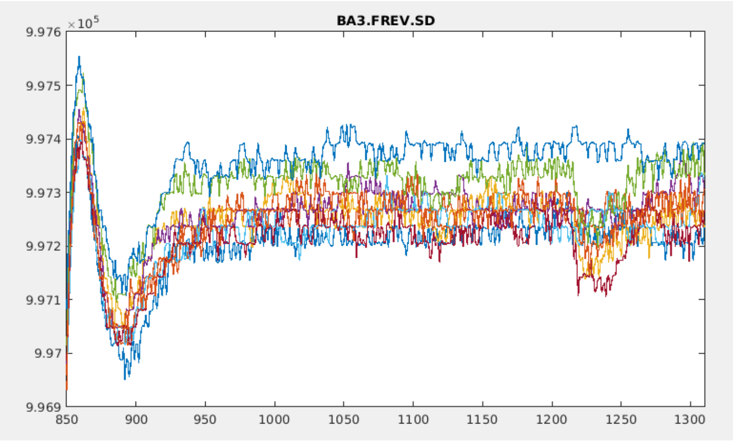


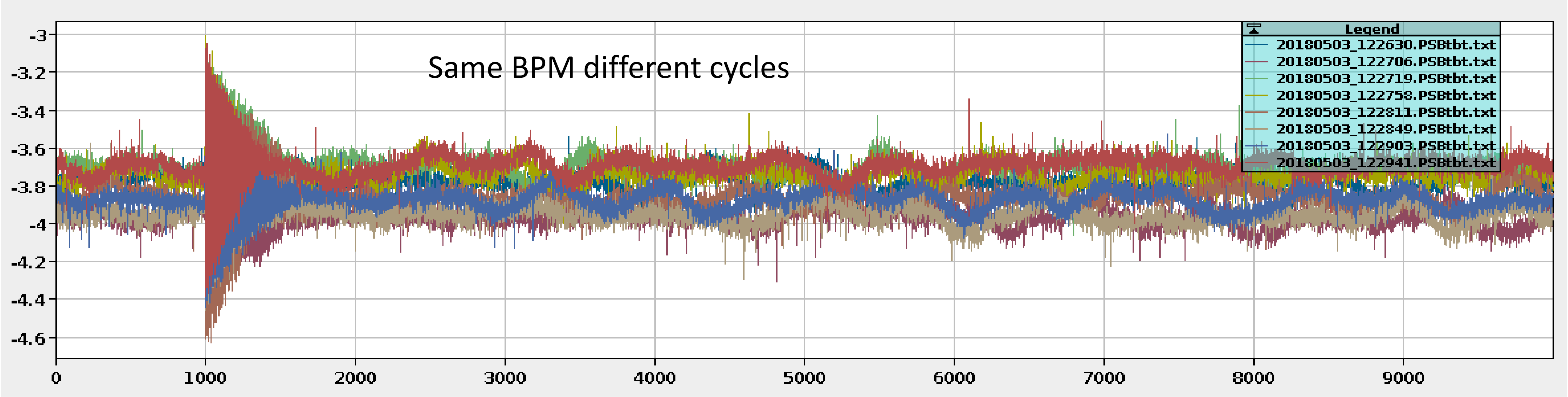
Vertical

Stability in the horizontal plane

- Drifts and jitter in
  - Horizontal position
    - Pattern of the drift is the same for all H BPMs;
      - beam energy fluctuations?
      - RF?
  - Revolution frequency

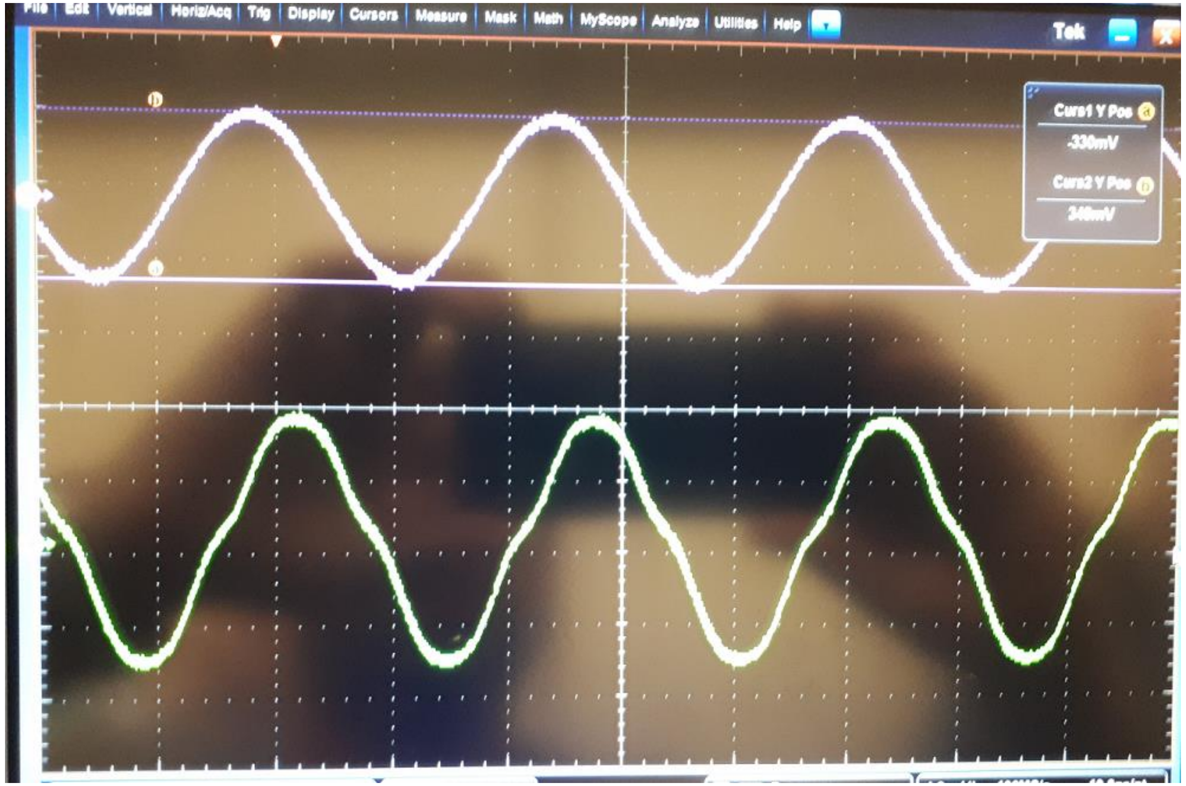
  reduce accuracy of the measurements





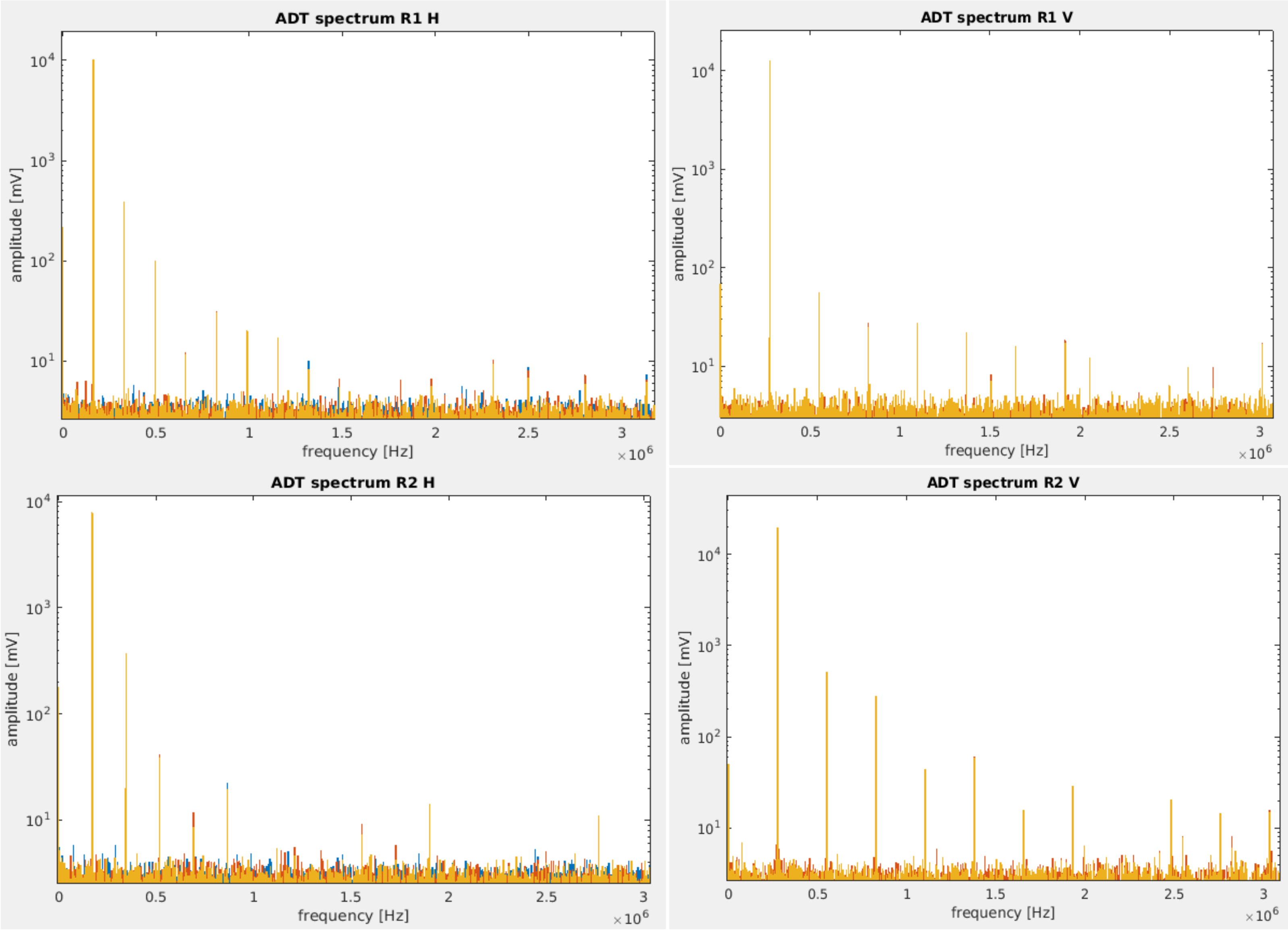
AC Dipole

- **Big thanks to Marek, Alfred and Gerd**
  for setting up the ADT as AC dipole!!!
- Amplitude needs to carefully tuned not to saturate the amplifiers



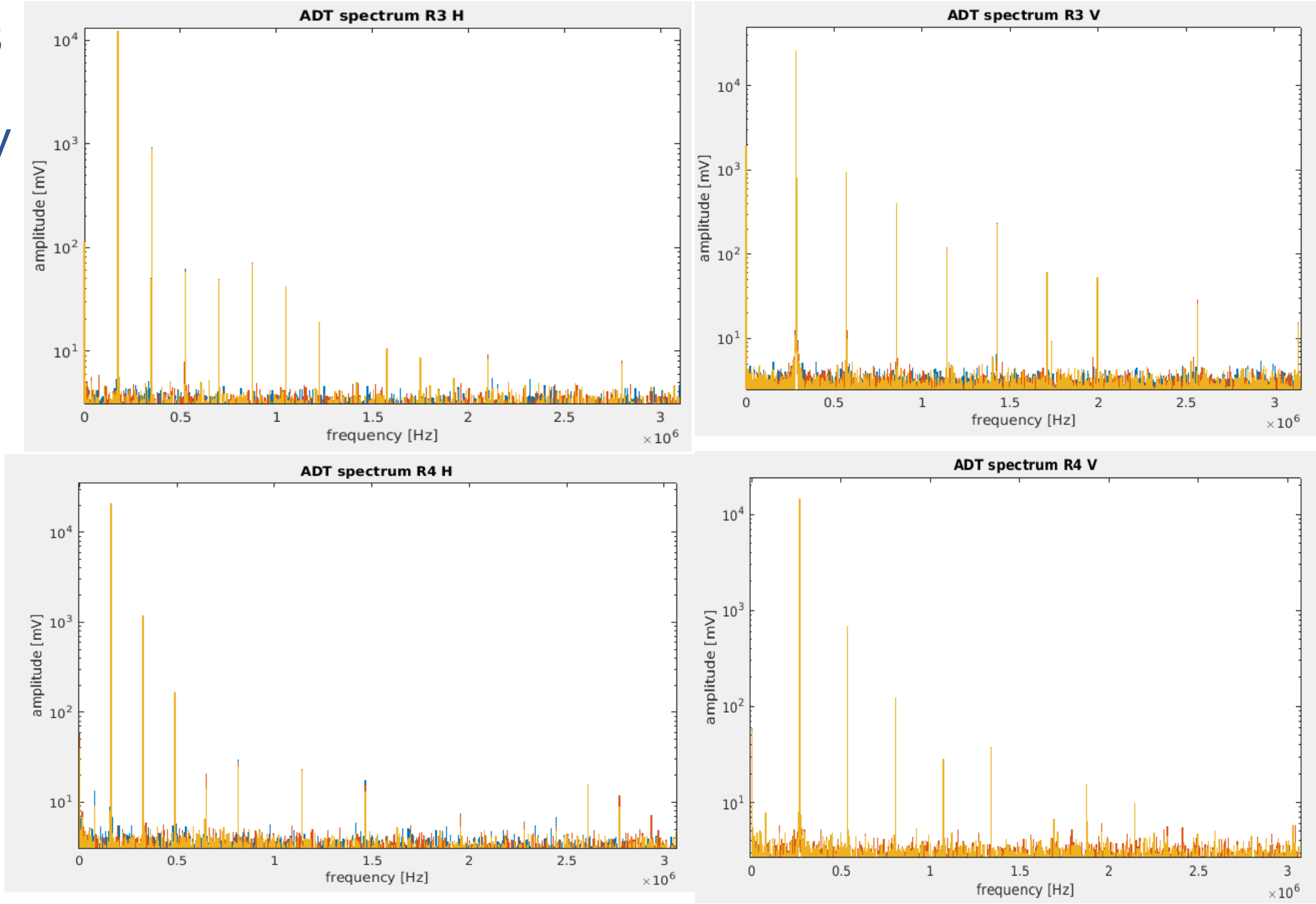
AC Dipole quality

- Signals measured at the outputs of the kickers show that there is no big jitter in frequency
- However, there is sizeable pollution of the higher order modes



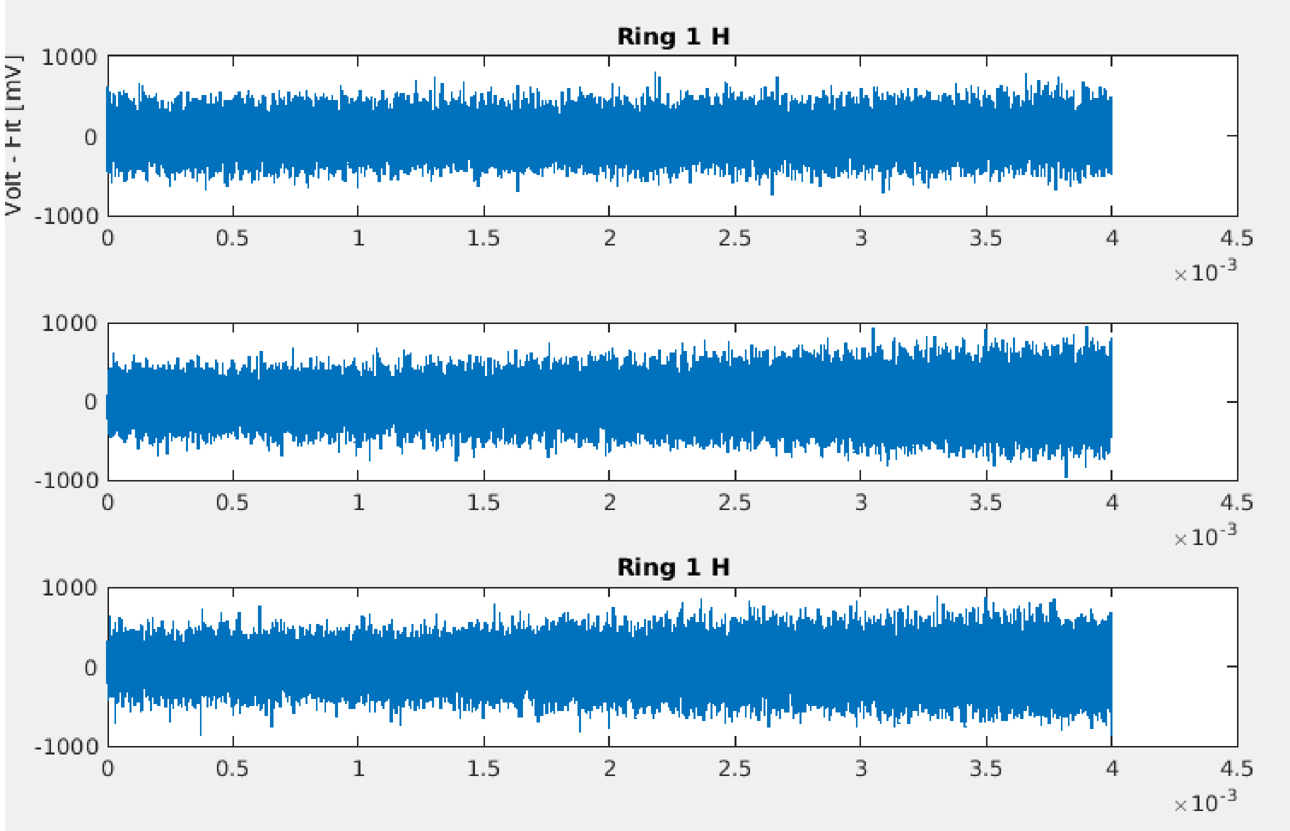
AC Dipole quality

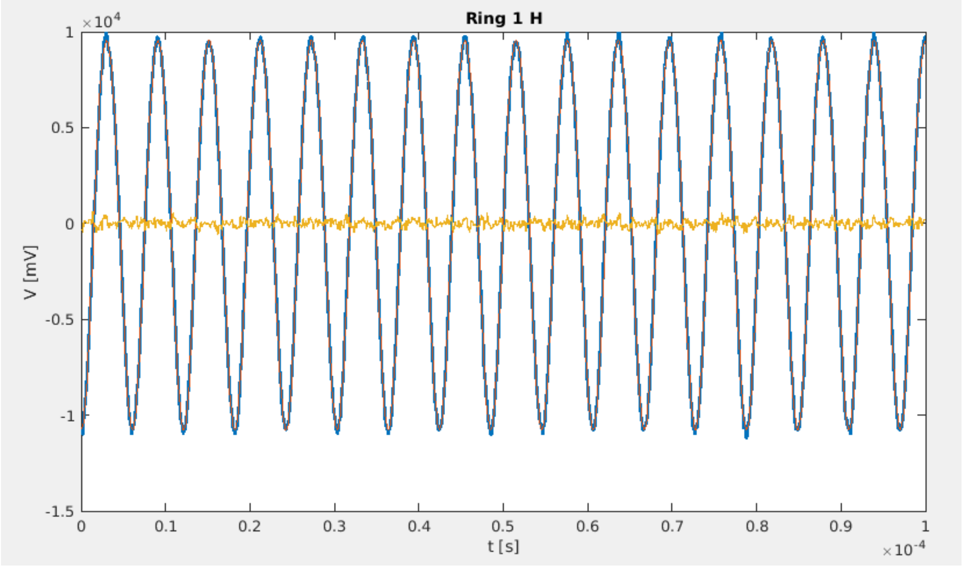
- Signals measured at the outputs of the kickers show that there is no big jitter in frequency
- However, there is sizeable pollution of the higher order modes
- We need to verify how it changes with gain



AC Dipole quality

- Check of uniformity
  - Fit a1*cos(ot*fi1) + a2*cos(2*ot+fi2) +offset
  - Plot difference between data and the fit
    - Data for 3 consecutive shots

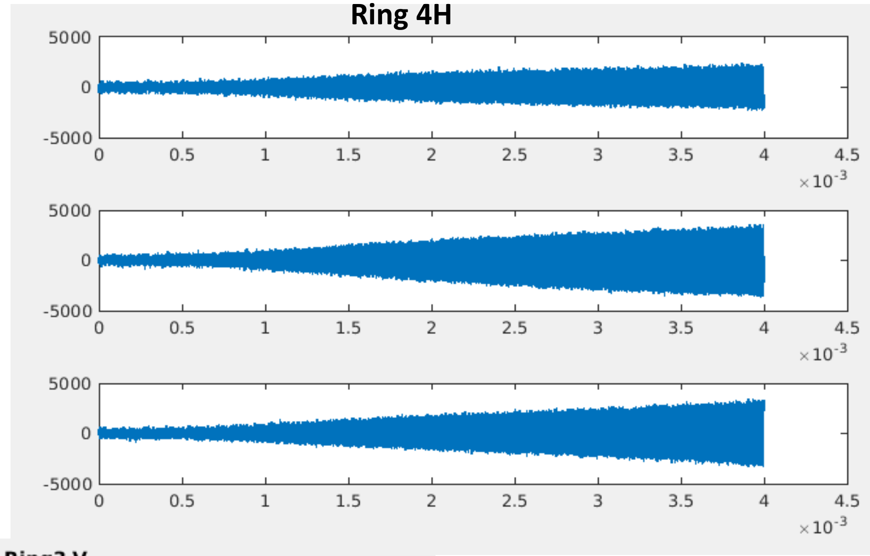


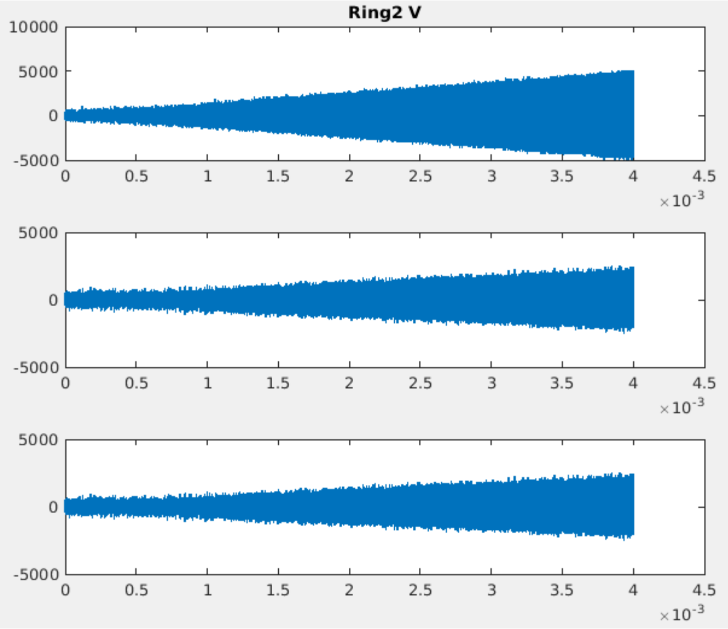


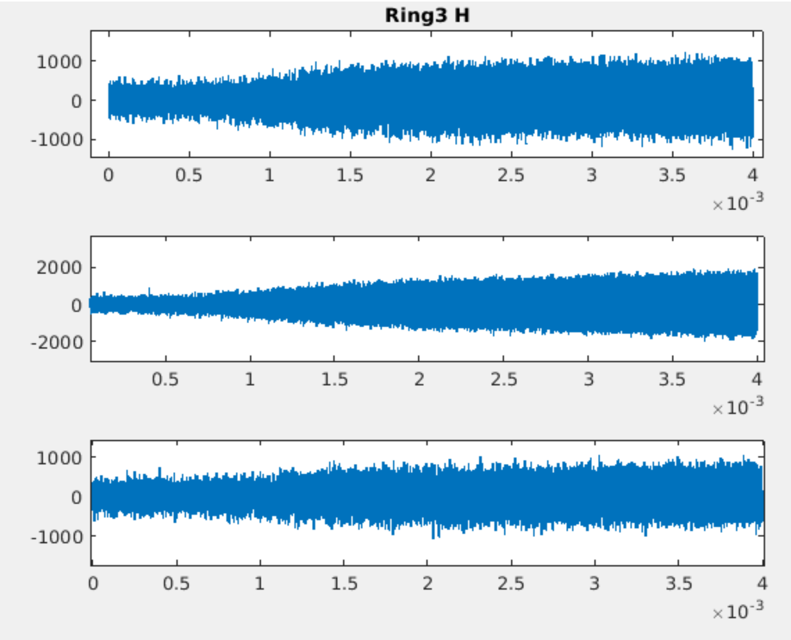
Ring 1 H is very good

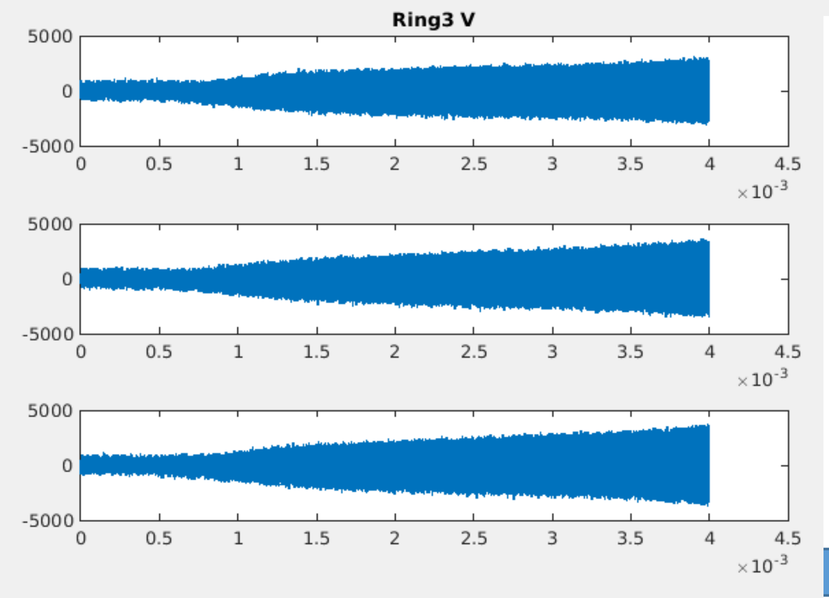
AC Dipole quality

- Check of uniformity









Software

- Data analysis is done using the machinery developed for the LHC by Rogelio Tomas and his collaborators (the OMC)
  - Model building
  - Data cleaning
  - FFTs (the best adapted ones for this purpose)
  - Correction for the driven frequency in ACD data analysis
  - Calculation of optics from the spectra
    - Global and segment by segment
  - Error analysis
  - Calculation of corrections
    - Local and global
- It is conceived to be an universal tool, still it was designed for the LHC and several adaptations still need to be done to be fully operational in PSB & PS

To do

- Fix bad BPMs, check suspicious calibration with the specialists
- Measurements with different optics to calibrate the BPMs
- AC Dipole measurements with both horizontal amplifiers plugged in
- Simultaneous H&V excitations with AC
- Reconstruct coupling
  - Try a correction ?

- Can we try some linear optics correction ?
- Use best knowledge model ?
  - Take into account the correcting magnets