Full coupling studies at ALBA

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Let's talk about coupling, why?

ALBA is a third generation light source located in Barcelona. As many other light sources we are venturing into the complex exercise of designing a low emittance upgrade...

We are looking into a 30 times emittance reduction:

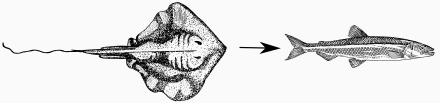
$$4.6\text{nm} \rightarrow 0.200\text{nm}$$

There are many difficulties operating a storage ring with such a small emittance, **lifetime remains indeed of great concern**

From flat to round beam

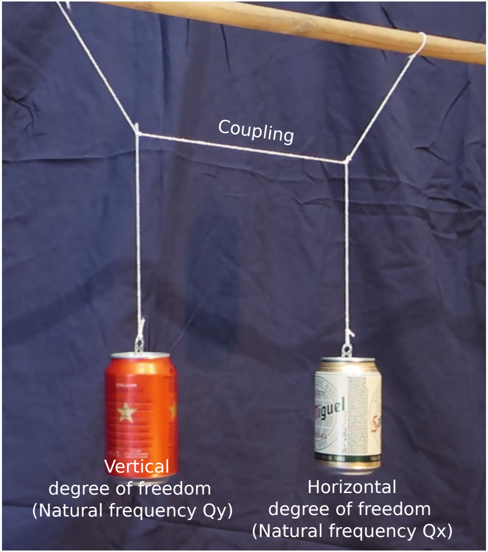
Electron beams in storage rings tend to be flat! Recoil due to synchrotron radiation produces some horizontal emittance (150pm), the vertical one is even smaller...

- Flat beams have small transverse cross sectional area
- In a small area electrons meet frequently...
- In **ALBAII** the beam losses due to **Touschek scattering** are massive! $\rightarrow$ **lifetime** $<$ **1h**

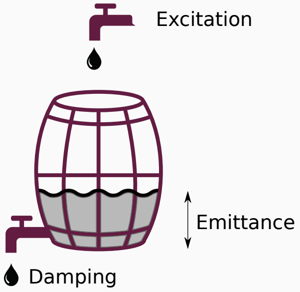


Can we turn our flat beam into a round one?

A first peek into coupling



Natural horizontal emittance

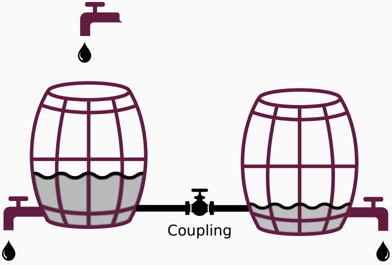


- Energy loss due to synchrotron radiation emission results in a horizontal betatron motion
- Synchrotron radiation emission is a stocastic process: each electron oscillate with different amplitude and phase
- Oscillation damping results from a combined effect of radiation emission and the RF field
- The horizontal natural emittance is defined by the equilibrium between damping and excitation!

Natural vertical emittance

- If there is no dispersion in the vertical plane (usually is the case)
- ...the energy loss due to radiation emission does not excite any betatron motion
- At equilibrium the vertical emittance is zero!

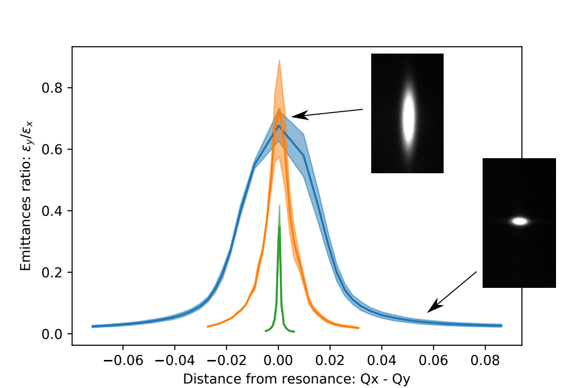
Emittances on the coupling resonance



- Coupling allows exchange of betatron actions between transverse planes
- Some of the horizontal emittance goes to the vertical plane
- Vertical emittance can never be equal to the horizontal...an infinite coupling would be rquired

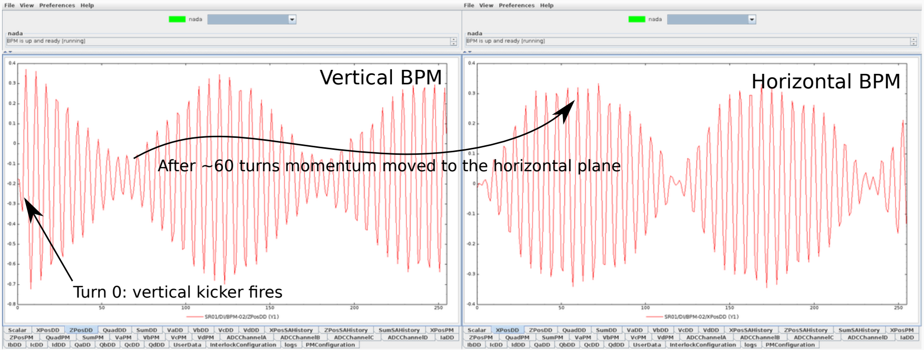
Measuring coupling with a pinhole

- **3 coupling settings:**
  strong → skew on to increase the coupling
  nominal → skew off, natural coupling
  weak → skew on to correct the coupling



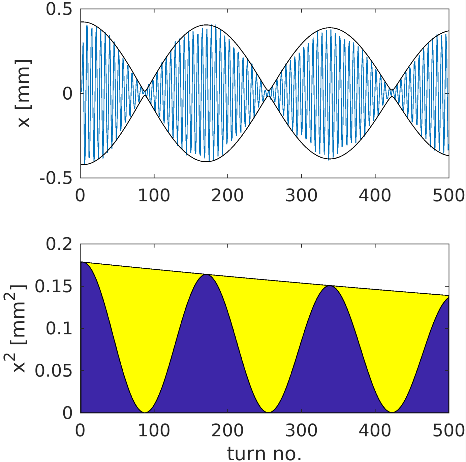
- The **tunes are scanned** around the difference resonance
- emittances are inferred from **beam size measurements at pinholes**
- Every point is the average of 2 pinholes, error bar is the difference
- **The 2 highest coupling settings reach ∼75% coupling while the corrected one does not...**

Measuring coupling with turn-by-turn BPMs



- A **transverse kick** excites a coherent betatron oscillation of the beam
- The momentum transfer between the transverse planes is observed with BPMs
- **How much momentum is transferred is a direct measurement of coupling!**

Measuring coupling with turn-by-turn BPMs



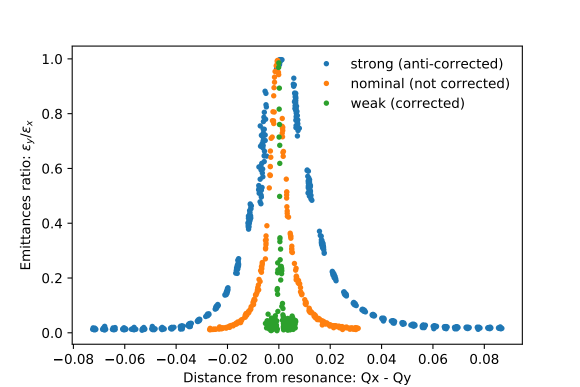
Pros:

1. Is **fast**: requires $<$ 1000 turns ($\sim$1 ms)
2. **Does not rely on complex hardware calibration or optics models**
3. ALBA is equipped with 120 turn-by-turn BPMs, providing a very good statistics

Cons:

1. Hard to distinguish coupling from **decoherence**: chromaticity should be $\sim$0
2. Doesn't work very well when the coupling term is too weak

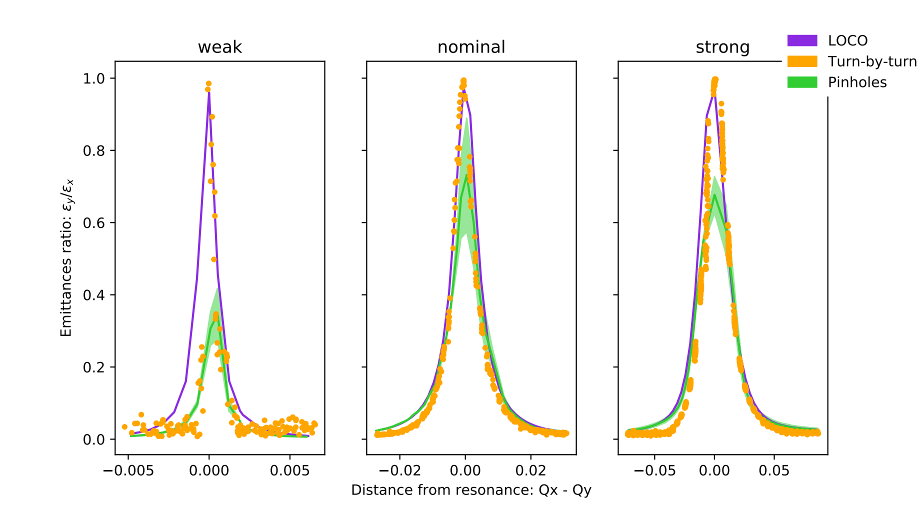
Measuring coupling with turn-by-turn BPMs



- Tune is inferred for each individual shot using a combined BPMs technique [1]
- **Every setting reach 100% coupling**
- **The width of the weak resonance is ∼4e-4, comparable to the tune stability**

[1] P. Zisopoulos et al., PRAB 22, 071002 (2019)

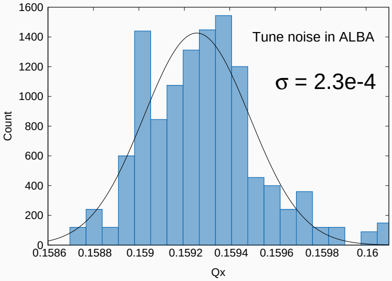
Pinholes vs Turn-by-turn vs LOCO fit model



- An **optics model** is derived from **closed orbit measurement** (LOCO)
- The model is used to **simulate coupling** along the tune scan

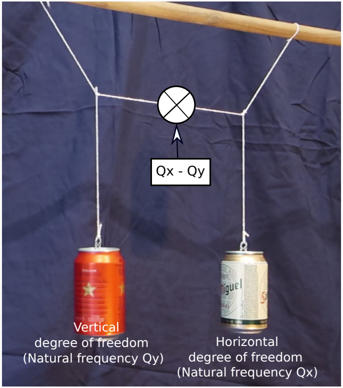
Tunes stability can pull the systsem out of resonance

- Machine stability: the **tunes fluctuate** due to **power supply noise** can easily pull the system out of resonance
- Insertion devices movement can produce effects even bigger
- Control of skew quadrupolar errors is important, cannot afford large errors: Optics correction is more involuted
- ...Also designing a machine with Qx=Qy is really annoying



Exciting coupling resonance with an A.C. skew quadrupole[1]

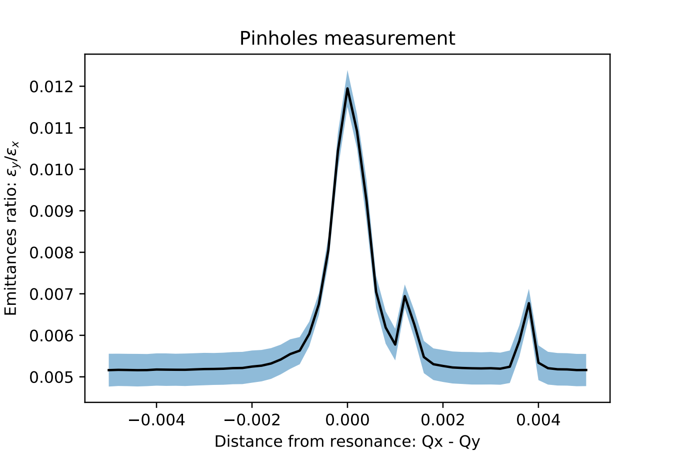
If Qx≠Qy we can "trick" each plane to "think" the other one has the same tune by modulating the coupling strength at frequency Qx-Qy



- At Alba we don't have a dedicated stripline for this studies
- Instead the tune excitation stripline was reconfigured to provide a skew quadrupolar field

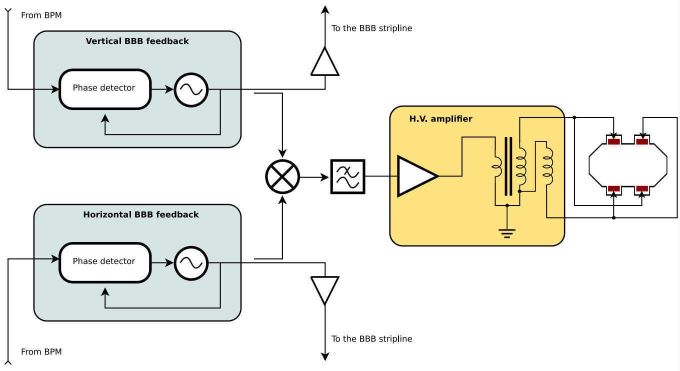
[1] P.Kuske, 8-th Low Emittance Rings Workshop, Frascati, Italy, 2020

A first A.C. skew quadrupole test at ALBA



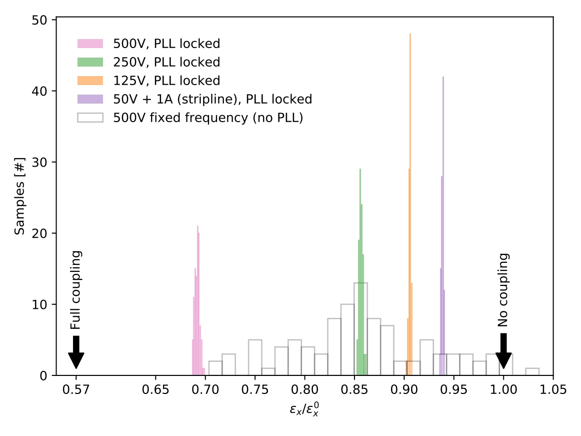
- ALBA is equipped with a short (15cm) tune excitation stripline
- The stripline was reconfigured to produce a skew quadrupolar field
- This **stripline is by far not an high power design!**
- **Nevertheless it was enough to get up to ∼1% coupling...**

Using a PLL to create a solid reference for Q_x and Q_y



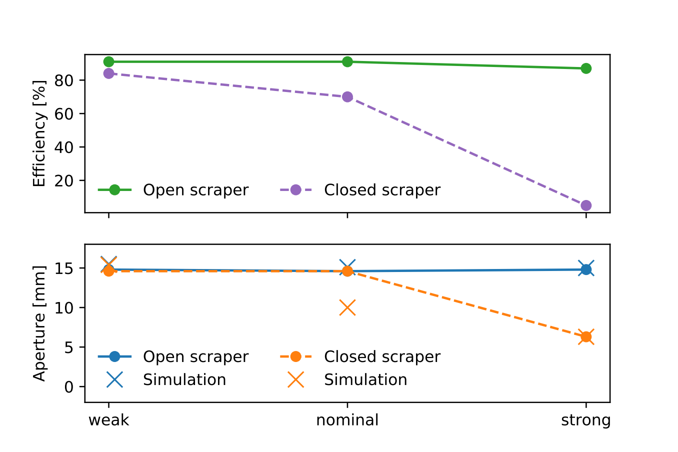
- Betatron tunes are not stable! (PSU noise, ID motion...)
- The AC skew frequency needs to be locked onto $Q_x - Q_y$: A tune following system is required
- A tune reference is provided by a PLL residing in the bunch by bunch feedback system
- The tune signals are mixed with an analog multiplier to produce the $Q_x - Q_y$ signal
- This system has sufficient bandwidth to track tunes fluctuations

Experimental results with the PLL tune tracking



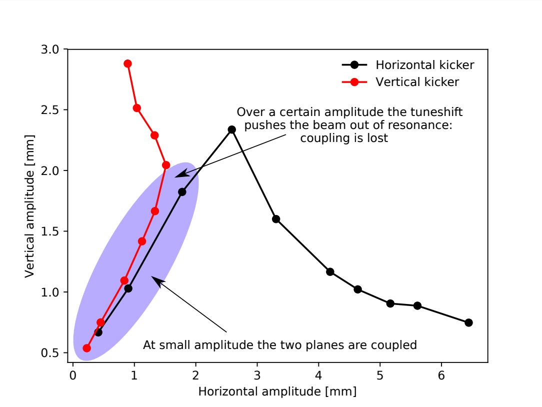
- Excitation frequency is produced by the tune following system and locked onto $Q_x - Q_y$
- The $Q_x - Q_y$ signal is amplified and fed to the electric deflector
- The amplitude of the signal is varied
- For each amplitude ~ 100 emittances measurements are obtained with the pinholes
- The same is repeated with the PLL system off: fixed excitation frequency

Injection efficiency and horizontal dynamic aperture



- Horizontal dynamic aperture was measured and compared against the model (LOCO)
- A substantial **drop is visible only for strong coupling and with vertical scraper closed...**

Tune shift with amplitude



- Coupling allows momentum to move from one plane to the other
- Kicking in the **vertical** plane a similar betatron amplitude is observed in the horizontal
- So as if kicking in the **horizontal** plane a similar amplitude is observed in the vertical
- But this is true only at small amplitudes
- At high amplitude the tune shift with amplitude pushes the beam out of resonance!

Is coupling good or bad for beam instabilities?

- In electron storage rings **transverse instabilities are dominated by vertical** impedances: vacuum chamber are flat (not the case for ALBAII), insertion devices are flat too
- An instability occurs when the overall excitation due to impedances overcome the damping (mainly due to radiation)

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Adding coupling

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- the **coupling term is "sucking" momentum from the vertical plane** to the horizontal
- The momentum removed from the vertical plane is damped by synchrotron radiation

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	Nominal optics	Full coupling
Multi bunch	**40 mA**	**65 mA**
Single bunch	**8.5 mA**	**8.5 mA (?)**

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