Full coupling studies at ALBA[1]

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[1] Z.Martí et al. Proceedings of IPAC22.

ALBA-II: low emittance, low lifetime

X axis ↓

Short (Touscheck) lifetime

Z axis ↑

Y axis ↑

Harmonic cavity (Not covered here).

AC dipole field sync. Side band (Diamond, not covered here)
- ✗ No horizontal reduction.

AC dipole field white noise (EBS, not covered here)
- ✗ No horizontal reduction.
- ✓ Simple and proven solution.

DC skew field **Full coupling** (Q_x=Q_y) (NSLS-II, APS, SPEAR-3, ALBA)
- ✗ Tune/Beam noise.
- ✗ Restricted set of optics.
- ✓ Horizontal emittance reduction.

AC skew field **Full coupling** (f=Q_x-Q_y) (BESSY, Spring-8, Diamond, ALBA)
- ✗ Tune/Beam noise.
- ✓ No working point restriction.
- ✓ Horizontal emittance reduction.

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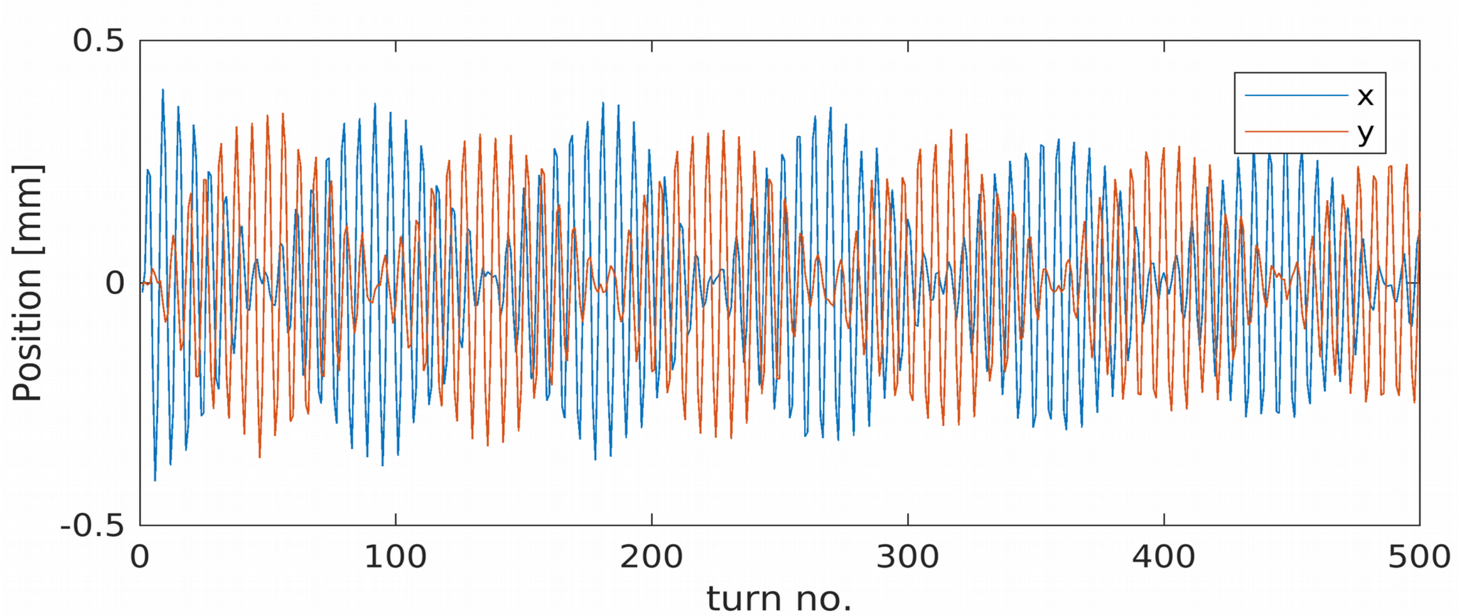
What is full coupling?

Two oscillators are coupled when they depend on each other.

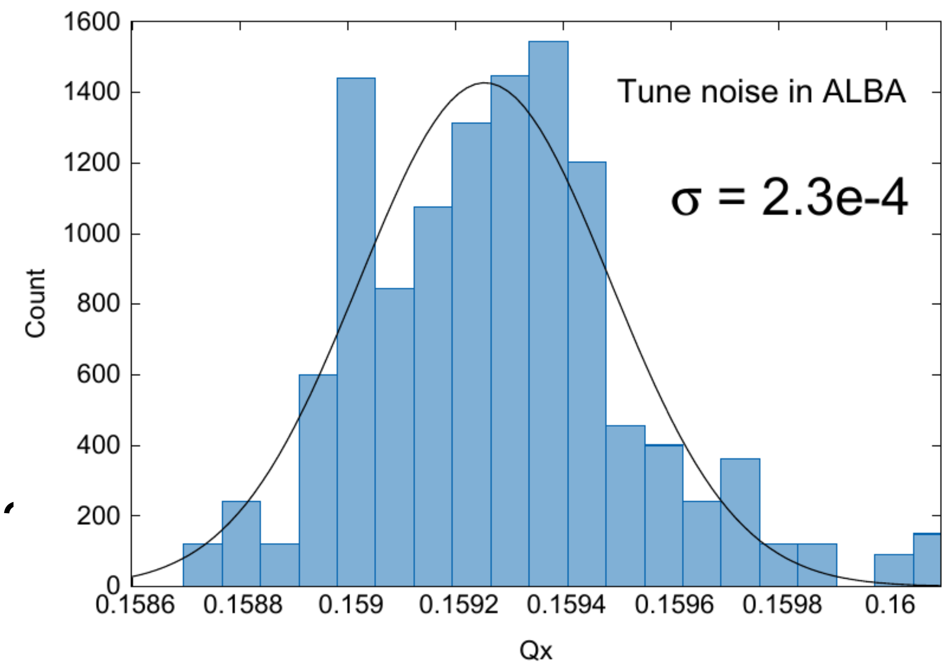
They reach full coupling if their modes of oscillation have the same frequency.

When fully coupled the action is exchanged as promptly as large is the coupling strength:



Initial concerns

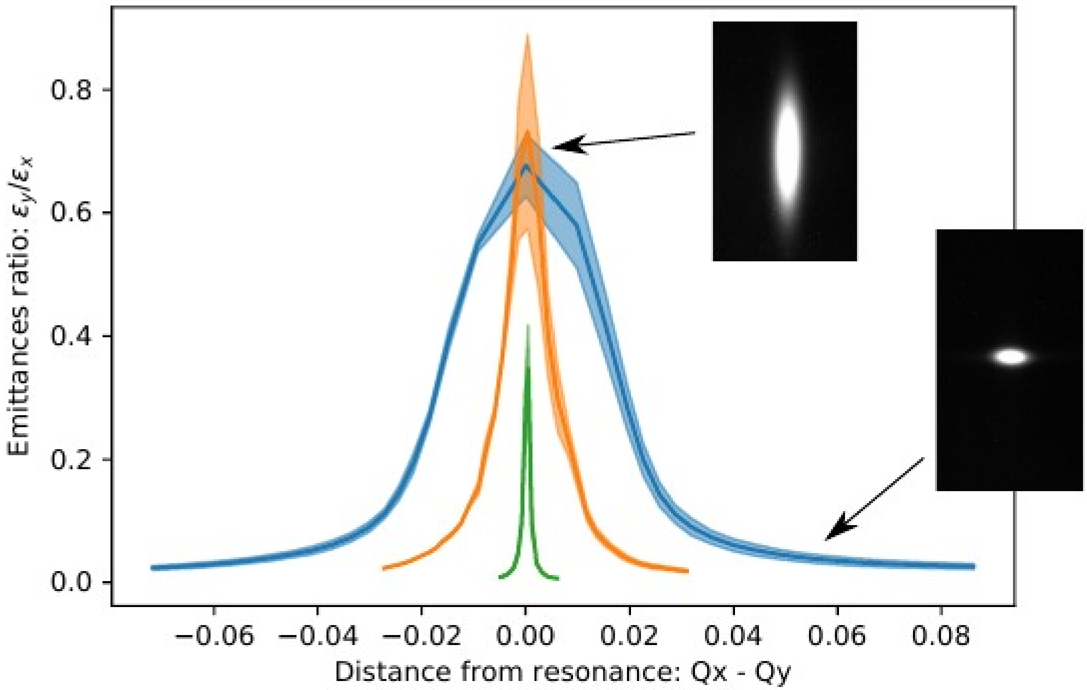
- How much is **linear optics** affected?
- Power supply noise: the **tunes fluctuate**, will we be able to stay on the resonance? Will the **beamlines** notice it?
- Are **injected beam** oscillations transferred to the vertical plane?
- How are **beam instabilities** affected?



To get acquainted with coupling we ran an experimental campaign using the ALBA ring. ALBA ≠ ALBA-II, still a valid benchmark to test our understanding

Measuring coupling with the pinhole

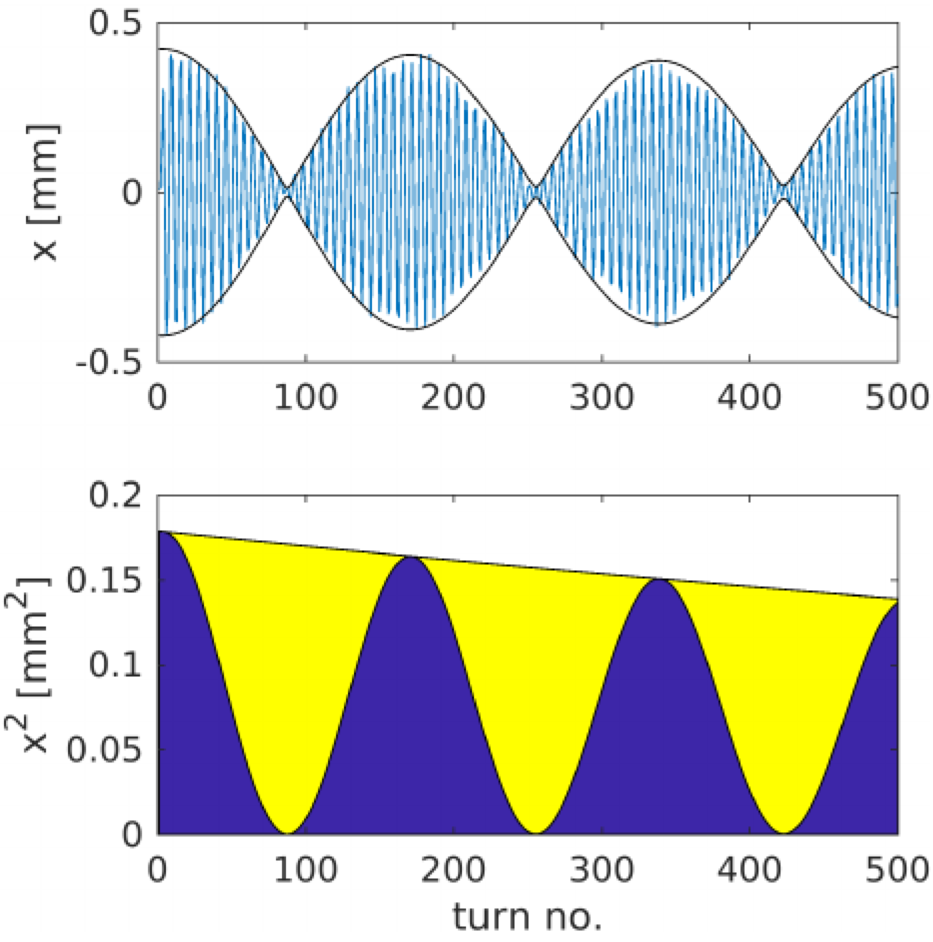
- 3 coupling settings selected:



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 (Optics from LOCO).
- The measurement takes typically hundreds of ms.
- The 2 highest coupling settings reach ∼75% coupling while the corrected one does not…

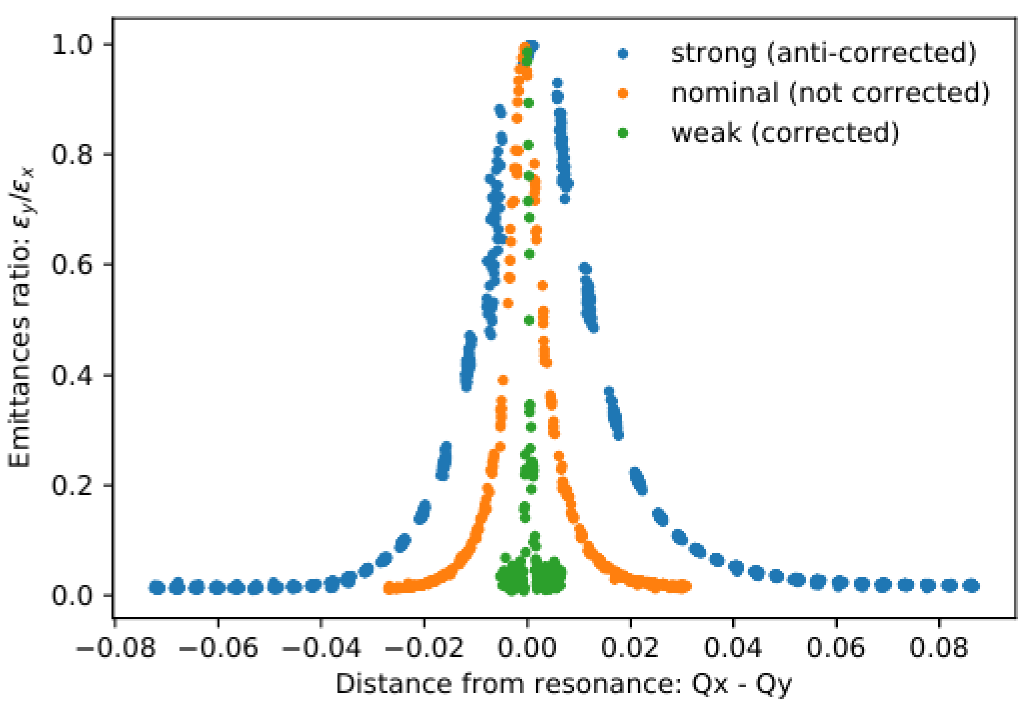
Measuring coupling with turn-by-turn BPMs



- Pros:
  1. Is fast: requires < 1000 turns (~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 ~0
  2. Doesn't work very well when the coupling term is too weak

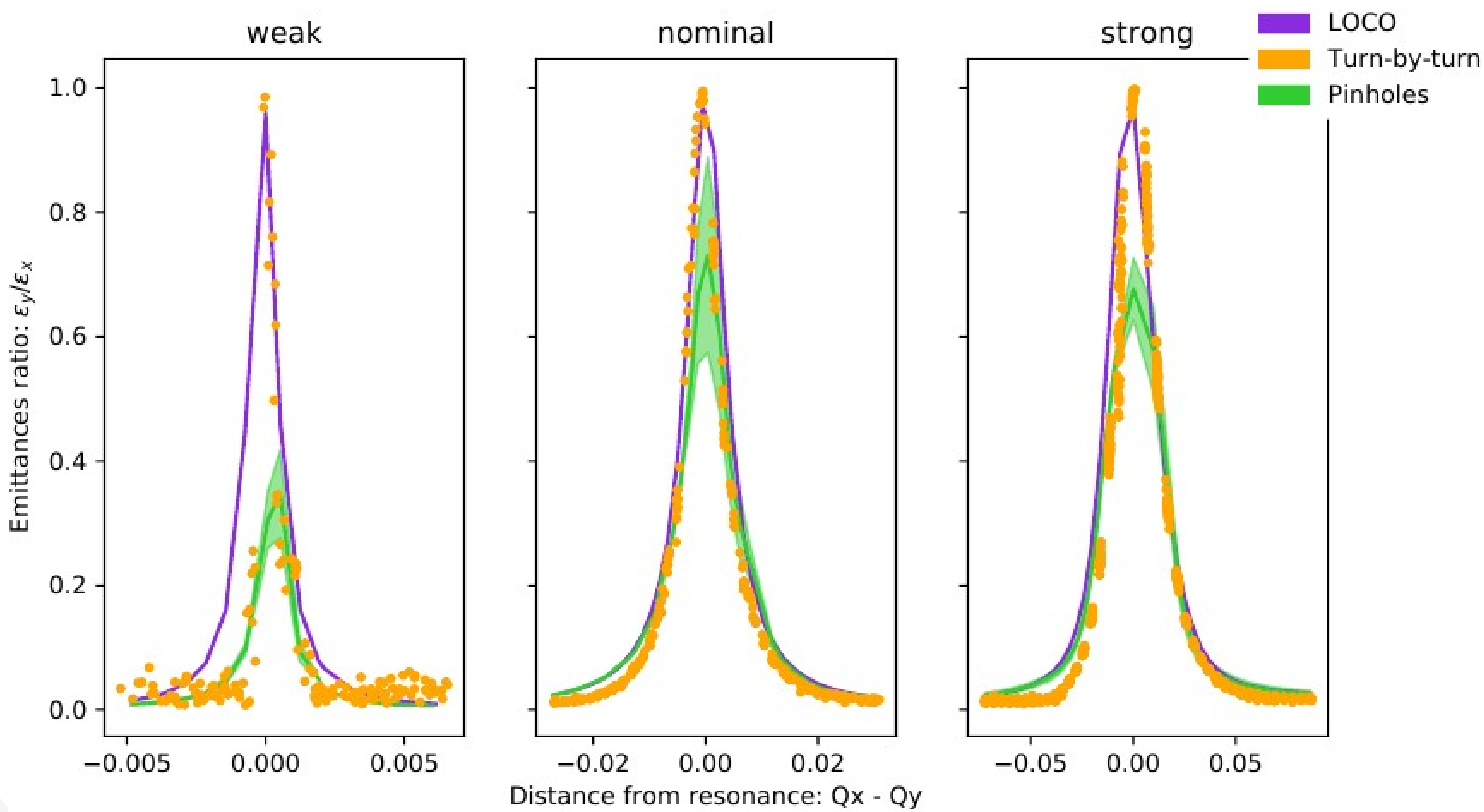
Measuring coupling with turn-by-turn BPMs



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

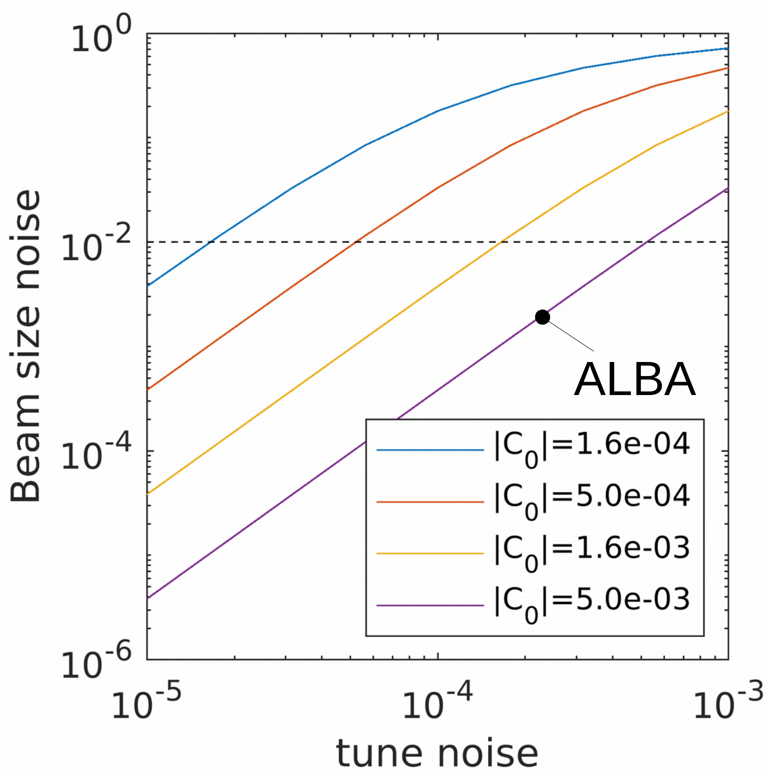
1 P. Zisopoulos et al., PRAB 22, 071002 (2019)

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

Optimum coupling strength



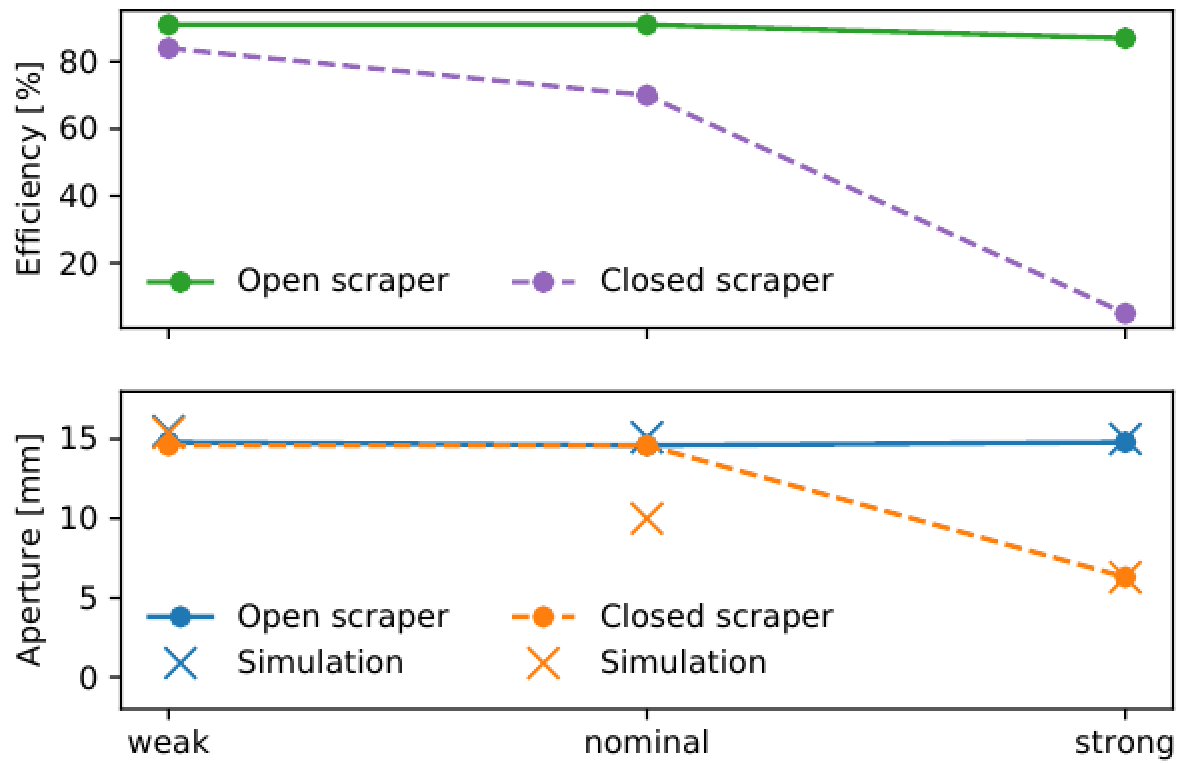
For ALBA-II, **if we work in full coupling,** we will need enough coupling strength $|C_0|$ to produce a **small beam noise**. Typically beamlines ask for a 10% but that should include also orbit stability. to be safe we should target few times 1%.

$$\frac{\epsilon_y}{\epsilon_x} \approx \frac{1}{1 + \frac{\Delta Q^2}{|C_0|^2}}$$

$$|C_0| = \frac{1}{2\pi} \left| \sum_w J_{w,1} \sqrt{\beta_x^w \beta_y^w} e^{i(\phi_{w,x} - \phi_{w,y})} \right|$$

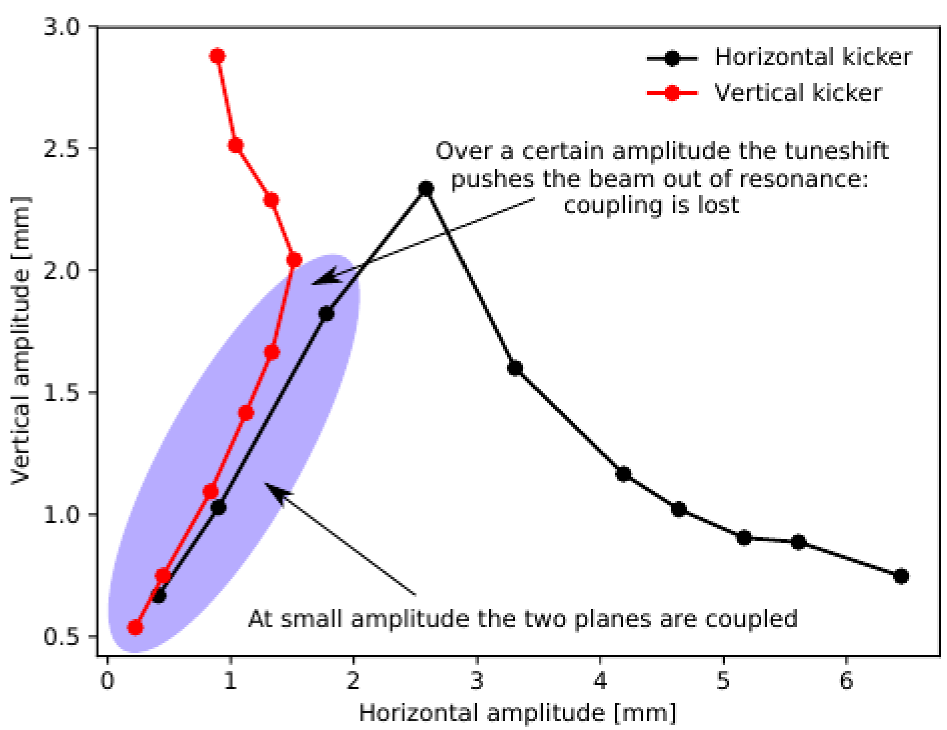
However, the larger $|C_0|$ the more distorted the machine optics and the worse the dynamic aperture.

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 shares momentum to move from one plane to the other
- 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 ALBA-II), insertion devices are flat too
- An instability occurs when the overall excitation due to impedances overcome the damping (mainly due to radiation)

Adding coupling

- The coupling term is ”sucking” momentum from the vertical plane to the horizontal
- That effectively increases the maximum allowed impedance kick

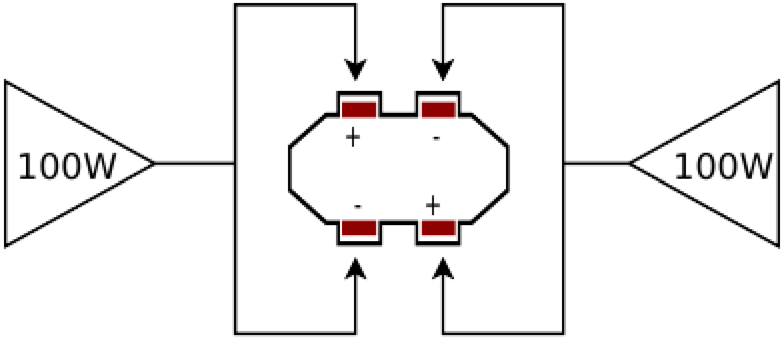
	Nominal optics	Full coupling
Multi bunch	**40 mA**	**65 mA**
Single bunch	**8.5 mA**	**8.5 mA (?)**

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

Qx=Qy implies a loss of optics flexibility...

If Qx≠Qy we can ”**trick**” each plane to ”think” the other one has the same tune by modulating a skew field at frequency Qx-Qy

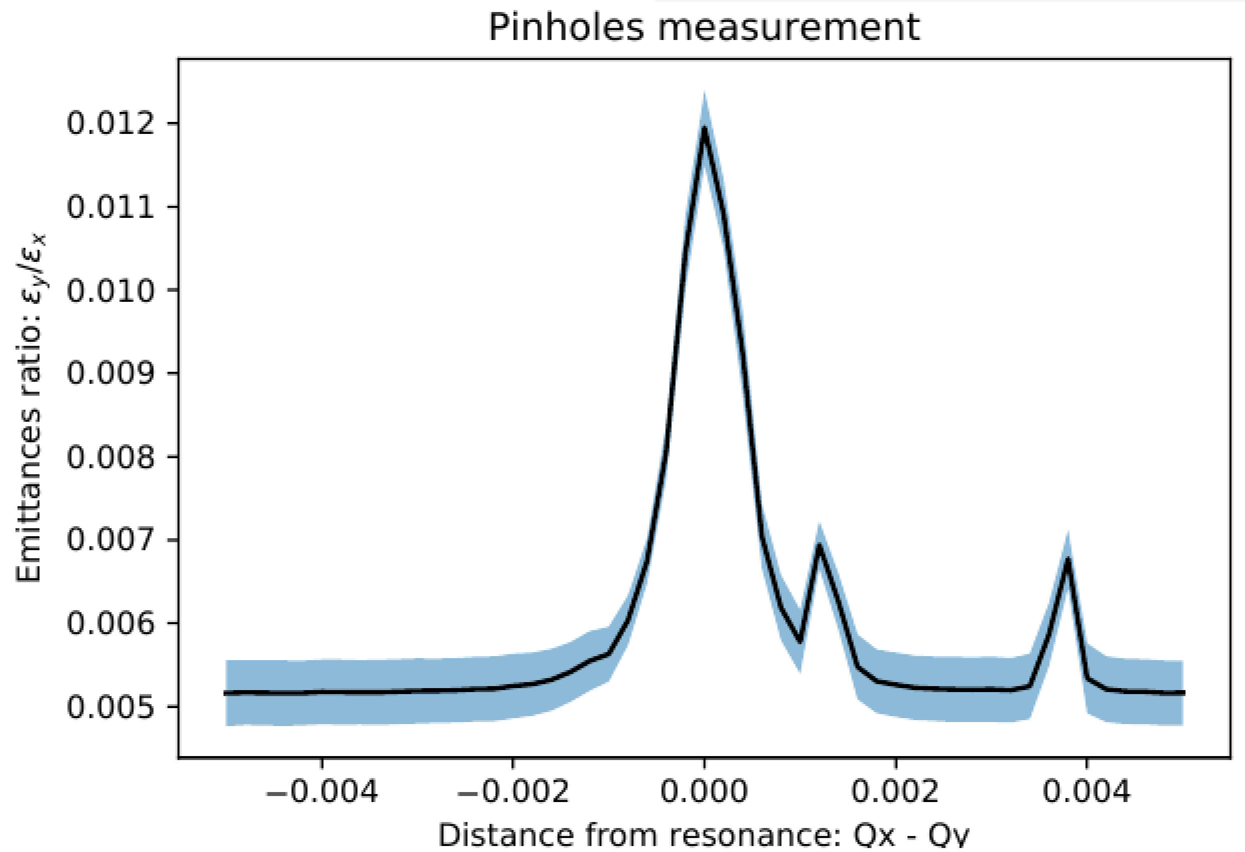
$$cos(2\pi(Q_x - Q_y)n)cos(2\pi Q_y n) \sim cos(2\pi Q_x n)$$
$$cos(2\pi(Q_x - Q_y)n)cos(2\pi Q_x n) \sim cos(2\pi Q_y n)$$



- At ALBA we don’t have a dedicated stripline for this study
- 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



- 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** is not an issue while 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: **~ 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 ALBA-II