Experimental Setup and Lattice Data Analysis for TbT Measurements at Alba

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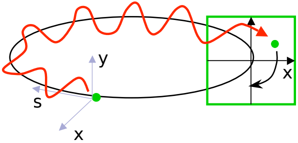
Experimental Setup and Lattice Data Analysis for TbT Measurements at Alba

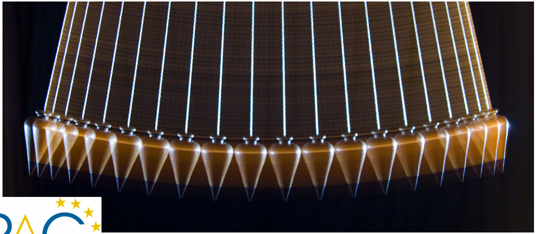
- Transverse beam dynamics
- TbT measurements
- Lattice error reconstruction:
  - Quadrupole
  - Skew Quadrupole
  - Sextupole
  - Transverse Impedance
- Conclusions

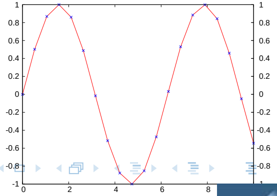
Transverse Motion in a Linear Lattice



- **Quadrupoles** excert a **linear force** on electrons. (Sextupole doesn't!)
- Traveling through quadrupoles electrons exhibit **betatron motion**.
- 120 beam position monitors measure turn after turn beam position.

Like a pendulum viewed through a stroboscope





Non linear transverse beam dynamics at small amplitude

Unluckily non-linearity can not be avoided...
...field errors, higher order magnets

- Hamiltonian is not integrable.
- We can break the Hamiltonian into integrable terms
- Build an integrator accurate to some order...

normal form analysis provide direct access to the **building block** of the **spectrum**: **Resonant Driving Terms**

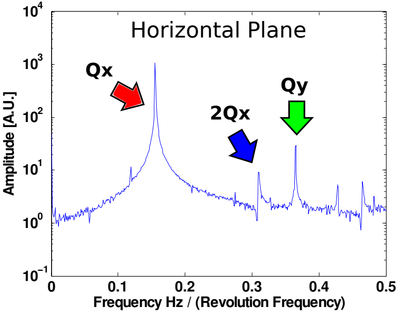
$$f_{jklm}(s) = \frac{\sum_{w,n} K_n \beta_{x,n}^{(l+m)/2} \beta_{y,n}^{(l+m)/2} e^{i((j-k)\Delta(s)_{w,x}+(l-m)\Delta(s)_{w,y})}}{1 - e^{2\pi i((j-k)Q_x+(l-m)Q_y)}}$$

The spectrum is composed by discrete lines, each line can be expressed as a *mixture* of driving terms

Non linear transverse beam dynamics at small amplitude

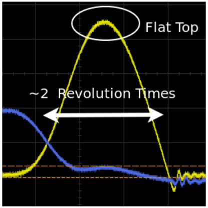
Every magnet play a different role in the spectrum

For example on the horizontal plane...



- Q_x Depends on the quadrupoles
- Q_y Depends on Skew quadrupoles
- $2Q_x$ Depends on sextupoles
- **Every spectral line tell us something about a different part of the optics**

Experimental Setup: A few issues for starter



- Kick coherently:

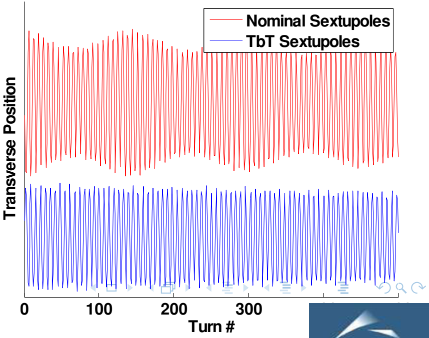
Kick pulse must be fast: less than 1 turn.
Kick pulse must be flat: all particles get kicked with the same amplitude

- Preserve the coherent motion:

Chromaticity & Tune shift with amplitude reduce strongly the observable number of turns

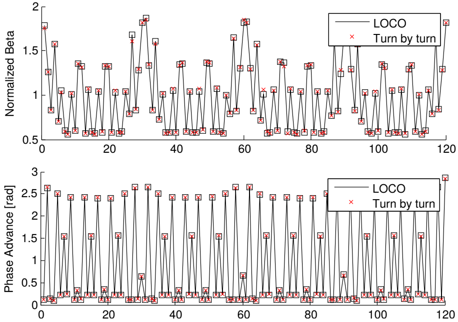
⇓

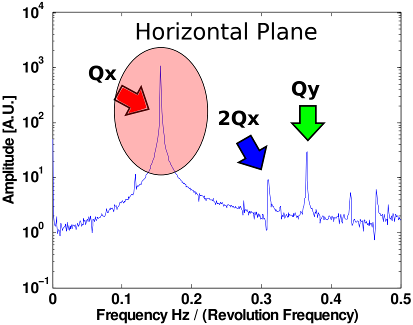
Special sextupole settings with low Chromaticity and small Tune shift with amplitude



Linear Lattice: Phase & Amplitude of the Betatron Motion

1. Kick the beam
2. Each BPM record beam position during 1000 revolutions
3. Calculate the transverse motion-spectra
4. Looking at the tune line (Q_x):





- Phase: **We expect the precision to be limited by mechanical errors and noise**
- Amplitude: **Precision is limited by BPM calibration**

Let's start with an easy one... Can we observe a known quadrupolar error $\vec{Q}_0$?

In simulation:

1. Calculate the β and phase to quadrupole response matrix:

$$M \times \vec{Q} = \vec{\Delta}$$

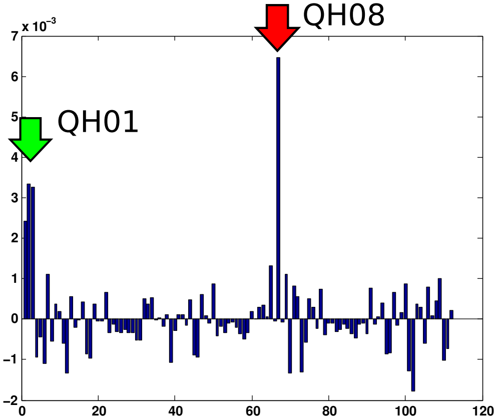
2. Calculate M^{-1} with an SVD

On the machine:

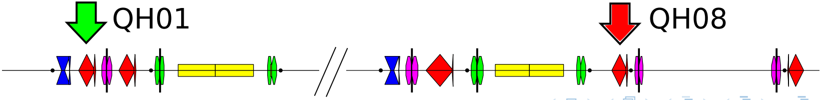
1. Measure $\bar{\beta}$ and phase
2. Change the strength of 2 Quadrupoles ($\vec{Q}_0$)
3. Measure again...
4. Build an error vector: $\vec{\Delta}$

$$\vec{Q}_0 = M^{-1} \times \vec{\Delta}$$

Quadrupole errors reconstruction

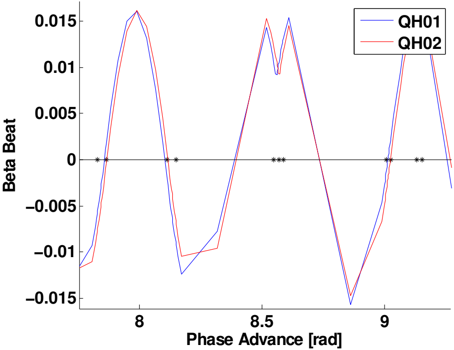


- 1% Error on QH01 & QH08
- QH08 is isolated
- QH01 belongs to a triplet



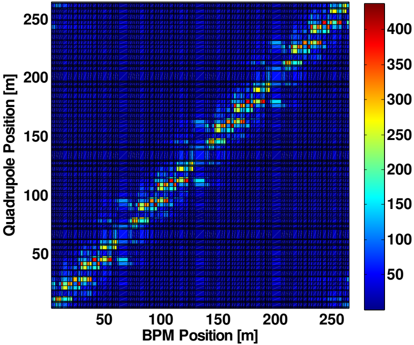
Error reconstruction is **LOCAL!**

β-beat produced by close error sources (QH01 QH02)



$\Rightarrow$ Close quadrupoles results in close β-beat patterns

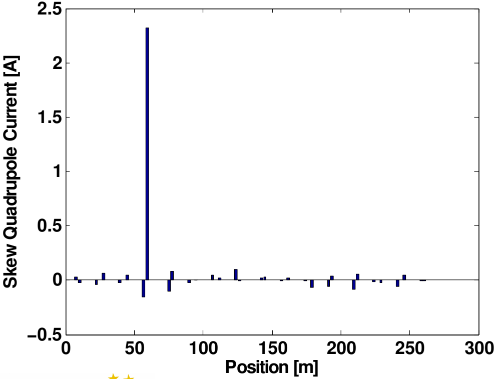
Looking at the inverse response matrix

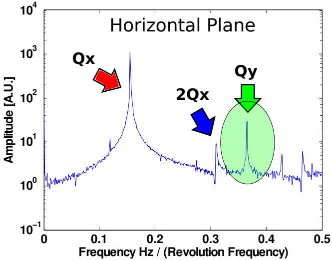


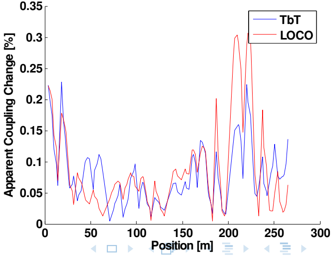
$\Rightarrow$ Only close BPMs are able to locate error sources

Coupling: Motion in one plain *leaks* into the other

- Looking at the coupling lines:
  - Q_y on the H-plane
  - Q_x on the V-plane
- Set 2 Amp error on 1 skew quadrupole

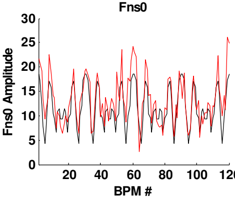


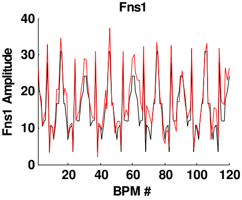




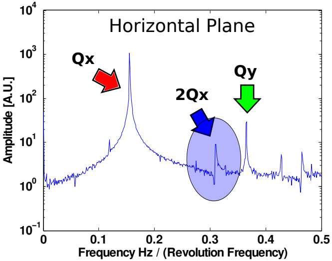
Sextupoles

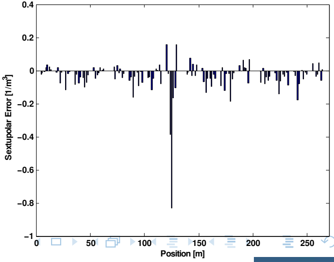
- Sextupoles are responsable for many spectral lines.
- Unlukily sextupoles are arranged in families
- A resistive shunt as been used to carry out the measurement





Fns3

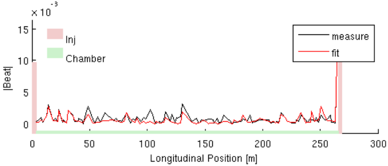


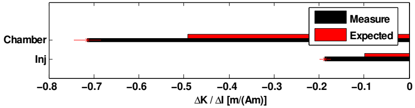


Collective Effects: Transverse Impedance Characterization

- Electromagnetic interaction of the stored particles with the vacuum vessel results in a defocusing effect
- The *defocusing effect* depends on bunch-charge

- Optics measurement has been repeated for different bunch charge
- Different impedance sources has been fitted to reproduce the measurements





Conclusions

After two years of hard work the experimental setup was finalized...

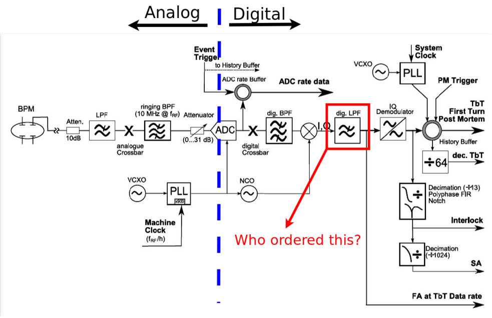
- Linear:
  Results match quite well LOCO predictions.
- Coupling:
  The overall accuracy is good, but the method do not permits to measure the coupling contribution coming from dispersion.
- Sextupoles:
  The overall accuracy is good, but the technical limits on the machine prevent to attempt a correction.
- Impedance:
  Very promising results, a new attempt with a refined method will follow in the next days.

Thank you

Michele Carlá

Anatomy of a Libera BPM

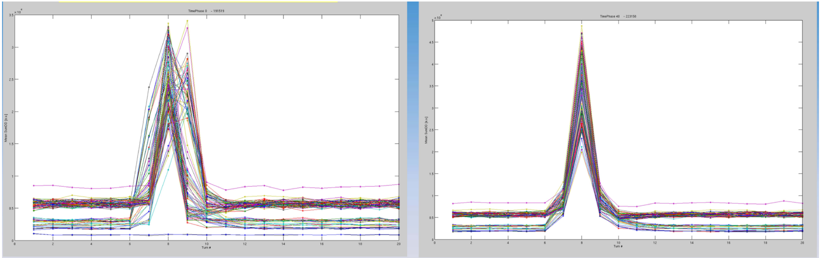
(What's wrong with my BPMs ?)



- Aggressive design taking profit of fast ADC!
- **A narrow low pass-filter is used to smooth the signal before demodulation**
- In the time domain the effect is **mixing signal from different turns!!!**
- The easy and dirty way: measure the response of the filter and deconvolute the signal
- The elegant solution: re-implement from scratch the digital domain filtering (MAF)

Smearing Work Around

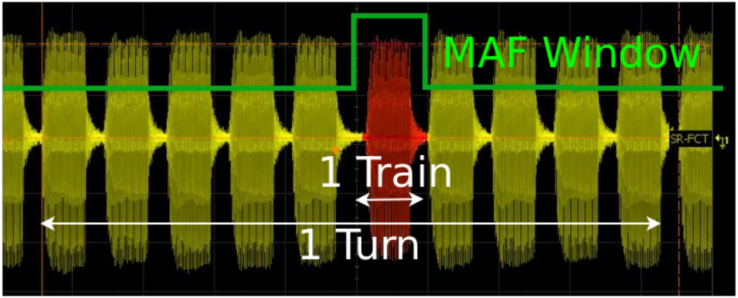
- One train is injected and dumped after one turn.



- BPM are synchronized with the beam.
- The single turn response of each BPM is measured.
- The output signal is deconvoluted with the measured single turn response.

Moving Average Filter (MAF): A smarter design

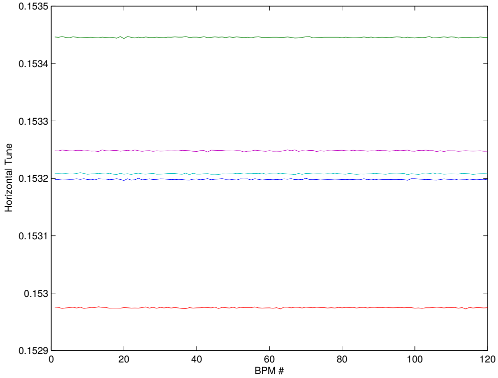
Replace the low pass filter with an integration window synchronized with the beam.



- Avoids turn mixing.
- Reduce the integrated noise: most of the revolution time contain no signal.
- Only available on Libera-Brilliance

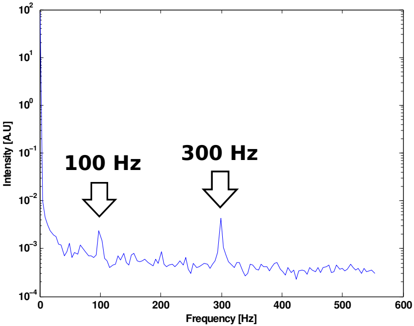
Tune Jitter...

- Every BPM sees the same tune! (Good)
- Every kick has a different tune! (Bad)
- **The Machine is Changing!**
- Who is the responsible ...?



$\sim$ 10 mA of noise in each quadrupole can produce the tune-jitter we are observing!

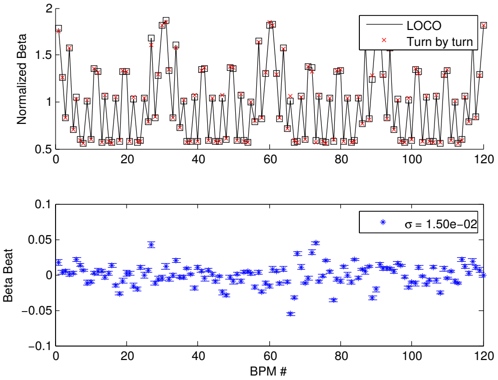
Tune Jitter Spectrum



- A kick do not last enough!
- Once in a while **instabilites** are our friends → *tuning the chromaticity close to 0 betatron motion get steadily excited*
- Enough to get a spectrum
- 100 & 300 Hz looks very suspicious...

∼ 10 mA of noise in each quadrupole can produce the tune-jitter we are observing!

Linear Lattice: *Relative* β-beat from Amplitude



- Kick strength is unknown. (with enough precision)
- We can still define a normalized $\bar{\beta}$:

$$\bar{\beta}_i = \frac{A_i^2}{\sum_{j=0}^{N} A_j^2} N$$

- **Precision is mainly limited by BPM gain**

Linear Lattice: phase-beat

- Phase advance between couples of BPM can be directly assessed
- The most reliable TbT observable!
- **We expect the precision to be limited by mechanical errors and noise.**