Single power supply optics correction for combined function dipoles[1]

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[1] Z.Martí et al. Proceedings of IPAC24.

Disclaimer

The study we have started is inspired by the previous work done with **A.Franchi** and **S.Liuzzo** [1] on analytical LOCO.

What we show in this presentation is part of an **ongoing study**.

The comments and formulas displayed in this presentation come with absolutely **no warranty.**

[1]: https://arxiv.org/abs/1711.06589

Why **not** using combined function dipoles (CFD)

CFD were not very popular in **3rd** generation light sources:

- To start pure CFD **do not exist!**

$$B_z = k\,r\,,\,B_r = k\,z$$

$$\nabla \times B = 0 \quad ✓$$

$$\nabla \cdot B = 0 \quad ✗$$

- Complex to use to correct the optics.
- Still they have been used in many cases: ALS, CLS, SPEAR3, Elettra, Sesame and ALBA among others.

Why using CFD

New more Compact **4th** generation light sources designs come with **plenty of** CFD, with different flavors:

- Permanent magnets solutions: optics corrected elsewhere.
- 2 power supply 4 pole 1 sector
- 2 power supply 2 pole 3 sectors.
- **Simplest**: 1 power supply 2 pole 1 sector?

Simple to build and operate, but...

Single power supply CFD **change optics and orbit** simultaneously.

To calculate its optics effect one needs to consider the orbit correction.

The **numerical** evaluation for large lattices with many CFD can be very time consuming. In particular, it takes **several hours** for ALBA-II in a single CPU.

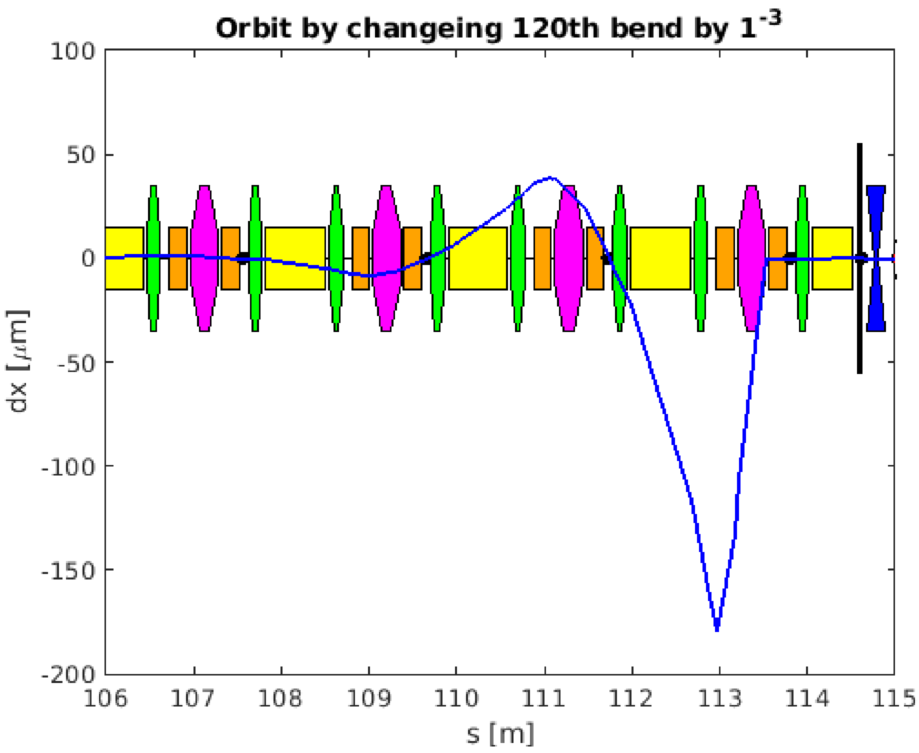
This motivates us to find an **analytic** evaluation.

Analytic CFD effect

CFD have extra optics effects:

- **Hor. Orbit change**: A change in a CFD will make the Horizontal Orbit Corrector Magnet (HCM) zero the orbit at the BPMs but not at the adjacent sextupoles.

- **Energy change:** The additional orbit kicks in the horizontal plane induce an energy shift, which also produces extra kicks at every dipole.



Analytic CFD effect

CFD have extra optics effects:

For leptons and constant RF

- **Hor. Orbit change**:*

$$R_{i,j}^{kick}=\frac{d\,x_i}{d\,\theta_j}=\frac{\sqrt{\beta_i\beta_j}}{2\sin(\pi Q_x)}\cos(|\phi_i-\phi_j|-\pi Q_x)-\frac{\eta_i\eta_j}{\alpha_c C}$$

From Wolski's formula[1]:

$$R_{i,k}=\frac{R_{i,k}^{kick}+\frac{dR_{i,k}^{kick}}{dq_k}q_k}{q_k R_{k,k}^{kick}-1}$$

- *i,n: BPM*
- *j,m: HCM*
- *l: sextupoles*
- *k: CFD*

- **Energy change:**

$$\frac{d\,\delta}{d\,\theta_j}=\frac{-\eta_j}{\alpha_c C}$$

** Thick versions are being developed.*
[1]: ATF internal report ATF-03-08

Analytic CFD effect

CFD have extra optics effects:

- **Hor. Orbit change**:

Kick angle, not bending angle!

$$\frac{dq_{l,k}}{dq_k} = 2s_l \frac{dx_{l,k}}{dq_k} = 2s_l \left[R_{l,k} - \sum_{m,n} R_{l,m} R^{-1}_{n,m} R_{n,k} \right] \frac{b_k}{q_k}$$

- where $q_{l,k}$ / q_k is the quadrupolar strength at the sextupoles/CFD.

- **Energy change:**

$$d\delta = -\frac{1}{\alpha_p C} \left[\eta_k - (r-1) \sum_{m,n} \eta_m R^{-1}_{n,m} R_{n,k} \right] \frac{b_k}{q_k} dq_k$$

- *i,n: BPM*
- *j,m: HCM*
- *l: sextupoles*
- *k: CFD*

Analytic CFD effect

CFD have extra optics effects (sorry several should be partial derivatives):

$$\left.\frac{dR_{i,j}}{dq_k}\right|_{CFD} = \frac{dR_{i,j}}{dq_k} + \sum_l \frac{dR_{i,j}}{dq_l}\frac{dq_{l,k}}{dq_k} + \frac{dR_{i,j}}{d\delta_k}\frac{d\delta_k}{dq_k}$$

Wl

$\frac{dR_{i,j}}{dq_l}$: Sextupoles contribute as a quadrupoles.

$$\frac{dR_{i,j}}{d\delta_k} = \sum_r \frac{dR_{i,j}}{dq_r} q_r$$

- *i,n: BPM*
- *j,m: HCM*
- *l: sextupoles*
- *k: CFD*

Analytic CFD effect

The result depends on the orbit feedback used. At ALBA, we presently use:

$$\Delta\,\delta^0_{COR}=\frac{-\sum_j \eta_j\theta^0_j}{\alpha_c C}$$

$$\Delta f_{RF}=r\times f_{RF}\frac{\sum_j \eta_j\theta^0_j}{C}\rightarrow\Delta\,\delta_{RF}=-r\frac{\sum_j \eta_j\theta^0_j}{\alpha_c C}$$

$$\Delta\,\theta_m=-R^{-1}_{mi}\,\eta_i\Delta\,\delta_{RF}=r\frac{\sum_j \eta_j\theta^0_j}{\alpha_c C}\sum_i R^{-1}_{mi}\,\eta_i$$

$$\Delta\,\delta^0_{COR}+\Delta\,\delta^1_{COR}=0\rightarrow r=\frac{-\alpha_c C}{\sum_{m,i}\eta_m R^{-1}_{mi}\,\eta_i}\approx\frac{1}{2}$$

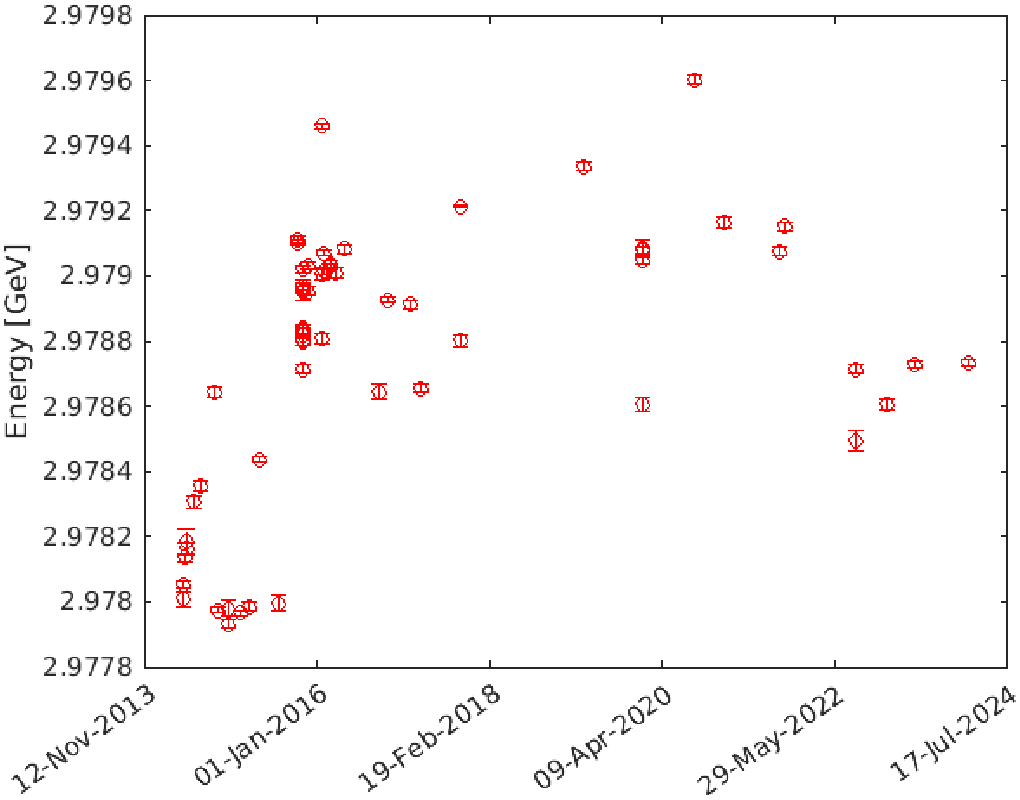
RF loop energy change:

$$\Delta\,\delta_{loop}=(r-1)\Delta\,\delta^0_{COR}$$

$$\frac{\sum_{m,i}\eta_m R^{-1}_{mi}\,\eta_i}{\alpha_c C}<0$$

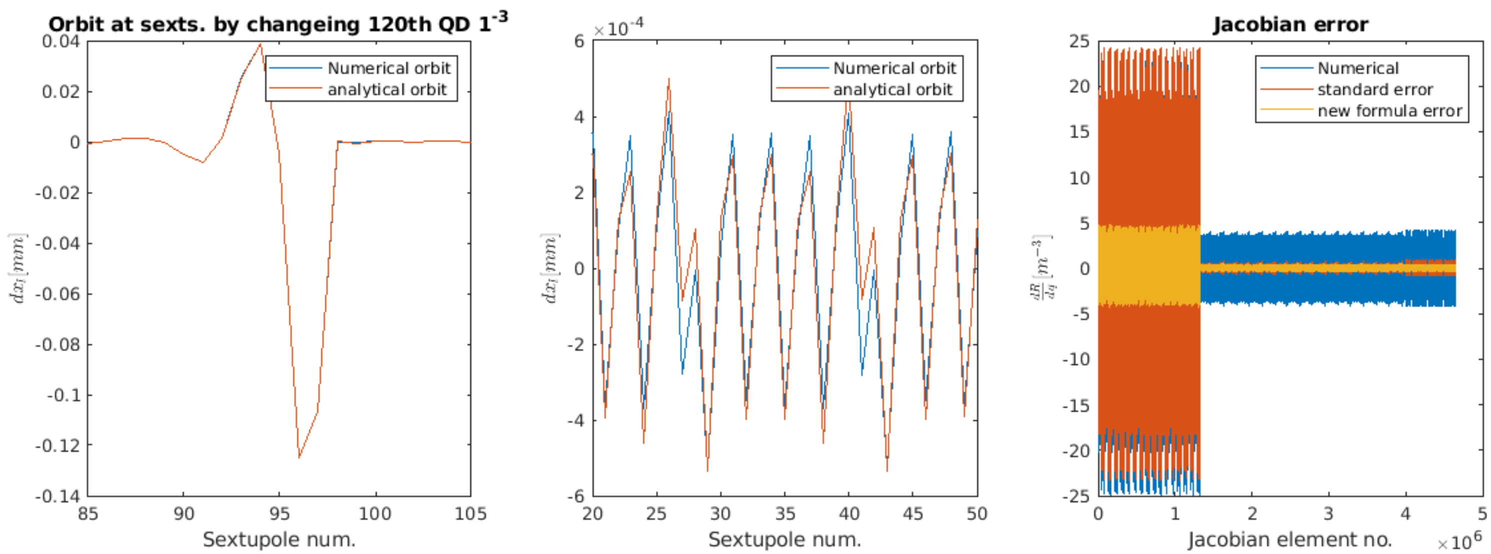
ALBA energy

The beam **Energy** has been stable though the years. Would it be a good idea to allow it to **change?**



Work in progress...

We are missing something, **around 20%!**

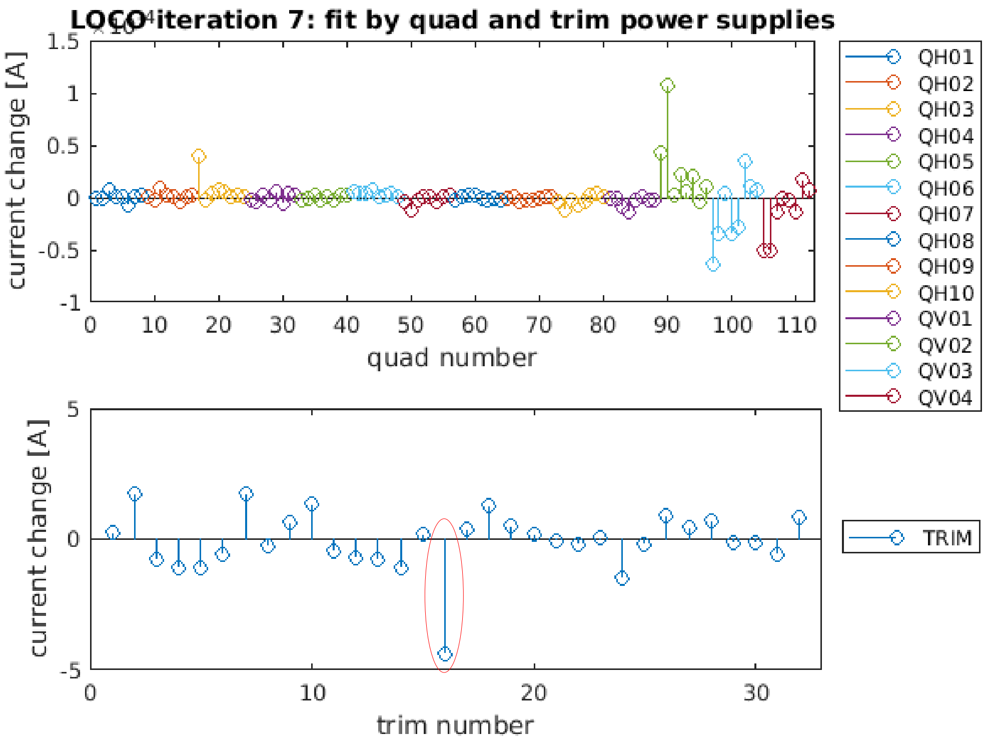


A substantial part corresponds to the Wolski's formula not being implemented yet (nor the thick version). But maybe there are other reasons...

Implementation on the present ALBA storage ring

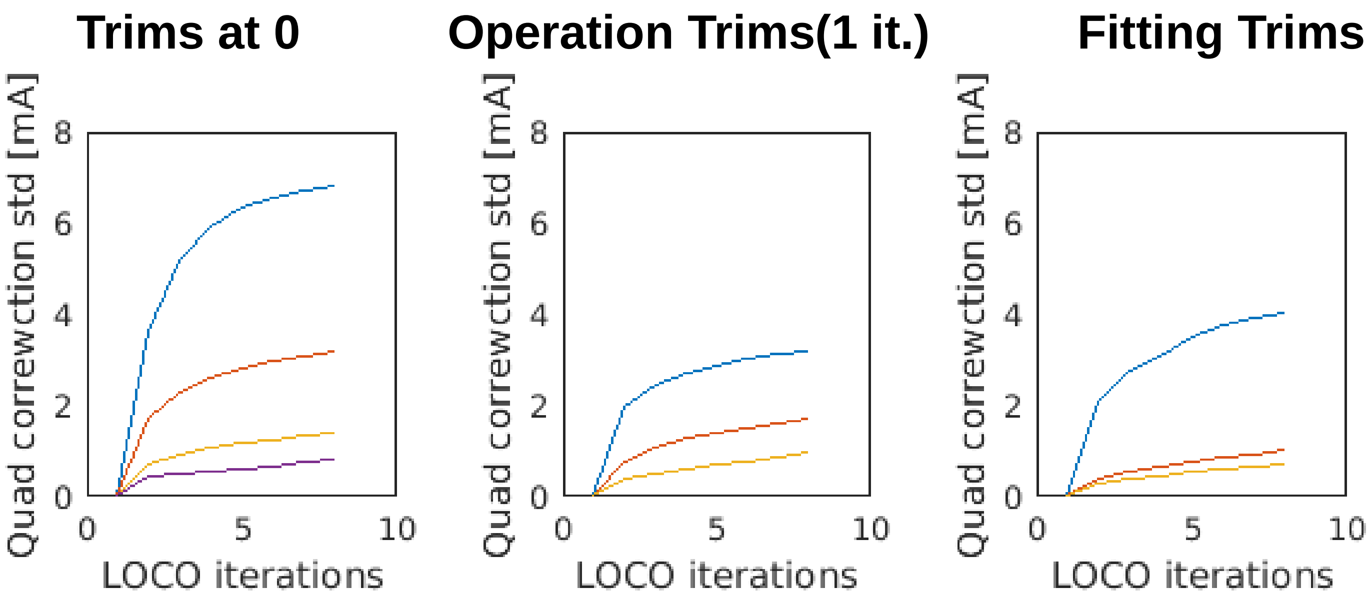
- ALBA has **112 QUADS** and **32 CFD**. Up to now only the QUADS are used regularly to correct the optics. Considering CFD as QUADS the optics correction does **not converge:** **only 1 iteration was applied**.

Even if **not exactly** correct, the new response matrix derivative has been used to spot a 5A **single CFD change**.



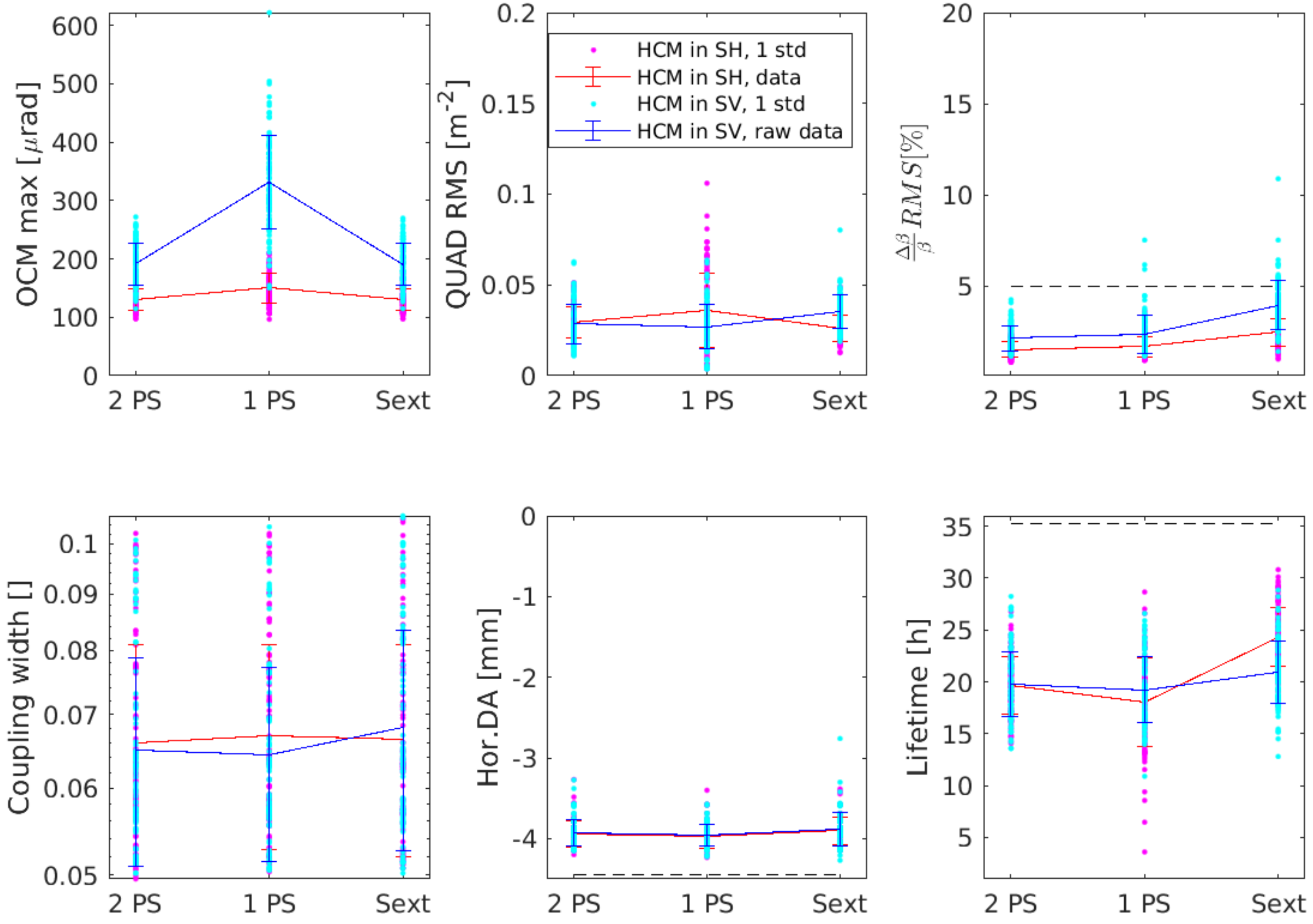
Implementation on the present ALBA storage ring

Starting from an **uncorrected lattice** the new CFD correction method produces much smaller quadrupole changes.



Alba-II Optics correction scheme

The **fast** CFD response matrix derivative calculation allows to correct many instances for **several different correction schemes** in **reasonable times**.



Conclusions

- Single PS CFD analytic optics correction seems **feasible**, although **there are open issues**. For example the **energy changed** associated to it.
- The technique has been successfully **applied at ALBA** present machine.
- Single PS CFD seem viable candidates for for **4^{th} generation** light sources. The present **ALBA-II** design relies on it.