MBA studies for the ALBA upgrade

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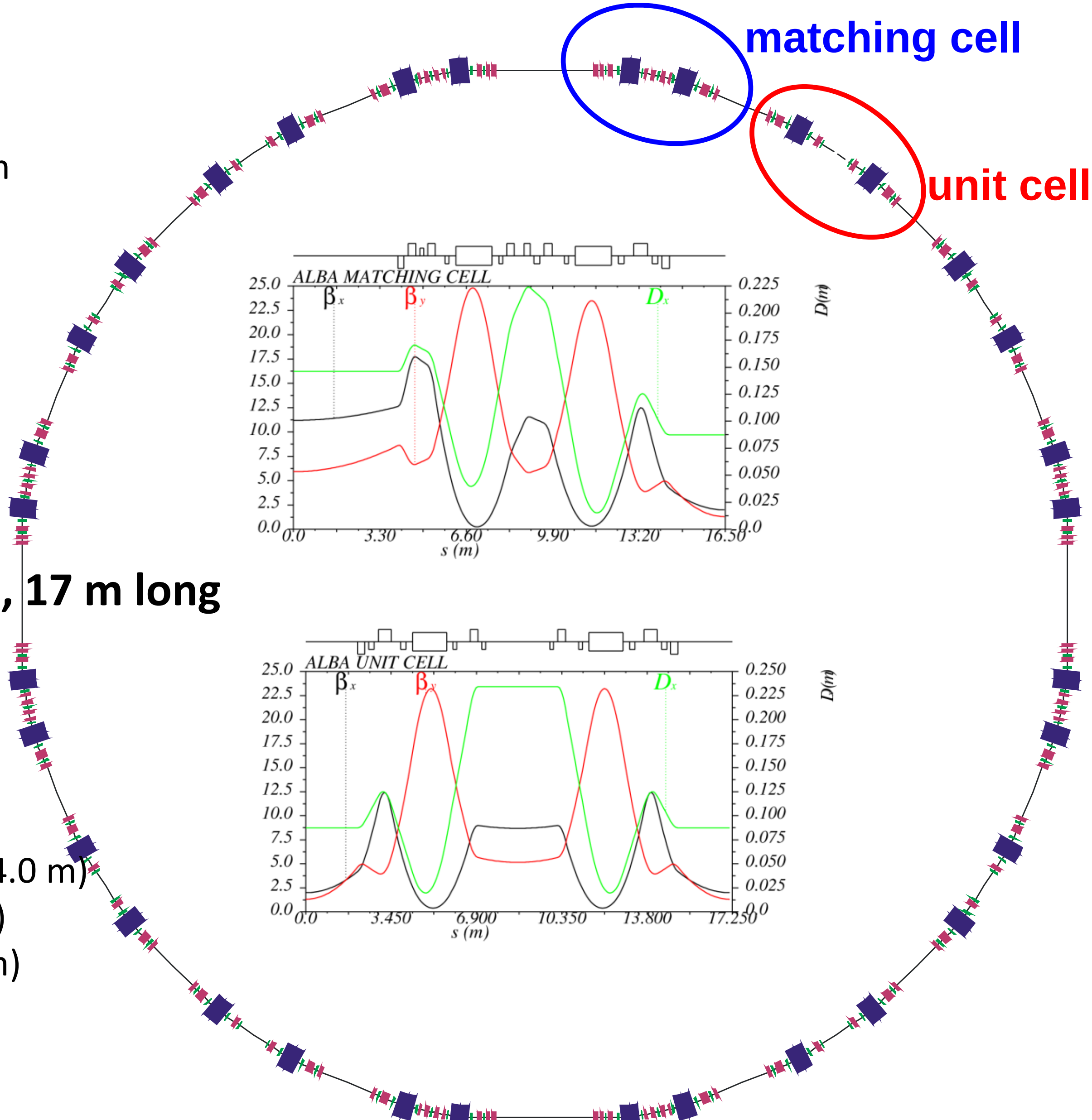
Summary

- The current ALBA lattice
- First study (2019): a dispersion bump H7BA cell for ALBA
- Second study (2020): an extensive search for a distributed sextupoles MBA cell
- A preliminary look at the magnets (preliminary)

Present ALBA Storage Ring Lattice

- Energy = 3 GeV
- Circumference = 268 m
- Symmetry = 4 fold



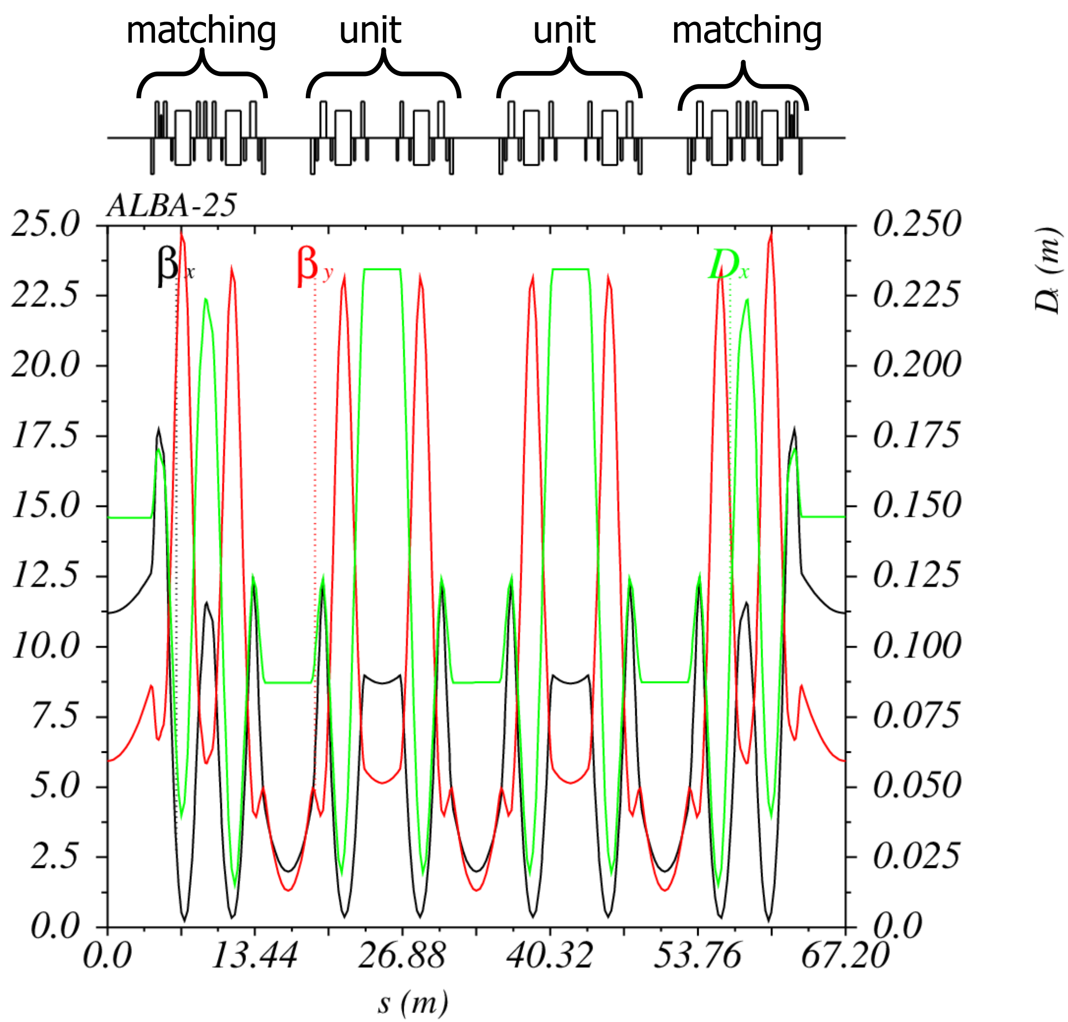
- **8+8 DBA-like cells, 17 m long**

Straight sections:

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

Current ALBA lattice

One quarter of the storage ring lattice:



circumference 268 m, energy 3 GeV, emittance 4.6 nm·rad

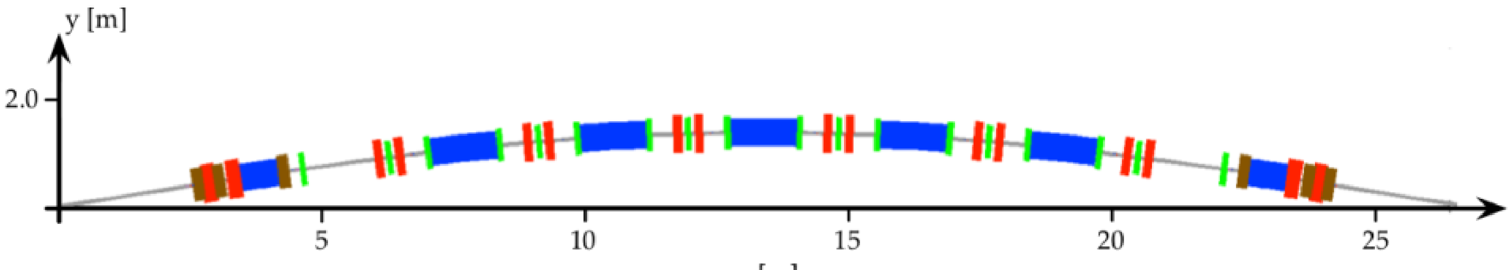
Low emittance options for a very compact cell

- What is the ideal **number of bends**?
- Chromaticity correction:
  - Double **dispersion bump** (ESRF-EBS)
  - **Distributed sextupoles** (MAX-IV)
  - **Bump-less** with a couple small bore **super-strong sextupoles**
  - Exotic ideas:
    - Vertical dispersion to **easy vertical chromaticity correction**
    - Moebius-strip to **avoid vertical chromaticity correction**

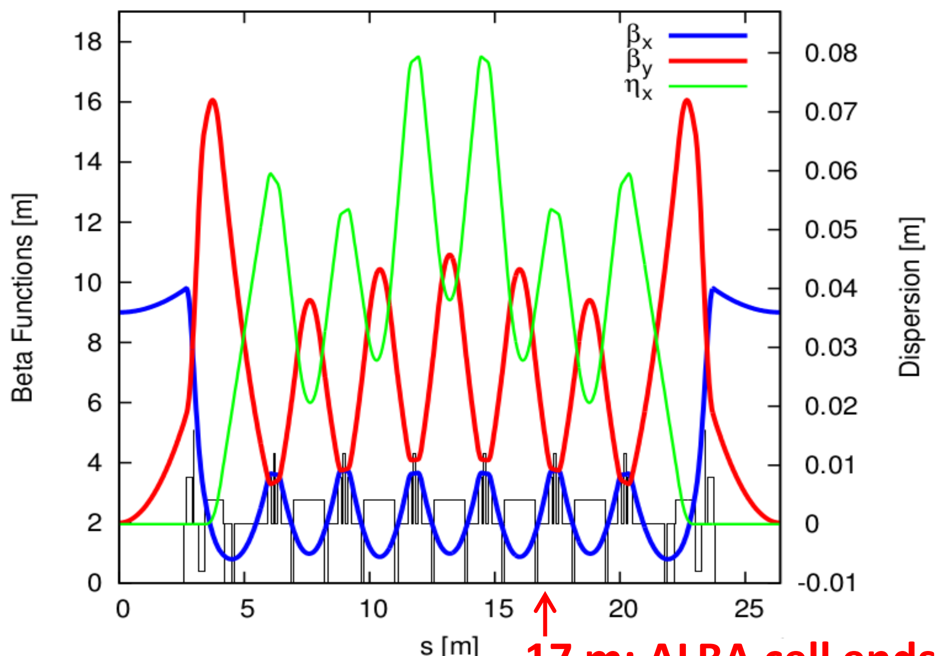
Given all the technological constrains,
which is the best solution for an upgrade?

MAX-IV lattice

- Energy=3 GeV, C=528 m, ε_x=328 pm·rad
- **20 7BA cells, 26 m long →** 20 straights: 4.6 m



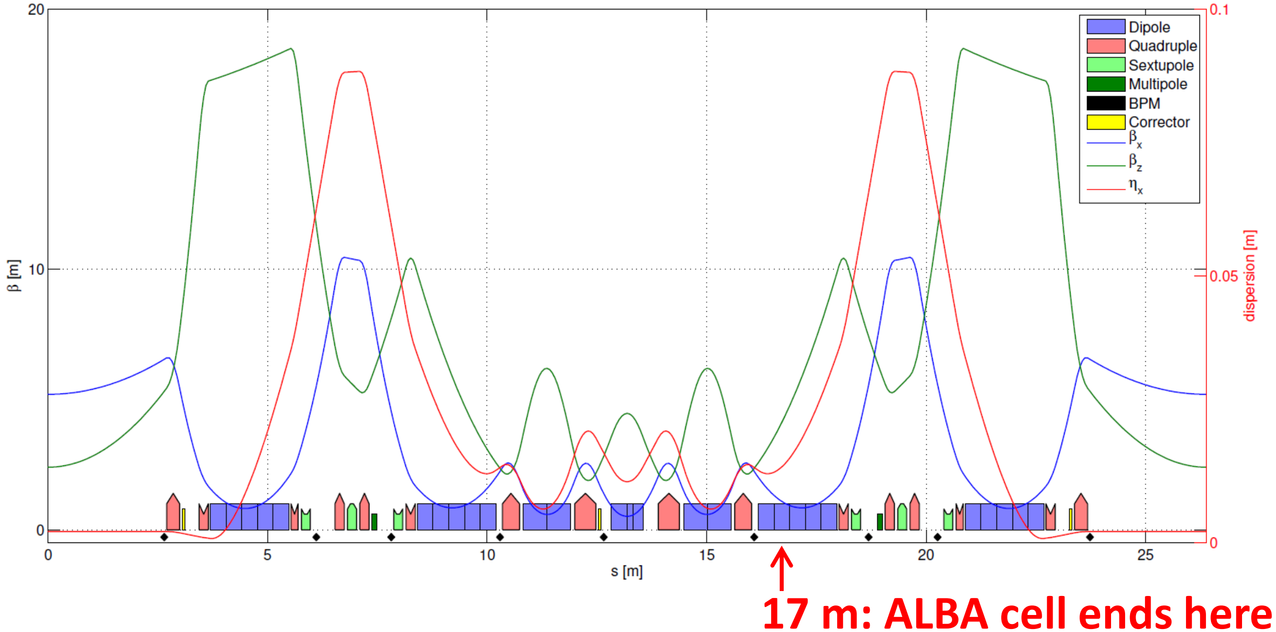
Many sextupoles spread in the cell



17 m: ALBA cell ends here

ESRF-EBS lattice

- Energy=6 GeV, C=844 m, ε_x=134 pm·rad
- **32 Hybrid 7BA cells, 26 m long**



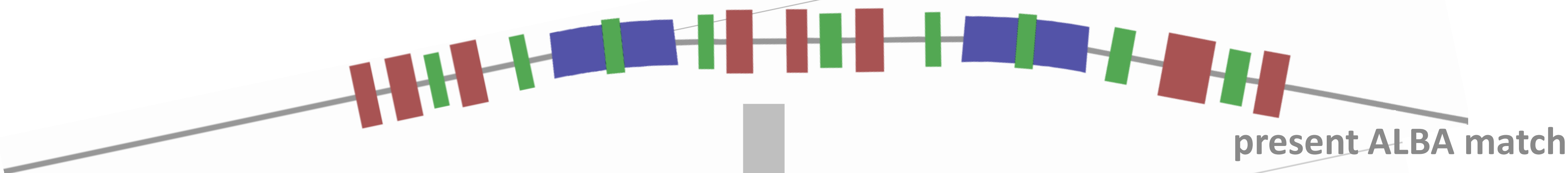
- Large dispersion for chromatic sextupoles
- Only 2 sext families with phase advance = π ("π trick")
- **longitudinal gradient dipoles**
- Long and strong dipoles are used to create dispersion bumps:
  - Emittance is mostly driven by those dipoles
  - Bumps take up a significant space

Specific constraints for ALBA

- Keep beam energy 3 GeV
- Tunnel (SR with similar compact circumference)
- Existing ID beamlines (preserve 16 cells and source points)
- Straight sections longer than 4 m, $\beta_x = \beta_y = 1\text{-}1.5$ m
- Reduce emittance at least by a factor 10
- Keep injector (present $\varepsilon_x^{booster} = 10$ nm·rad)
- Keep infrastructures, as much as possible

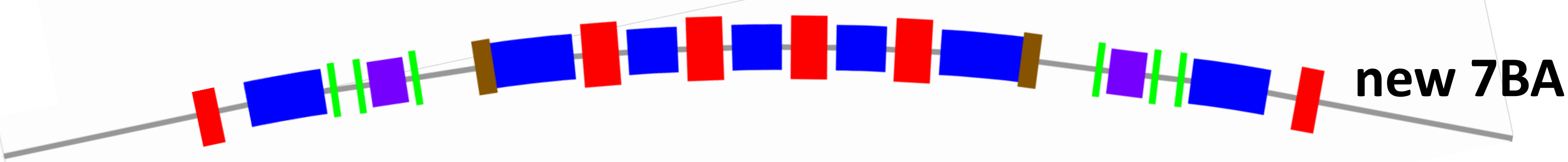
First Study: from DBA to H7BA

Following SOLEIL's IPAC2018 example, in 2019 we started testing a H7BA cell:



8 unit + 8 matching cells → 12 medium straights 4.0 m + 4 long straights 7.8 m

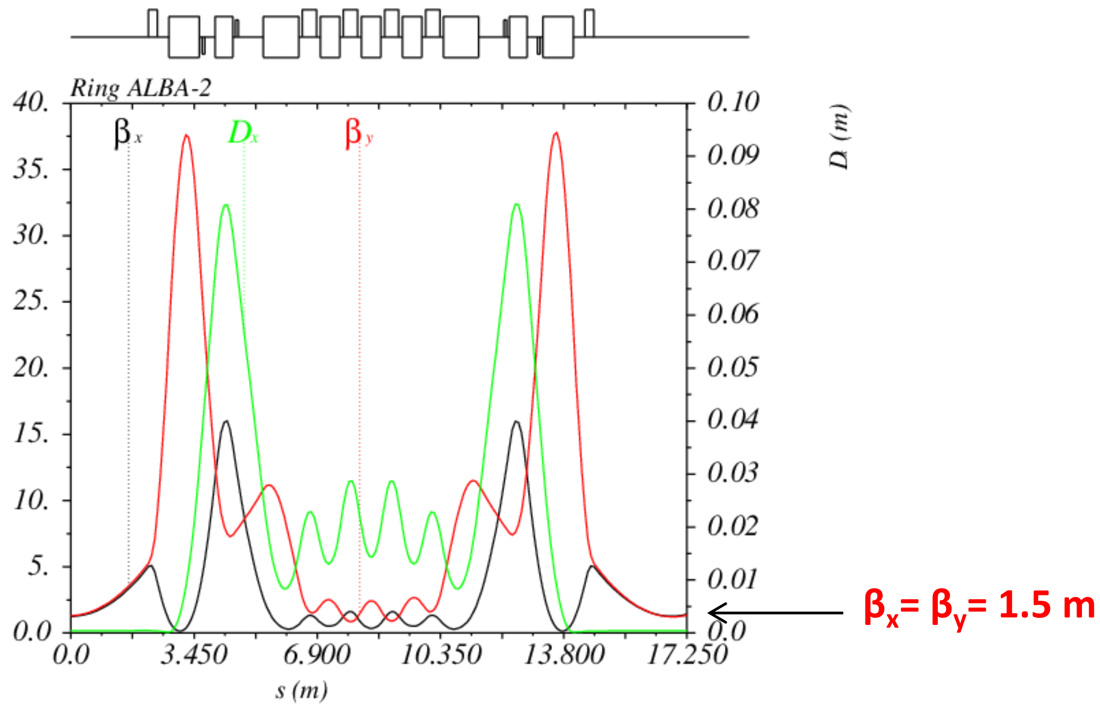
16 hybrid 7BA with anti-bend identical cells → 16 straights 4.35 m



7 transversal gradient BENDS (no longitudinal gradient)
6 focussing QUADS (< 90 T/m)
2 ANTI-BENDS: knob to minimise dispersion in BEND 2 and 6
3 families of paired SEXT with "π trick" (<2000 T/m^2)

H7BA cell for ALBA

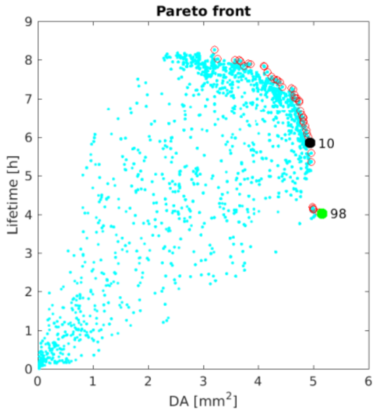
"First study for an upgrade of the ALBA lattice", IPAC 2019



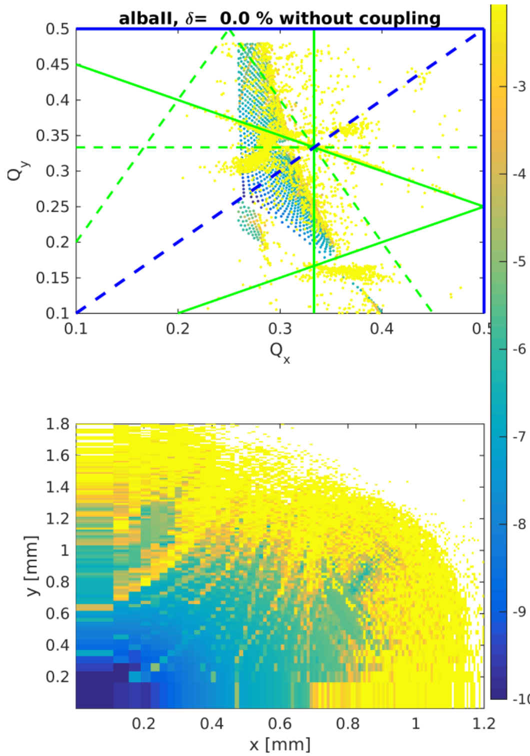
ε_x= 160 pm·rad without longitudinal gradient in bending magnets

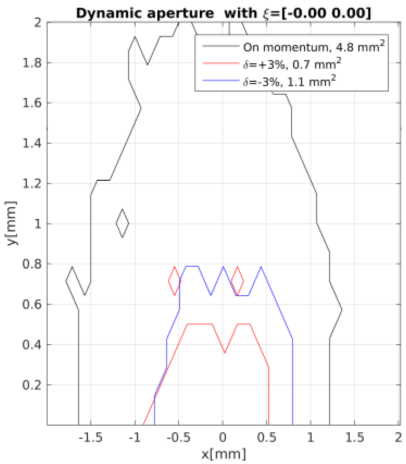
(with longitudinal gradient ε_x= 140 pm·rad)

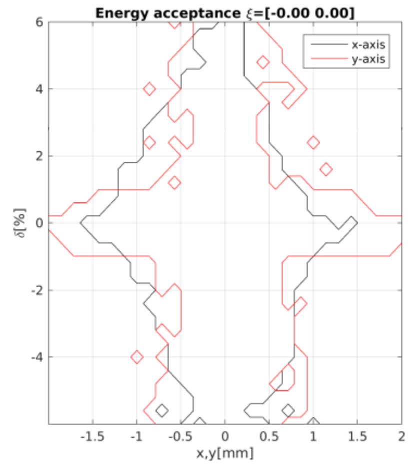
Dynamic and Momentum Aperture in H7BA



The 3 sextupole strenghts were found with MOGA to optimise lifetime, DA and MA

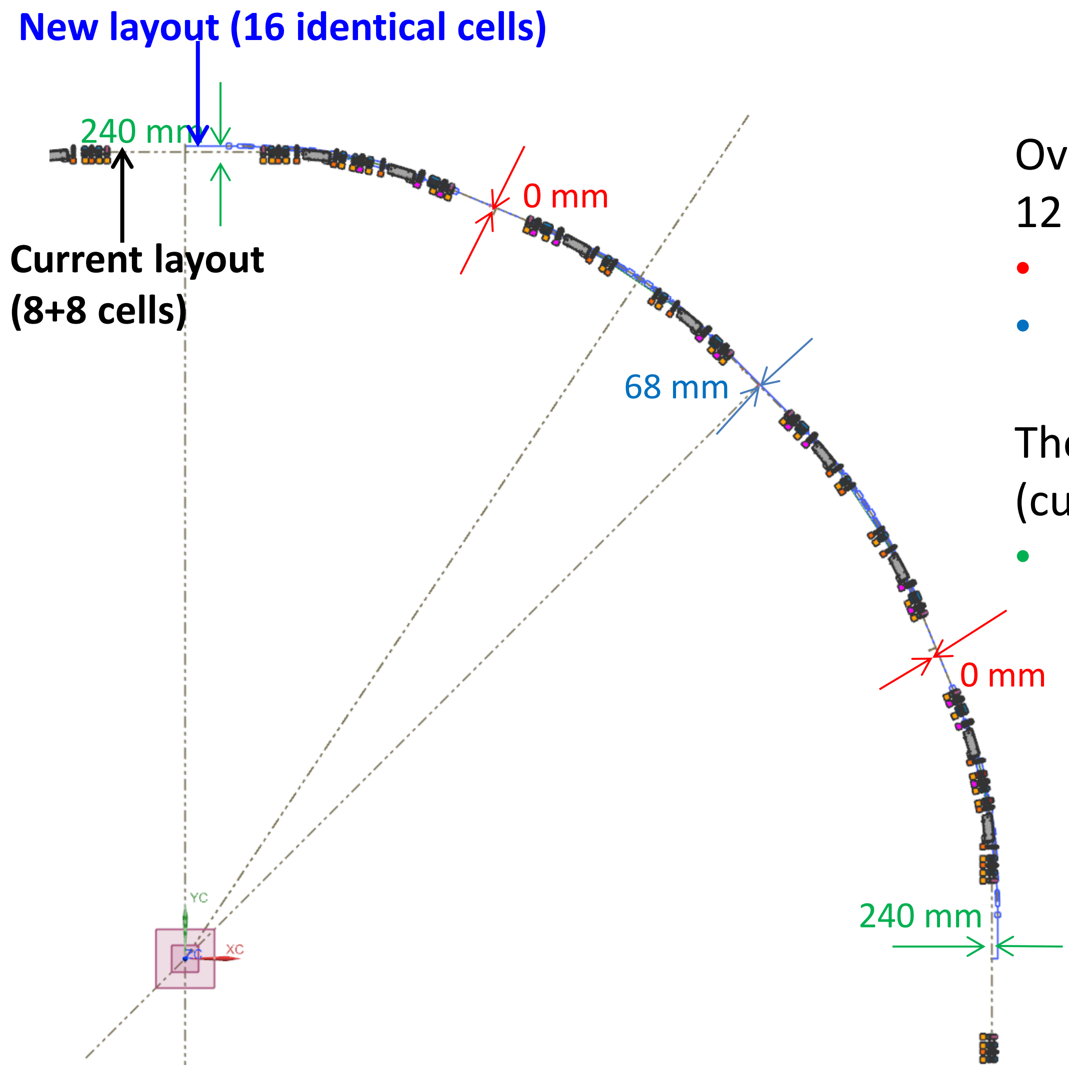






Dynamic aperture quite small and momentum aperture even much smaller

BLs Source Points: New *vs.* Present Layout



Over the source points of the present 12 Medium Straight Sections:

- **8 would be preserved**
- **4 radially shifted by 68 mm**

The present 4 Long Straight Sections (currently not used yet for BLs):

- **All radially shifted by 240 mm**

Any other layout based on 16 identical cells gives very similar shifts for the BLs source points.

Second Study: distributed sextupoles

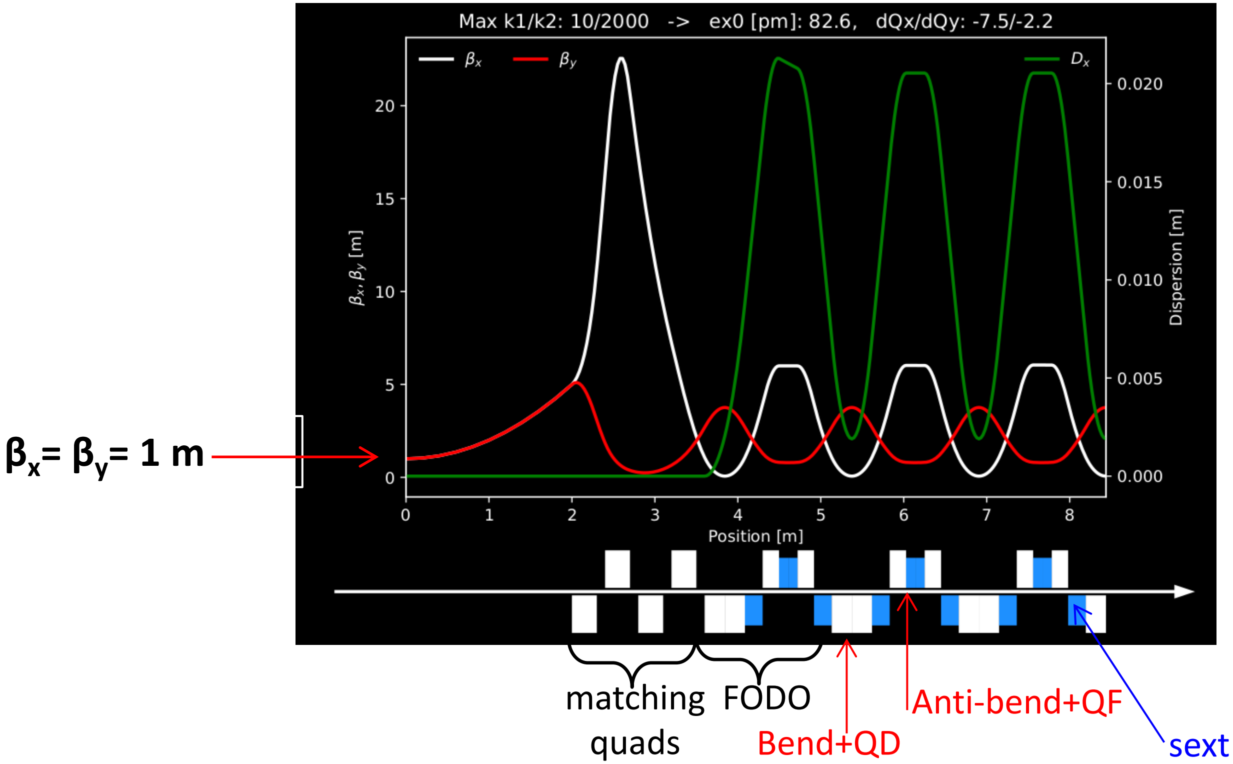
A compact cell with double dispersion bump (H7BA) for ALBA gives **small dynamic and momentum aperture**:

… is there any better solution for ALBA?

In February 2020 we covered a new position only dedicated to the ALBA upgrade studies and we have restarted the quest for the best lattice solution.

Distributed sextupoles lattice

Example of half 7BA cell:



- The FODO is made of **quadrupoles combined with dipole and reverse dipole**
- The reverse dipole decrease the emittance by a factor 2
- Many small sextupoles are introduced in the FODO
- An exhaustive search is required to test all the possible configurations (number of bends, maximum gradient strength...)

Optimisation Algorithm

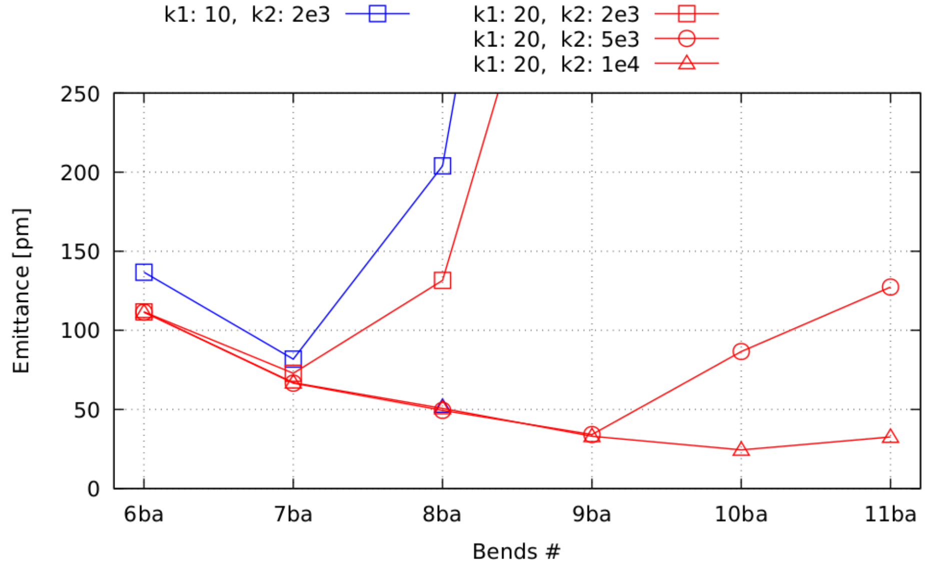
- Lattices are generated from a set of parameters: magnet length, strength... and constraints: maximum fields, gradients…
- Parameters are randomly sampled to generate lattices
- A lightweight optics solver (a simplified lattice code written in house) selects the best solutions
- Final solutions are checked against MAD-X and Elegant

Optimization was run for different **number of bends**: 6BA → 11BA
and for different sets of constraints (max quad and sext gradients)

Distributed sextupoles solutions

We run the optimiser for two values of the maximum quad gradient and looking for emittance below 200 pm·rad:

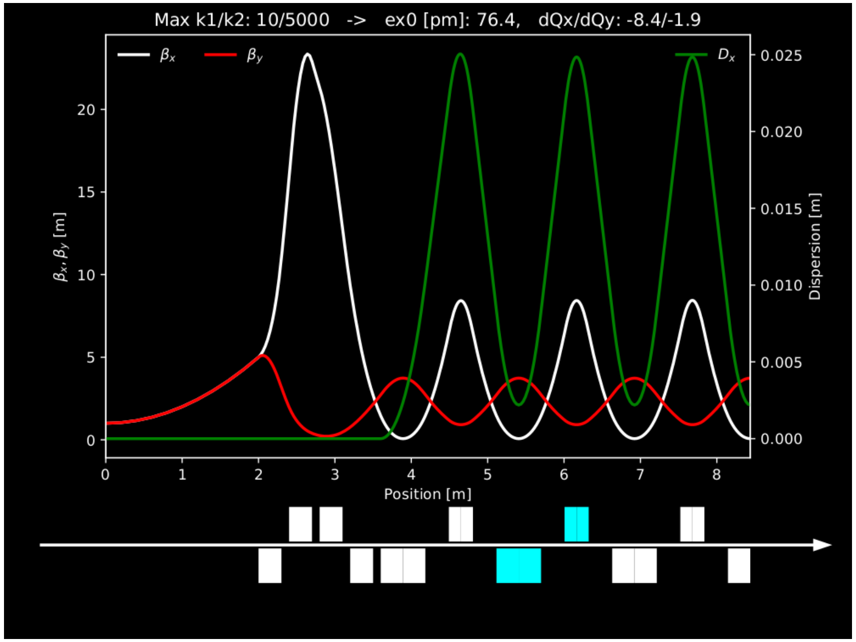
- 100 T/m (blue), aperture 20 mm (state of the art of current lattice upgrades)
- 200 T/m (red), aperture 10 mm



- Each point is the best out of 5 seeds
- Each curve represents a different max sextupole strength
- For 100 T/m quad gradient: best solution would be a **7BA with ε_x= 75 pm·rad**
- For 10 m^{-2} quad strength (100 T/m), the max required sext strength is 2000 m^{-2} (20000 T/m^2) → **sextupoles with smaller aperture (≈10 mm)**

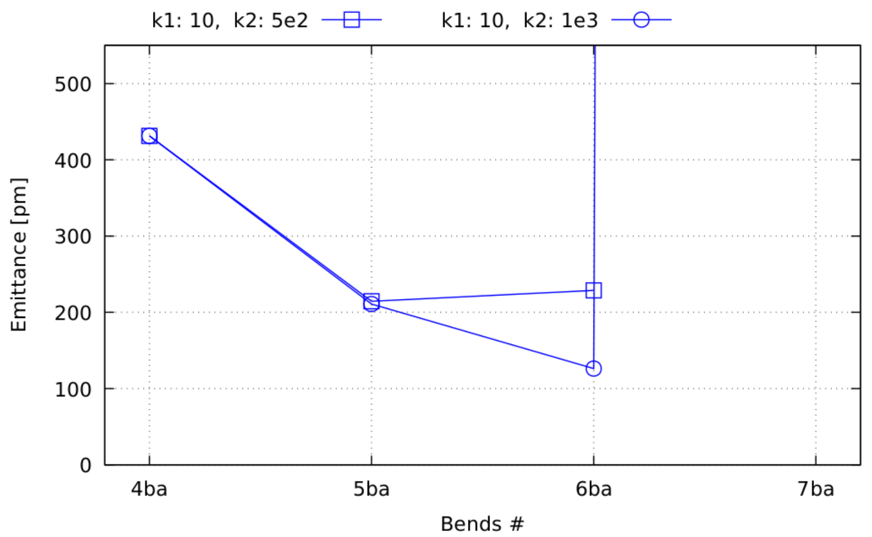
Chromaticity correction with 2 sextupoles (no bump)

7BA chromaticity correction with coupled sextupoles and no dispersion bump:
ε_x= 76 pm·rad

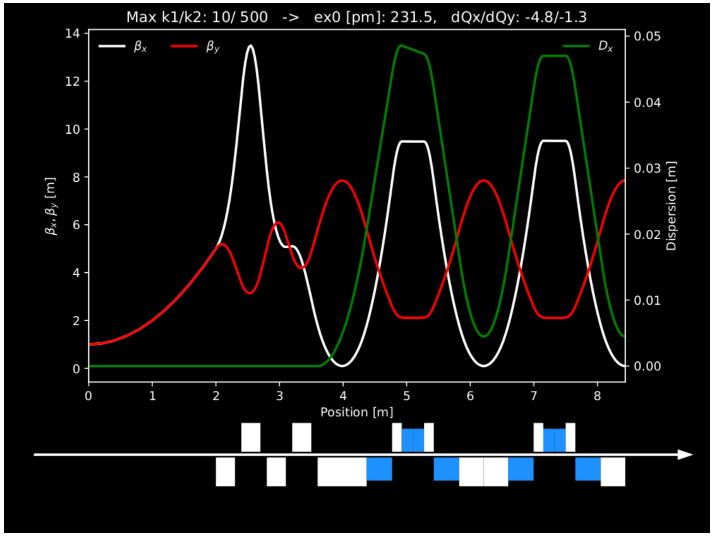


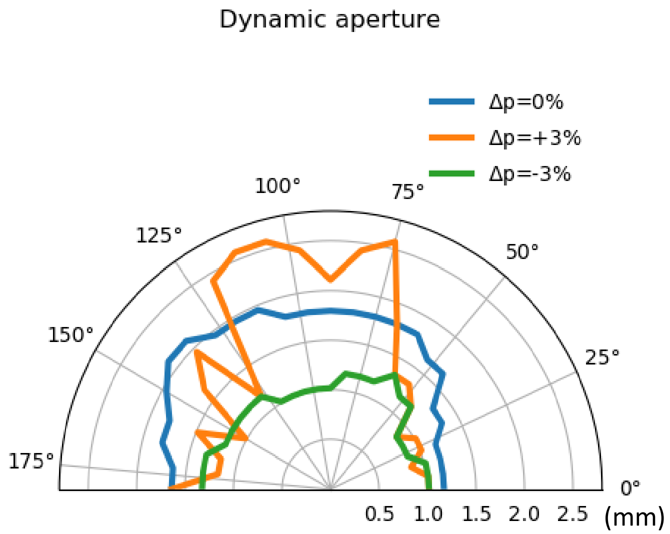
- 100 T/m max quad gradient
- **Strong sextupoles** are restricted to two locations (as in the ESRF lattice) but without β_x and dispersion bumps
- Only 4 sextupoles required, but much stronger! (50000 T/m^2)
- The vacuum chamber should have a smaller aperture (≈8 mm) only at sextupole locations

Relaxing the sextupoles



A relaxed solution with 5000 T/m^2 sextupoles is a **5BA with ε_x= 230 pm·rad**

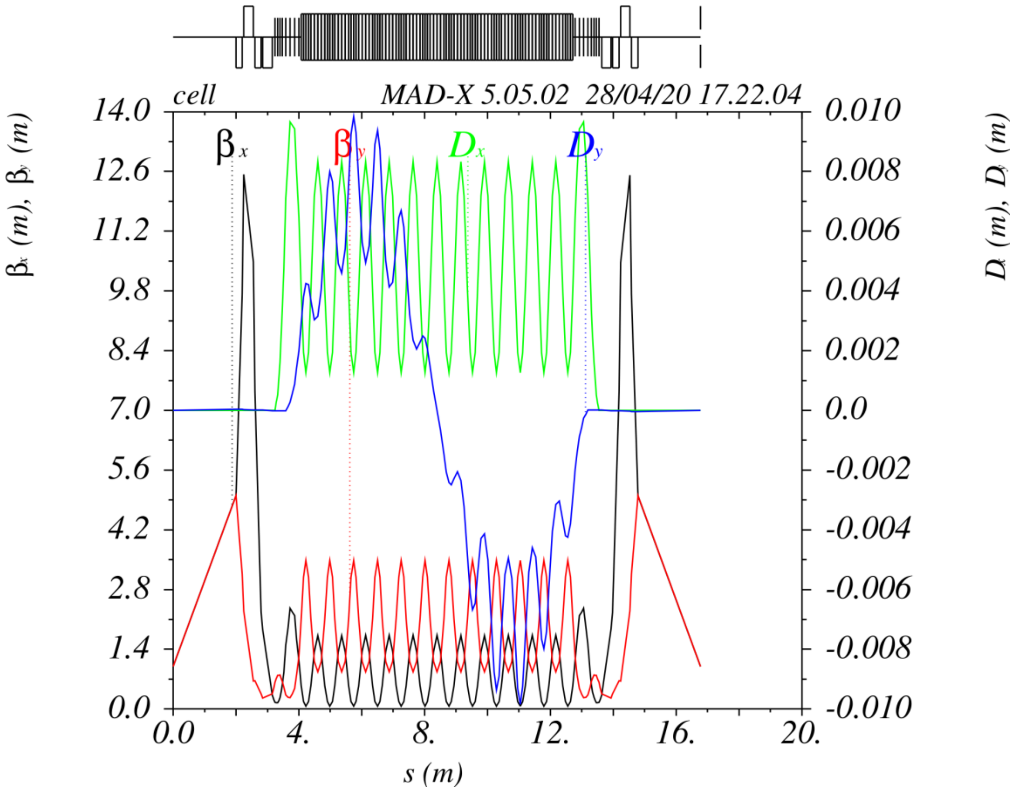




Dynamic aperture and lifetime larger than H7BA and optimisation has not been performed yet

Exotic ideas 1: Vertical Dispersion

Vertical chromaticity correction is harder than horizontal one:
can we easy the process by introducing some **vertical dispersion**?

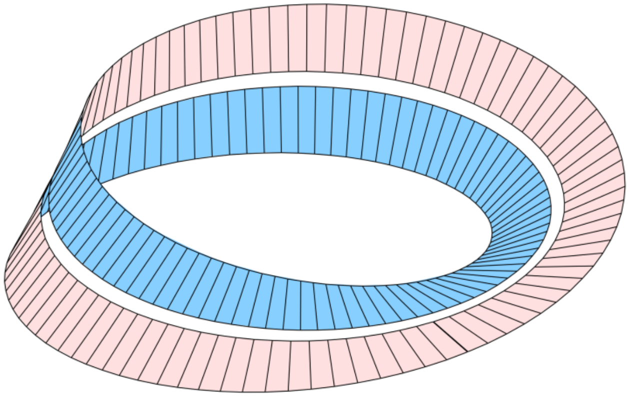


The added constraints results in complicated optics

- Substantial vertical emittance
- Up and down bumps in vertical orbit

...Not really promising

Exotic ideas 2: Moebius String

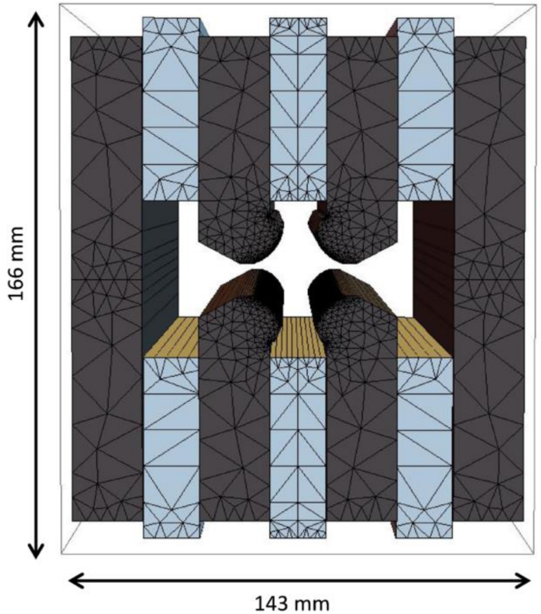


- The rotation is obtained by means skew-quadrupoles
- Phase space is rotated in the transverse plane 90^{o} each turn
- Horizontal and vertical planes are fully coupled
- The machine exhibits one tune → one chromaticity
- **Only horizontal sextupoles are required to correct chromaticity**
- DOES IT REALLY WORKS? ... it was tested once in Cornell

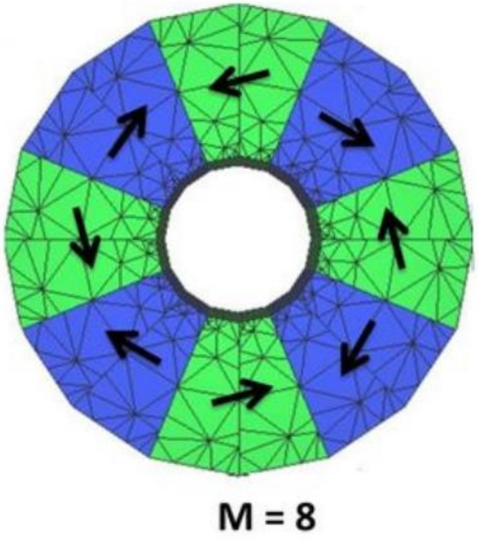
(Richard Talman, Phys.Rev.Letters 74, 1995)

Permanent magnets (very preliminary)

Miniaturisation issues, studying two options: iron dominated (hybrid) and Halbach arrays



(P.N'gotta et Al. PRSTAB 19, 2016)



NdFeB:

- Remanence: 1.4 T
- Temperature coeff: 0.1%/C
- Rad. damage threshold: 10^{15} n/cm^2

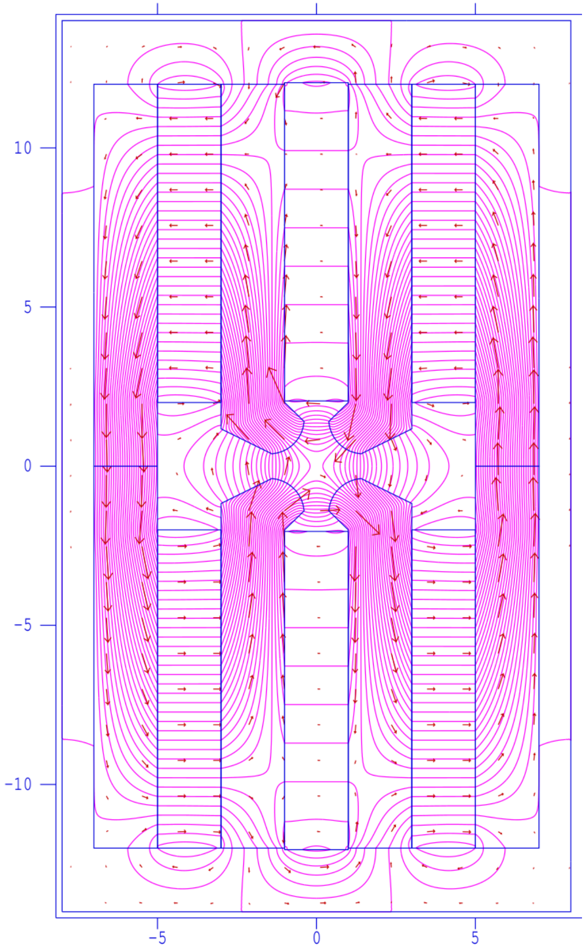
SmCo:

- Remanence: 1.1 T
- Temperature coeff: 0.03%/C
- Rad. damage threshold: 10^{19} n/cm^2

(N.Tsoupas et Al., Physics Procedia 90, 2017)

ESRF inspired quadrupole

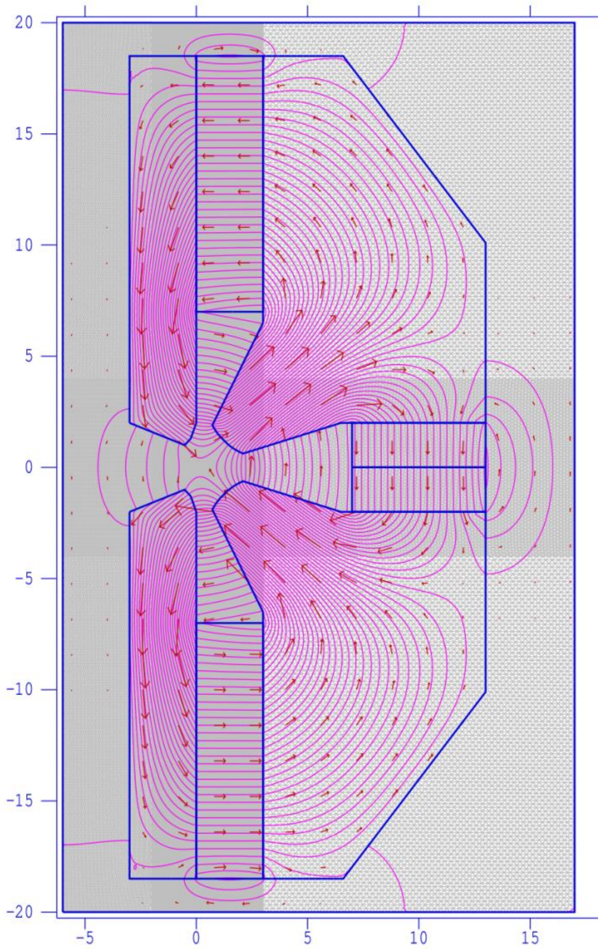
First rough 2D simulation:



- Hybrid: steel + permanent magnet
- Considered 3 steel alloys:
  - AISI 1006
  - 1010 (low carbon steel)
  - Fe-Co 50-50 (Special alloy)
- Medium grade NdFeB similar to SmCo
- Bore radius: 10 mm
- Gradient:
  - 114 T/m
  - 104 T/m
  - 125 T/m
- Good field region: ~5mm
- Best gradient error ~0.3%
- Pole tip roughly optimized
- **Disassembly required to install beam-pipe**

Combined function quadrupole-dipole

First rough 2D simulation:



- The two left poles cross the zero field region (center of quadrupole)
- The ideal shape for the left poles is a plane, but a 20 mm gap is added to get the beam-pipe in
- **No disassembly required to install the beam-pipe**
- Quadrupole gradient ~70 T/m
- Dipolar field ~0.5 T
- Pole tip needs optimization, field quality ~2%

What’s next

- Continuing the studies to define a MBA for ALBA:
  - Number of sextupole and locations
  - Clear some room in the centre of the cell to house RF cavities and diagnostics?
  - Solutions for Dipole beamlines
- Collective effects studies and apertures of the vacuum chamber
- Injection scheme
- High gradient and small aperture magnets solutions
- …and by 2021 chose a lattice for the ALBA upgrade

ALBA has two advantages for an upgrade:

- Currently many straight sections are not used yet by beamlines
- The **injector is already suitable** for a low emittance SR

Thank you for your attention!

Questions?