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:

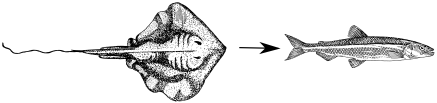
$$4.6\text{nm} \rightarrow 0.150\text{nm}$$

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

From flat to round beam

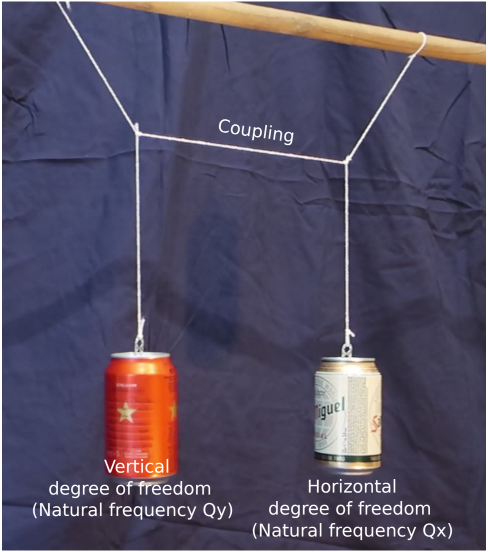
Electron beams in storage rings tend to be flat! Recoil due to synchrotron radiation produces some horizontal emittance (150pm), the vertical one is even smaller...

- 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**



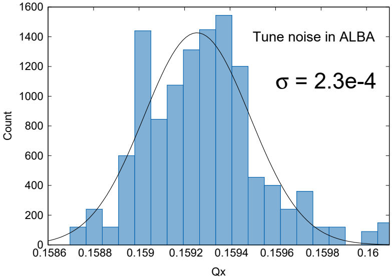
Can we turn our flat beam into a round one?

A first peek into coupling



What could go wrong?

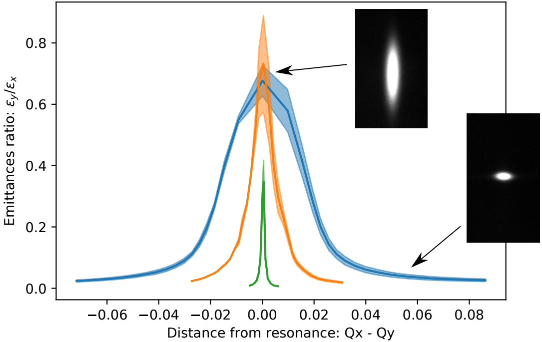
- Is linear optics affected? **Can we measure it?**
- Machine stability: the **tunes fluctuate** due to **power supply noise** (check picture). Will we be able to stay on the resonance?
- How does **beam instabilities** are affected?
- Are **injected beam** oscillations transferred to the vertical plane? We don't want to lose the beam onto insertion devices!



To get acquainted with coupling
we ran an experimental campaign using the ALBA ring.
ALBA $\neq$ ALBAII, still a valid benchmark to test our understanding

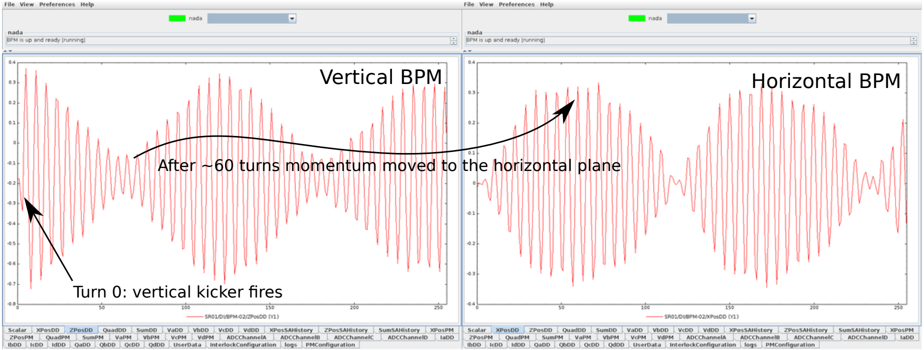
Measuring coupling with a pinhole

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



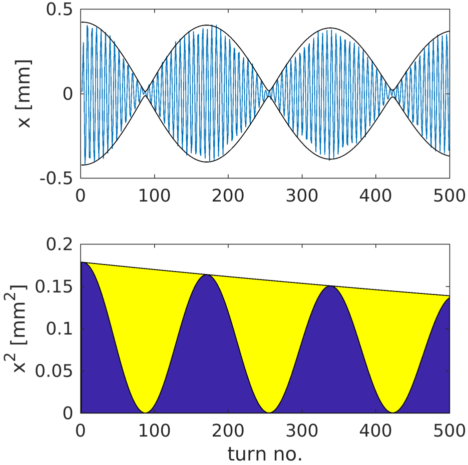
- The **tunes are scanned** around the difference resonance
- emittances are inferred from **beam size measurements at pinholes**
- Every point is the average of 2 pinholes, error bar is the difference
- **The 2 highest coupling settings reach ∼75% coupling while the corrected one does not...**

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



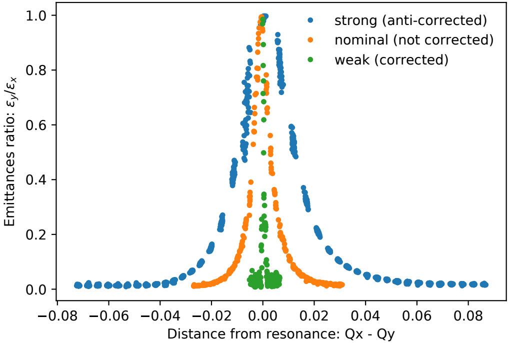
Pros:

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

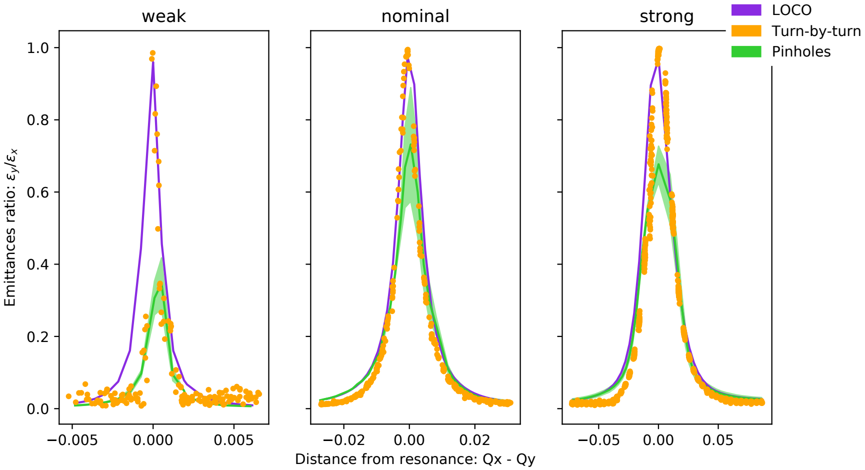
Measuring coupling with turn-by-turn BPMs



- 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**

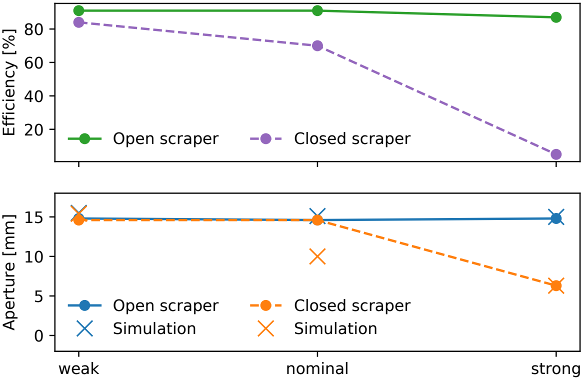
[1] P. Zisopoulos et al., PRAB 22, 071002 (2019)

Pinholes vs Turn-by-turn vs LOCO fit model



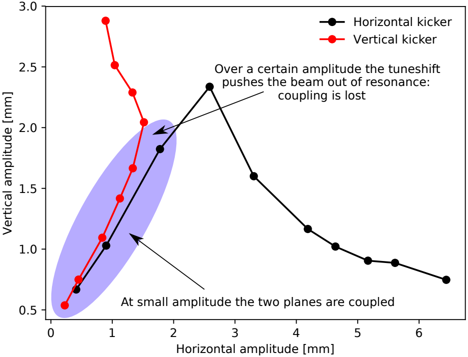
- An **optics model** is derived from **closed orbit measurement** (LOCO)
- The model is used to **simulate coupling** along the tune scan

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)

$\downarrow$

Adding coupling

$\downarrow$

- 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

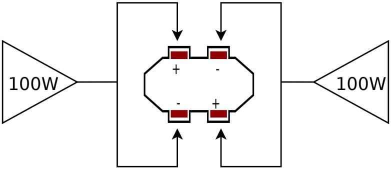
$\downarrow$

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

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

- Loss of optics flexibility (Qx=Qy)
- Control of skew quadrupolar errors is important, cannot afford large errors: Optics correction is more involuted

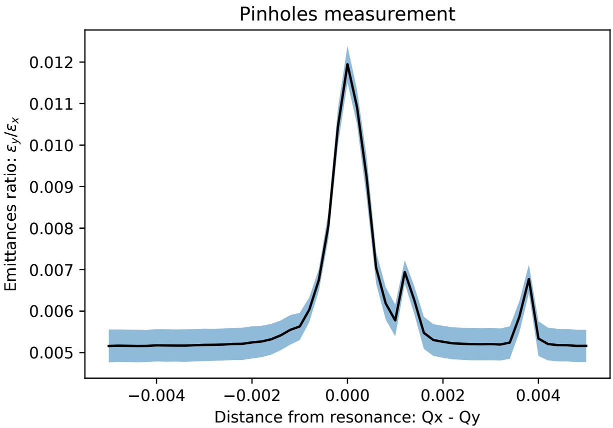
If Qx≠Qy we can "trick" each plane to "think" the other one has the same tune by modulating the coupling term at frequency Qx-Qy



- 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

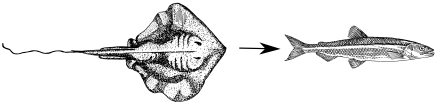


- ALBA is equipped with a short (15cm) tune excitation stripline
- The stripline was reconfigured to produce a skew quadrupolar field
- This **stripline is by far not an high power design!**
- **Nevertheless it was enough to get up to ∼1% coupling...**

Conclusions and outlook

- Optics **measurement and simulation** tools have shown **robust and reliable** results
- Machine stability can be an issue (**resonance width** $>$ **tune noise**)
- Tune shift with amplitude can indeed be used to inject (**resonance width** $<$ **injected beam tune shift**)
- Beam instabilities are not affected, if not positively, by full coupling operations

Exploiting the coupling resonance to move from a flat to a round beam seams a viable solution!



- Just started **investigating A.C. skew quadrupole to excite the coupling resonance**
- The current A.C. skew quadrupole in ALBA has limited strength: $\sim$ 1% coupling
- Does A.C. excitation behaves the same as D.C. at higher coupling? ...should, but does it?
- Define a viable A.C. skew quadrupole design for ALBAII