Transverse Impedance Localization Update

N.Biancacci

- Method
- Measurements in PS
- Measurements in SPS
- Measurements in LHC

Acknowledgement

PS, SPS and LHC operators and LHC collimation team.
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Outline

- Transverse impedance localization method.
- Observable: phase advance
    - Accuracy of phase advance detection for noisy signals.
    - Accuracy of slopes for measurements with error bars.
    - Impedance induced phase advance beating
- Application to the PS
    - Measurement of local quadrupolar orbit errors.
    - Measurements with single bunch, injection, V-plane.
- Application to the SPS
    - BPM system.
    - Measurement with single bunch, injection, V-plane.
- Application to the LHC
    - Status of analysis.

- Conclusion and overview.

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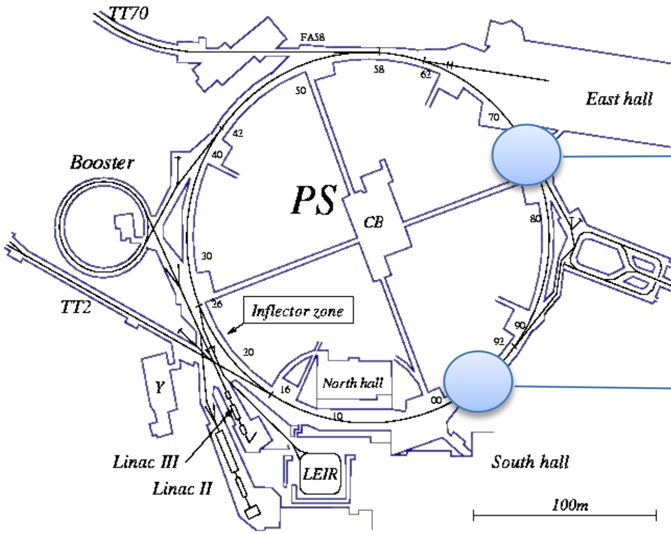
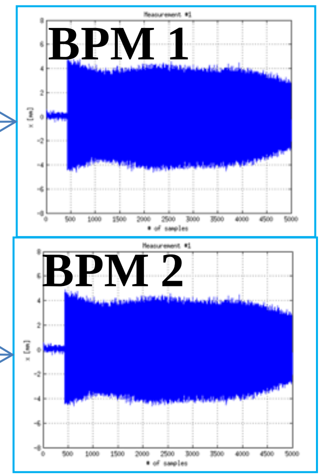
Transverse Impedance Localization Method

The transverse beam coupling impedance can be measured both globally and locally:





In the local coupling impedance measurements we measure the variation of phase advance between BPMs with intensity.

$$\Delta\varphi(N_b)_{1\to 2} \propto Z_{1\to 2\,(TOT)}$$

In the global coupling impedance measurements we measure the variation of tune frequency with intensity.

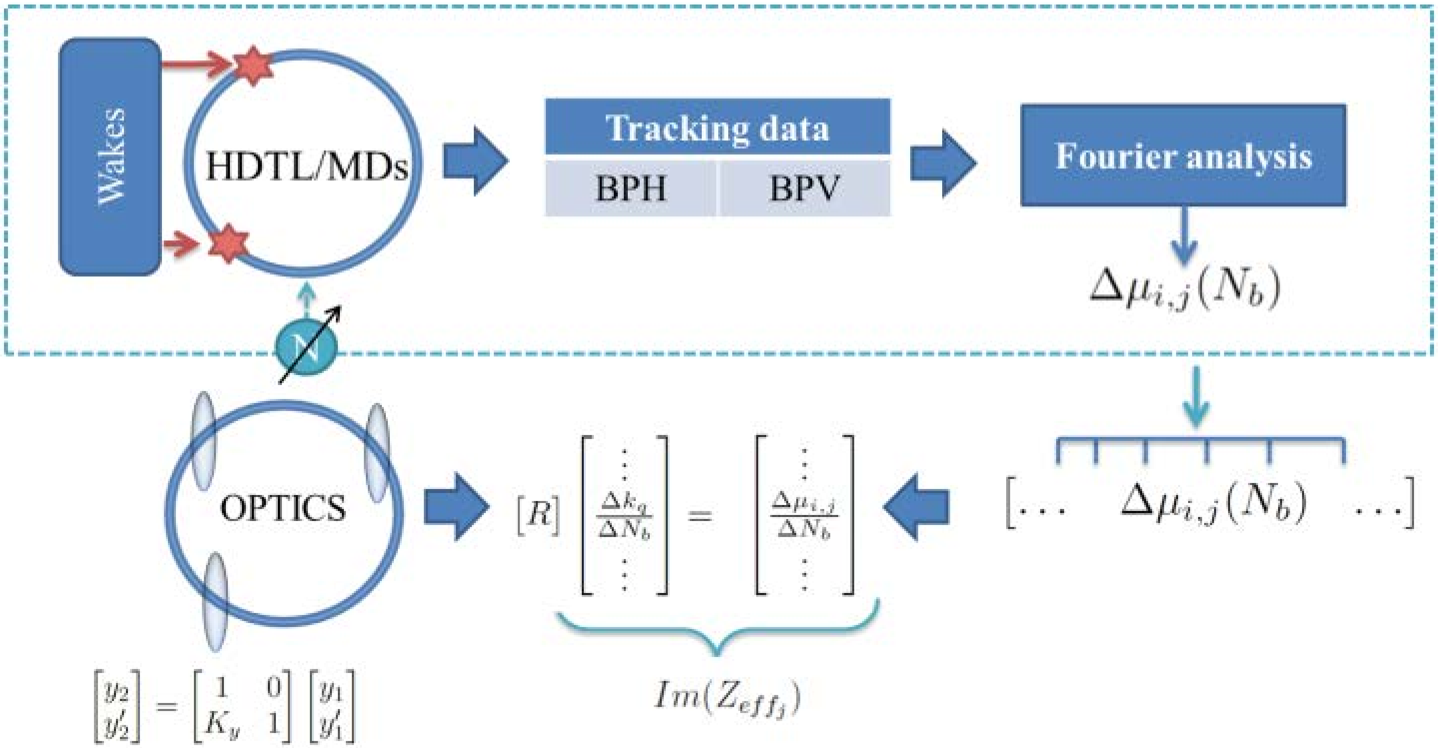
$$\Delta Q(N_b) \propto Z_{\perp\,(TOT)}$$

The method for local measurements was proposed and applied by G. Arduini et al. in 2004 and 2009 in SPS [1,2] and benchmarked with HEADTAIL.

[1] "Localizing impedance sources from betatron-phase beating in the CERN SPS", G. Arduini, C. Carli , F. Zimmermann EPAC'04.
[2] "Transverse Impedance Localization Using dependent Optics" R.Calaga et al., PAC'09.

Transverse Impedance Localization Method

The aim of the measurement is: correlating the phase advance beating variation with intensity with a local source of impedance.
In "optical" terms, an impedance would behave as a (de)focusing intensity dependent quadrupole.



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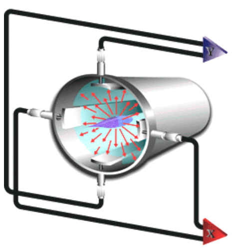
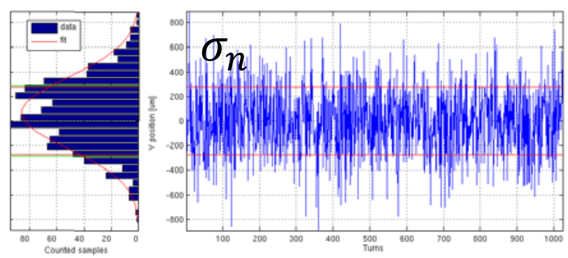
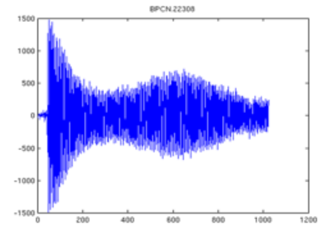
Observable: Phase advance

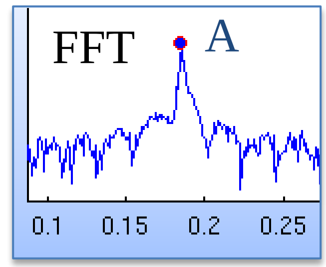
The uncertainty chain:



BPM system

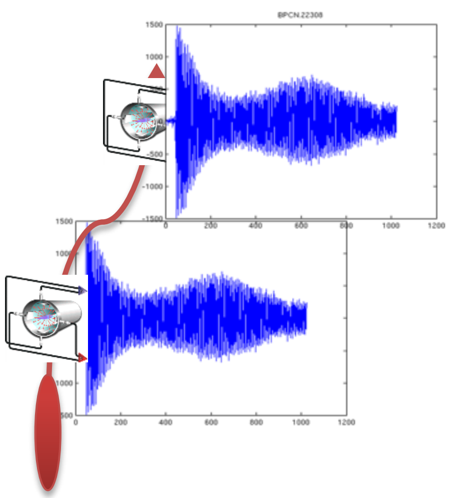






$$\text{NSR} = \frac{\sigma_n}{A}$$

Noise Signal Ratio



$$\sigma_{\Delta\varphi}$$

Phase advance accuracy

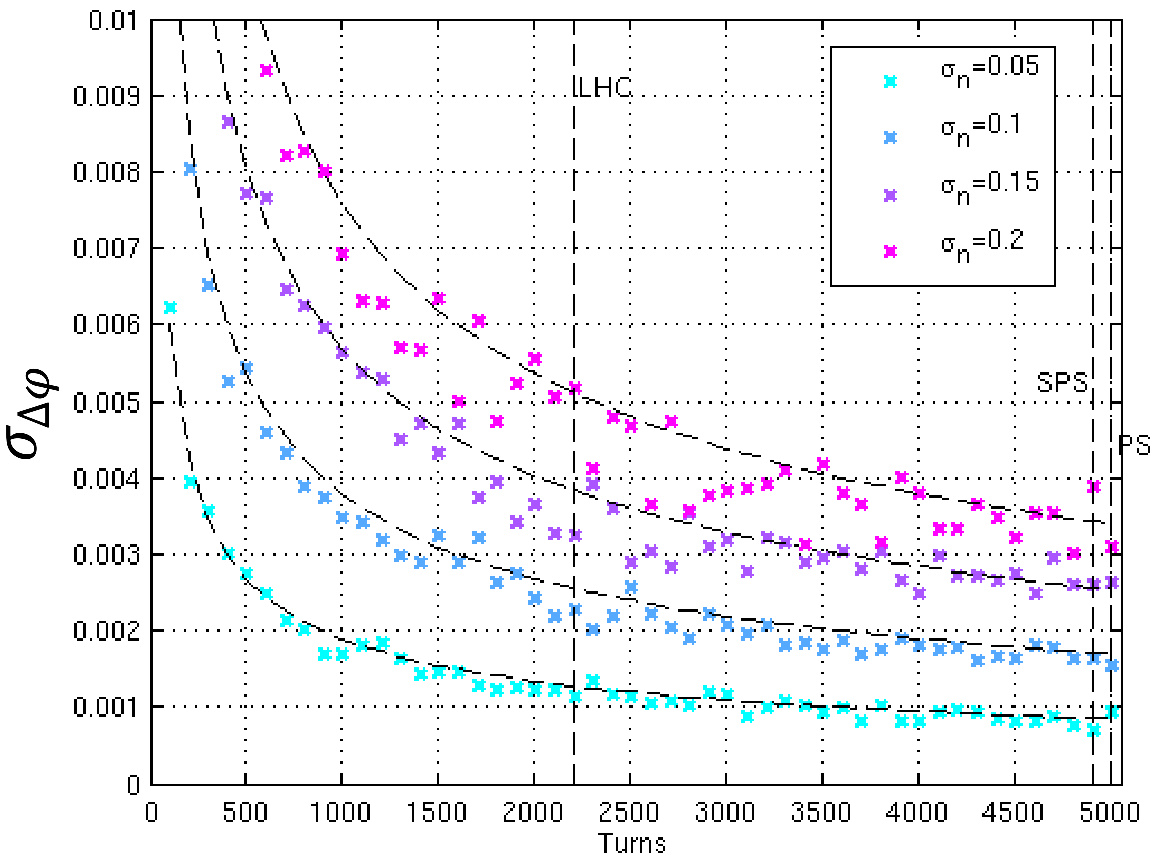
$$\frac{\sigma_{\Delta\varphi}}{\Delta N}$$

Phase advance slope accuracy

Accuracy of phase advance detection for noisy signals

Numerical estimation of phase uncertainty on simulated signal:

- Take 2 aleatory sinusoidal signals, with additive Gaussian noise of sigma σ_n, same tune and fixed phase advance $\Delta\varphi$, amplitude A=1 (NB: NSR=σ_n/A=σ_n in this case).
- Run 100 times and measure the phase advance.
- Measure the standard deviation $\sigma_{\Delta\varphi}$ for the phase advance (accuracy in measurements).
- Fit.



$$\sigma_{\Delta\varphi} \approx 1.2\frac{\sigma_n}{\sqrt{N}}$$

and in general,

$$\sigma_{\Delta\varphi} \approx 1.2\frac{NSR}{\sqrt{N}}$$

Note that phase is in MAD units (rad/2pi)

Accuracy of phase advance slope measurements

Given a set of **M** measurements of $\boldsymbol{\Delta\varphi}$ with equal error bars $\boldsymbol{\sigma_{\Delta\varphi}}$, obtained along an intensity scan **X** , we can calculate $\boldsymbol{\sigma_{\frac{\Delta\varphi}{\Delta N}}}$ using standard straight line least squares:

$$\sigma_{\frac{\Delta\varphi}{\Delta N}} = \frac{\sigma_{\Delta\varphi}}{\sigma_X \sqrt{M}}$$

with σ_X standard deviation of the intensity scan X.

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with σ_X standard deviation of the intensity scan X.

Comparing with the previous formula one has:

$$\sigma_{\frac{\Delta\varphi}{\Delta N}} = \frac{1.2\ NSR}{\sigma_X\sqrt{N}\sqrt{M}}$$

To be reduced
(noise level, kicker strength, BPMs gain, BPM transfer function)

To be increased: M= number of measurements. Usually a 100 points it's the case.

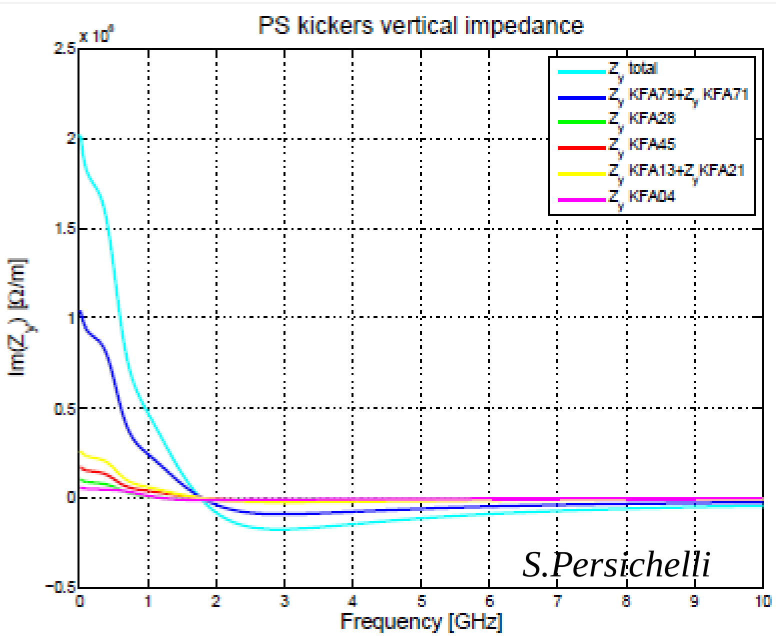
To be increased: It is the width of the scan of intensity. Upper threshold can be TMCI. Lower is BPM sensitivity.

To be increased: N=Number of turns. Depends on ability on hardware and data trasmission from BPM to storage.

Impedance induced phase advance beating

A phase beating is induced by impedance kicks similarly to what is done by a quadrupolar kick. From standard formulas we can calculate the phase beating amplitude and therefore compare it with the accuracy we can get in measurements.

Example: PS kickers



1) Calculate impedance: Tsutsui's model for the kickers.

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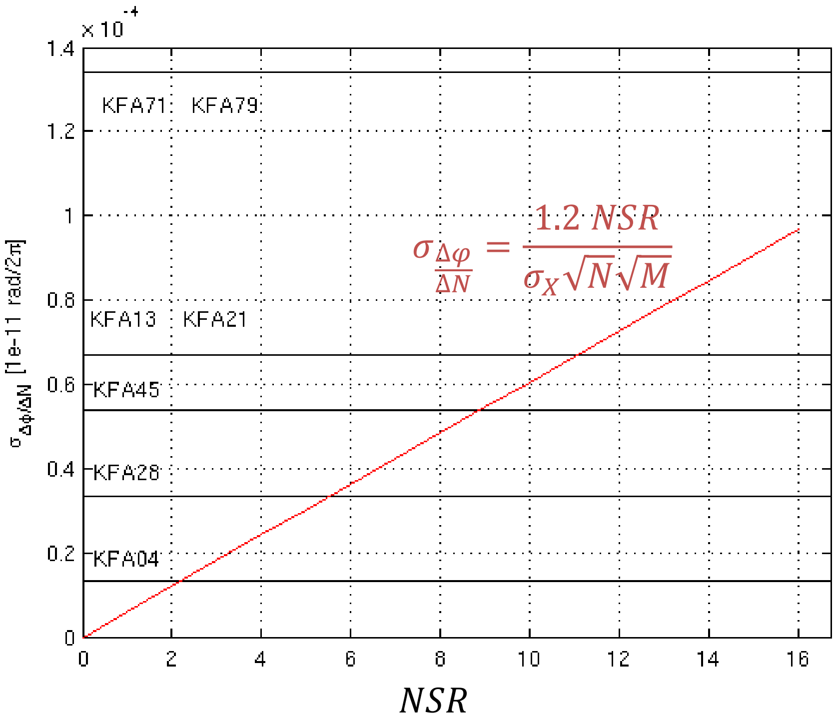


1) Calculate impedance: Tsutsui's model for the kickers.

2) Merging Sacherer formula and phase beating formula [1] we calculate the beat amplitude from impedances as:

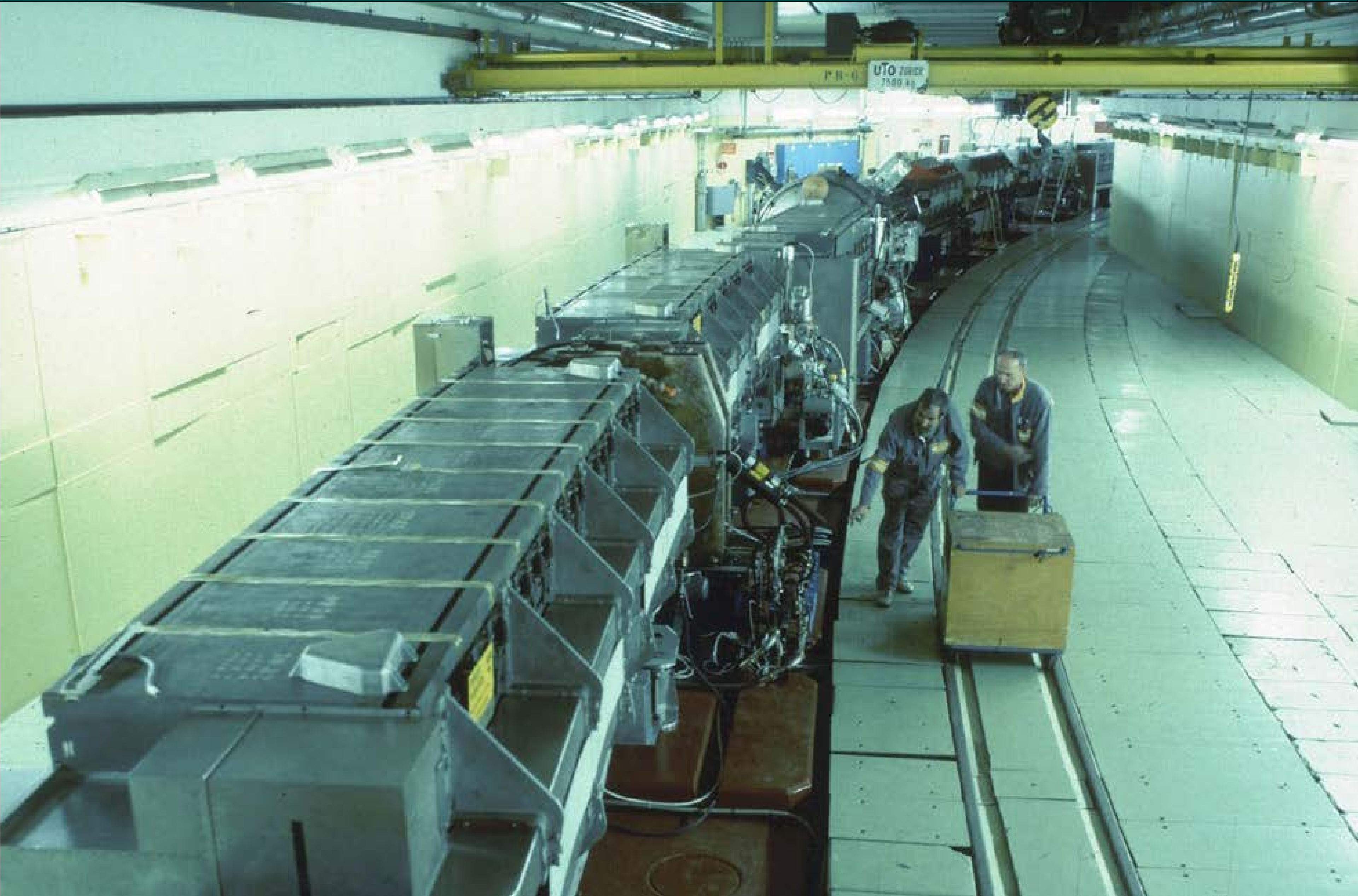
$$A = \frac{q^2}{(2\pi)^2 T_0} \frac{\sqrt{\pi}\ Im\{Z_{eff}\}}{\gamma m_p \omega_0 Q_0 \sigma_z} \left(\frac{\delta_s}{2} + \frac{1}{2\sin(2\pi Q_0)} \right)$$

and compare with measurements and the estimation:

$$\sigma_{\frac{\Delta\varphi}{\Delta N}} = \frac{1.2\ NSR}{\sigma_X\sqrt{N}\sqrt{M}}$$

[1] "Localization of transverse impedance sources in the SPS using HEADTAIL macroparticle simulations" IPAC12, N.Biancacci et al.

PS



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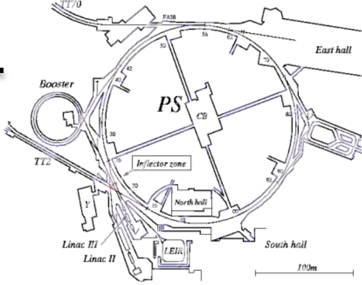
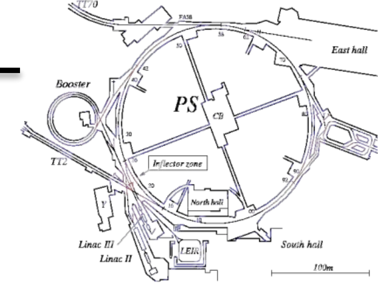
QSE current variation



Method validation:

- take a couple of quadrupoles.
- vary their current in order to provoke a tune shift of ~0.02.
- Try to localize back the quadrupoles.

QSE current variation



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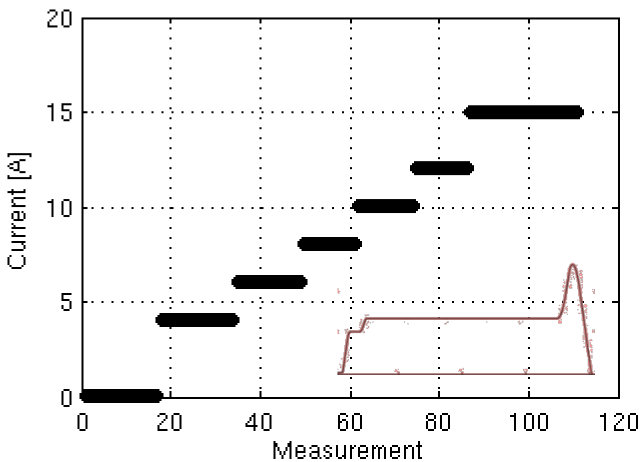
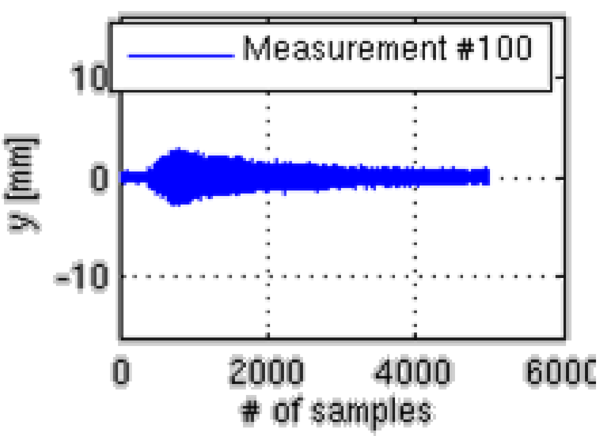
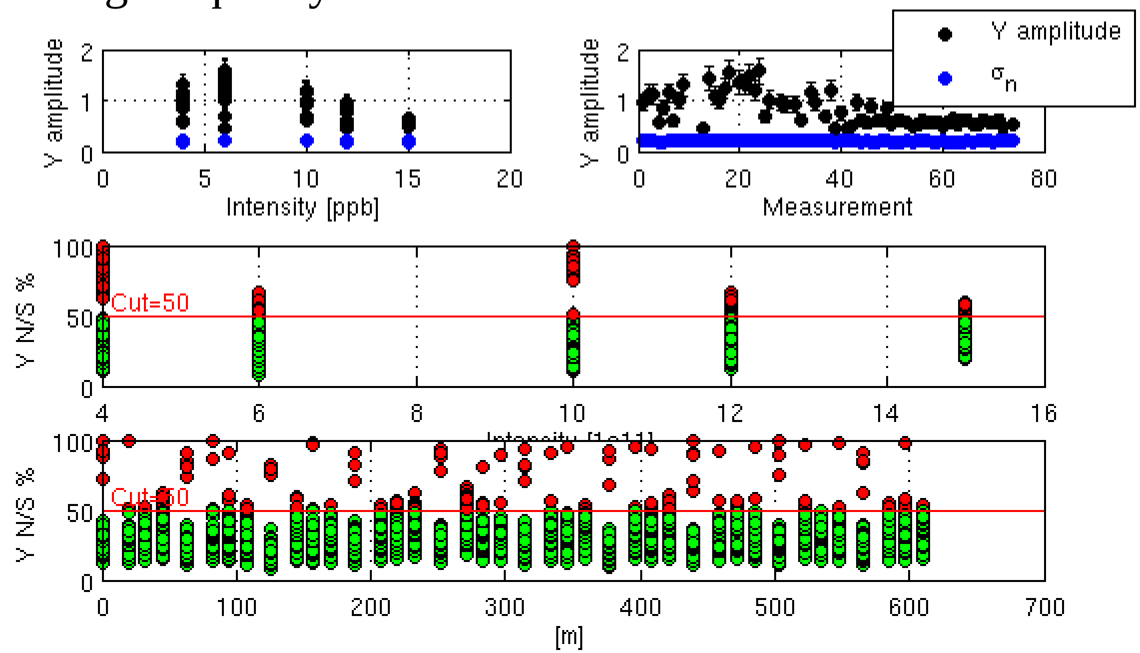
Current in the quadrupoles

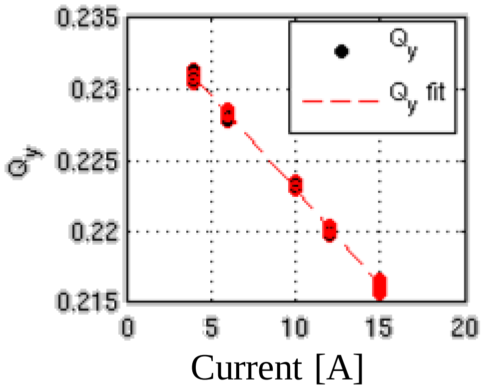




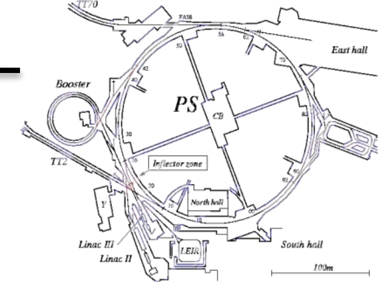
Signal quality

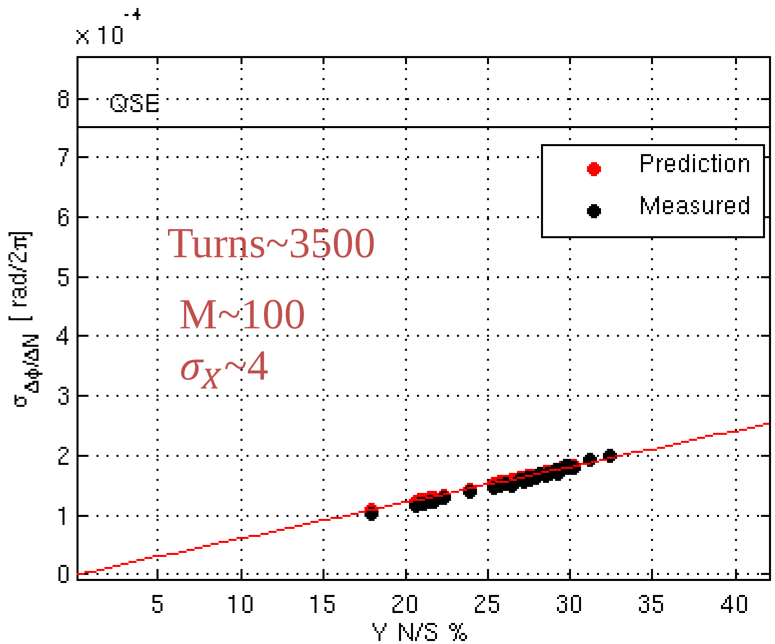


QSE current variation



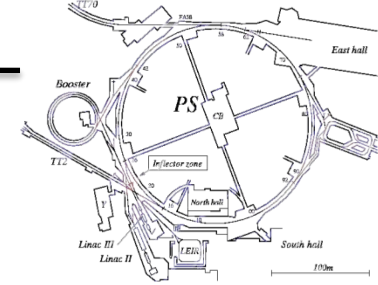
From the tune shift we verified that a considerable scan was achieved.

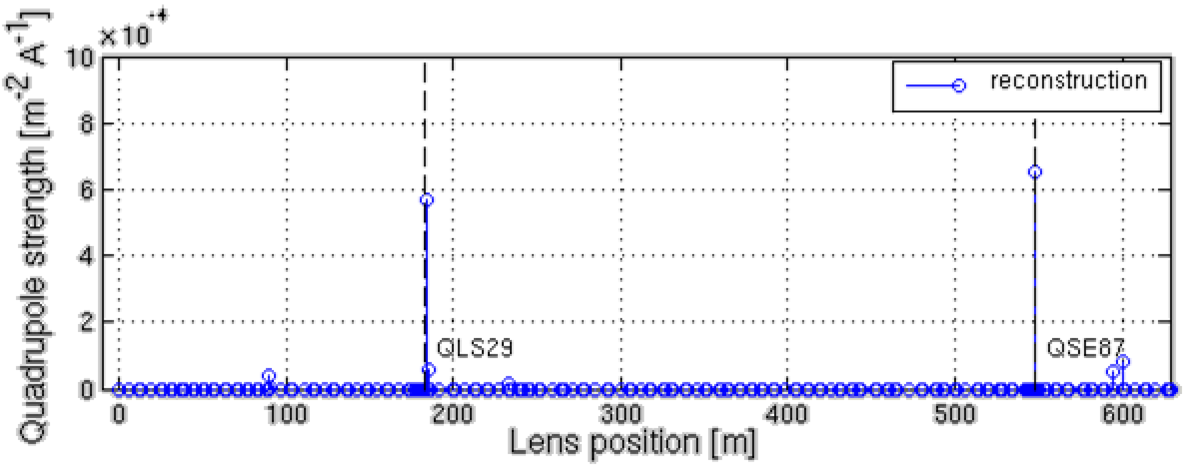


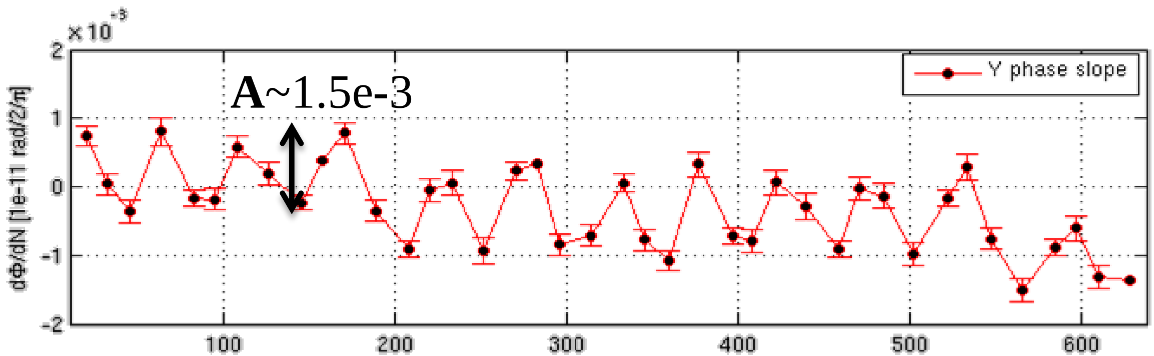


An error in a QSE quadrupole provokes a beat of amplitude A~7.5e-4. This is well within the accuracy limit. QSE are 2, so the beating waves can interact constructively or destructively.

QSE current variation



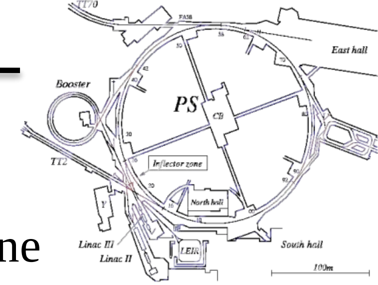




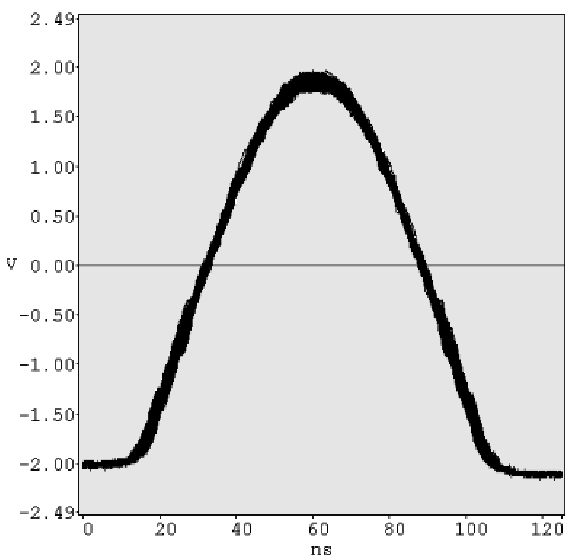
The two quadrupoles provoke beating waves that interact constructively: sum of beating amplitude A~1.5e-3 agrees with the measured one.

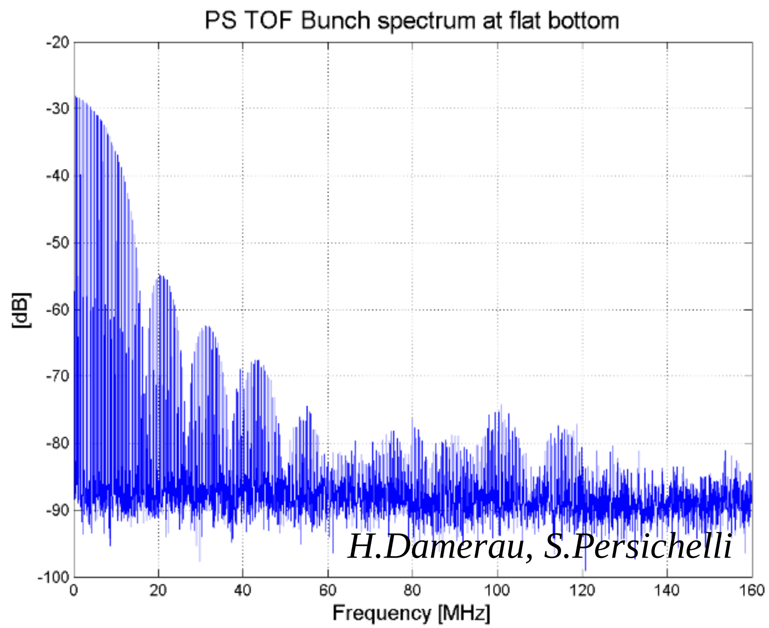
Both slope and reconstruction are good.

Even if it's not a really "intensity dependent" experiment from a beam point of view, it proves that the reconstruction method can work.

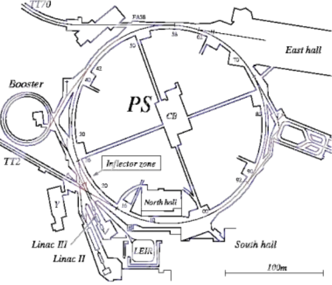


- The measurement with single bunch at injection energy 2GeV, was done with a TOF beam.
- Intensity scan from 1e12 to 6e12 ppb.
- TFB was used as vertical kicker.
- The smallest bunch length is 90ns (4σ) with 200kV in 10MHz cavities.





Measurement with single bunch V plane



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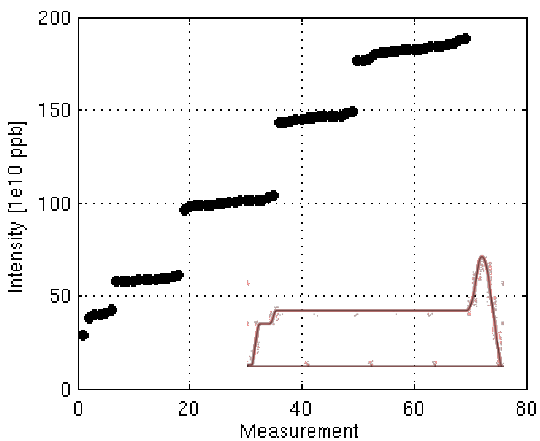
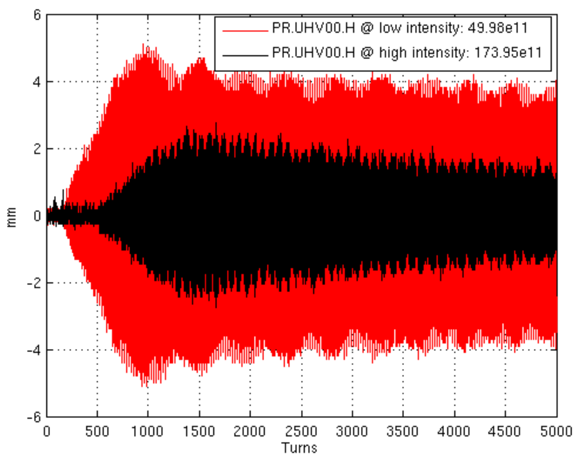
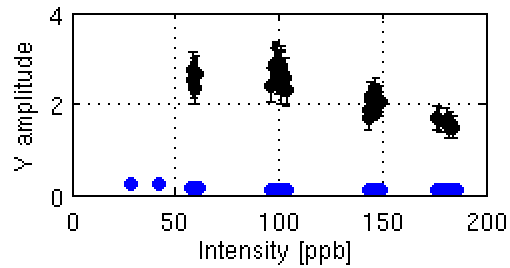
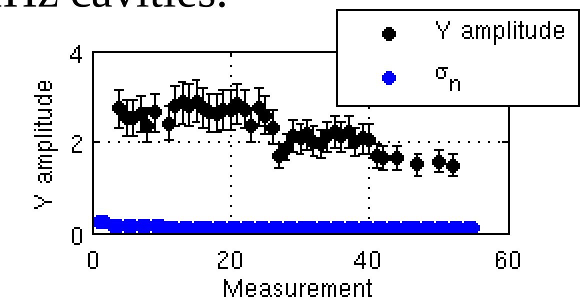
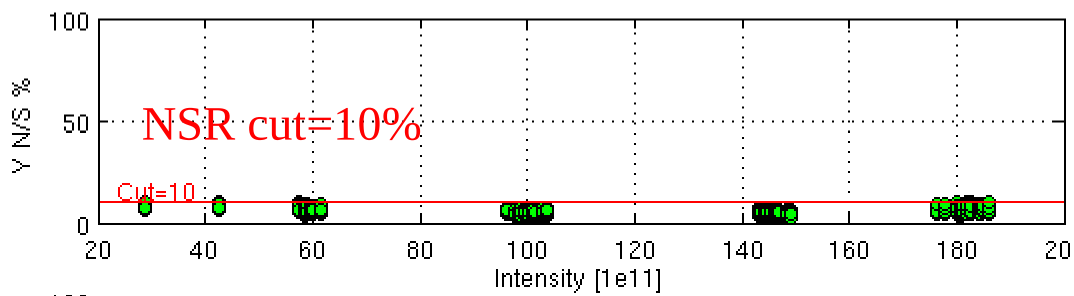
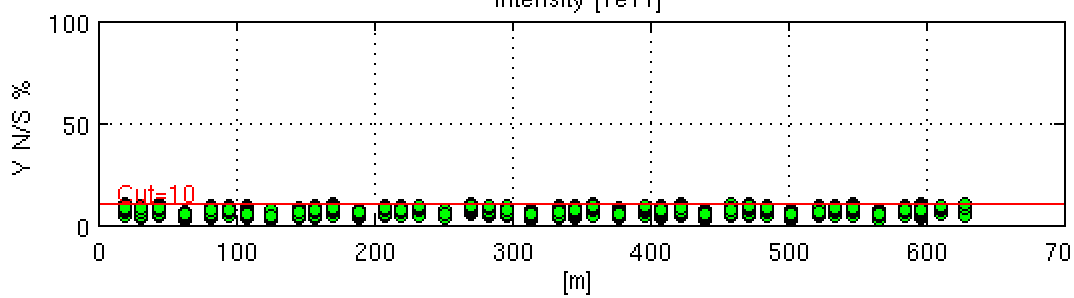




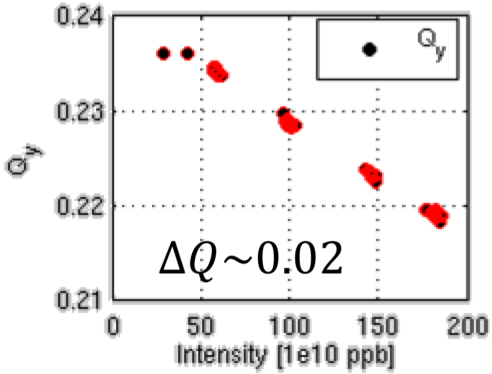


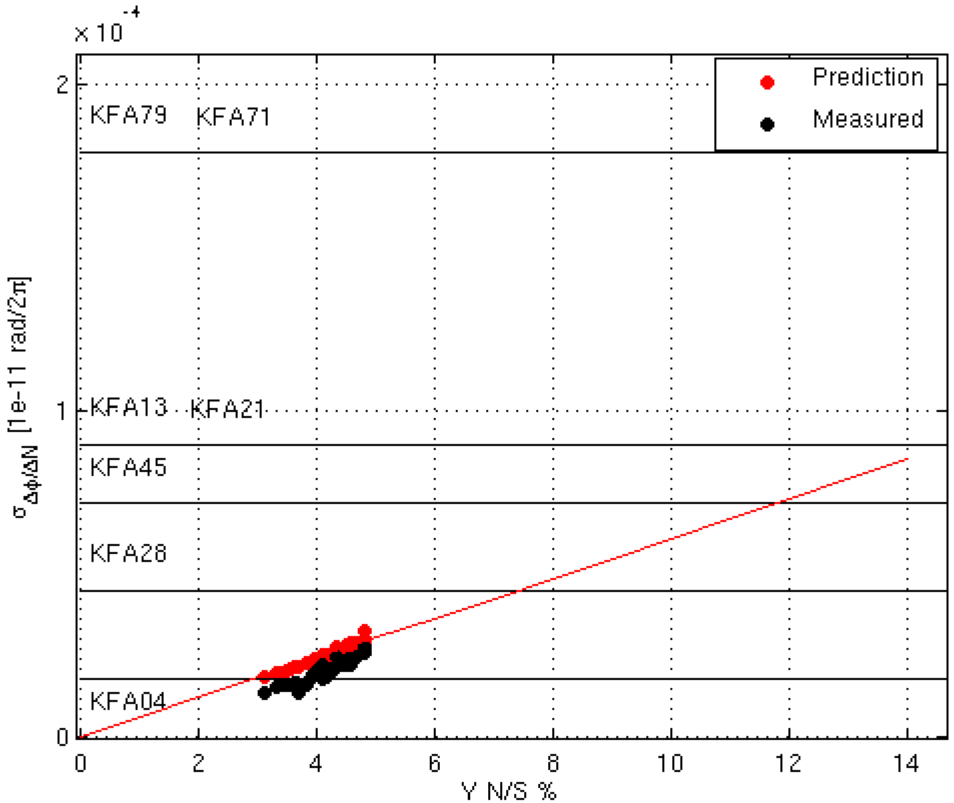


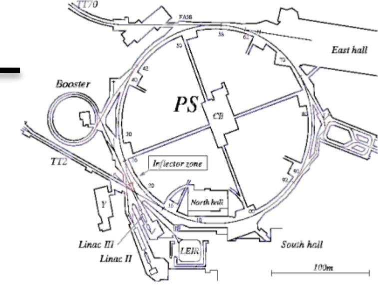




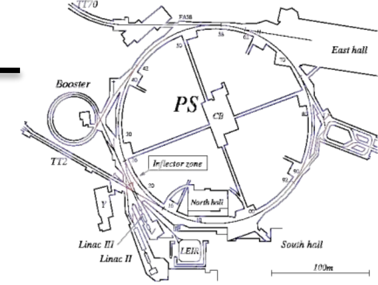
Measurement with single bunch V plane

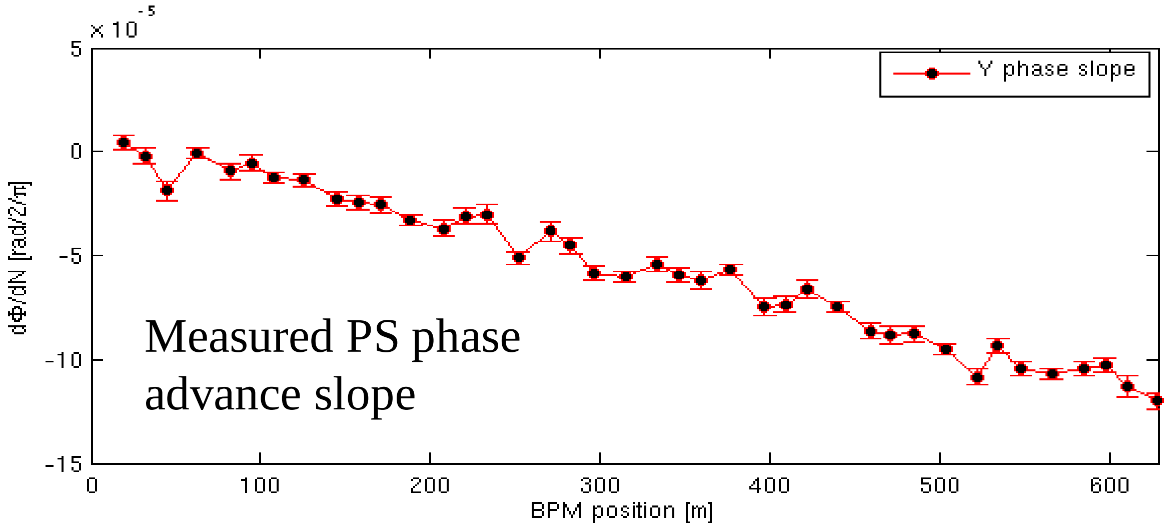


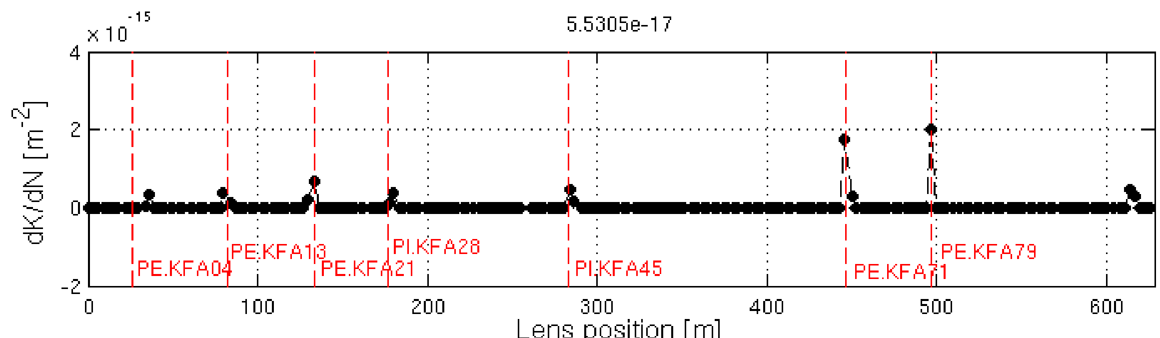


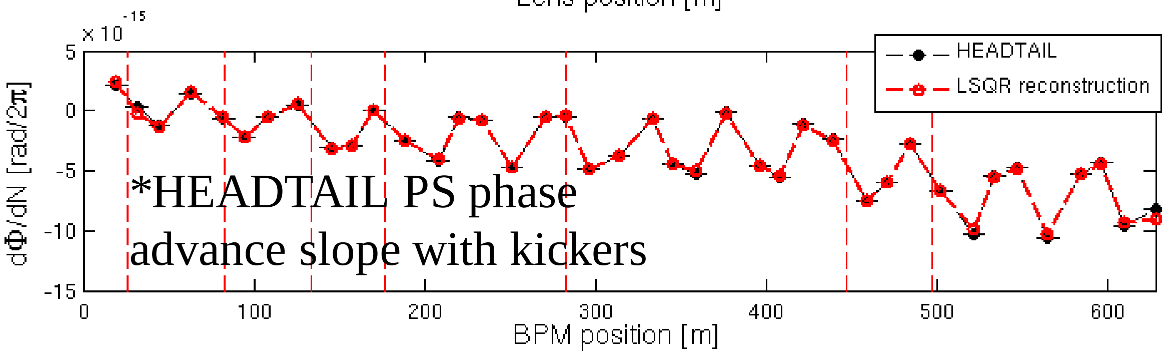


Measurement with single bunch V plane





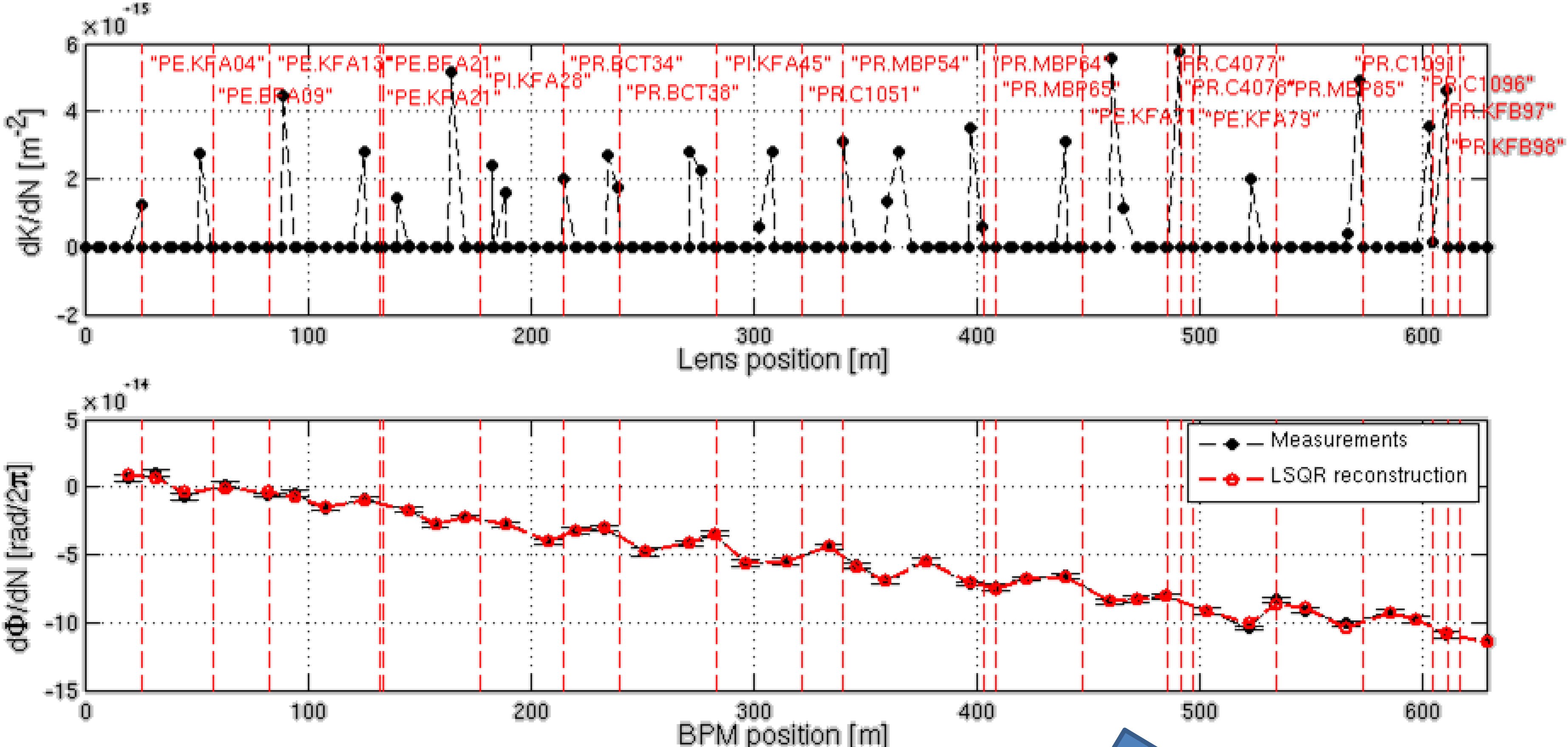




- Measurement is rather clean.
- The step like behaviour expected from HEADTAIL simulation is smoothed.
- Probably SC contribution?
- Resistive wall tune shift contribution should be cut out?

* Impedance calculated with Tsutsui's model

Reconstruction of PS-30-01-2013_V3:



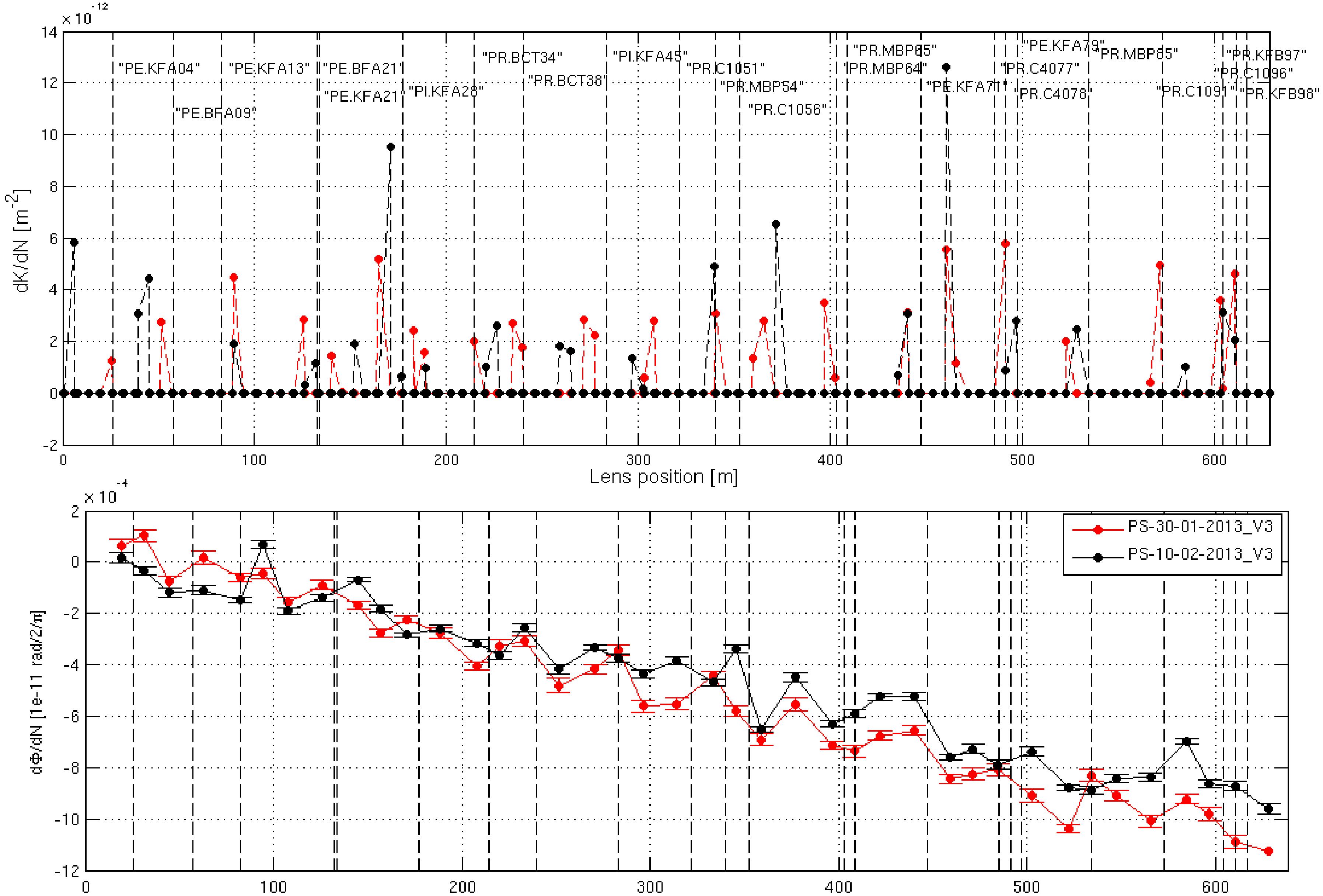
Identified elements:

- KFA04
- BFA09
- KFA13
- KFA21
- KFA28
- KFA45
- KFA79

- BCT34/38: Beam current transformer
- C1051/56: RF cavity
- C4077/78: RF cavity
- MBP64/65: Wire scanner
- KFB97/98: Feedback

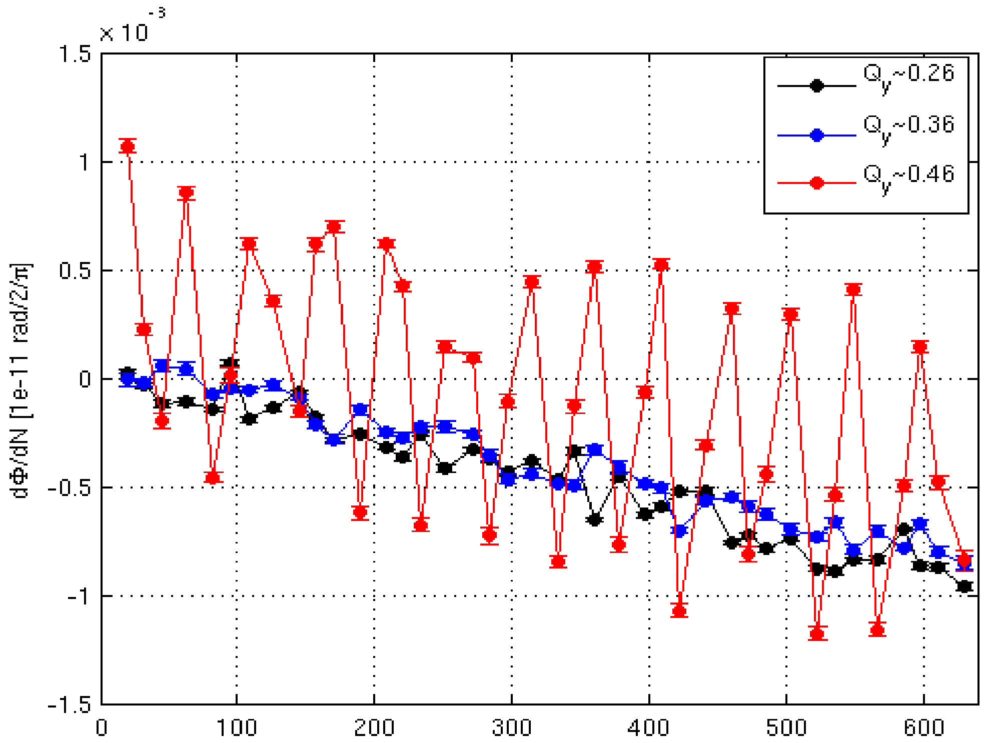
Preliminary

Measurements reproducibility: 10/02 Vs 30/01,



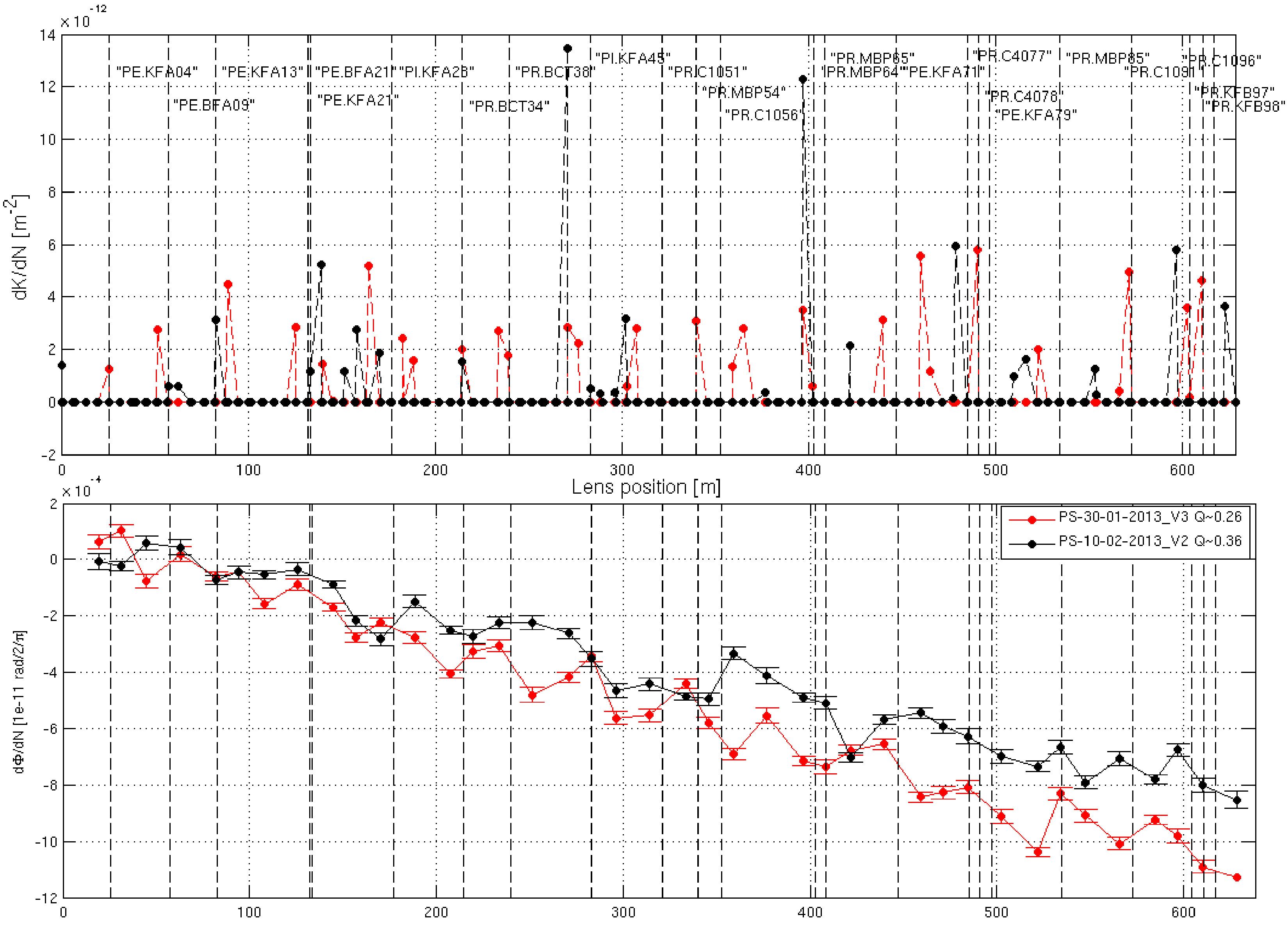
Trying with tunes closer to half resonance Qy~0.5, the signal should increase.

$$A = \frac{q^2}{(2\pi)^2 T_0} \frac{\sqrt{\pi}\, Im\{Z_{eff}\}}{\gamma m_p \omega_0 Q_y \sigma_z} \left(\frac{\delta_s}{2} + \frac{1}{2\sin(2\pi Q_y)} \right) \longrightarrow \begin{cases} 0.26 \rightarrow \text{x1} \\ 0.36 \rightarrow \text{x1.2} \\ 0.46 \rightarrow \text{x4} \end{cases}$$



But the optics model is very compromised close to the resonance due to the natural optics errors.

Measurements reproducibility: 30/01 Qy~0.26 Vs 10/02 Qy~0.36



SPS

SPS

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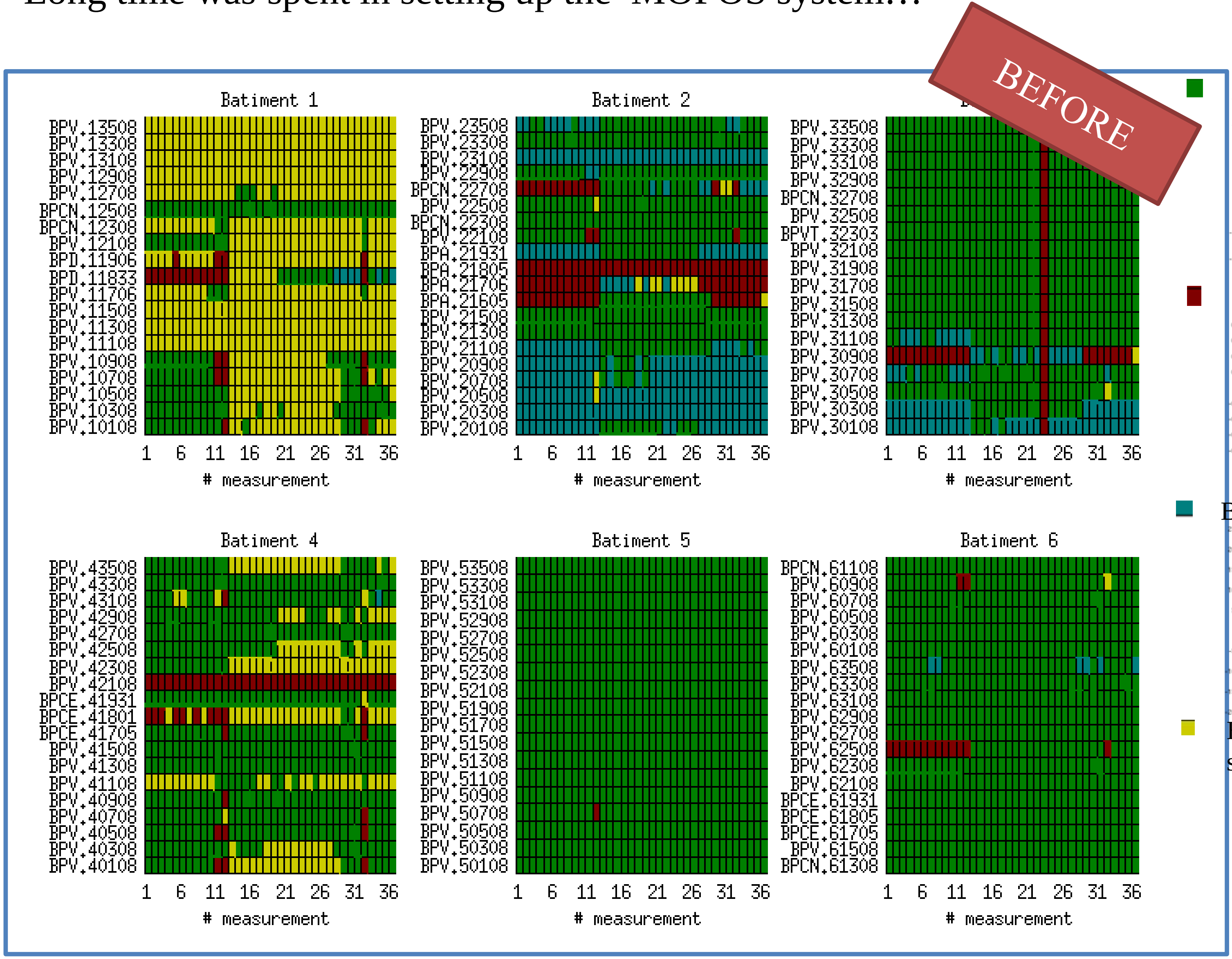
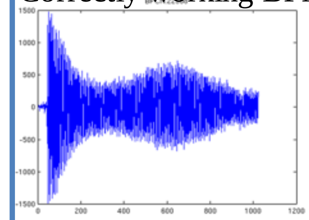
SPS

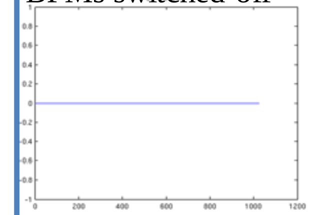
Long time was spent in setting up the MOPOS system…



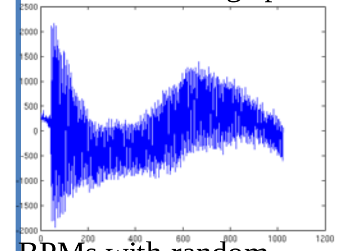
Correctly working BPMs



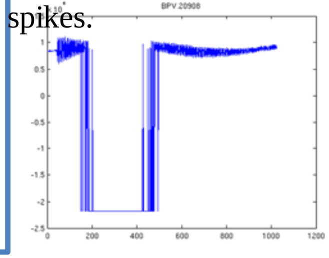
BPMs switched off



BPMs with strange patterns

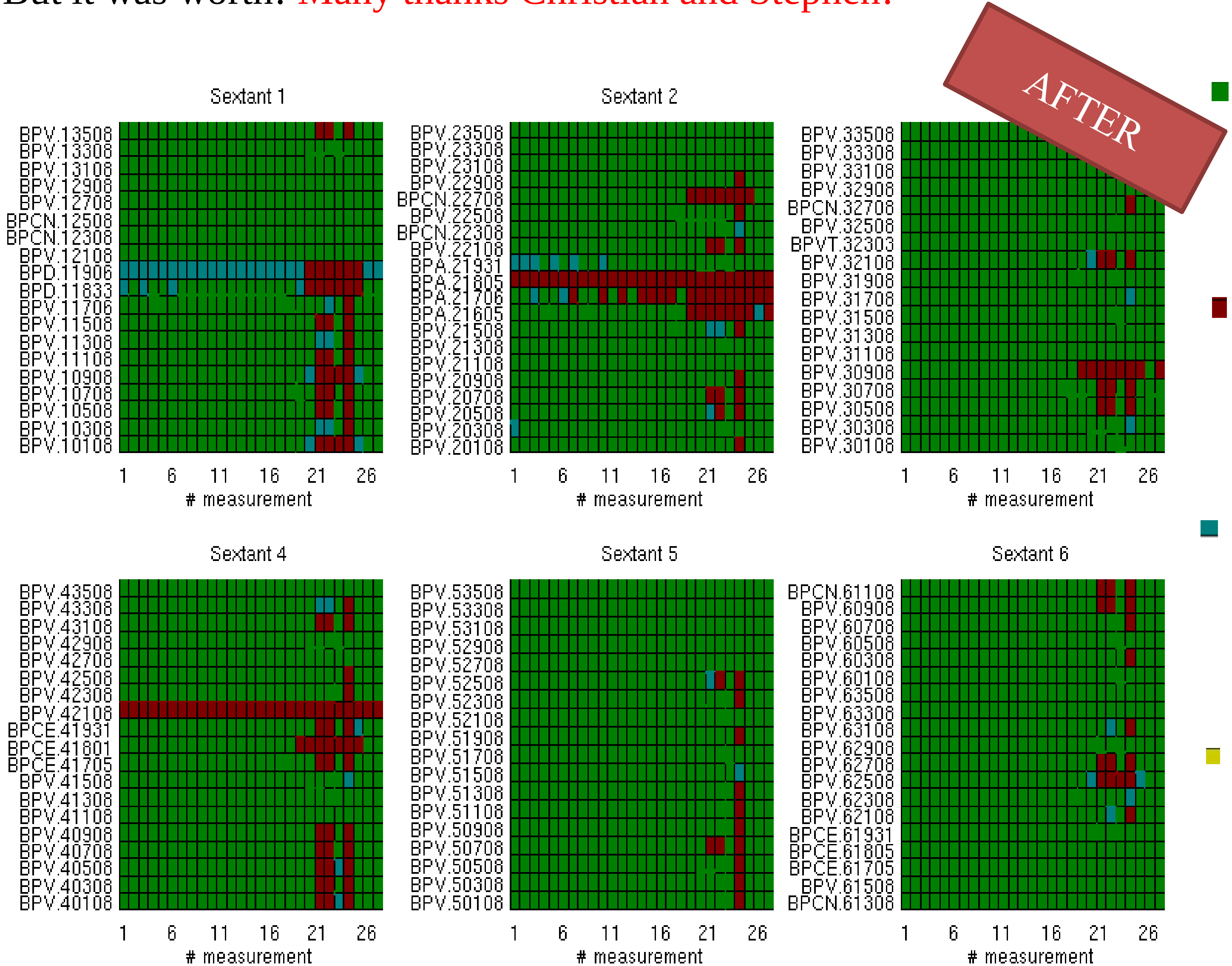


BPMs with random spikes.

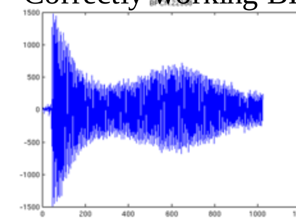


SPS

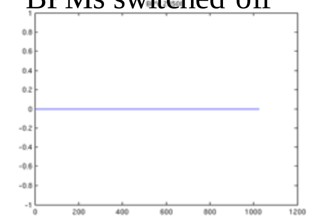
But it was worth! Many thanks Christian and Stephen!



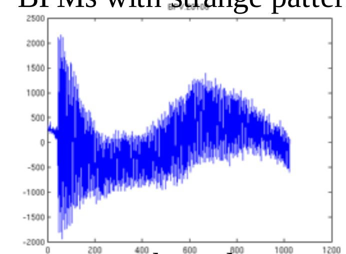
Correctly working BPMs



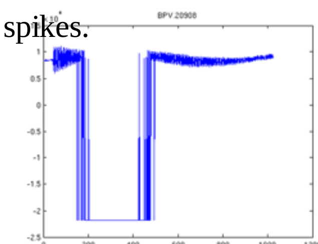
BPMs switched off



BPMs with strange patterns

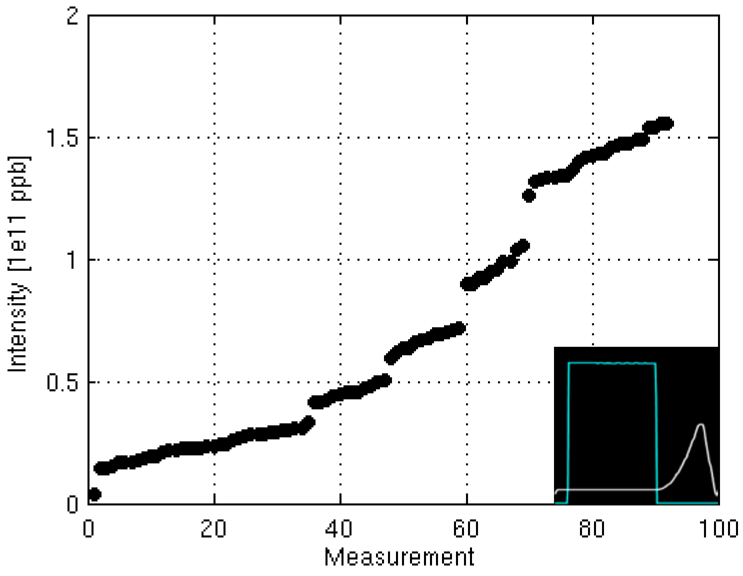


BPMs with random spikes.

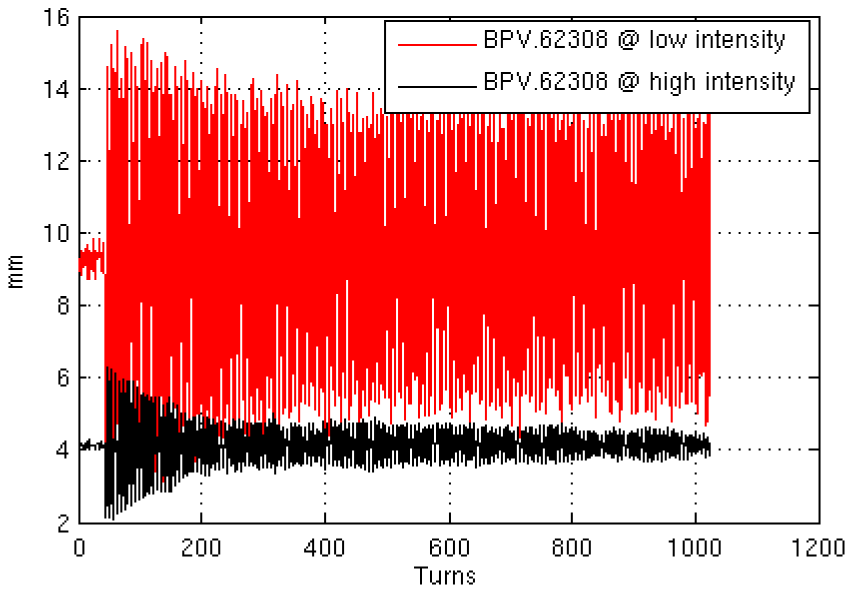


SPS

A scan in intensity is done from 4e10 to 1.6e11 for a LHCINDIV type of beam at flat bottom (26GeV).

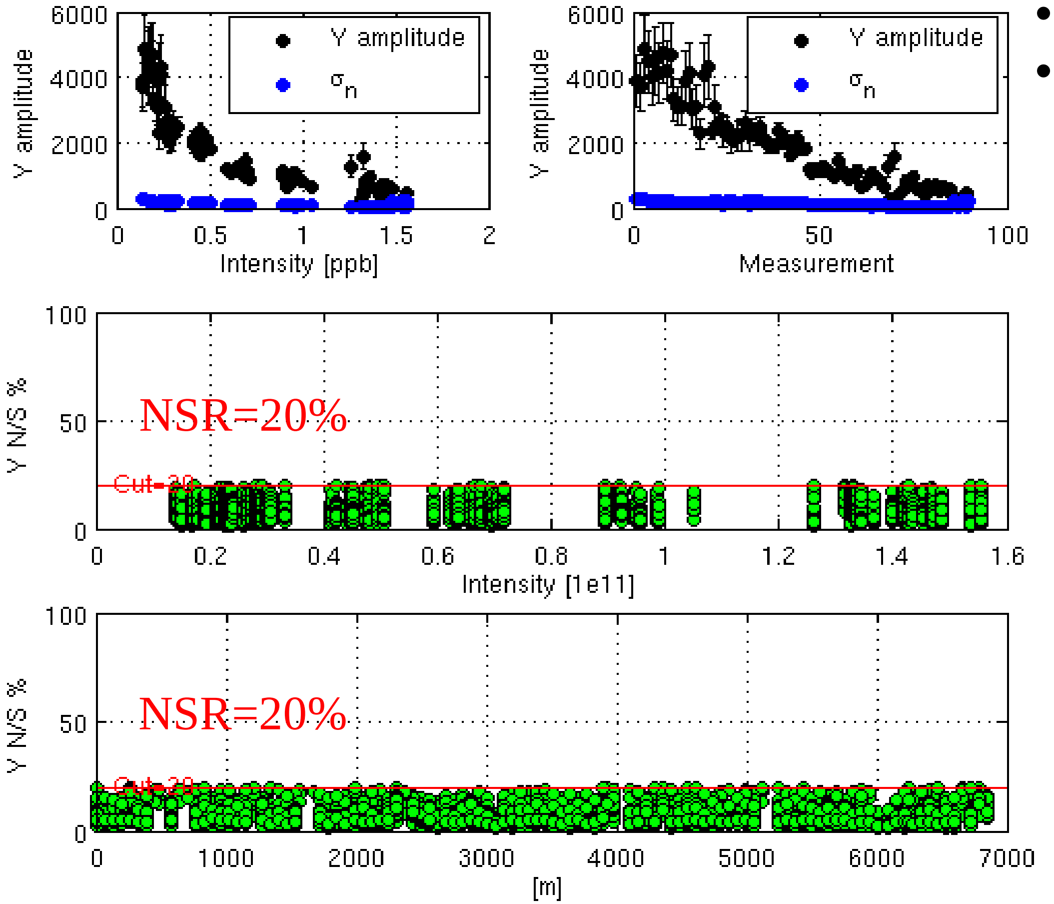


Min Y aperture: MBA, 17mm half height



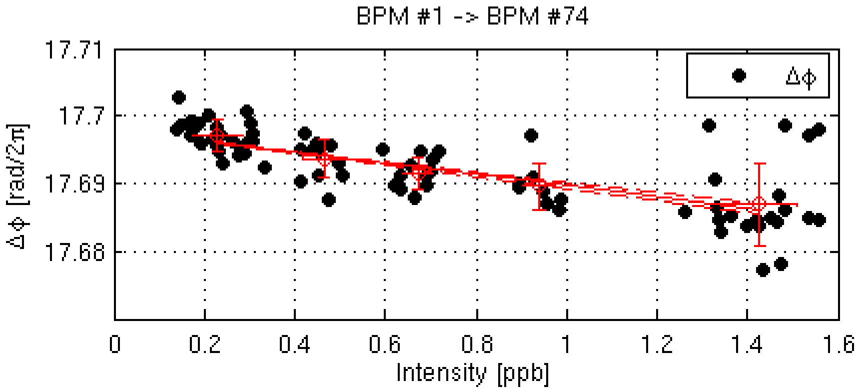
NB: Chromaticity is set almost to zero in Y plane. At high intensity measurement are taken with beam almost unstable in order to get the maximum number of turns.

SPS

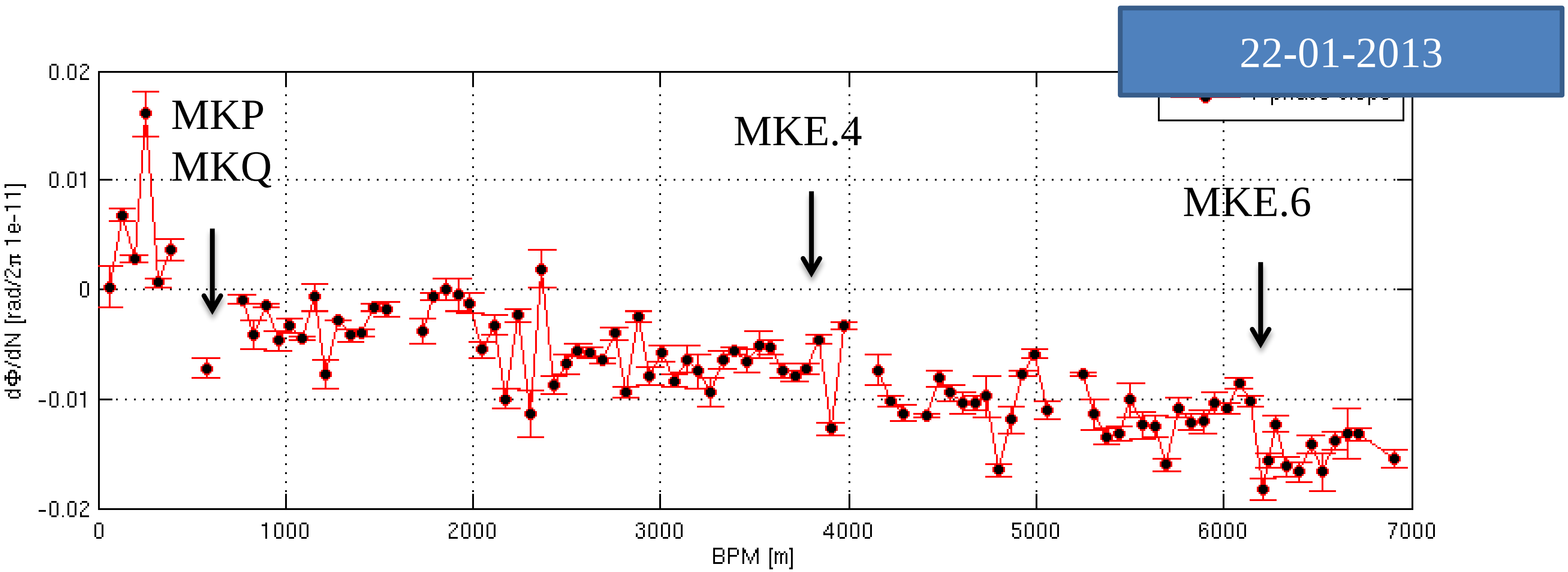


- ~1000 turns are analyzed.
- Phases are collected only for signals with NSR<20%.

SPS

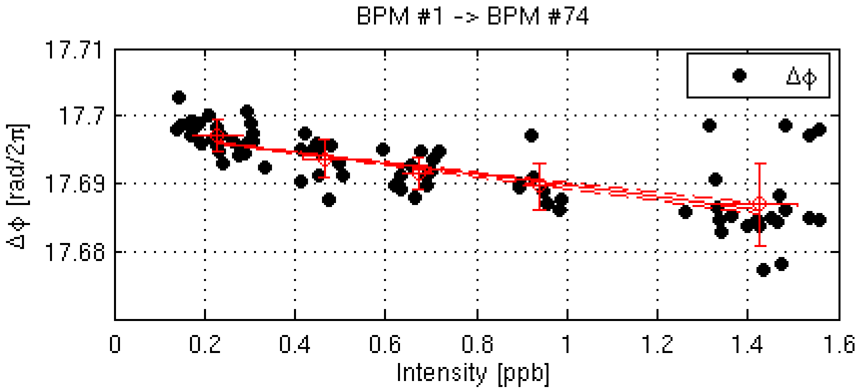


- Example of phase advance slope from BPM #1 to BPM #74.

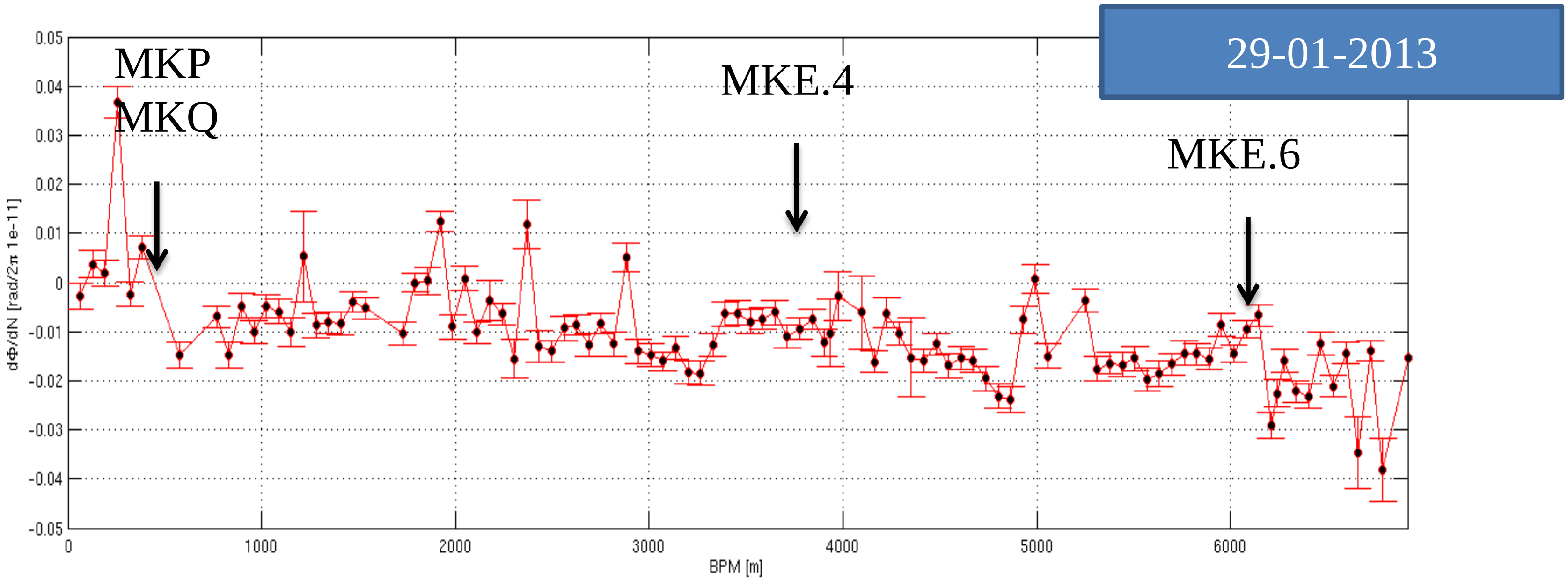


- Finally we get a slope. It exhibits the typical decreasing behavior.
- More refined analysis is ongoing to recover the empty sections (NSR>20…)
- Some hint on impedance position can already be seen.

SPS



- Example of phase advance slope from BPM #1 to BPM #74.



- Finally we get a slope. It exhibits the typical decreasing behavior.
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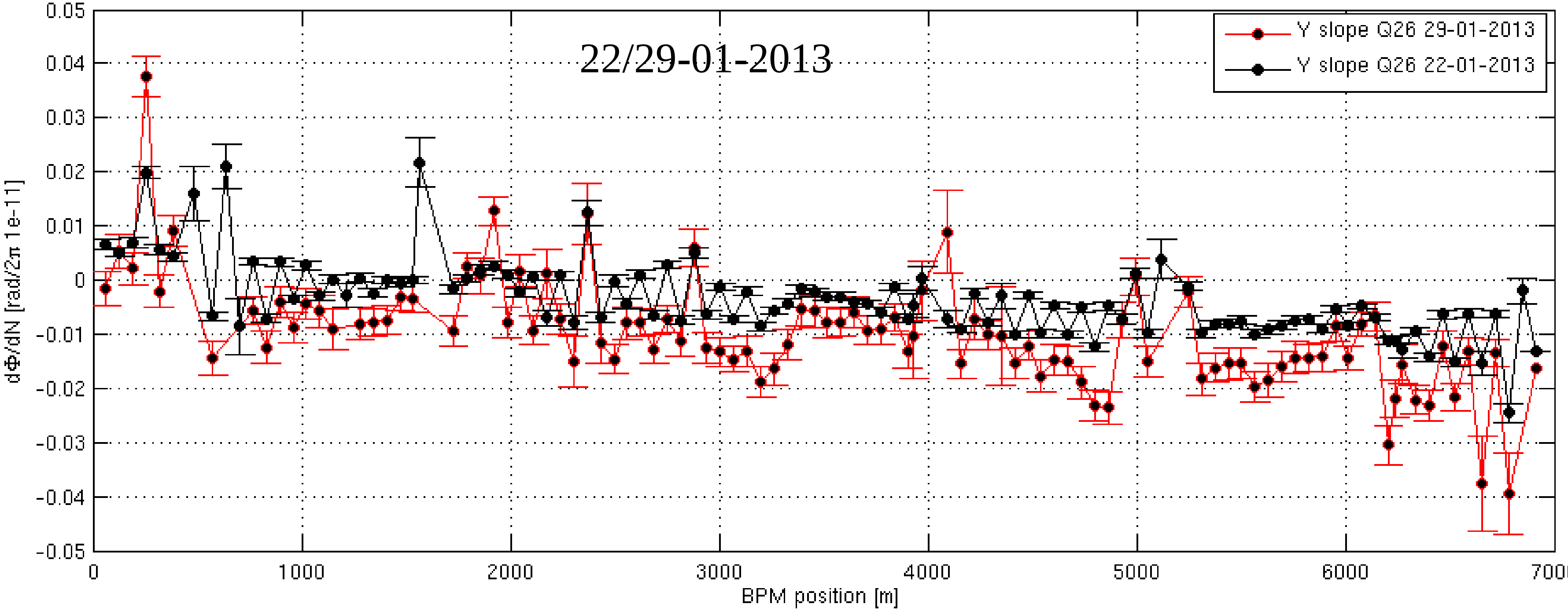
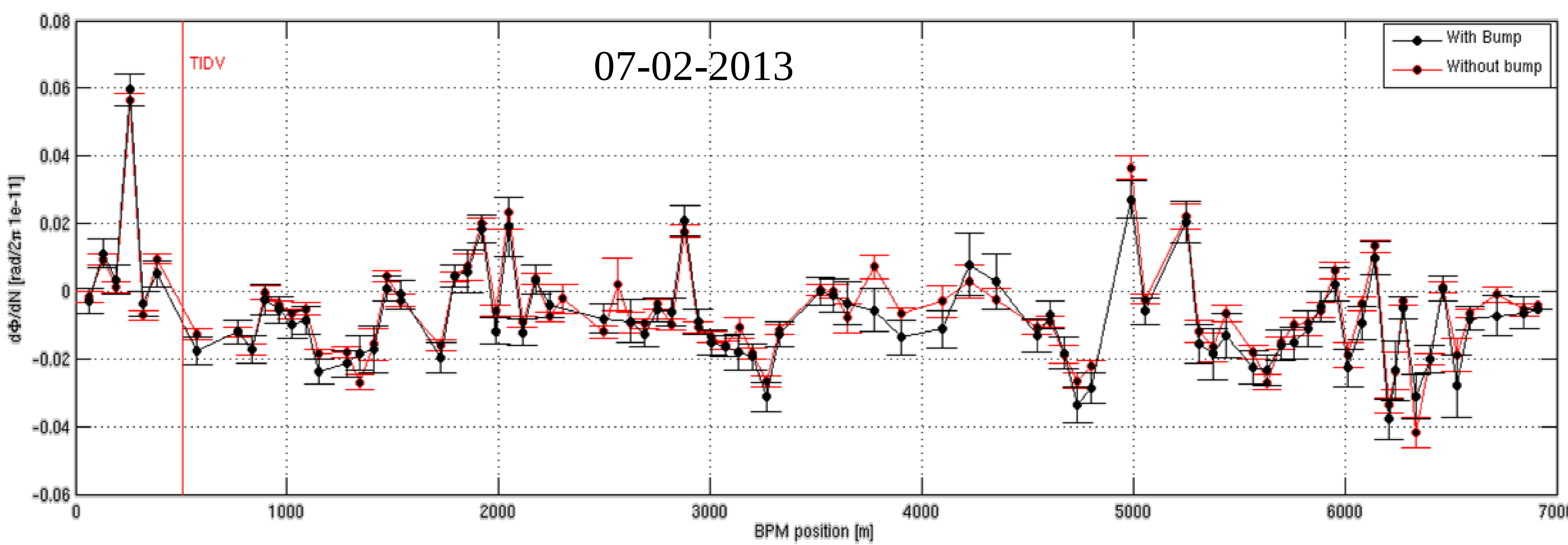
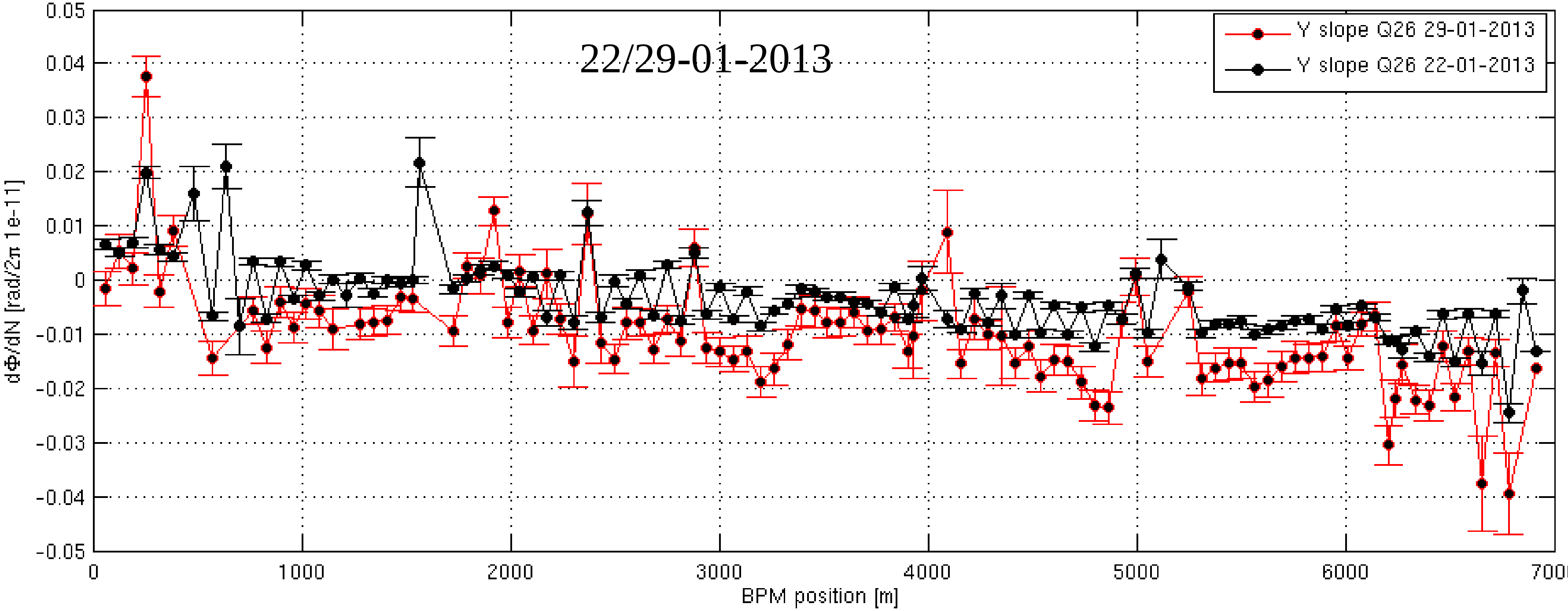


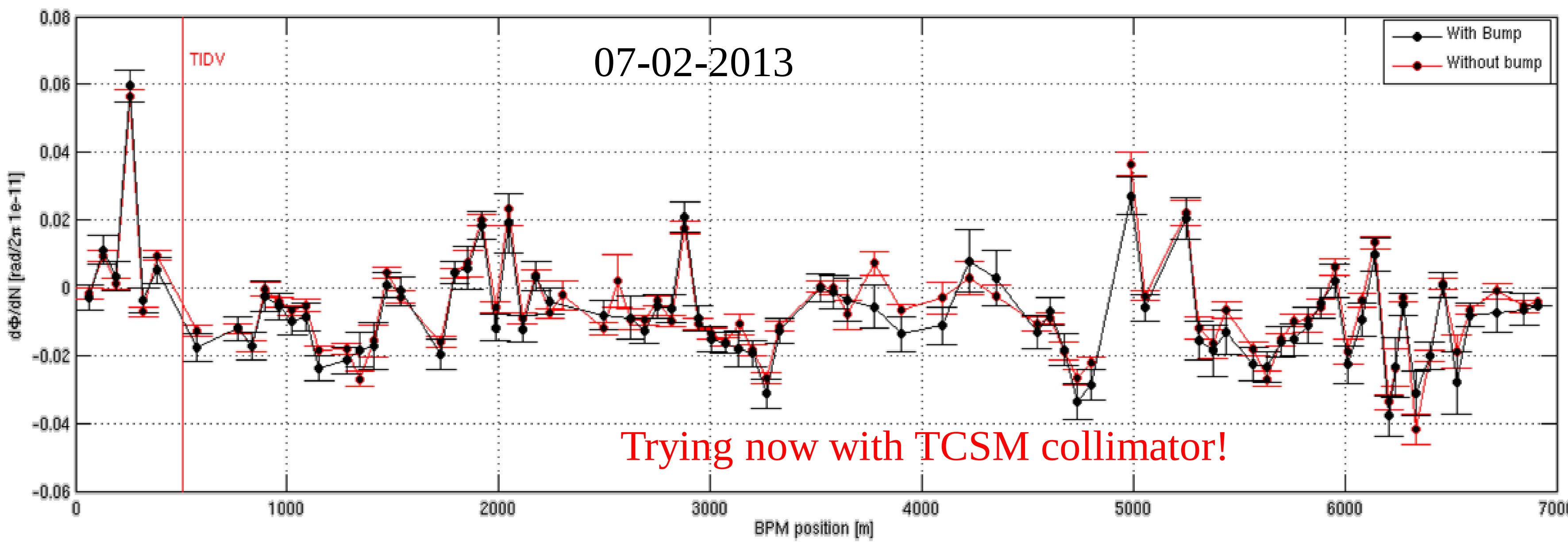
22/29-01-2013
Y slope Q26 29-01-2013
Y slope Q26 22-01-2013
dΦ/dN [rad/2π 1e-11]
BPM position [m]



07-02-2013
TIDV
With Bump
Without bump
dΦ/dN [rad/2π 1e-11]
BPM position [m]



22/29-01-2013
Y slope Q26 29-01-2013
Y slope Q26 22-01-2013
dΦ/dN [rad/2π 1e-11]
BPM position [m]

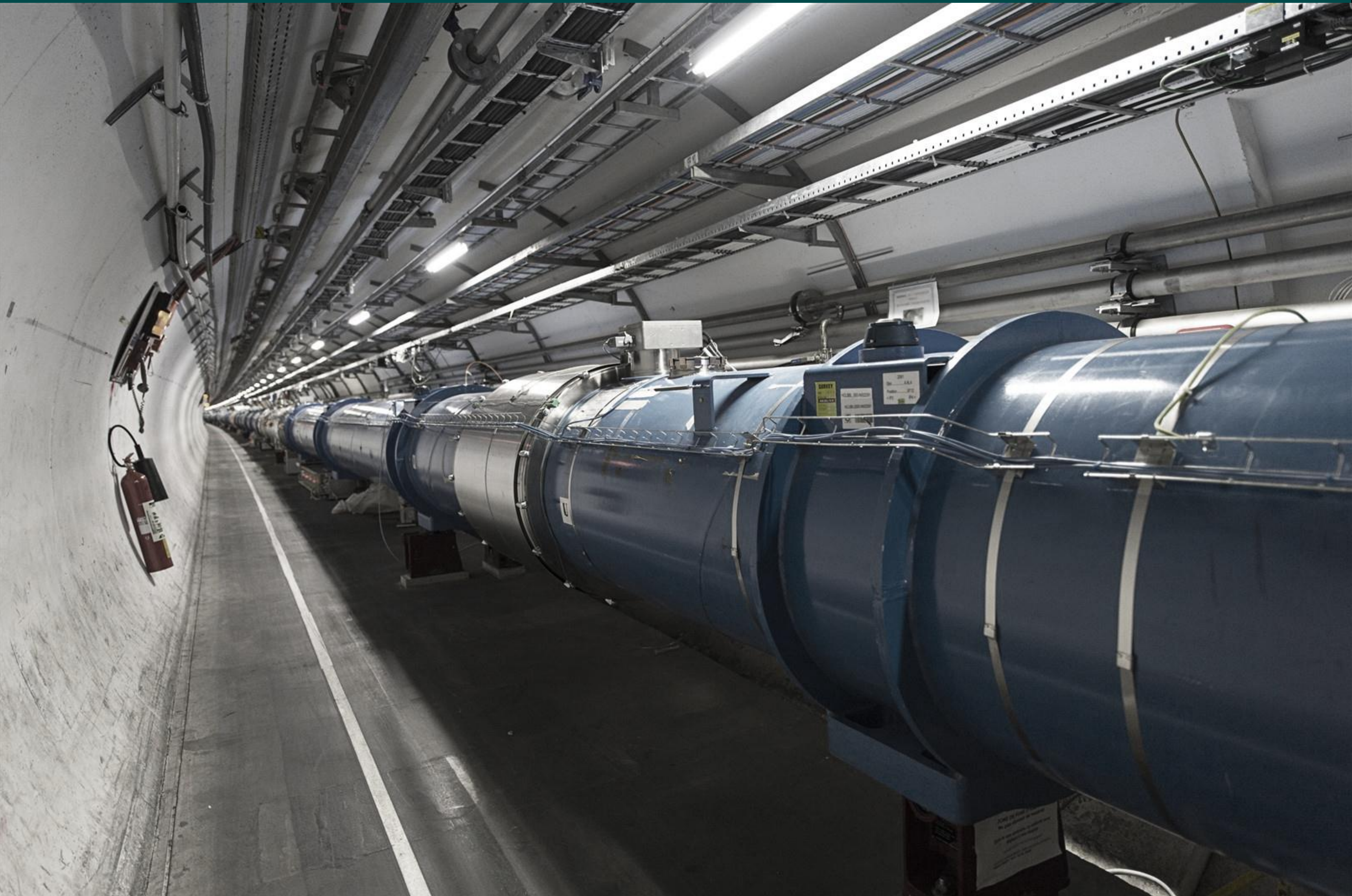


07-02-2013
TIDV
With Bump
Without bump
dΦ/dN [rad/2π 1e-11]
BPM position [m]
Trying now with TCSM collimator!

- Transverse impedance localization method.
- Observable: phase advance
  - Accuracy of phase advance detection for noisy signals.
  - Accuracy of slopes for measurements with error bars.
  - Impedance induced phase advance beating
- Application to the PS
  - Measurement of local quadrupolar orbit errors.
  - Measurements with single bunch, injection, V-plane.
- Application to the SPS
  - BPM system.
  - Measurement with single bunch, injection, V-plane.
- **Application to the LHC**
  - **Status of analysis.**

- Conclusion and overview.

LHC



MD Summary

MD purpose:

Measure phase advance variation with intensity -> Gives hint of impedance locations.

MD requirements:

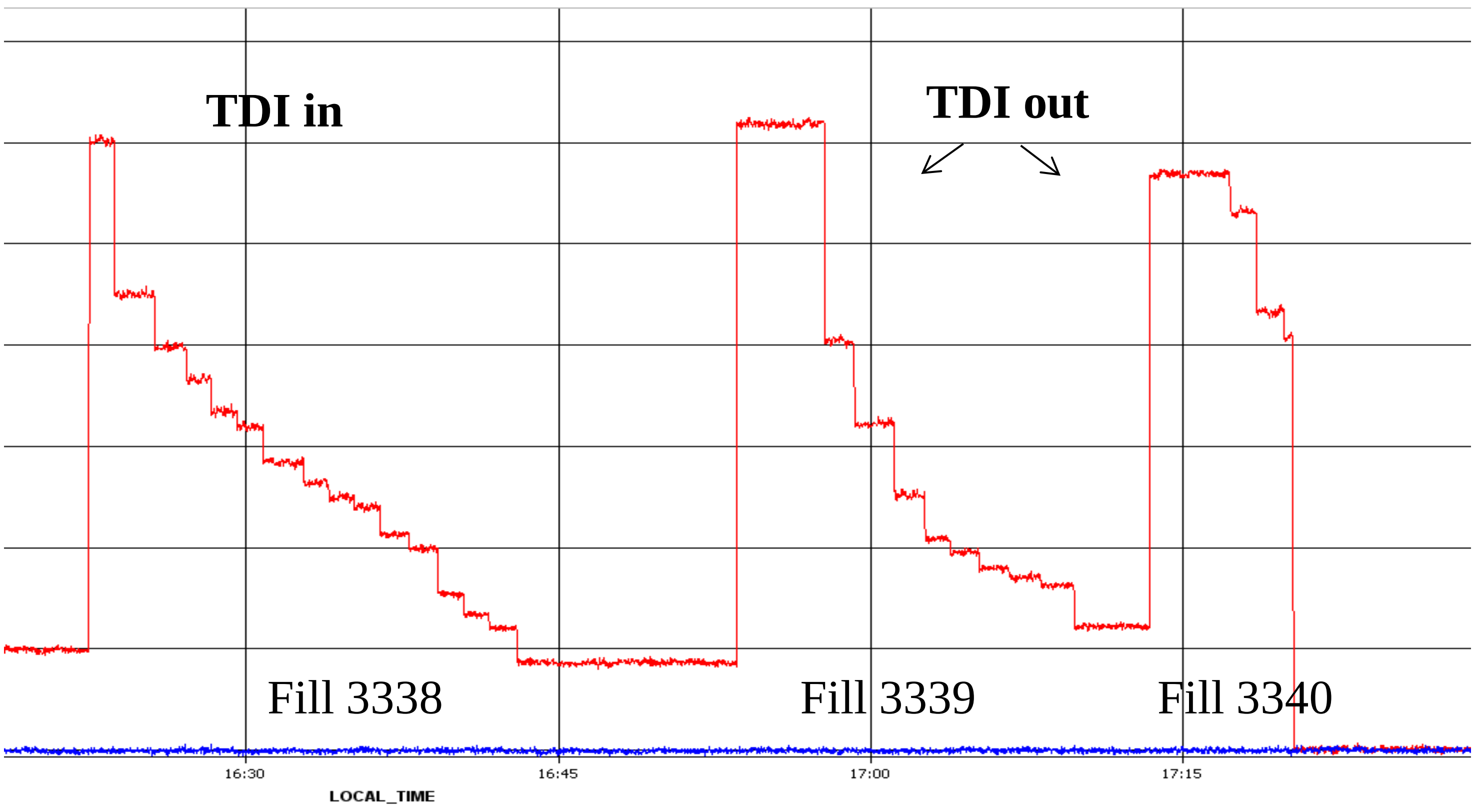
- 2h MD time.
- Single bunch on B1, B2, excited with AC dipole.
- Measurements with TDI position parked IN and OUT.
- Acquisition with both BPM system and ADT.

What we had:

- 1h45 MD time;
- Only B1 due to interlock problem on B2 dump system.
- Trouble in synchronization made ADT measurements difficult.
- 3 intensity scan for B1 (Fills 3338/3339/3340)
- Efficiently working BPM system (almost all BPMs working with N/S ~ 15%)

MD Summary

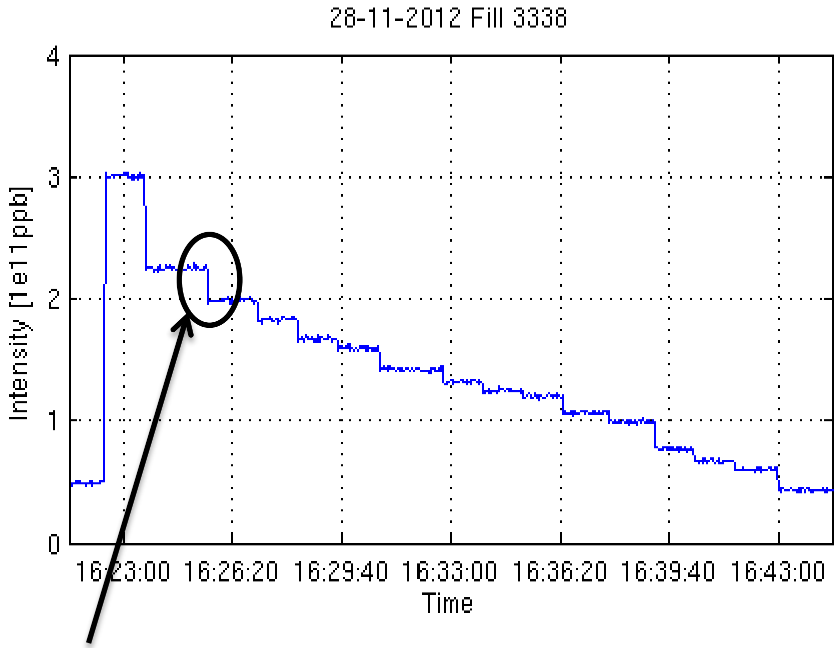
MD overview:



Fill 3338

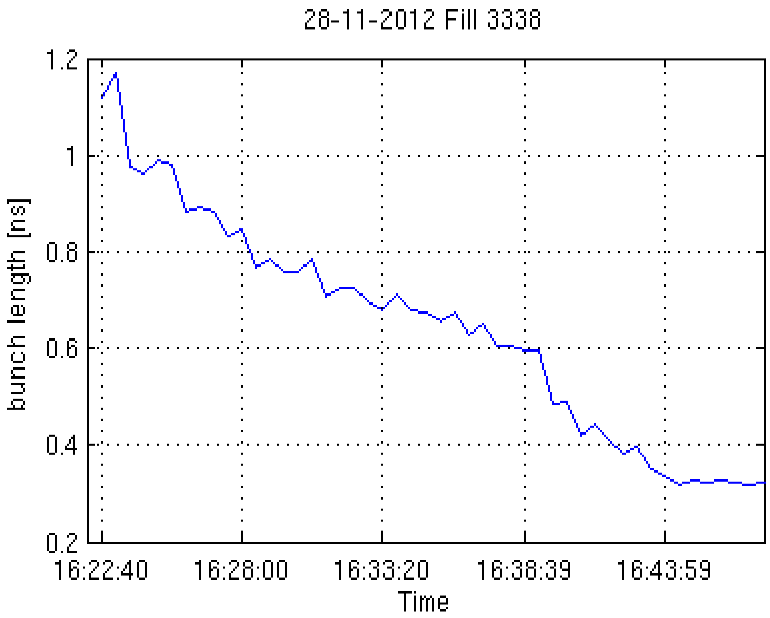
Fill 3338 as an example:

Intensity



Steps obtained by kicking the beam with AC dipole.

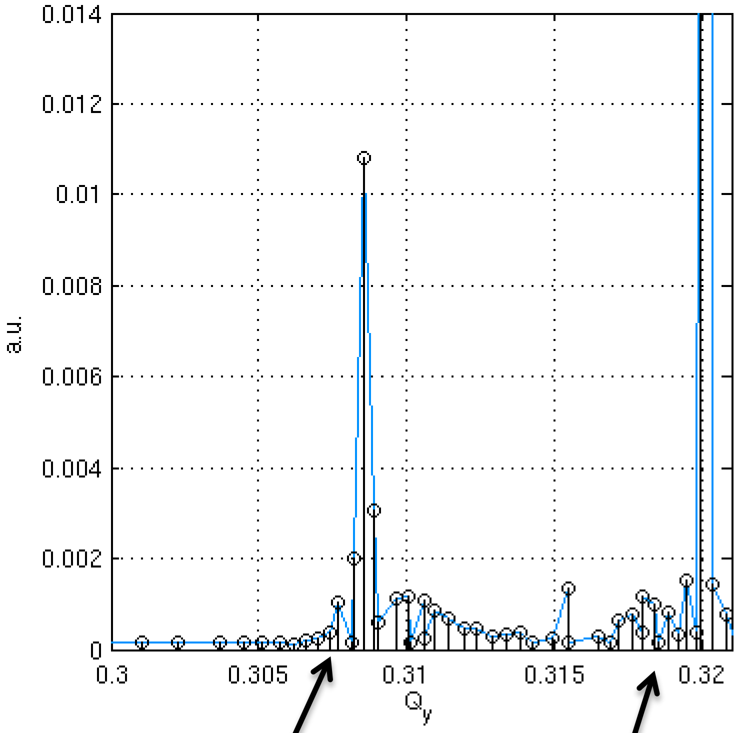
Bunch length



Bunch length decreases after the scraping.

Status of Analysis

The tune frequency is needed to correct the optics from the TBT data measured at the AC dipole frequency.

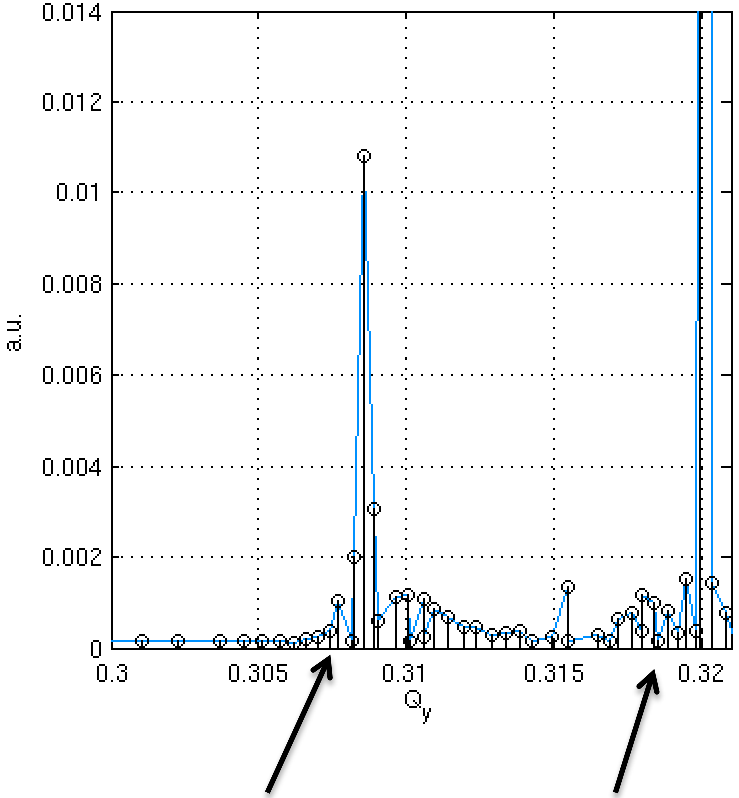


Free oscillation tune (~0.308)

AC dipole tune (0.32)

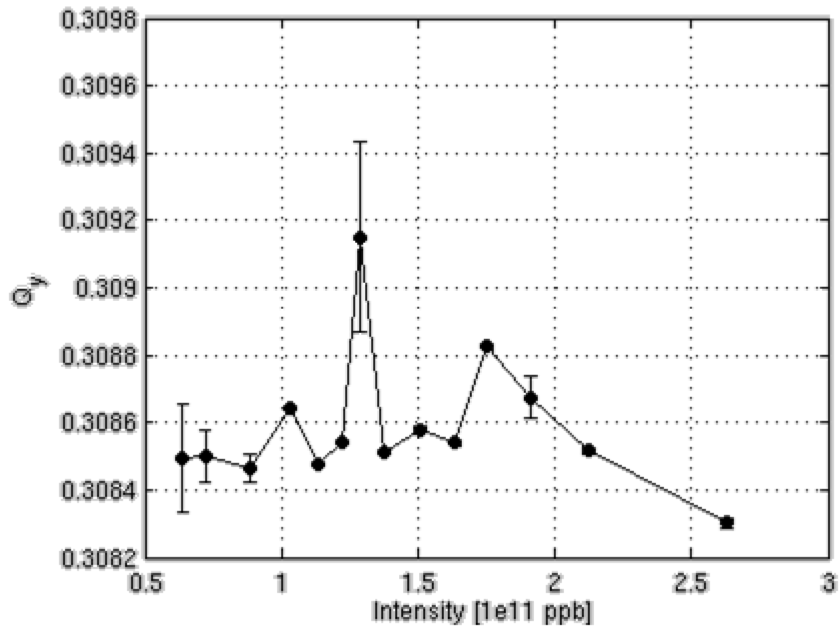
Status of Analysis

The tune frequency is needed to correct the optics from the TBT data measured at the AC dipole frequency.



Free oscillation tune (~0.308)

AC dipole tune (0.32)



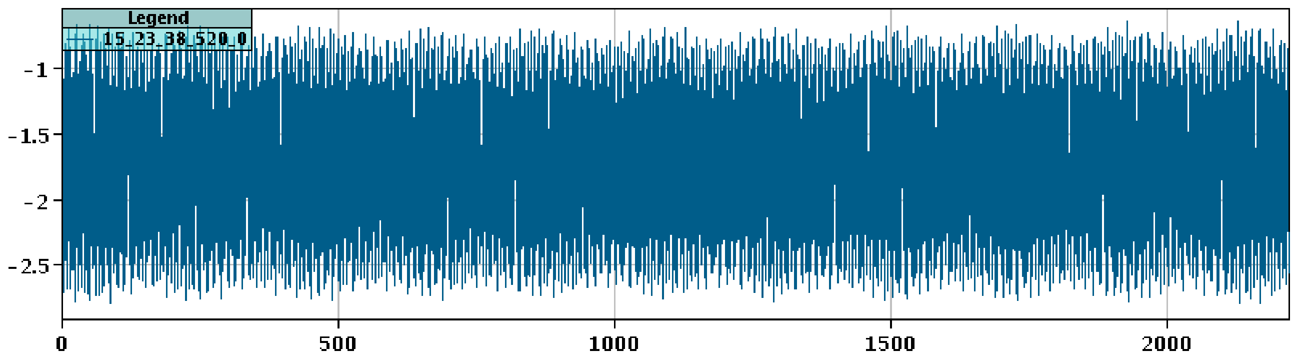
The vertical tune shift with intensity looks puzzling…

More checks are to be done.

Status of Analysis

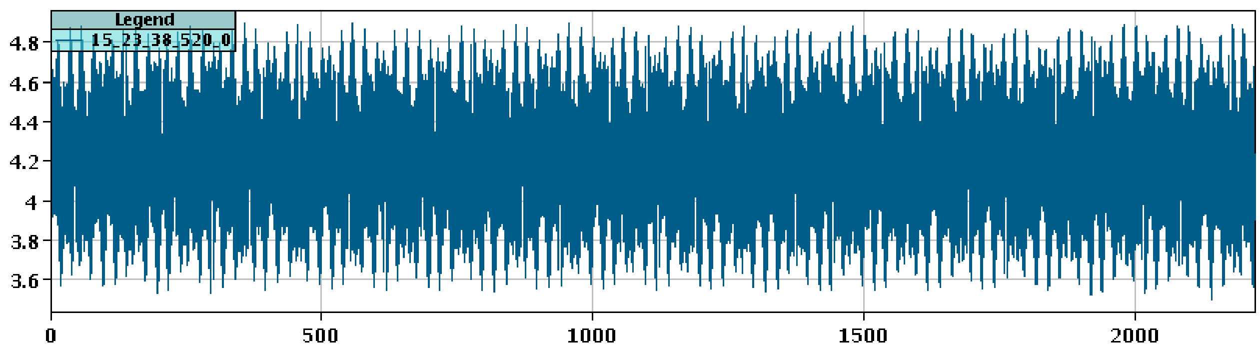
Optics measurements from turn by turn data with the AC dipole:

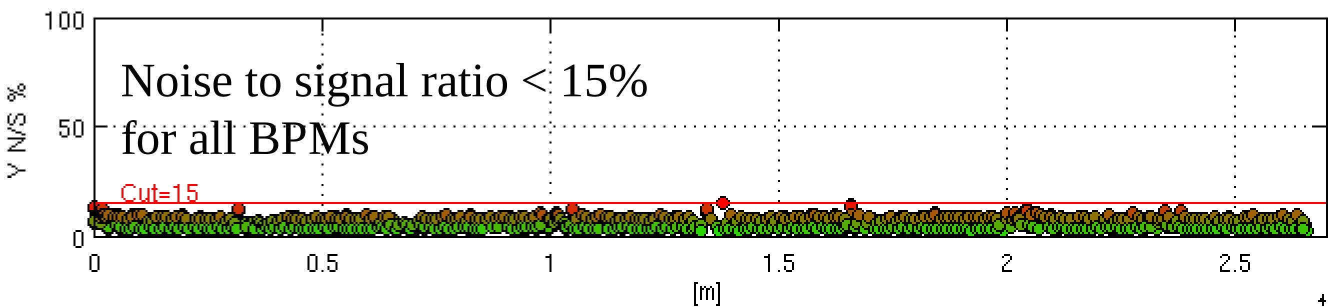
X



2220 turns

Y

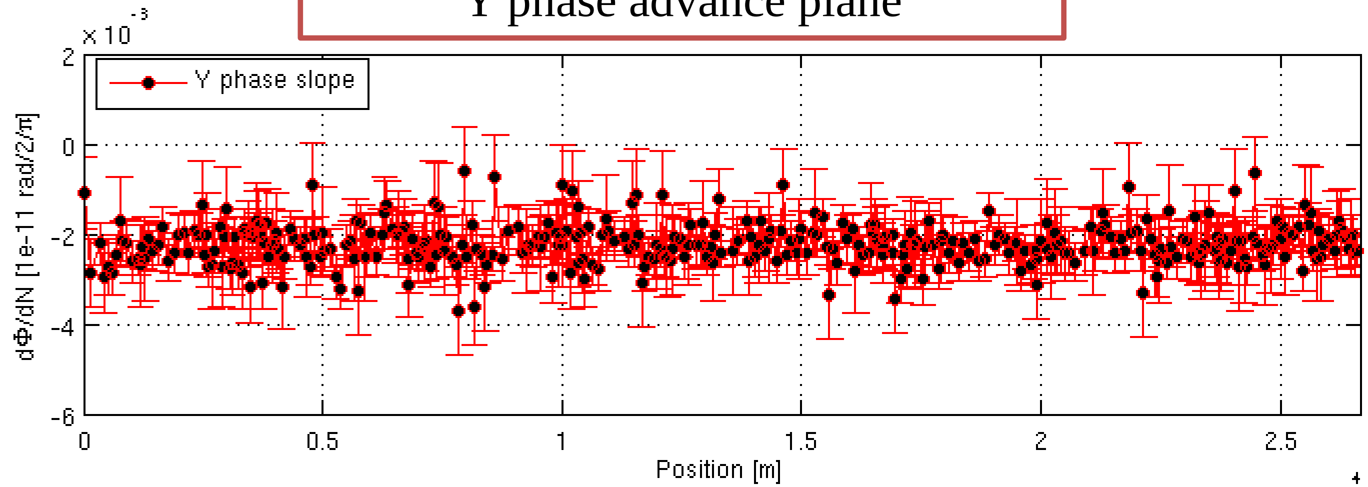


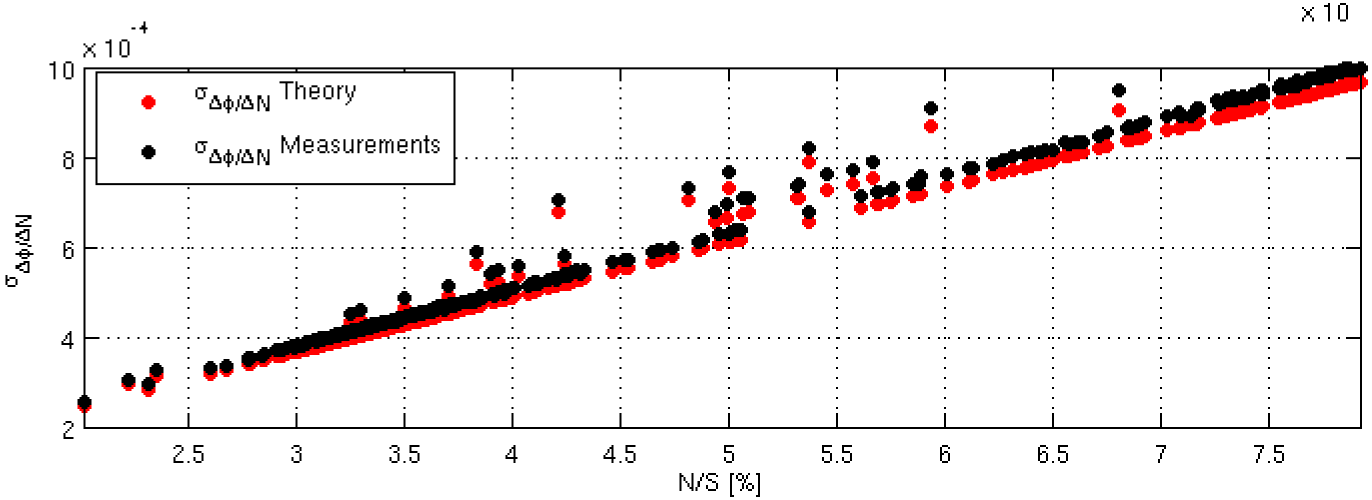


Noise to signal ratio < 15%
for all BPMs

Status of Analysis

Y phase advance plane





Good agreement between accuracy expectation and measurements, but we need to quantify the impedance beating to really judge the feasibility of this measurement in LHC.

Conclusion and overview

Resuming:

- A better understanding of the major constraints in the impedance localization measurement has been achieved.
- Measurements for PS are well between error bars but reconstruction is not straightforward.
- SPS measurements are still on going, especially for Q20 (see backup). Trials with moving collimators are on going.
- Measurements for LHC have still to be analysed in detail, especially to understand the puzzling tune behaviour.

Simulation plan:

- Better understanding/implementation of the reconstructing algorithm.
- Trying to reconstruct with more constraints (e.g.: putting already the impedance we know in the model)
- HEADTAIL studies to quantify <u>uncertainty in position</u> with respect to the measured data quality.
- HEADTAIL studies of <u>phase beating amplitude</u> and compare with accuracy got in measurements: *it's the link to conclude a priori on feasibility!*
- HEADTAIL studies of chromaticity variation impact on measured phase.
- Any other suggestion you could have!

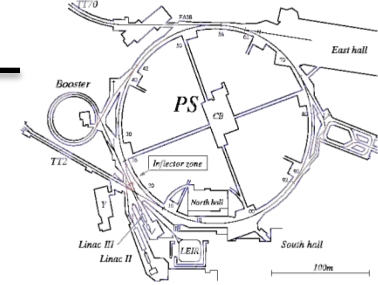
Measurements plan:

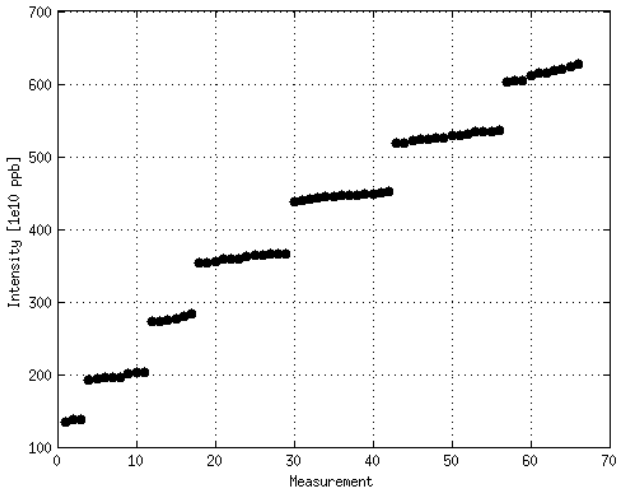
- Thanks to Simon White and Wolfram Fischer …. Measurements in RHIC on 14-27/04/2013!!

Thanks!

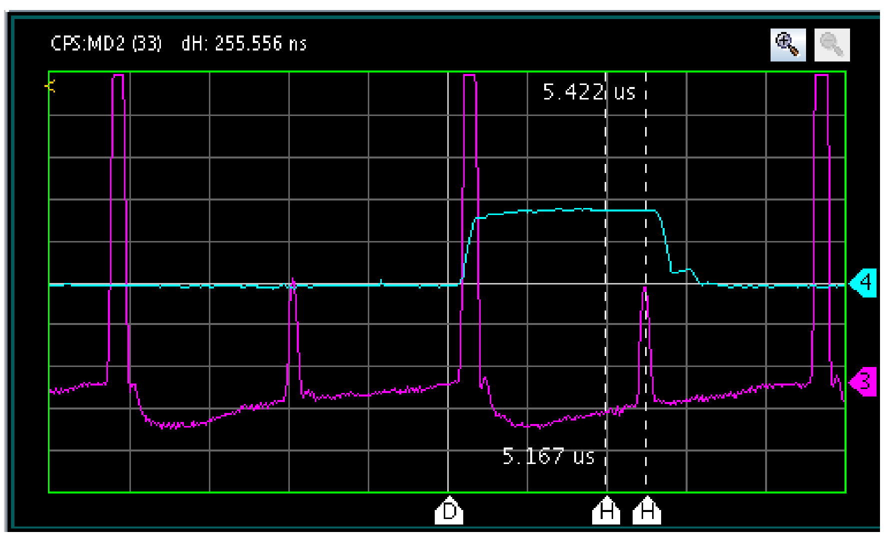
BACKUP

Measurement with two bunches V plane



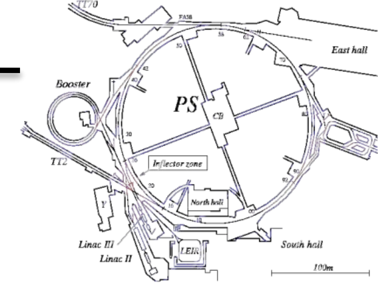


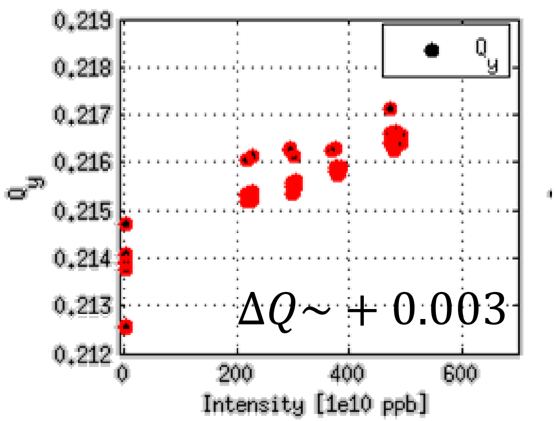
Using two bunches whose the leading one is bringing all the charge, and the trailing one is used as probe, we could measure the effects seen by the probe.



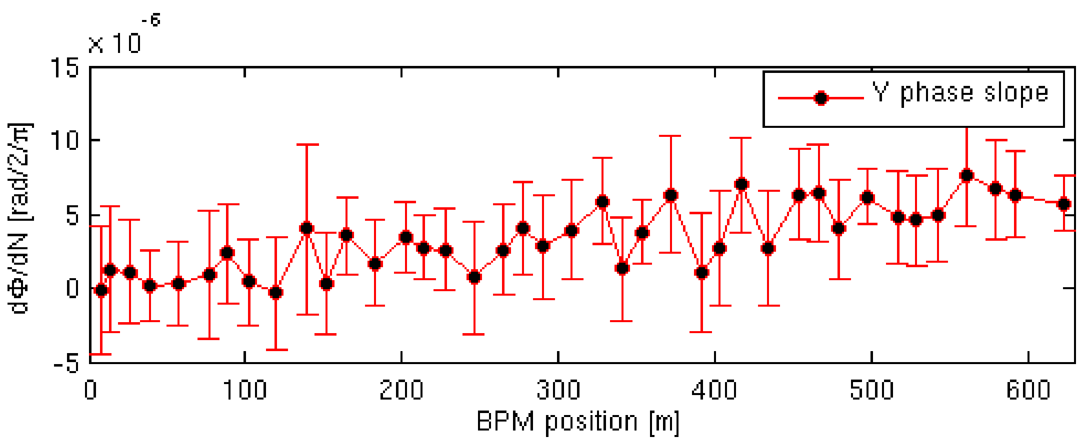
- Bunches are separated of half the machine (1us).
- Kicker is acting horizontally only on the trailing.
- By coupling we measure the trailing in vertical plane.
- Scan in intensity from 1e12 to 6e12.

Measurement with two bunches V plane





- Tune shift is due to coupled bunch effects.
- Is going up as corresponds to the horizontal tune.
- Is considerably reduced respect to the single bunch case.
- Imposed NSR~10% led to $\sigma_{\Delta\varphi} \sim 0.002$ as expected.



Unfortunately, being the tune shift lower, the error bars become considerably big…

Q20 13/02//2013