Six bend higher order achromat lattice for ALBA-II

Gabriele Benedetti, Michele Carlà, Zeus Martí

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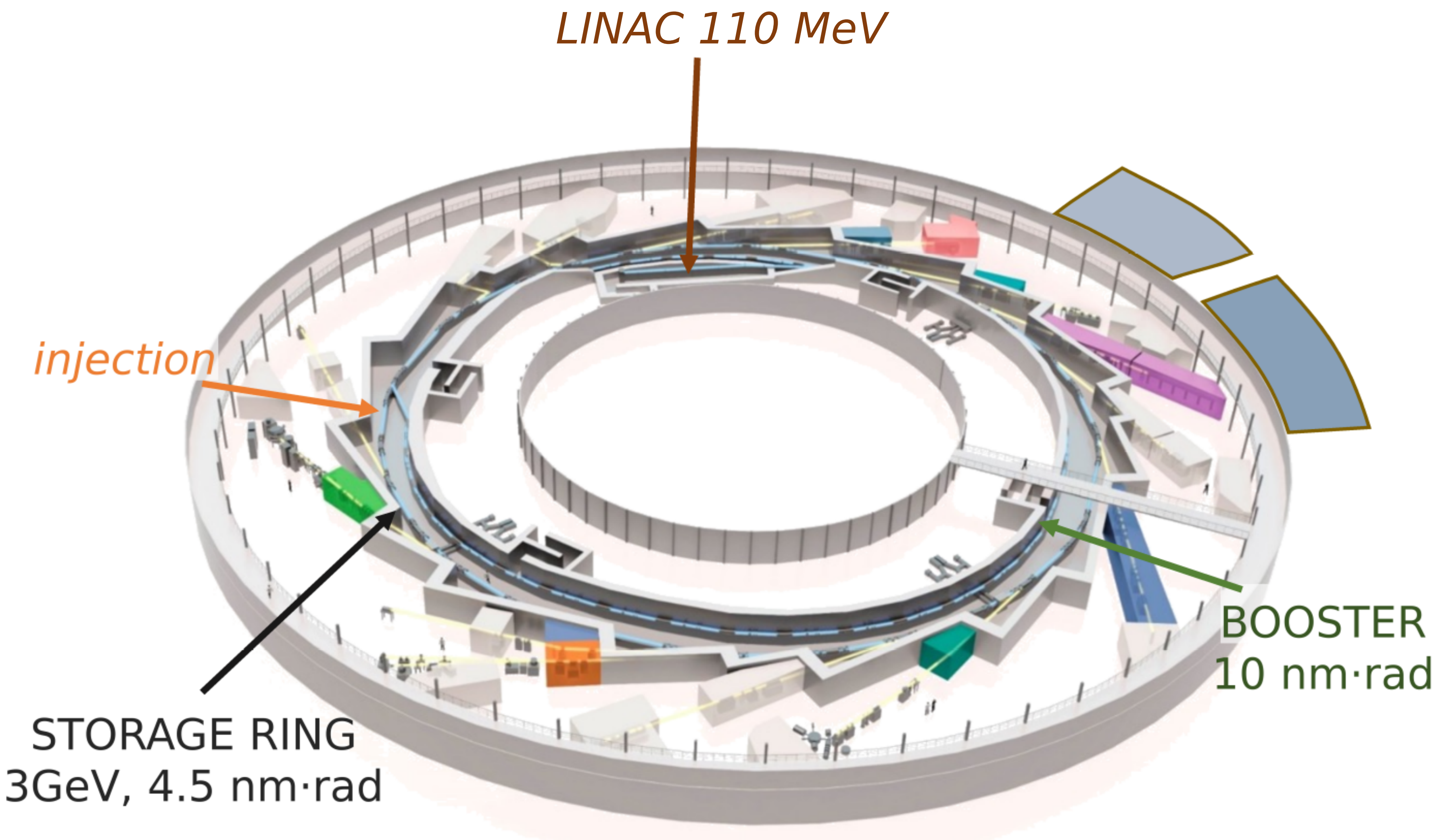
ALBA as today



equipped with 10 ID + 3 Dipole beamlines

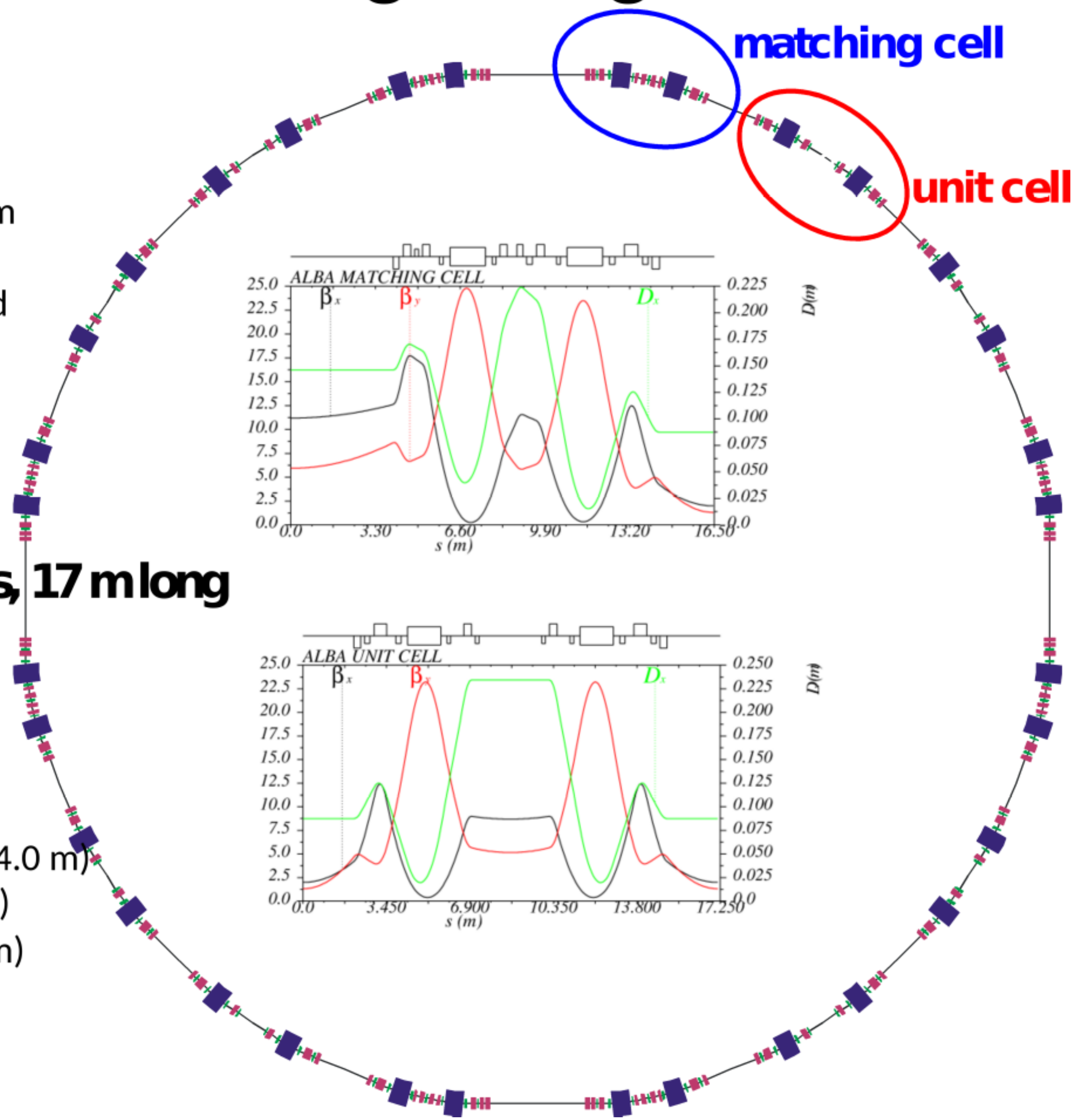
ALBA storage ring lattice

- Energy = 3 GeV
- Circumference = 268 m
- Symmetry = 4 fold
- Emittance = 4.5 nmrad

- **8+8 DBA-like cells, 17 m long**

Straight sections:

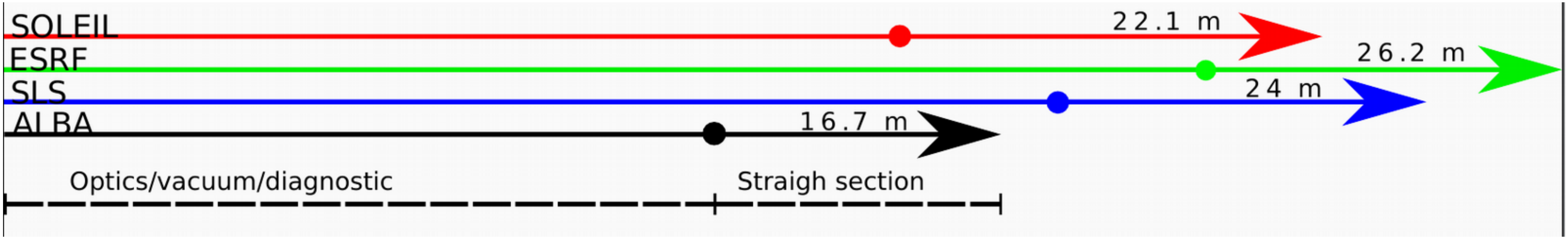
- 12 medium straights (4.0 m)
- 4 long straights (7.8 m)
- 8 short straights (2.3 m)



Boundary conditions and requirements for the ALBA-II baseline lattice

- Keep existing tunnel: SR with **same compact circumference 268 m**
- Keep beam energy at **3 GeV**
- Existing ID beamlines: preserve **16 cells** and source points
- **Straight sections at least 4 m long and $\beta_x^* \approx \beta_y^* \approx$ 1-2 m**
- Keep existing injector $\varepsilon_x^{booster}$ = 10 nm·rad
- Emittance < **300 pm·rad**

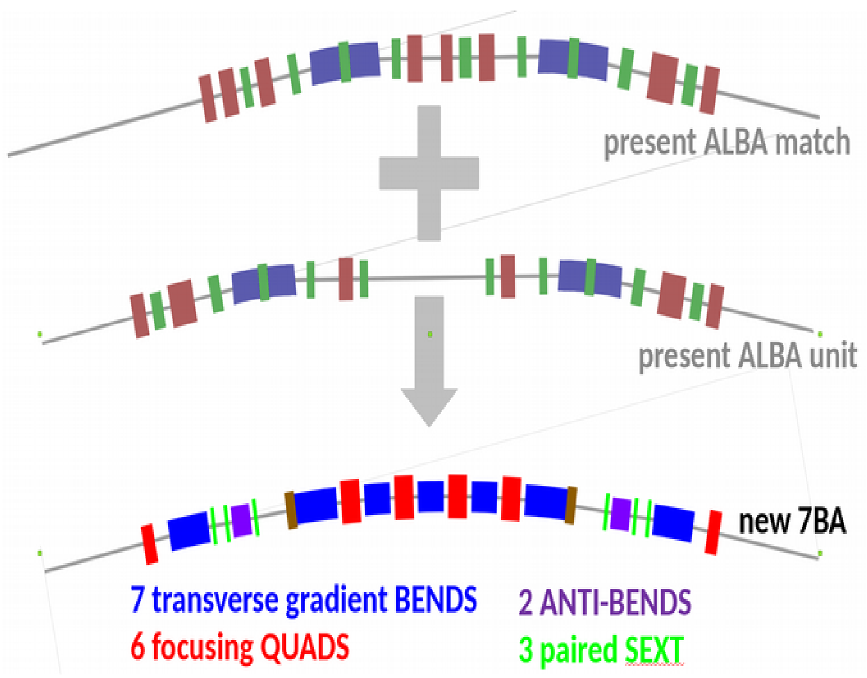
ALBA is a very compact ring

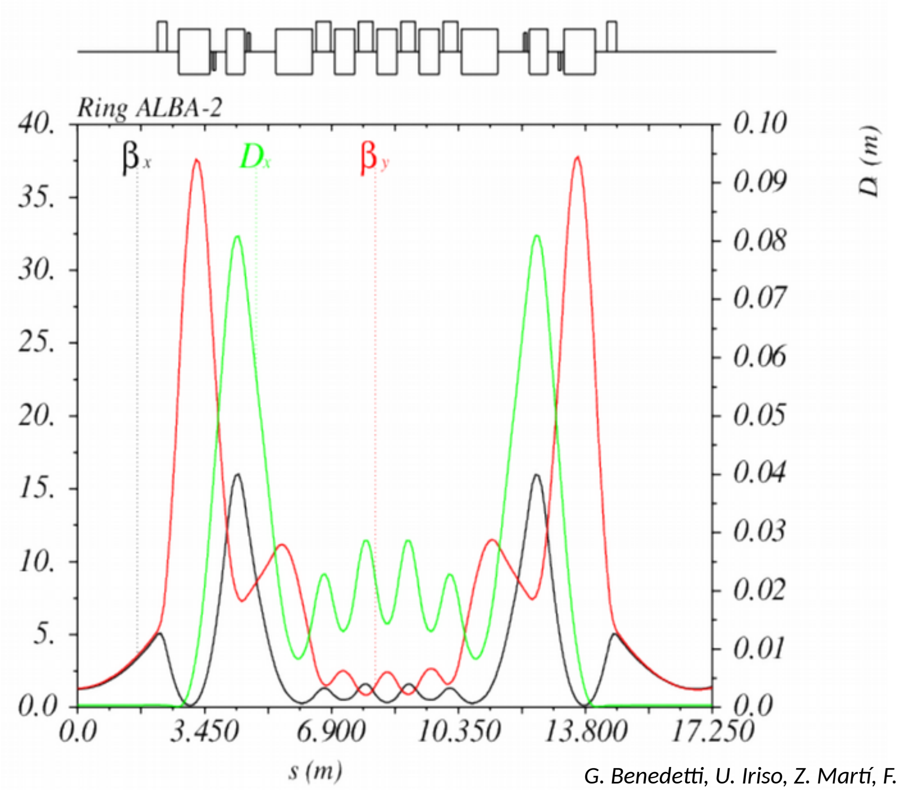


- 16 cells in 268 m → 16.7 m per cell
- 2 types of straight sections in ALBA: ~8m and ~4m
- In ALBA-II all the straight sections will be 4m
- **The space left for magnets/diagnostics/vacuum is 16.7m – 4m = 12.7 m**

Hybrid 7BA with dispersion bump

In 2019 we started a study for the lattice upgrade based on 16 identical cells.
A hybrid 7BA with dispersion bump and paired sextupoles had an emittance **ε_x= 155 pm·rad**.





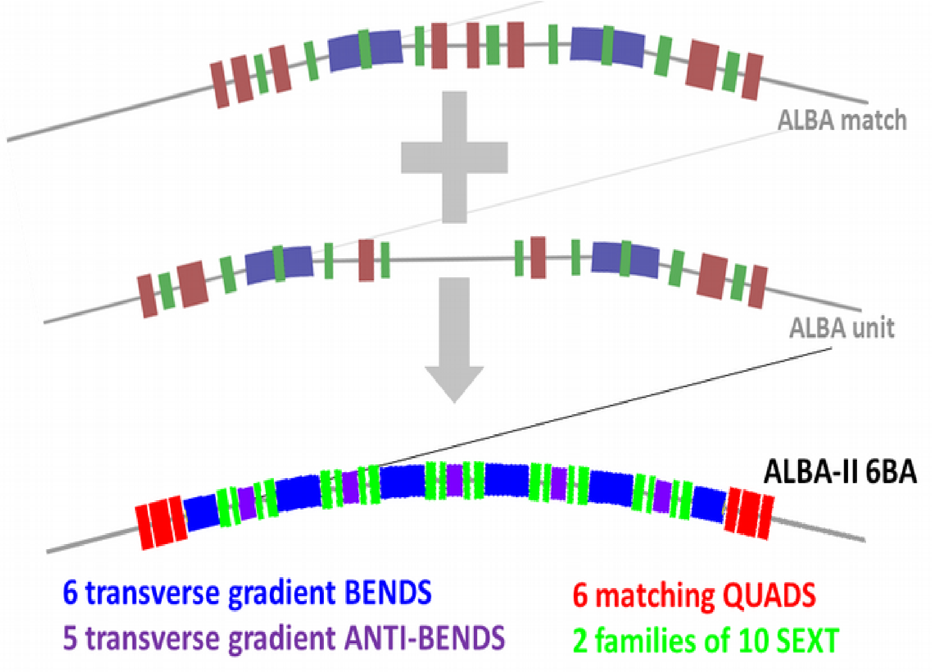
G. Benedetti, U. Iriso, Z. Martí, F. Pérez, "First study for an upgrade of the ALBA lattice", IPAC 2019

The limitation of this lattice was the **small dynamic aperture (~1.5 mm) and momentum acceptance** and the **lack of flexibility**.

MBA with distributed sextupoles

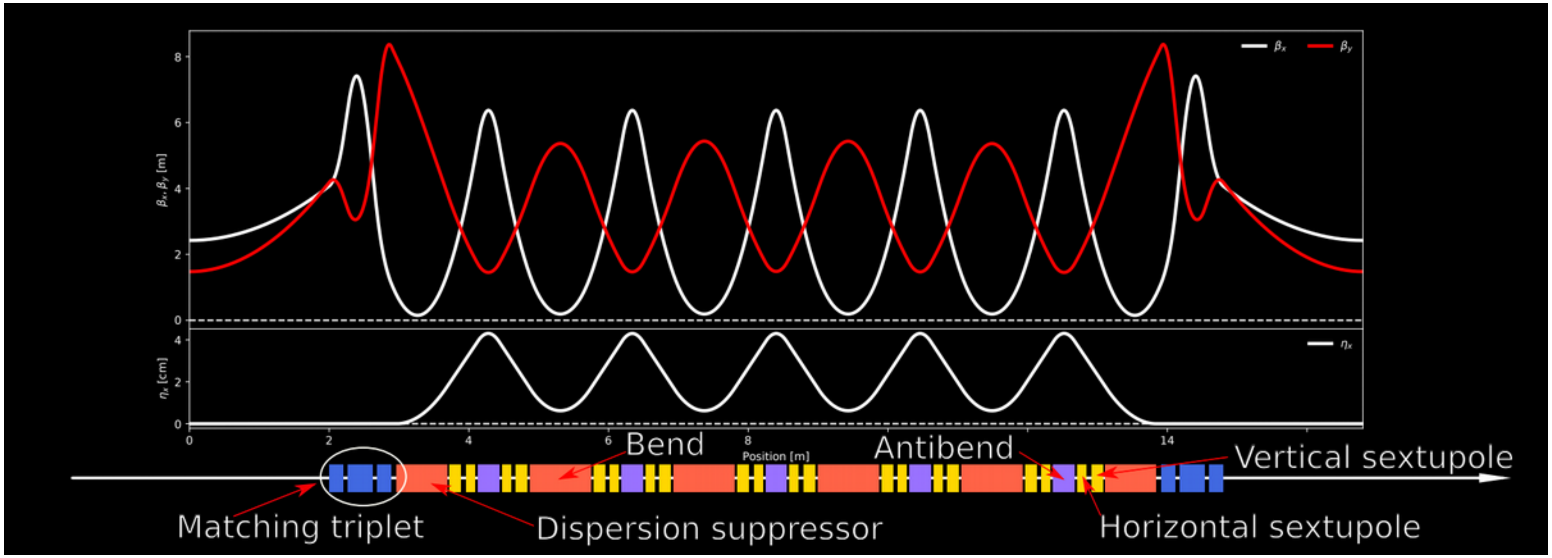
In 2020 we changed approach and started a systematic study to find the best MBA for ALBA-II

MBA + anti-bends + distributed sextupoles



G. Benedetti, M. Carlà, U. Iriso, Z. Martí, F. Pérez, "A distributed sextupoles lattice for the ALBA low emittance upgrade", IPAC 2021

A MBA tailored for ALBA-II



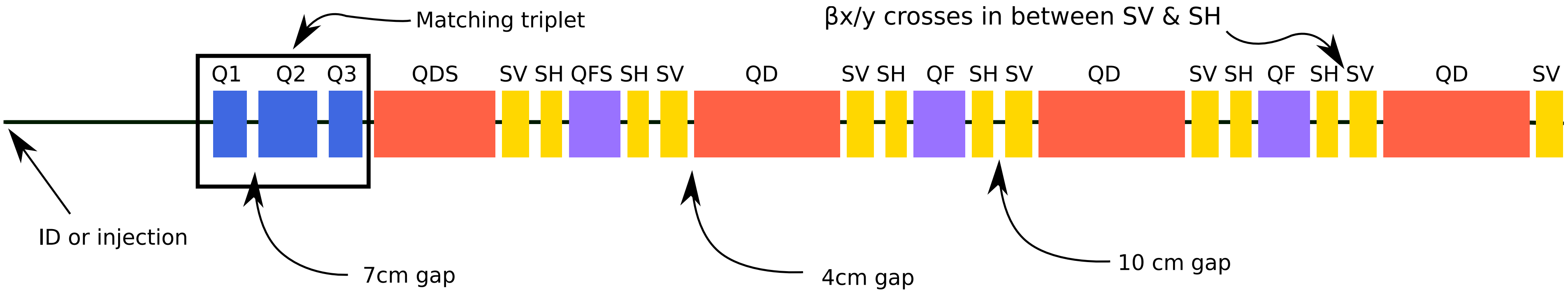
- How many bends per cell? Field strengths and magnet length?
- Optimzing all these params is a huge computational task: requires to **compute DA and lifetime millions of times**

...ideally a **fast optics solver and a big computer** are required

Strategy to approach the lattice design and optimization

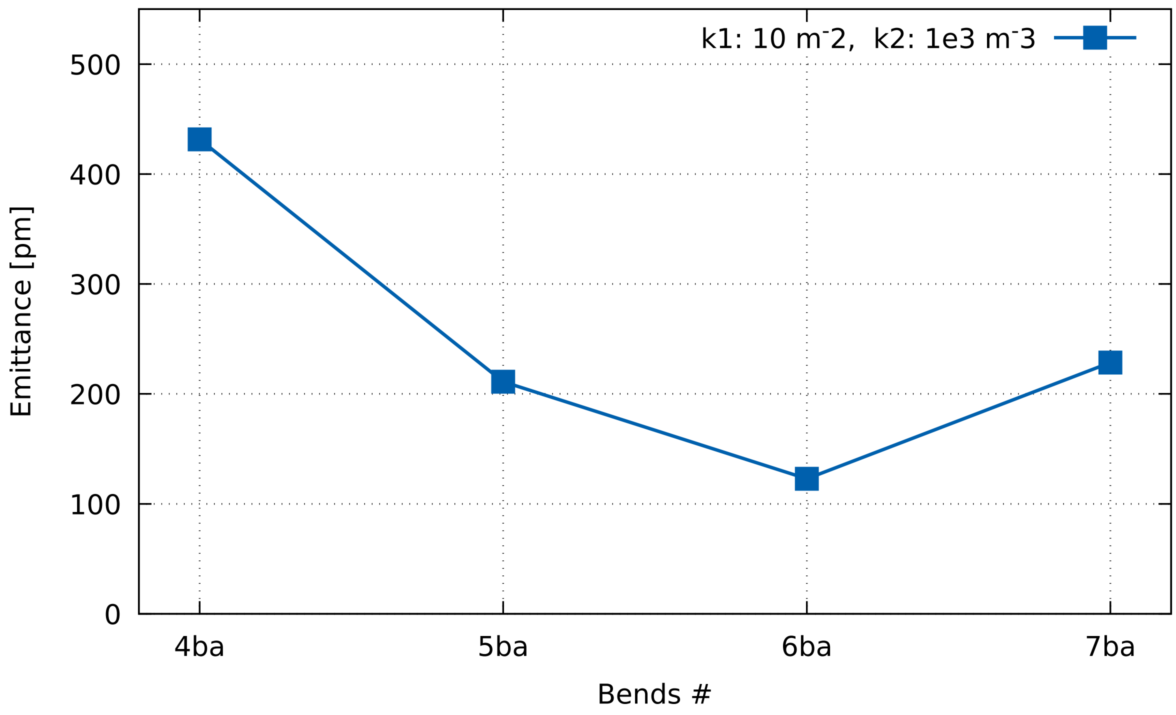
- Developing a light-weight and efficient **tracking code (UFO running in GPUs) to speed-up the evaluation of millions of lattices** (see Michele Carlà talk and IPAC 2022 ...)
- The chosen baseline lattice has to be **not too aggressive in terms of maximum fields**, but we have to invest on **technical solutions for small magnet-to-magnet gaps**
- The chosen baseline lattice has to allow an **injection scheme based on well known and tested solutions** (off-axis, multipole injection kicker)

Details of a cell

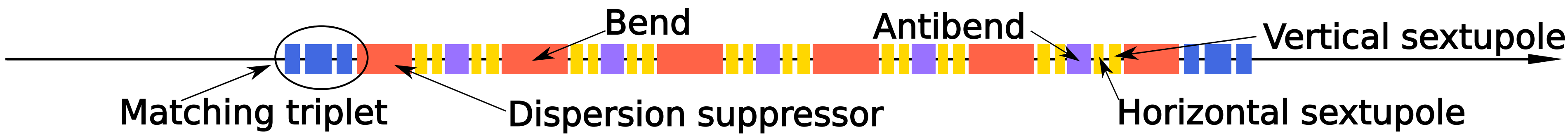


- **Injection and ID straights are physically identical**, only the setpoints of the triplet are different
- **QF and QD** are **combined function** dipoles
  - QD is a weak bend/weak quadrupole
  - **QF** is a weak **antibend**/strong quadrupole
- We start the design process with **only two** main families of **sextupoles** (SH, SV)
- Quadrupoles up to **100 T/m**
- Sextupoles up to **5000 T/m^2**

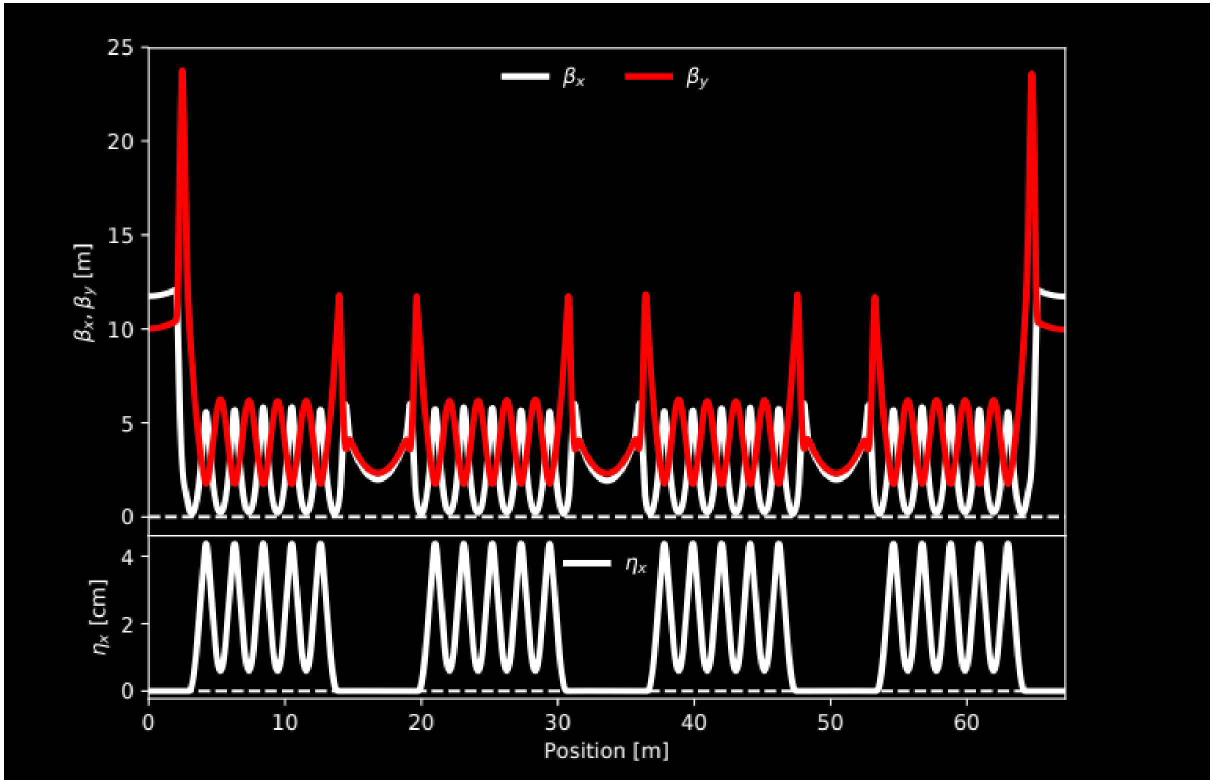
Number of bends and optimization



1. **Optimize arc** (“6BA block”) targeting: ε_x, α_c, $\psi_{x,y}$ (10k iterations)
2. **Add matching triplet** and mutate randomly the arc until closed solution is found
3. **Optimize the entire ring** targeting: ε_x, **DA**, **lifetime**, α_c, (10k iterations)

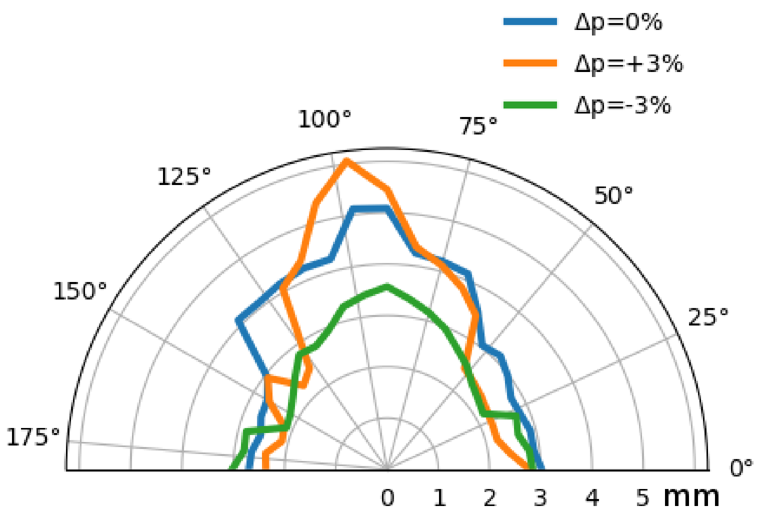


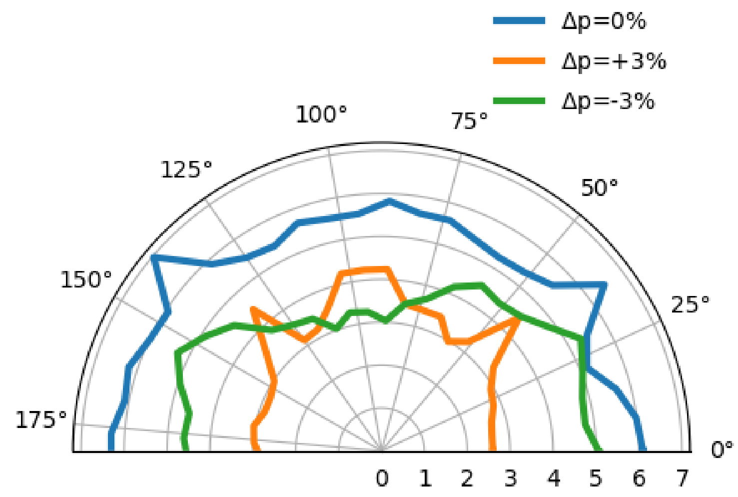
The 6BA for ALBA-II



- **16 cells** reflecting the current ALBA **4-fold symmetry** (quadrant = high beta - low beta - low beta - high beta)
- **High β_x** sections are used for **injection** and RF cavities
- **<u>Equilibrium emittance: 137 pm·rad</u>**
- Energy loss: 843 keV/turn
- **Qx /Qy : 43.68 / 11.67, Chromaticity: -94 / -51**
- α_c : 0.8·10−4
- $\beta_{x,y}$ at ID: 2 m

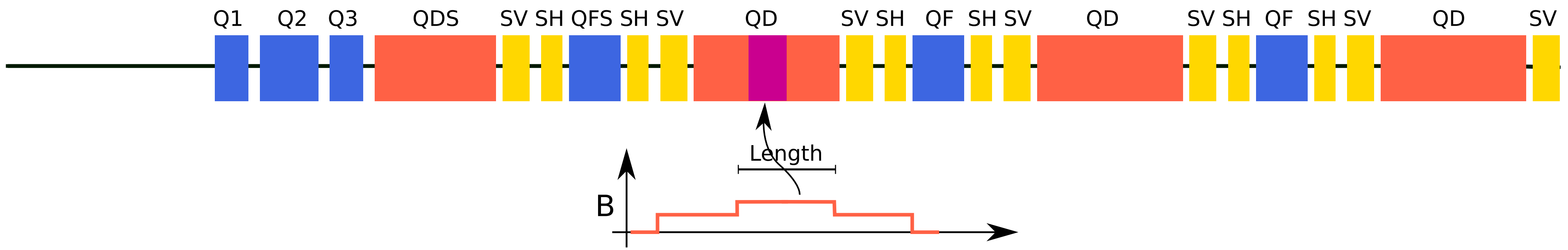
DA and high betas straight sections



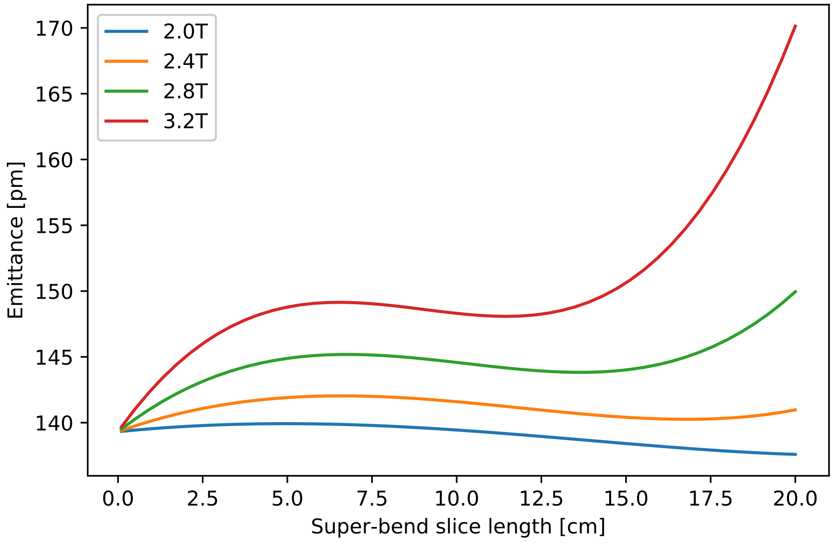


- In the **16 identical cells** configuration the dynamic aperture is too small to inject (**left**)
- **β_x is increased** (2m → ~10m) at the injection (4 straights to preserve symmetry) to magnify the horizontal DA (**right**)
- In both cases only **2 families of sextupoles** are used!

Super-bends



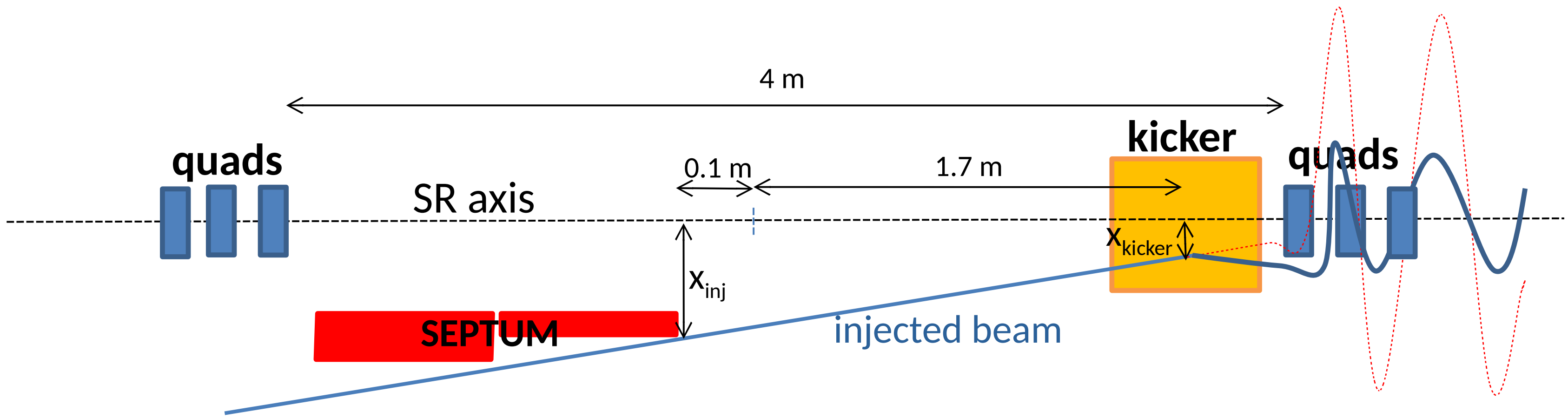
- ALBA-II dipoles have ~1T
- Superbend geometry has a direct **effect** on linear optics (**emittance**)
- **Length** and **field** have been **scanned**
- The simulation refers to one superbend per cell (**16 superbends total**) if only **8 superbends** are installed **the effect is halved**!



→ **from an optics standpoint 10 cm 3.2 T superpend looks acceptable**

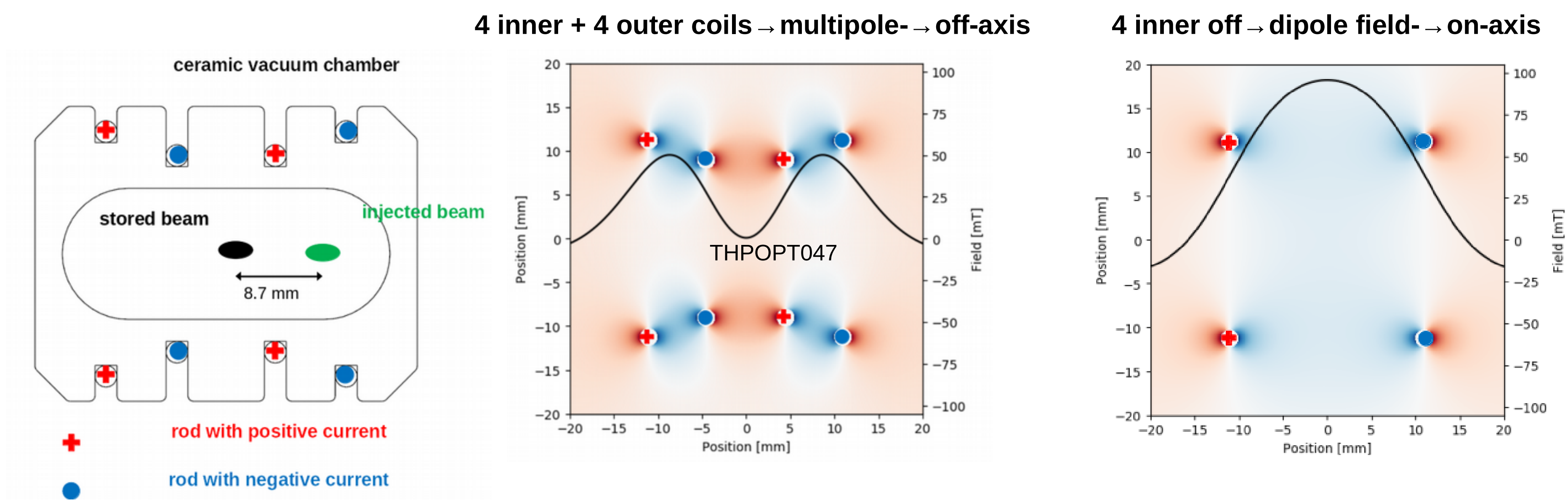
Off-axis injection scheme

- The ALBA-II lattice is very dense, all the injection elements should fit in a 4 m dedicated straight section
- The beam from the booster is injected off-axis
- To capture the injected beam, a multipole magnet kicks it to reduce its large oscillations within the DA



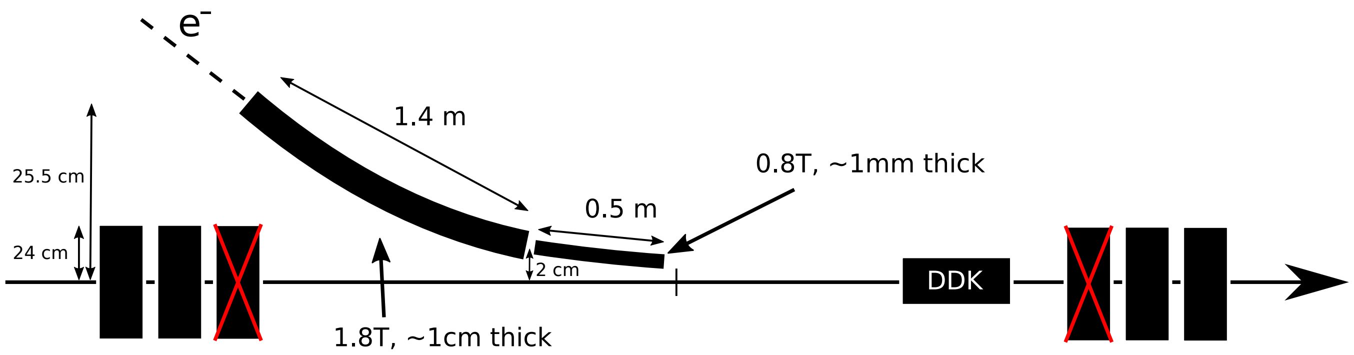
DDK: the ALBA-II multipole injetion kicker

A **novel topology** has been proposed for the coils positions: **Double Dipole Kicker**



- The DDK field is designed for off-axis injection
- Switching off the 4 outer rods, a dipole field is obtained, useful for on-axis injection during the first turn commissioning and saving a dipole kicker in the injection section
- A **prototype** of DDK is now under design and will be tested in ALBA *(see IPAC 2022 THPOPT047)*

Two septa scheme: quad rearrangement



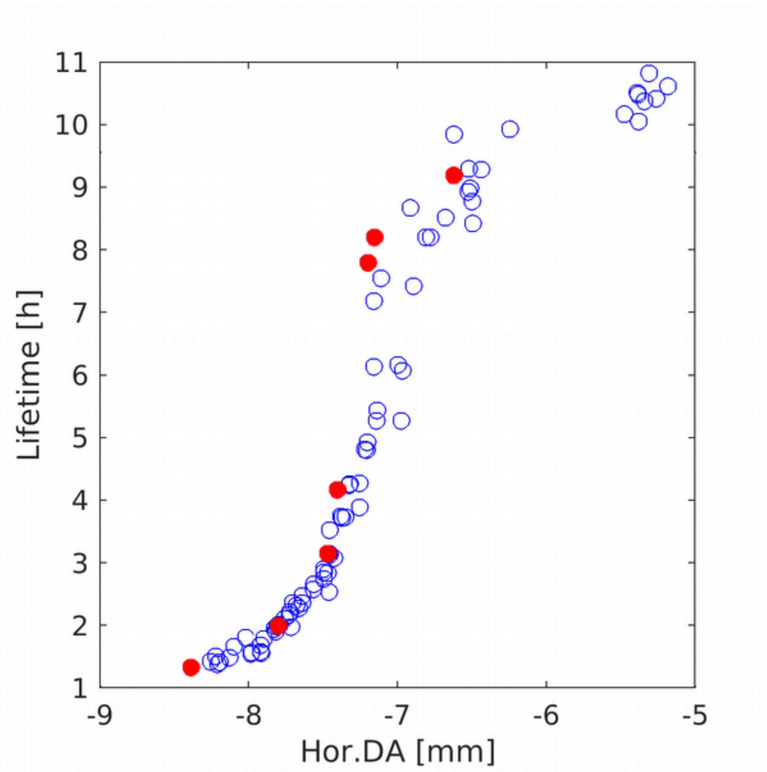
- The required fields and septa thickness are ~ within reacheable values
- To reduce the effort required in the design of such magnets a possibility is to **remove a quadrupole in each triplet** and enlarging the straight section by 30-50cm (this is not trivial from a beam dynamics point of view)

	+30cm	+40cm	+50cm
Thin septum field	0.64T	0.55T	0.50T
Thick septum field	1.4T	1.3T	1.1T

- Fields are changed to keep the same injected beam trajectory
- The injection is always at 5 mm from the stored beam

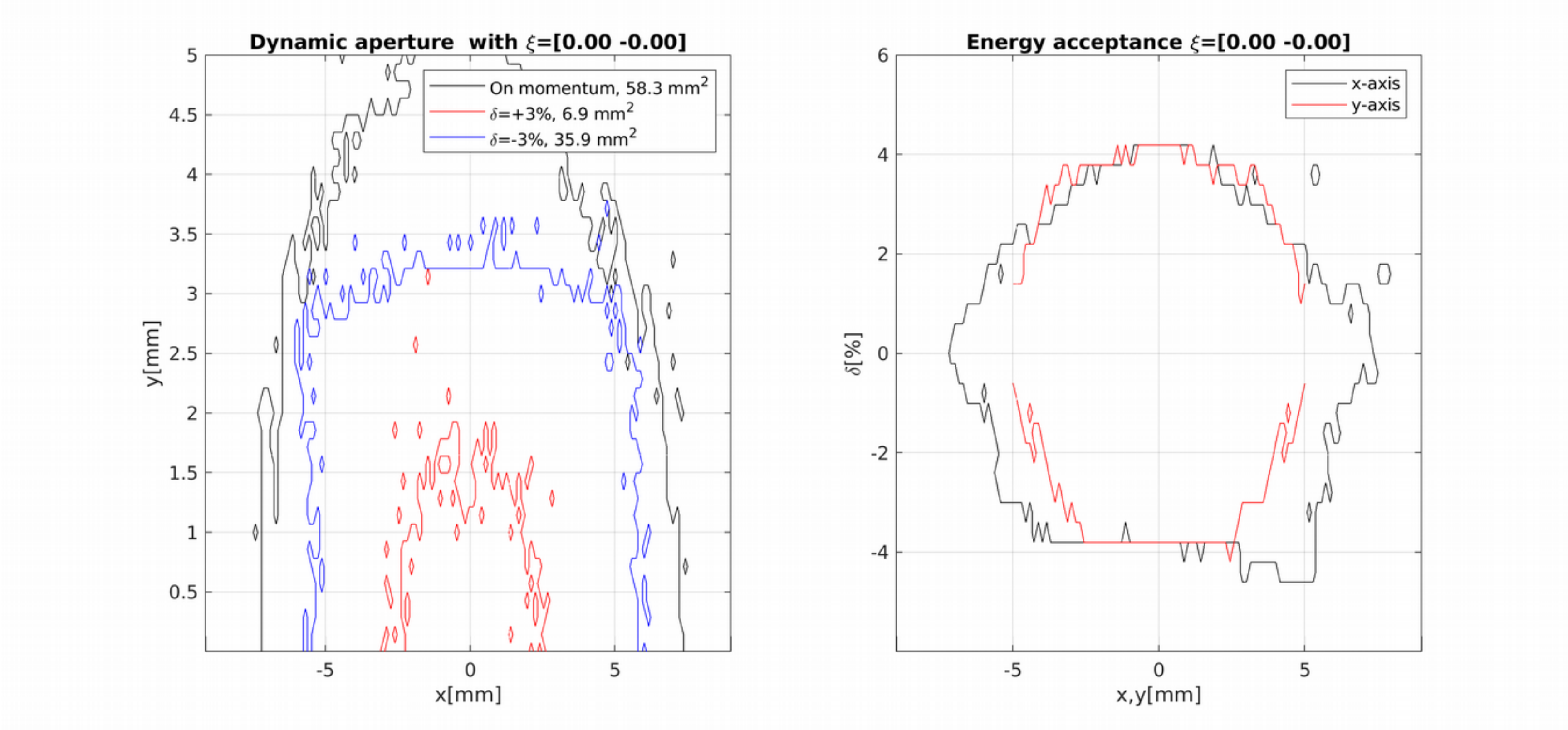
...on going work

MOGA and DA with more than 2 sexts



- Run a first test to optimize 6 families of sextupoles with a genetic algorithm (NSGAII) using AT
- Results are promising: horizontal DA can be pushed above 8mm even though a substantial reduction in lifetime is observed

Non-linear optics with 6 sextupole families



- Off-energy DA is considerably reduced causing the drop in lifetime next MOGA will be
- implemented in UFO and a complete study carried out.

...systematic study pending

ALBA vs ALBA-II

	DBA	6BA
Emittance	4.5 nm·rad	**140 pm·rad**
Energy	3 GeV	**3 GeV**
Circumference	268.8 m	**268.8 m**
Number of cells	8+8	**16**
Number of straights	4 / 12 / 8	**16**
Straight lengths	7.8 / 4 / 2.3 m	**4.00 m**
Straight ratio	36%	**24%**
Working point	18.15, 8.36	**43.68, 11.67**
Chromaticity	-39, -29	**-94, -51**
Mom. Comp. factor	$8.9 \cdot 10^{-4}$	$\mathbf{0.8 \cdot 10^{-4}}$
Energy spread	$1.0 \cdot 10^{-3}$	$\mathbf{1.1 \cdot 10^{-3}}$
Energy loss per turn	1023 keV	**843 keV**
Damping times	4 / 5 / 3 ms	**3 / 6 / 6 ms**

Conclusions

<u>Where are we?</u>

- A **6BA + reverse bend + HOA** lattice has been selected as best candidate for **ALBA-II**, given all the space constraints and engineering limits
- A **GPU based code (UFO)** was developed on purpose to speed up the optics optimization (*<u>see Michele Carlà talk</u>*)

<u>Open points:</u>

- An **off-axis injection scheme** is under design with a **novel** multipole kicker design (**DDK**)
- Studies on the impact of **field and alignment errors as well as correction schemes** are on going
- The effect of operating the optics in **full coupling is beeing investigated** with tests carried out in the ALBA storage ring *(<u>see Zeus Martí talk</u>)*
- The optimization of the **dynamic aperture** is still on going
- **Magnet-to-magnet gap** is a critical parameter! To be confirmed by magnets engineering
- Overall **seeking inputs from engineering, vacuum and magnets**: many optics parameters need likely rework!

Acknowledgments

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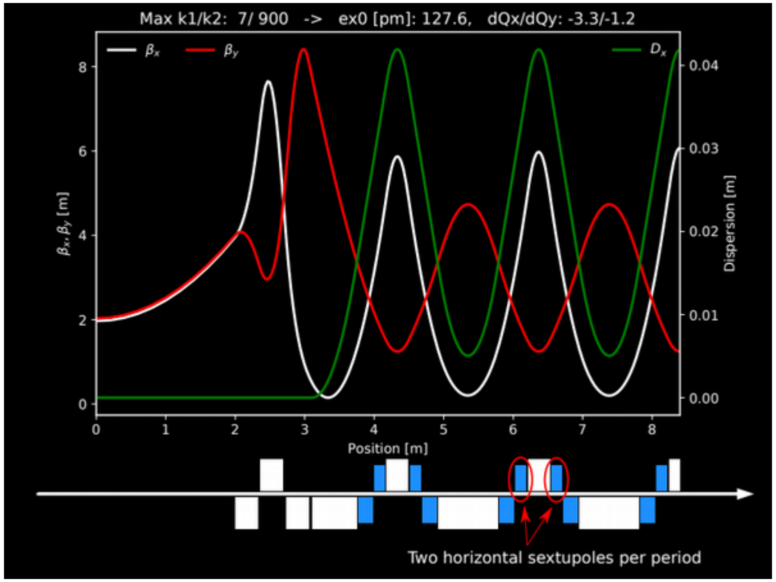
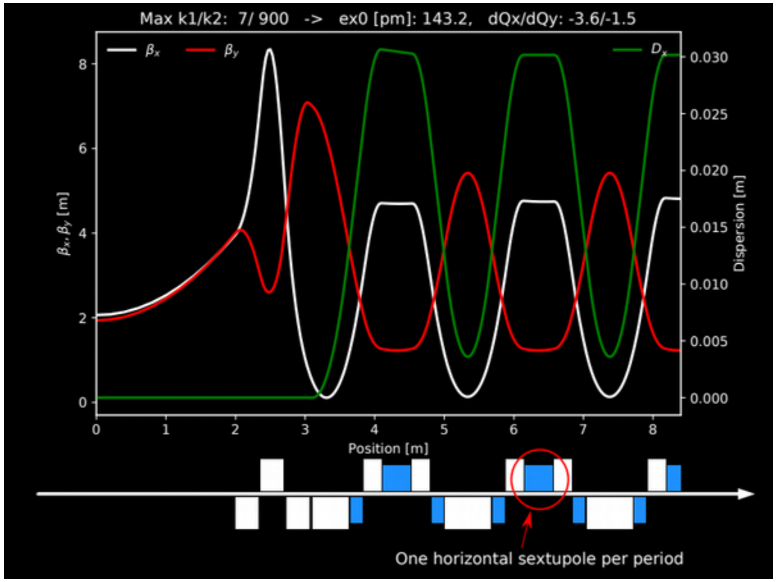
for useful discussions, suggestions and ideas.

Backup slides

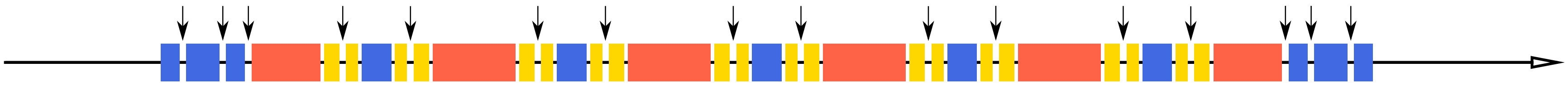
Alternative arrangement for sextupole SH

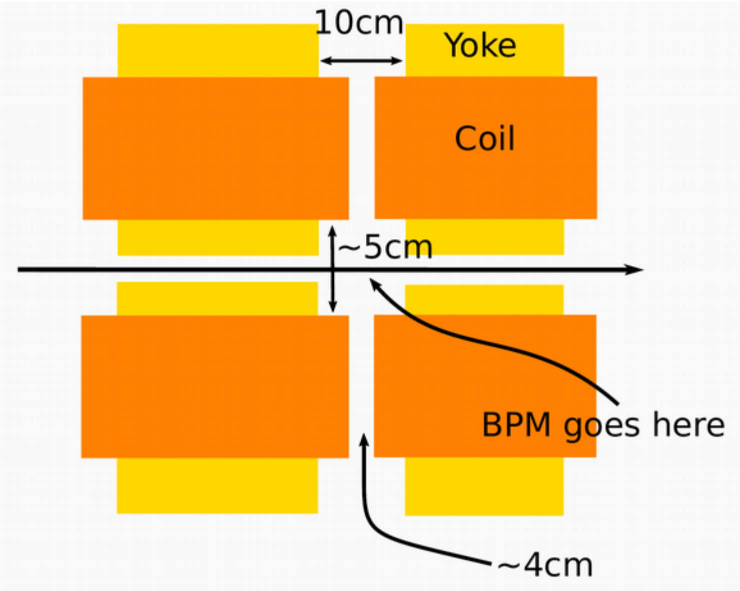




- The one the right (Double-SH) performs slightly better for the ALBA-II 6BA
- Other upgrades (SOLEIL, ALS, BESSY…) use the one on the left (Single-SH)
- No particular reason to prefer one over the other at this stage!

Beam position monitors





- BPMs could be placed in the 10 cm gaps between sextupoles and 7 cm quadrupoles
- Between sextupoles $\beta_x \sim \beta_y$, therefore they should be effective in both planes
- The sextupoles gap can be made slightly larger without too much penalty