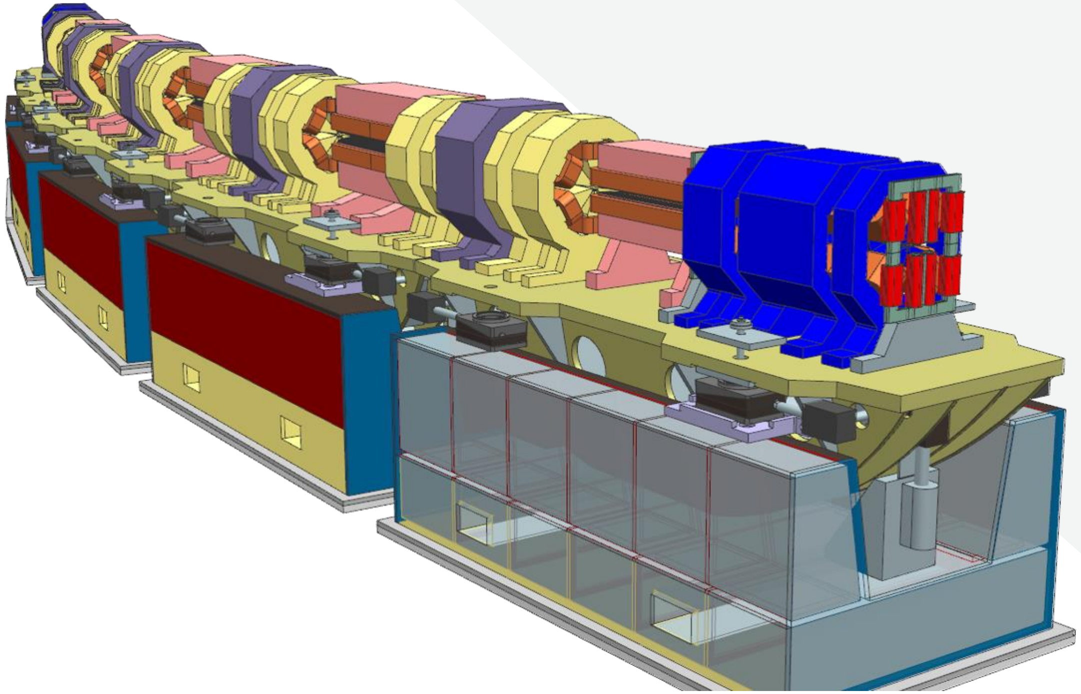
# Design of magnets for ALBA II




Jordi Marcos

on behalf of IDMAFE section


16th February 2023

TE-MSC Seminar @CERN

# Outline

- Introduction to ALBA
- Motivation for upgrade
- Description of ALBA II project
- ALBA II magnet requirements
- Magnets group at ALBA
- ALBA II magnets design
- Conclusions

# Outline

- **Introduction to ALBA**
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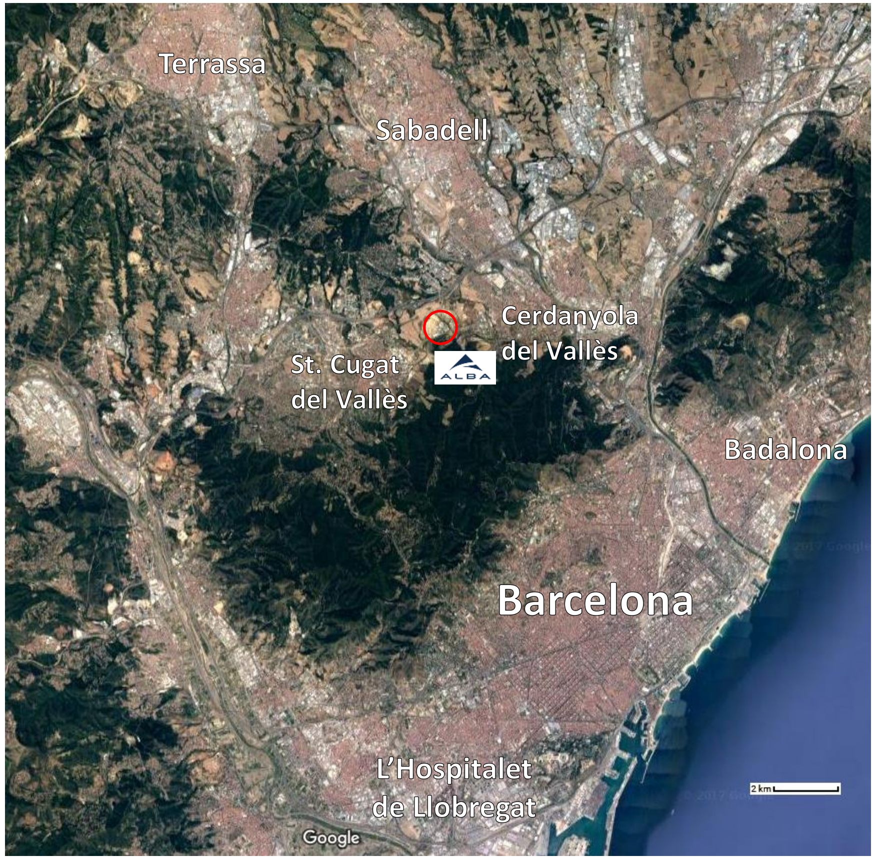
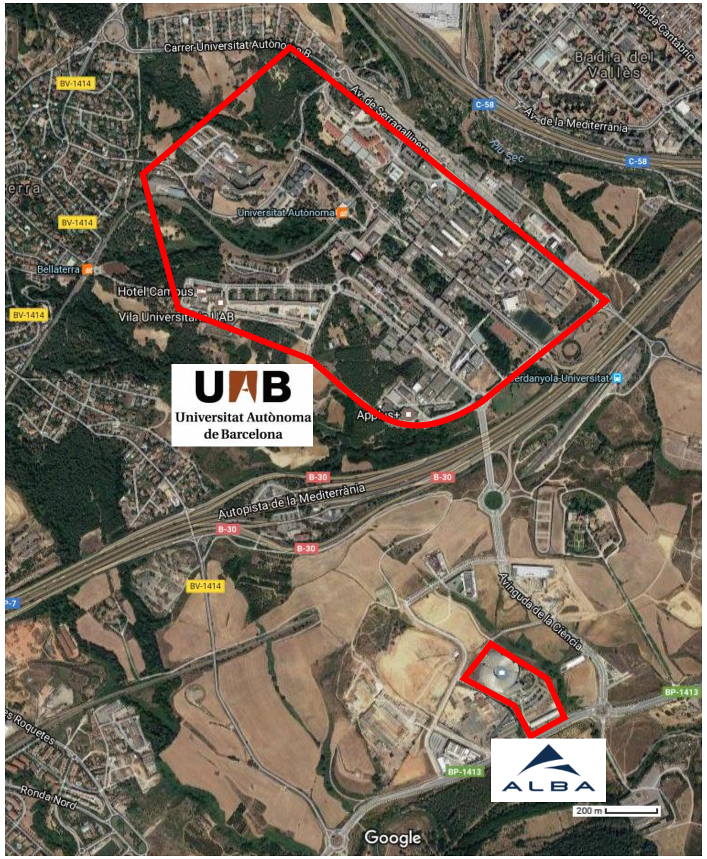
# Introduction to ALBA

- **ALBA** is a **3rd generation Synchrotron Light source** in **operation for users since 2012** in Cerdanyola del Vallès, close to **Barcelona**.



# Introduction to ALBA

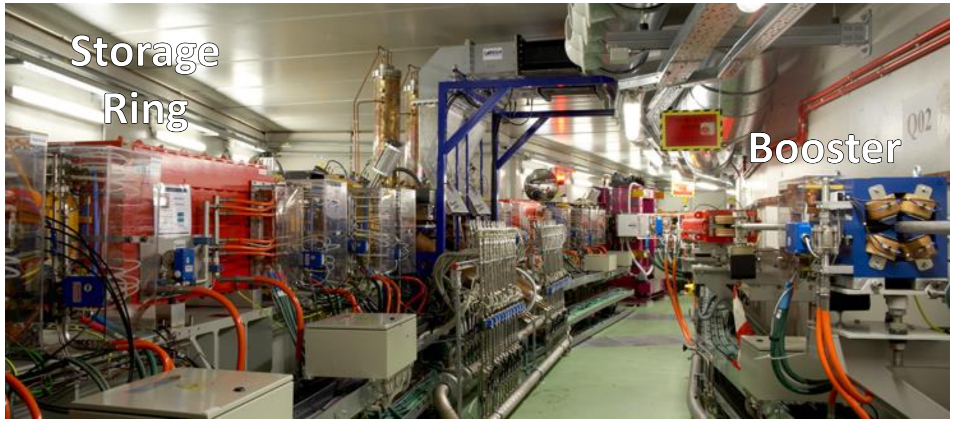
- The **public consortium** in charge of building and running the facility (**CELLS**) was founded on **2003**.


*Aerial view of ALBA site*


*Inside Main Building*

# Introduction to ALBA

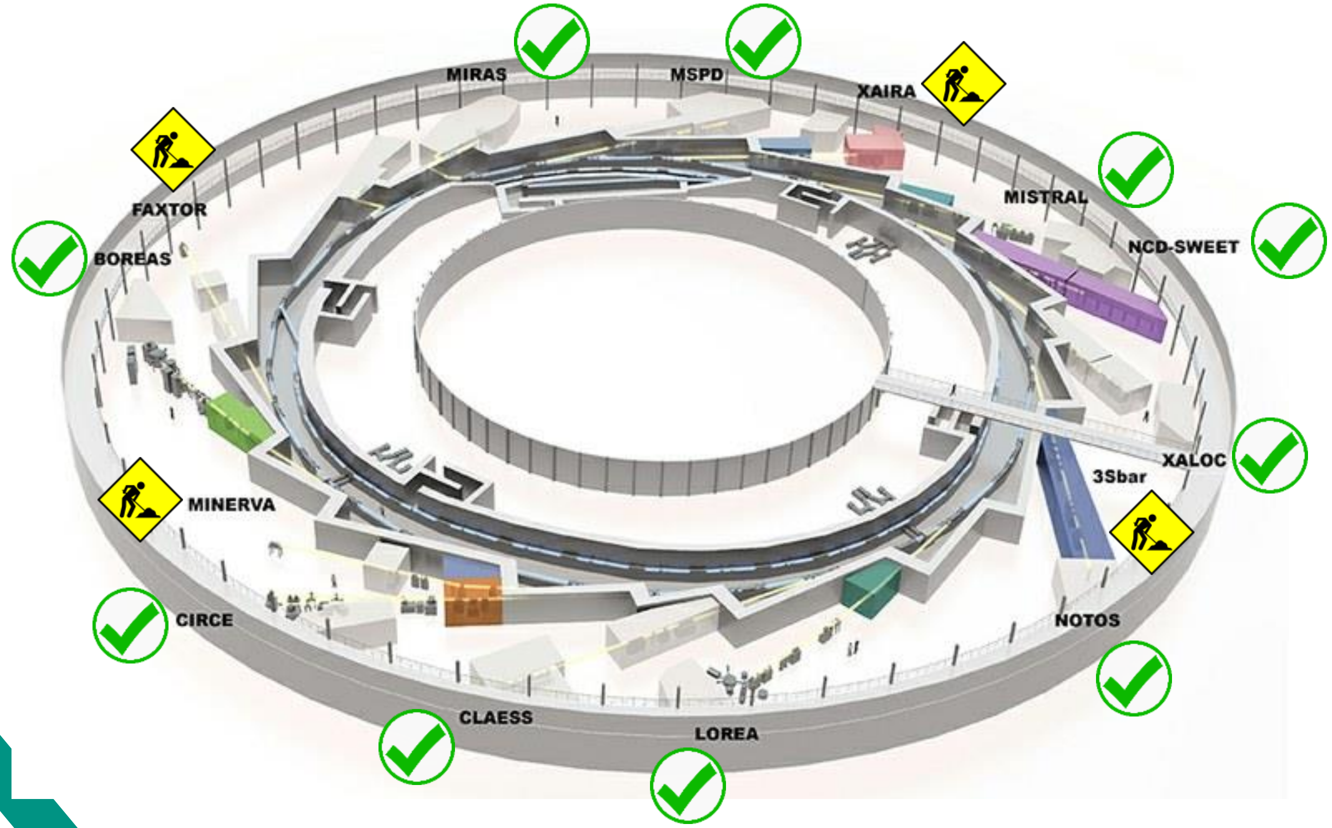
- The **complex of accelerators** consists of:
  - A 10m-long **100MeV LINAC**
  - A low-emittance, **full-energy Booster** sharing the tunnel with the Storage Ring
  - A 268m-long **3GeV Storage Ring**
- ALBA currently operates at **250mA** in **Top-up mode**



*Inside ALBA accelerator tunnel*

# Introduction to ALBA

- ALBA currently has **10 operational beamlines** comprising **soft** and **hard X-rays**, which are devoted mainly to biosciences, condensed matter and materials science. In addition, there are **4 beamlines under construction**.

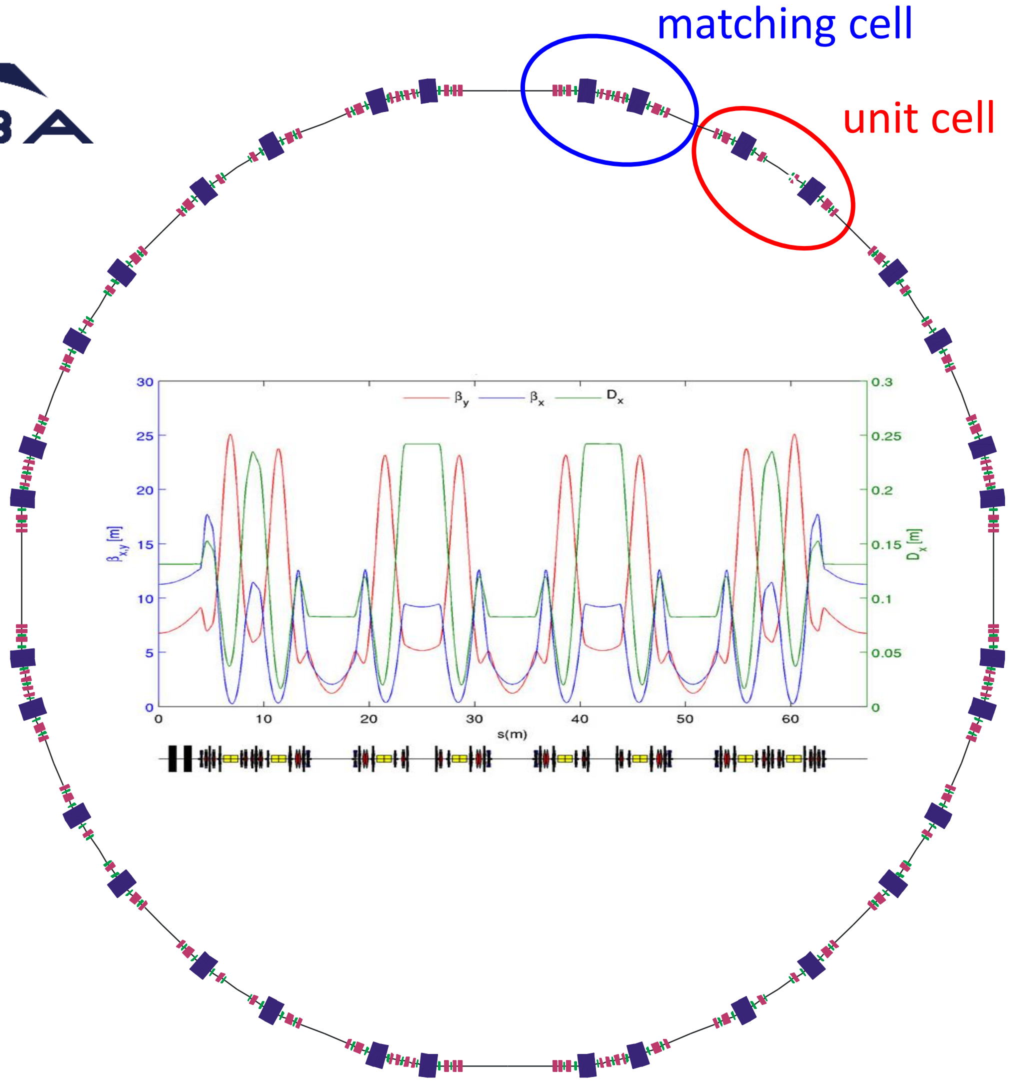



*Experimental hall and CIRCE beamline (soft X-ray)*

# Introduction to ALBA

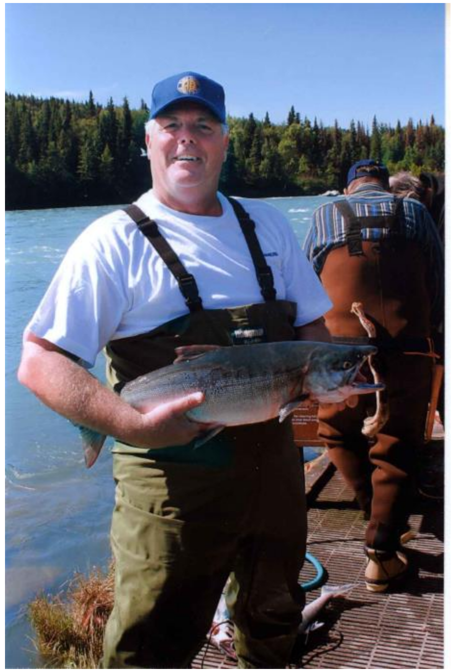
- ALBA Storage Ring lattice
  - **8+8 DBA-like cells**

| Parameters | |
|---|---|
| **Energy** | **3 GeV** |
| Circumference | 268 m |
| Symmetry | 4-fold |
| **Emittance** | **4.5 nm·rad** |
| Nº of cells | 8+8 |
| Nº of straights | 4 / 12 /8 |
| Straight length | 7.8 / 4.0 / 2.3m |



# Introduction to ALBA

- Why are we at **synchrotron light sources** so obsessed with **emittance**?

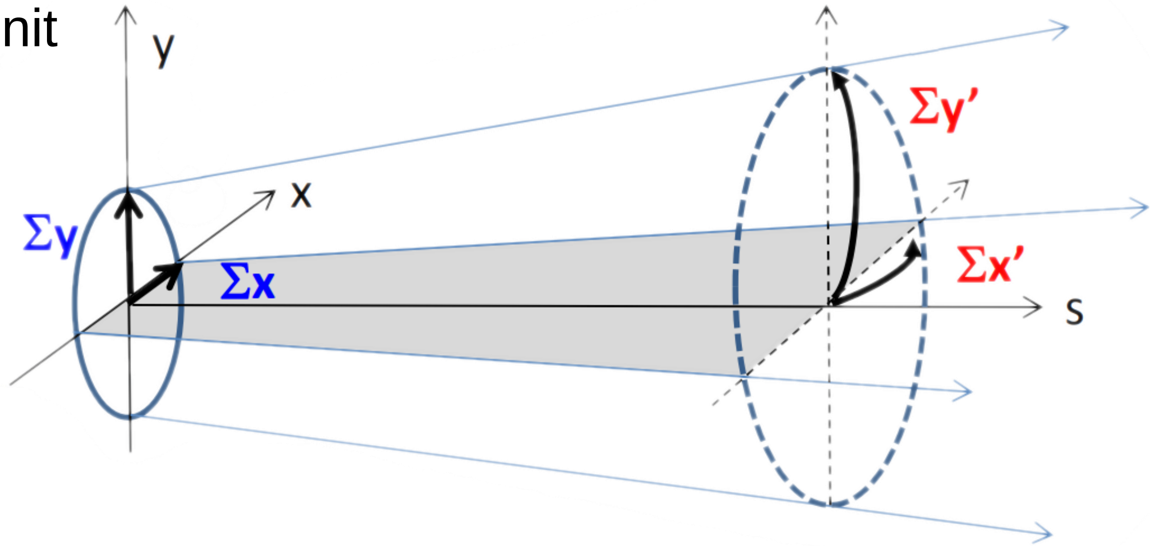

- **Does** (electron beam) **size really matters that much?**

# Introduction to ALBA

- **Electron beam emittance** is directly related with the **Brightness of the generated photon beam**, and hence it is one of the main parameters of an accelerator-based light source.

- **Brightness** is the **phase space density of photon flux** (photon flux per unit area and unit solid angle).

$$\mathcal{B} = \frac{\mathcal{F}}{4\pi^2\, \Sigma_x \Sigma_y \Sigma_{x'} \Sigma_{y'}}$$




- Given that **Brightness** is **invariant under propagation through optical elements**, it uniquely characterizes the strength of a radiation source.

# Introduction to ALBA

$$\mathcal{B} = \frac{\mathcal{F}}{4\pi^2\, \Sigma_x \Sigma_y \Sigma_{x'} \Sigma_{y'}}$$

- In Gaussian approximation:

$$\Sigma_x = (\sigma_x^2 + \sigma_R^2)^{1/2} = (\varepsilon_x \beta_x + \varepsilon_R \beta_R)^{1/2}$$

$$\Sigma_y = \left(\sigma_y^2 + \sigma_R^2\right)^{1/2} = \left(\varepsilon_y \beta_x + \varepsilon_R \beta_R\right)^{1/2}$$

$$\Sigma_{x'} = (\sigma_{x'}^2 + \sigma_{R'}^2)^{1/2} = (\varepsilon_x / \beta_x + \varepsilon_R / \beta_R)^{1/2}$$

$$\Sigma_{y'} = \left(\sigma_{y'}^2 + \sigma_{R'}^2\right)^{1/2} = \left(\varepsilon_y / \beta_y + \varepsilon_R / \beta_R\right)^{1/2}$$

Electron beam sizes/divergences

Photon beam **intrinsic** sizes/divergences

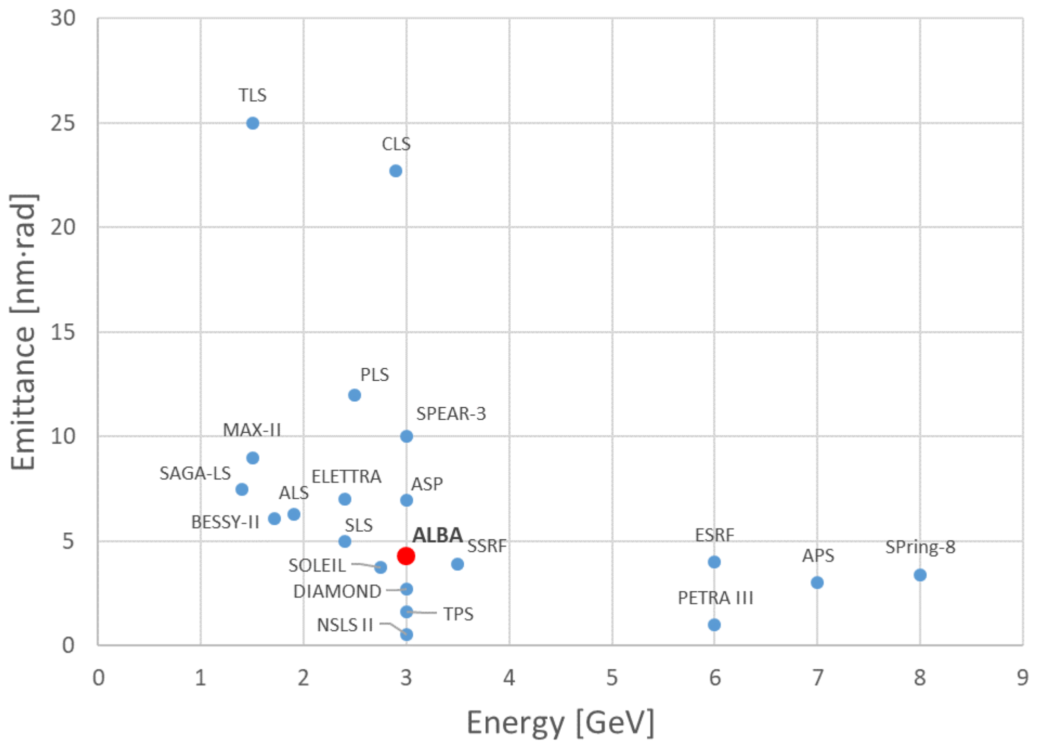
Electron beam emittance

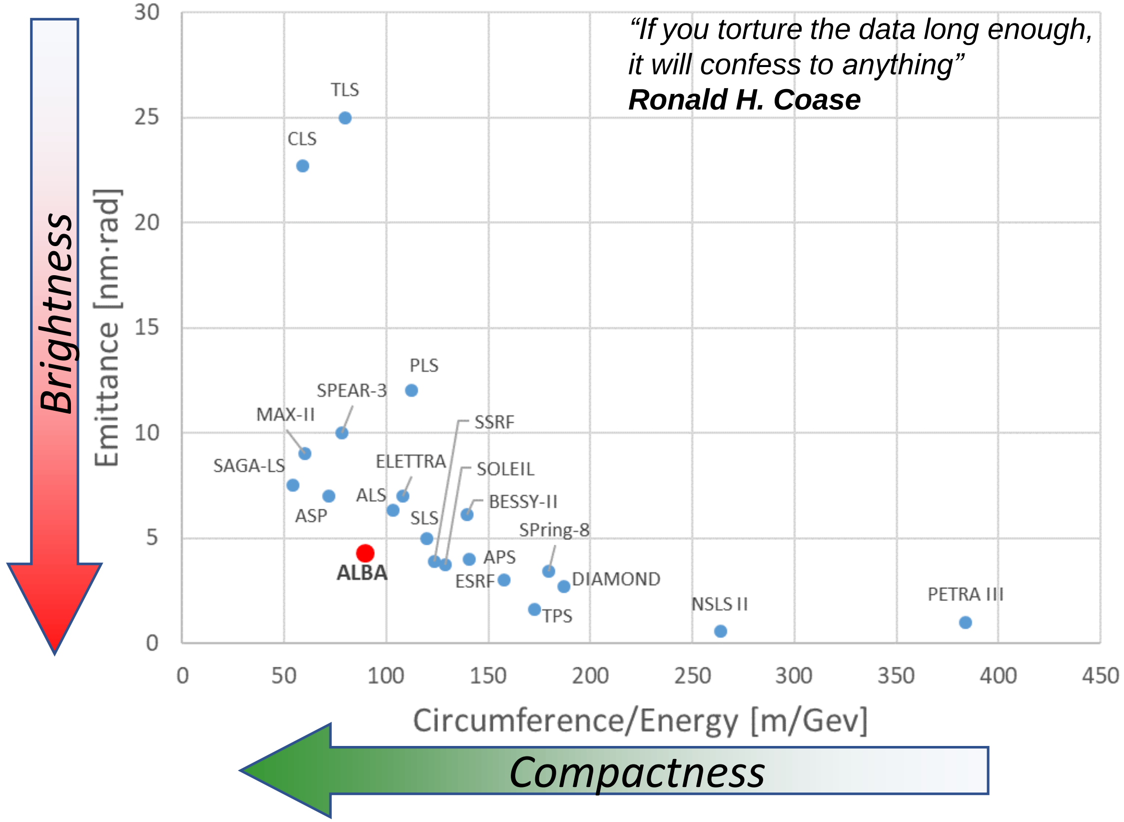
The **smaller the electron beam emittance**, the **higher the photon beam Brightness**

- ✓ **Faster experiments**
- ✓ **Improved resolution**
  - Either spatial, in time or in energy
- ✓ And more…

# Introduction to ALBA

- **ALBA** among **3rd generation Synchrotron Light Sources** (1990s and 2000s)
  - At ALBA a **nice compromise** between **low emittance** and **compactness** was achieved.



# Outline

- Introduction to ALBA
- **Motivation for upgrade**
- Description of ALBA II project
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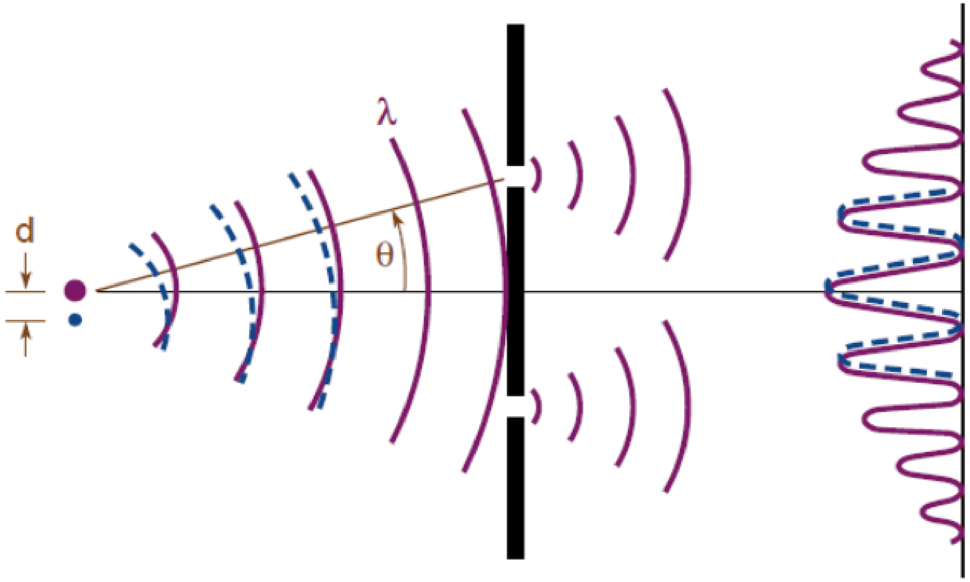
# Motivation for upgrade

- The quest for the **“Diffraction limited” regime**:
  - When the **electron beam emittance is small enough**, the properties of the emitted radiation are **dominated** by the **intrinsic properties of the emitted photons**.
  - Under these circumstances, the **radiation Brightness is not degraded** by the electron beam emittance and the **radiation is transversally coherent**.

The smaller the transversal **distance *d*** between electrons… (∝ emittance)




…the **sharper** the **contrast** of the **superposing diffraction patterns**

# Motivation for upgrade

- The quest for the **“Diffraction limited” regime**:

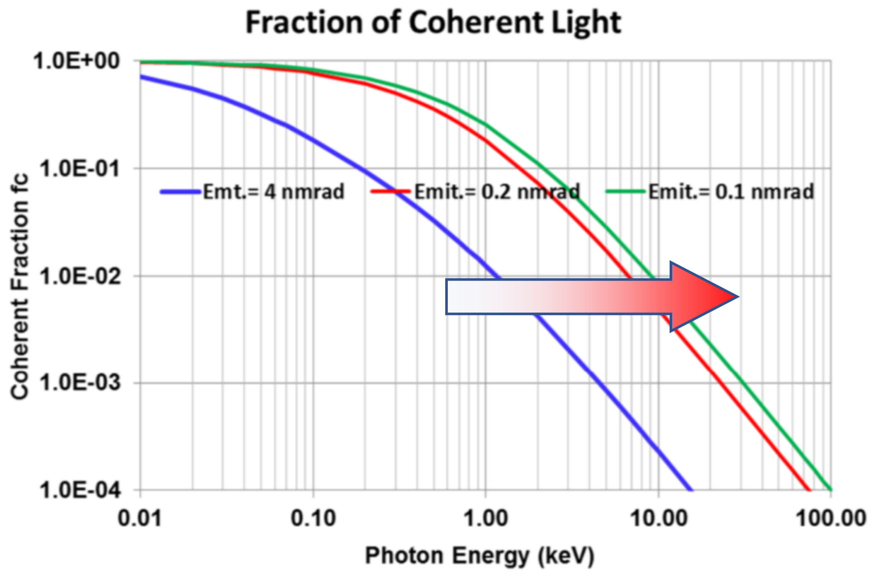
This so-called “Diffraction limited” regime **depends on the photon beam energy**!

$$\Sigma_x = (\varepsilon_x \beta_x + \varepsilon_R \beta_R)^{1/2} \qquad \Sigma_{x'} = (\varepsilon_x / \beta_x + \varepsilon_R / \beta_R)^{1/2}$$

$$\Sigma_y = (\varepsilon_y \beta_x + \varepsilon_R \beta_R)^{1/2} \qquad \Sigma_{y'} = (\varepsilon_y / \beta_y + \varepsilon_R / \beta_R)^{1/2}$$

Diffraction limit condition: $\varepsilon_{x,y} \approx \varepsilon_R(\lambda) \approx \frac{\lambda}{4\pi}$

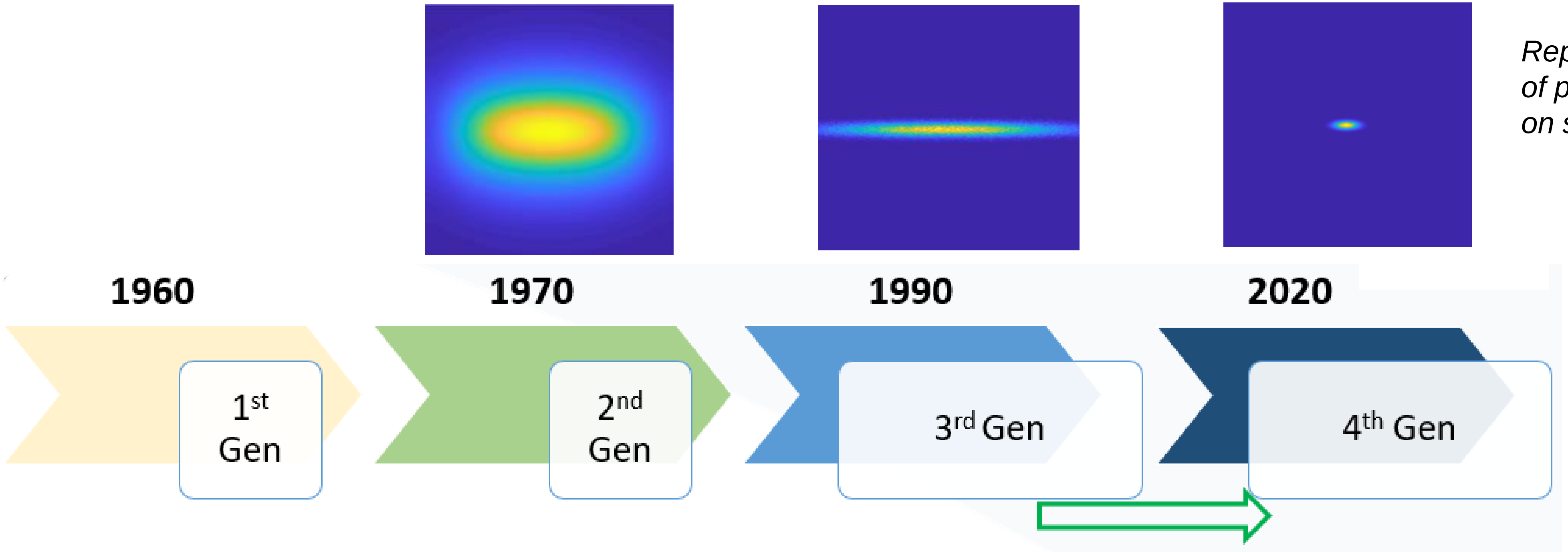
| | | |
|---|---|---|
| ALBA: | $\varepsilon_x = 4.5$ nm·rad | $\lambda_{DL} \approx 60$ nm (20 eV)<br>E-UV |
| 4th gen LS: | $\varepsilon_x = 0.1$ nm·rad | $\lambda_{DL} \approx 1$ nm (1.2 keV)<br>Soft X-ray |




**Emittance reduction** pushes the **transversal coherence** to **higher photon energies**

# Motivation for upgrade

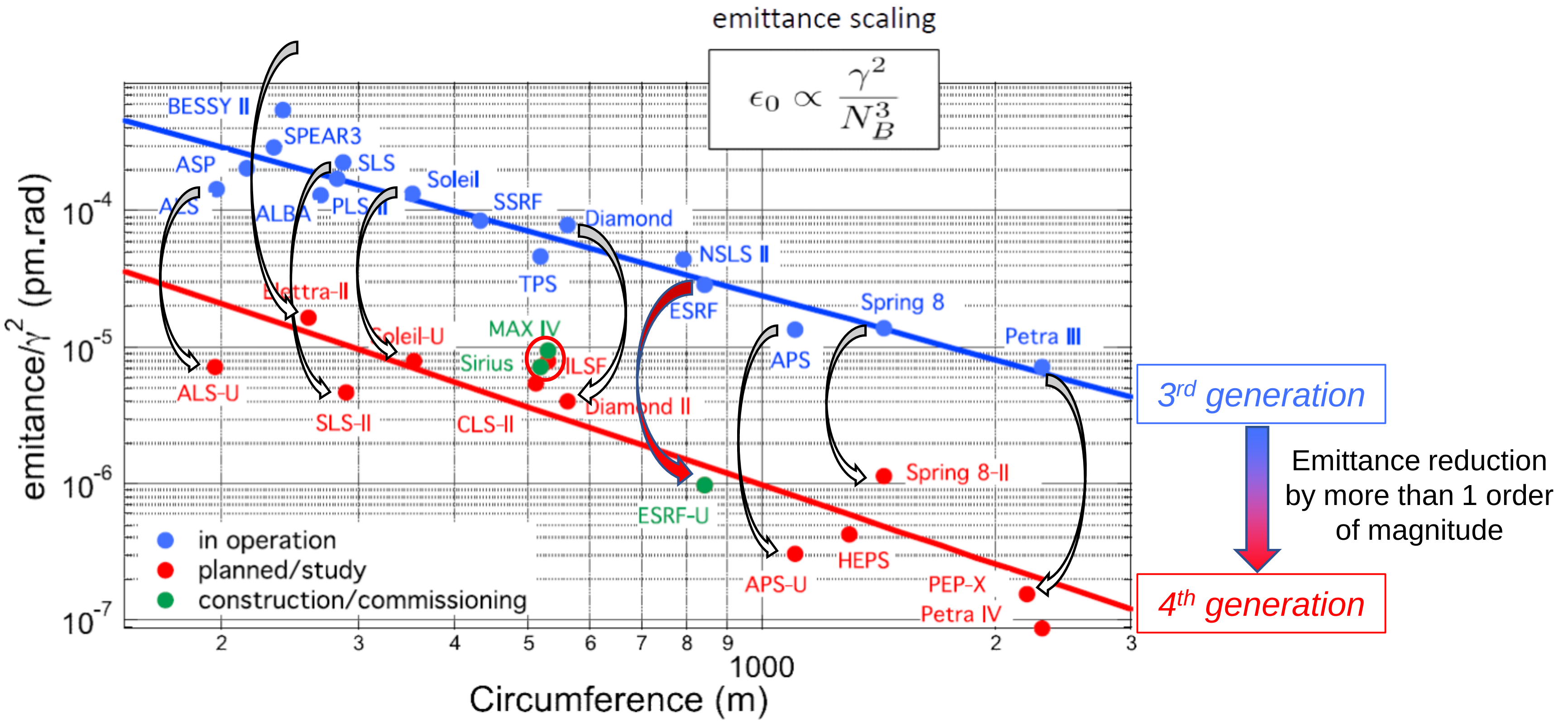
- The quest for the **“Diffraction limit” regime**:
  - Therefore, **on top of the intrinsic benefit of the increase in photon beam brightness** (smaller spot sizes, larger photon flux densities, etc.), **ultra-low emittance facilities** are opening the door to **new experimental techniques exploiting the transversal coherence** properties of the X-ray beams (ptychography, coherent diffraction, etc.)




*Representation of photon beam on sample*

# Motivation for upgrade

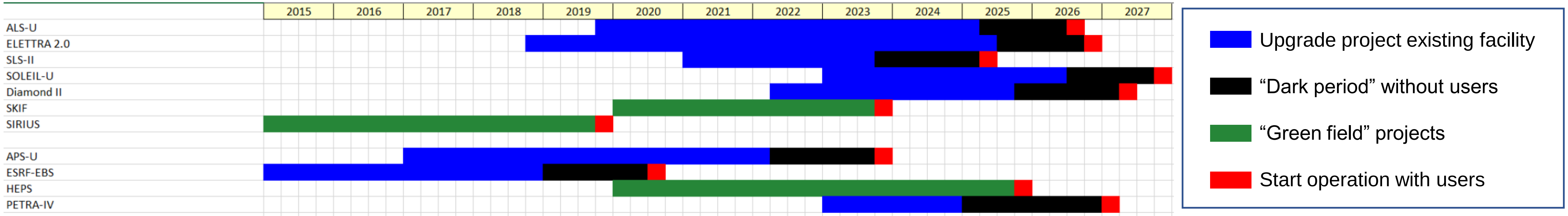
- The implementation of the **Diffraction Limited Storage Ring** (**DLSR**) concept was spearheaded by a couple of **brand-new** facilities: **MAX IV** in Sweden **(2016)** and **SIRIUS** in Brazil **(2020)**. However, immediately afterwards **many existing 3$^{th}$ generation** light sources **followed suit** or planned to do so:




*Reproduced from: Liu Lin "Towards Diffraction Limited Storage Ring Based Light Sources", IPAC17, Copenhagen (2017)*

# Motivation for upgrade

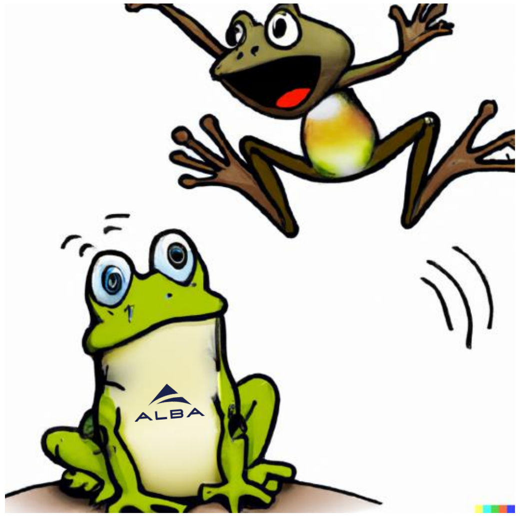
- **Upgrade plans** of several 3rd generation facilities (in blue)




*Reproduced from: R. Bartolini “Overview of ongoing 4th generation light source projects worldwide”, 7th DLSR Workshop (2021)*

- As the adage goes: *“If your fellow frogs start to jump around you, you better jump as well”*

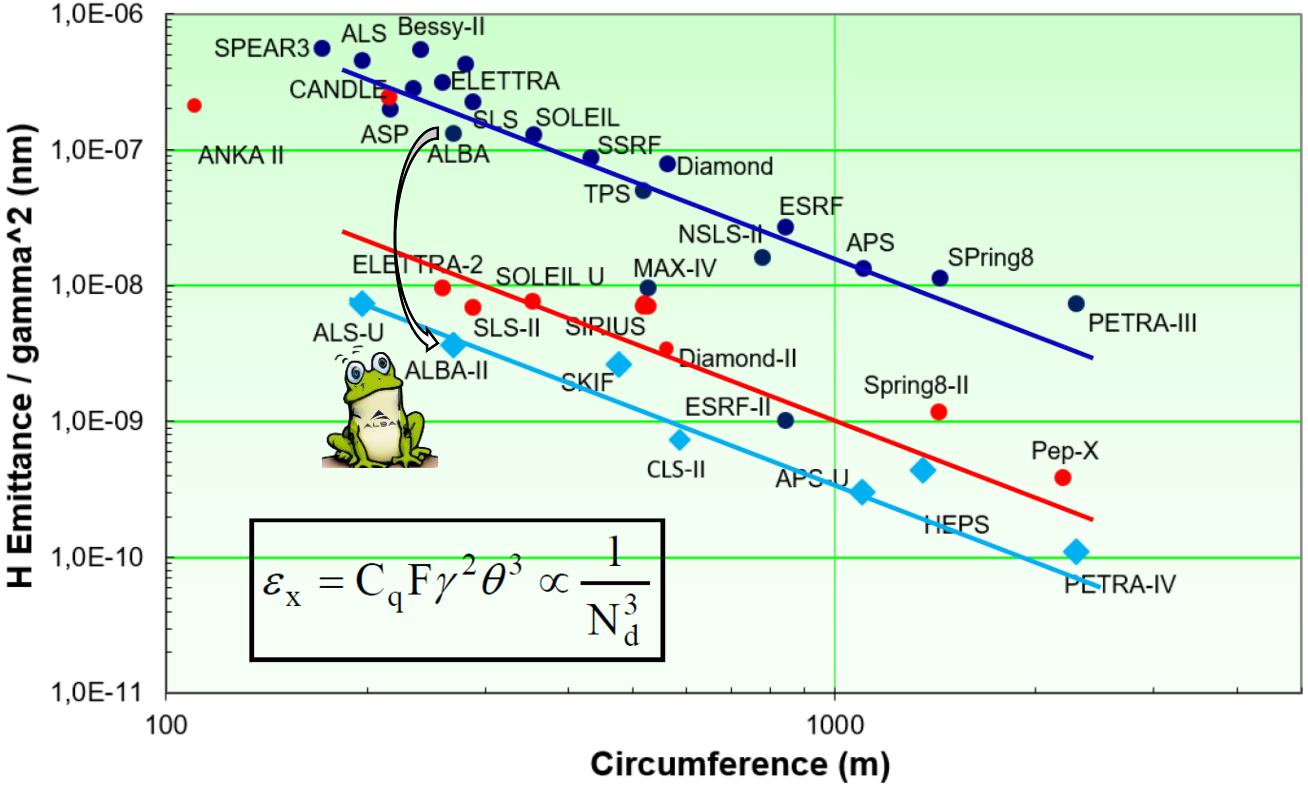
*Dramatized representation of decision making process by ALBA management*



# Motivation for upgrade

- Therefore, on **2018 ALBA** started to think on its own **plans for upgrade**.

  (at least we managed to be included in the comparative plots of the community…)




*Reproduced from: R. Bartolini "Overview of ongoing 4th generation light source projects worldwide", 7th DLSR Workshop (2021)*

# Motivation for upgrade

- **What is needed to reduce the emittance of a Synchrotron?**

To make a long story short, one basically has to **split the bending action** among a **larger number of dipoles** → **<u>Multi-bend achromat</u> (MBA)** concept

Equilibrium emittance scaling law: $\varepsilon_x \approx \mathcal{F} \frac{C_q \gamma^2}{J_x} \varphi^3 \propto \gamma^2 \varphi^3 \propto \frac{1}{N_d^3}$

$C_q$: constant

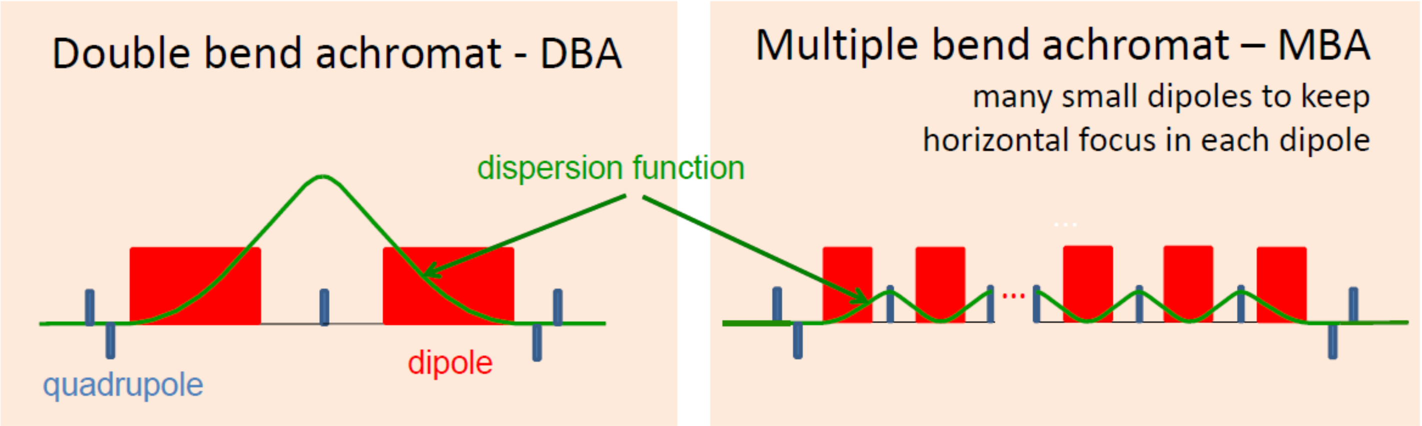
$J_x$: Robinson partition number

$\mathcal{F}$: lattice scale factor

$\gamma$: Lorentz factor

$\varphi$: deflection angle per bending

$N_d$: number of bendings




*Reproduced from: Liu Lin "Towards Diffraction Limited Storage Ring Based Light Sources", IPAC17, Copenhagen (2017)*

# Motivation for upgrade

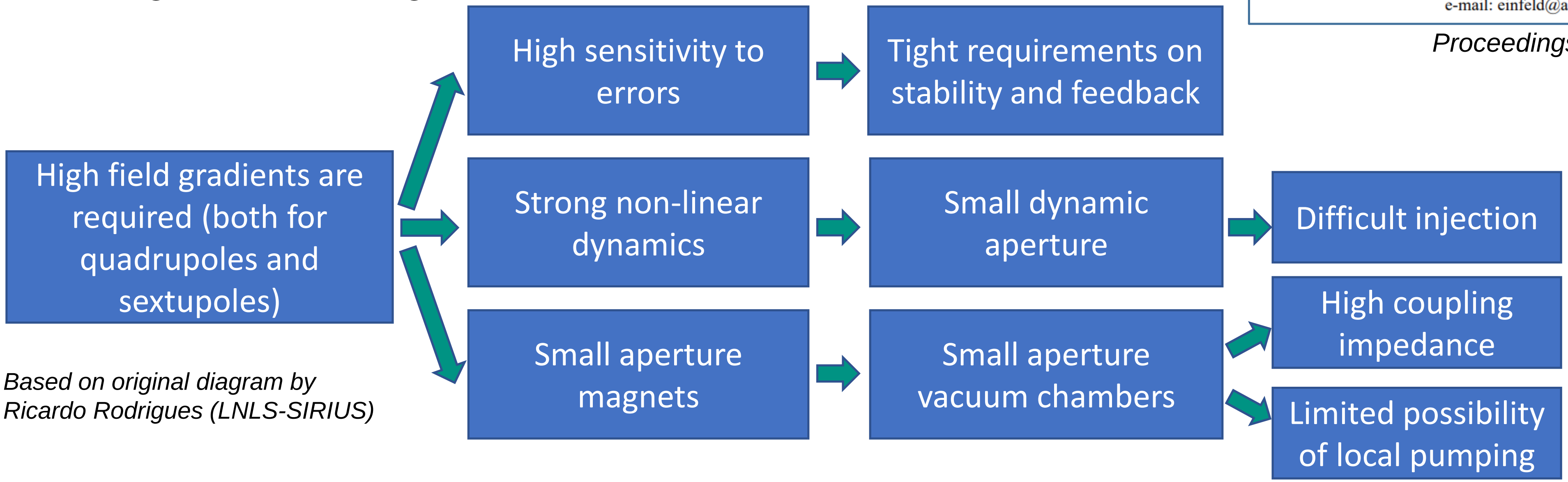
- However, the **MBA concept** had already been developed during the **early 1990s**. **Why has it taken so long to bring it to reality?**

**Design of a Diffraction Limited Light Source (DIFL)**

D. Einfeld, J. Schaper, Fachhochschule Ostfriesland, Constantiaplatz 4, D-26723 Emden
M. Plesko, Institute Jozef Stefan, Jamova 39, P.O.B. 100, SLO-61111 Ljubljana
e-mail: einfeld@alpha.fho-emden.de

*Proceedings PAC 1995*

- Among other challenges…




*Based on original diagram by Ricardo Rodrigues (LNLS-SIRIUS)*

- It was not until **mid 2000s** that, thanks to the **experience gained with 3rd generation facilities** and to the **availability of NEG-coated vacuum chambers** for distributed pumping, the **first designs** of facilities **taking profit of the MBA cell** were developed (MAX IV design report issued on 2008)

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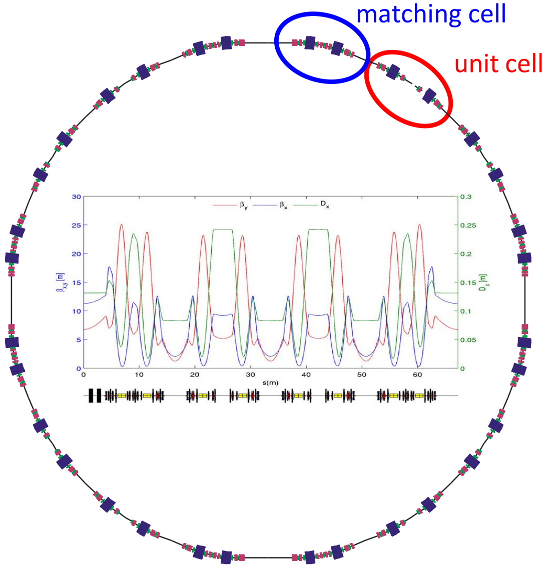
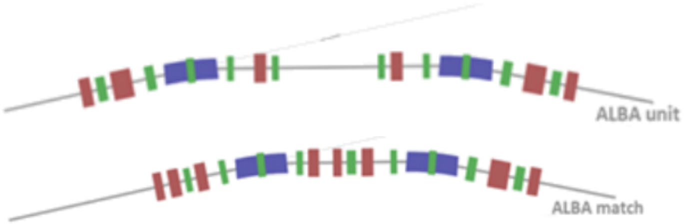
# Description of ALBA II project

- **ALBA II constraints/requirements:**


  - **Keep beam energy** @ 3GeV
  - **Keep the tunnel** → SR with similar compact circumference
  - **Keep existing ID beamlines** → preserve 16 cells and source points
  - **Dipole** beamlines **can be relocated**
  - **Keep injector** (present Booster $\epsilon_x^{Booster}$=10nm·rad)
  - **Keep infrastructures** (as much as possible)
  - Straight sections ~4m with $\beta_x \sim \beta_y$ ~2m
  - **Reduce SR emittance by more than factor 10** (**<400pm·rad**)

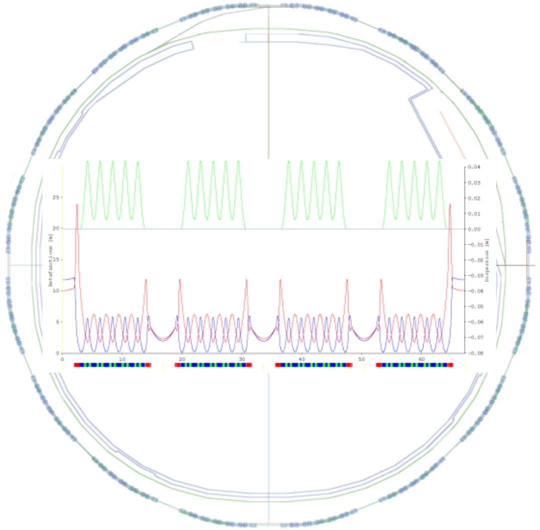
# Description of ALBA II project

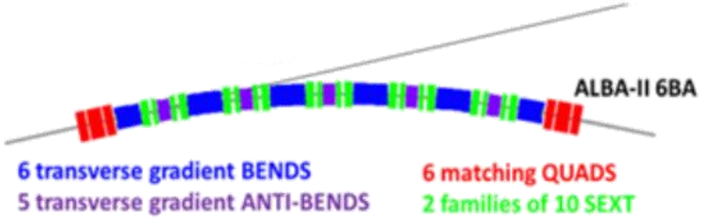



| | ALBA | ALBA II |
|---|---|---|
| **Energy** | **3 GeV** | **3 GeV** |
| Circumference | 268.8 m | 268.8 |
| Symmetry | 4-fold | 4-fold |
| Lattice | 8×2-DBA cells | 16×6BA cells |
| **Emittance** | **4.5 nm·rad** | **140 pm·rad** |
| Nº of cells | 8+8 | 16 |
| # of straights | 4 / 12 /8 | 16 |
| Straight length | 7.8 / 4.0 / 2.3m | 4.0 m |

÷30





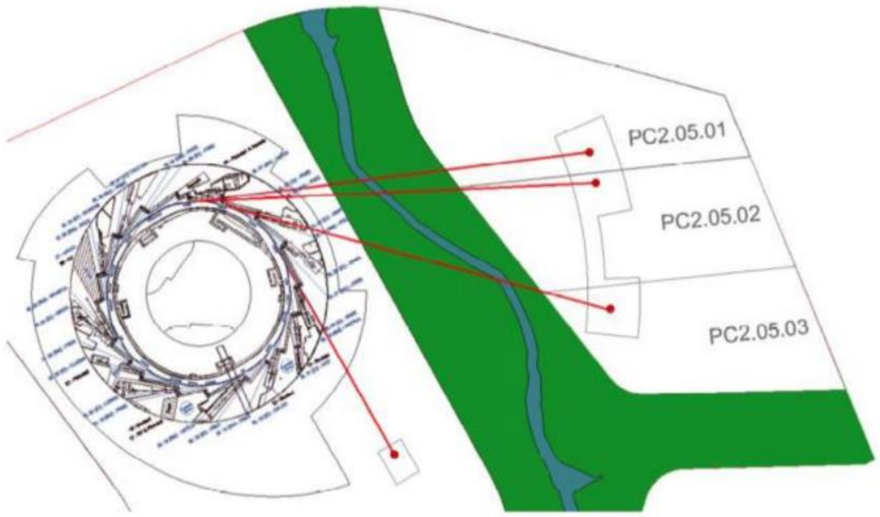

Benedetti et al. *"A distributed sextupoles lattice for the ALBA low emittance upgrade"*, **IPAC21, WEPB074**

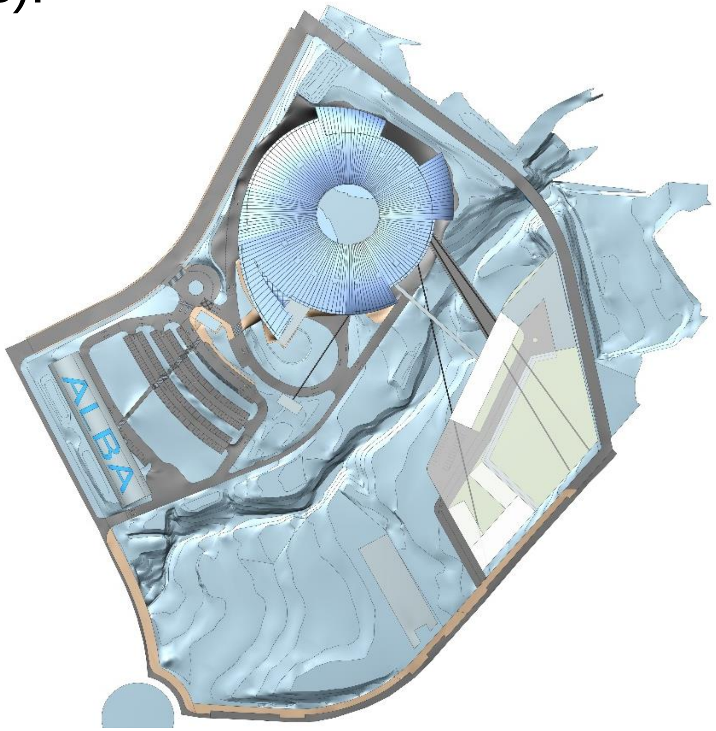
# Description of ALBA II project

- The **tentative cost** for the upgrade is **120M€**, to be added to ALBA budget along **10 years** (increase of **30%** on average)
- The upgrade project **is still not funded**, but we have received the **approval (Dec 2020) from our Governing Body** to start a **design study**
- The project's **White Paper** is foreseen to be issued during the first quarter of 2023
- In parallel, a **4-year** project (**ALBA01**) devoted to the development of prototypes and funded with **7.5M€** is already **ongoing**
  - Development of **<u>magnets</u> (1.76M€)**, **vacuum chambers**, **girders**, **IDs** and **nanopositioning systems** for BL optics & instrumentation

# Description of ALBA II project

- By the **end of 2022** the **plots adjacent to our site** were **transferred to ALBA**.
- This enlargement of the facility will allow the construction of **very long beamlines** (**>250m**) that will **take profit** of some of the **enhanced characteristics of ALBA II** (**nanoprobing** and **coherence-related** techniques).

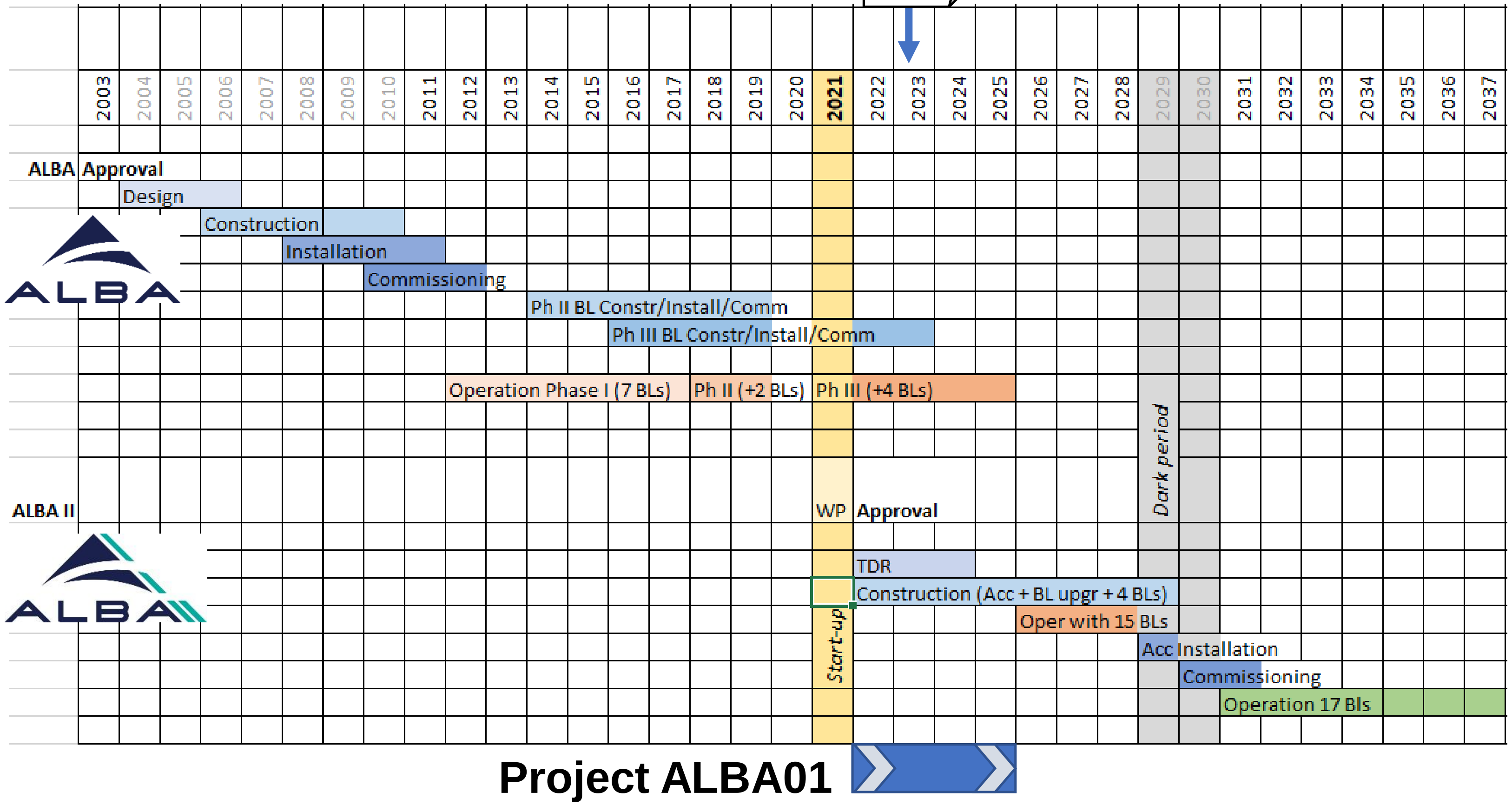


# Description of ALBA II project

- **Tentative ALBA II timeline**

**ALBA II White Paper (Spring '23)**



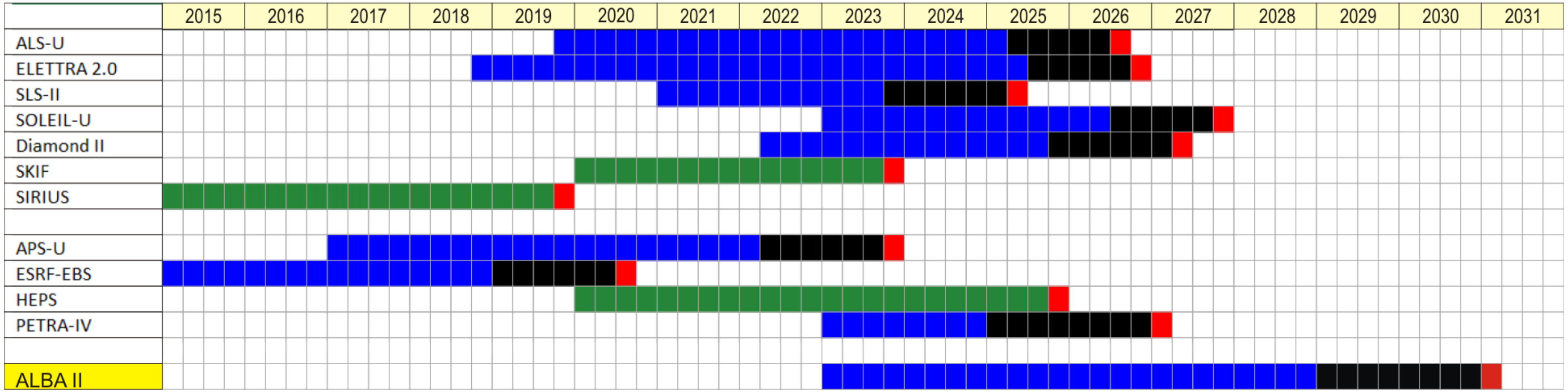

**Project ALBA01**

"Enabling advanced technologies for ALBA II"

# Description of ALBA II project

- **Tentative ALBA II timeline**

Upgrade project existing facility
"Dark period" without users
"Green field" projects
Start operation with users




*Modified from: R. Bartolini "Overview of ongoing 4th generation light source projects worldwide", 7th DLSR Workshop (2021)*

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# ALBA II magnet requirements

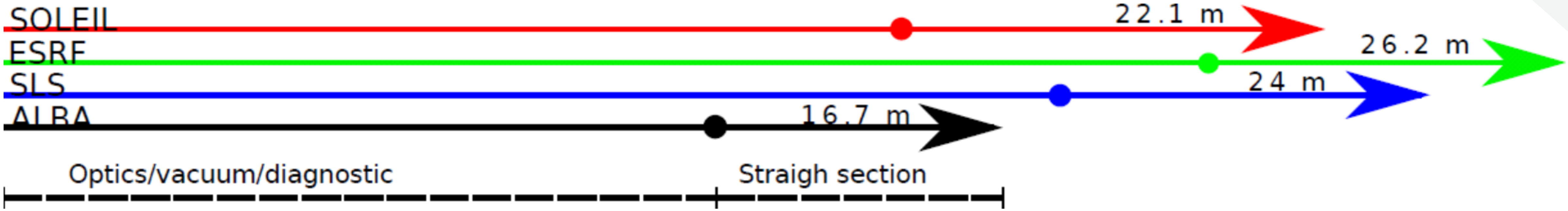



*diagram courtesy of M. Carlà (ALBA Acc. Division)*

**Space requirements** for ALBA II are **particularly tight**:

- 16 straight sections in 268m → **16.7m per cell**
- In ALBA II every straight section will be **4m**
- The space left for magnets/diagnostics/vacuum is 16.7m – 4m = **12.7m**

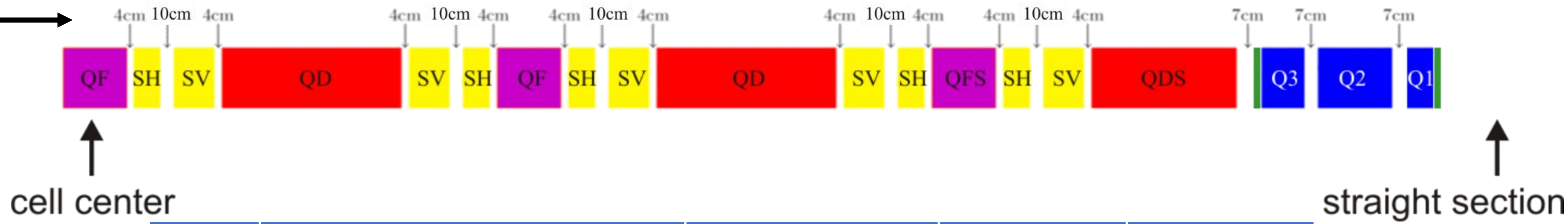
# ALBA II magnet requirements

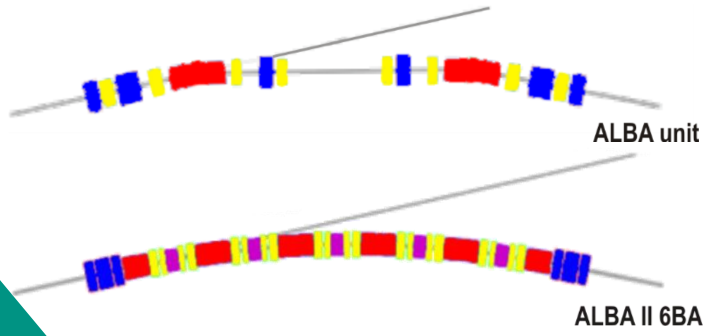
- **ALBA II** lattice is based in **16 identical 6BA cells**, with **10 magnet types**, for a total of **656 individual magnets** (currently 264 magnets at ALBA SR)

Distances between magnets' **effective lengths**

Yoke-to-yoke distances will be larger by at least 1cm

*Half 6BA unit cell*

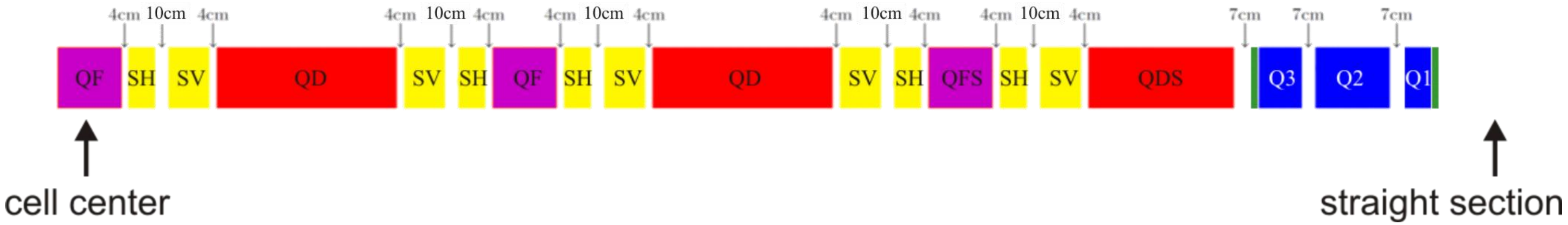



| Code | Magnet description | Types | # per cell | # in SR |
|---|---|---|---|---|
| (red) | Bend with trans grad | 2 (QD, QDS) | 6 | 96 |
| (purple) | Antibend with trans grad | 2 (QF, QFS) | 5 | 80 |
| (blue) | Quadrupoles | 3 (Q1, Q2, Q3) | 6 | 96 |
| (yellow) | Sextupoles | 2 (SH, SV) | 20 | 320 |
| (green) | Fast Correctors | 1 (COR) | 4 | |
| | **Total** | **10** | **41** | **656** |

# ALBA II magnet requirements

- **Beam dynamics group** has defined a **primary set of requirements** (**field/gradient strengths** and **lengths**) for the magnets of ALBA II lattice:




| Magnet description | Types | Length [m] | Field [Tesla] | Gradient ($K_1$) [T/m] | 2nd order grad ($K_2$) [T/m²] |
|---|---|---|---|---|---|
| Bending with transversal gradient | QD | 0.8669 | **1.009** | -15.41 | |
| | QDS | 0.6310 | 0.819 | 2.03 | |
| Antibending with transversal gradient | QF | 0.2972 | -0.394 | 70.05 | |
| | QFS | 0.2972 | -0.425 | 70.05 | |
| Quadrupoles | Q1 | 0.1000 | | -89.75 | |
| | Q2 | 0.3500 | | 91.97 | |
| | Q3 | 0.2000 | | **-108.22** | |
| Sextupoles | SH | 0.1042 | | | **4936** |
| | SV | 0.1823 | | | -4084 |

Relationship between gradients and pole-tip field:

- quadrupoles: $B_{tip} \simeq K_1\, r$
- sextupoles: $B_{tip} \simeq K_2\, r^2$

# ALBA II magnet requirements

- How **demanding** are these parameters?

| Facility | ALBA II | ESRF-EBS | APS-U | Diamond II | Elettra 2.0 | PETRA IV | BESSY III | SLS 2.0 | ALS-U | SOLEIL-U |
|---|---|---|---|---|---|---|---|---|---|---|
| Aperture [mm] | ? | 25.2 (quad)<br>38.4 (sext) | 26 (quad)<br>28 (sext) | 24 | 26 (quad)<br>30 (sext) | 26 | 25 | **21 (quad)<br>22 (sext)** | **20 (quad)<br>24 (sext)** | **16** |
| Quad term [T/m] | **110** | 90 | 80 | 85 | 62 | 92 | <65 | **98** | **105** | **140** |
| Sext term [$T/m^2$] | **5000** | 3200 | 2500 (ST)<br>3500 (VP) | 3850 | 2850 | 4300 | <4000 | **5850** | **5000** | **8000** |
| Yoke-to-yoke distance [cm] | ~6 QD-sext<br>~8 quad-quad | 4.7 dip-quad<br>7.5 quad-sext<br>6 oct-quad | 5 | ¿? | 5-7 | ¿? | 10 | ¿? | 7.5 | ¿? |

**Sources:**
**ESRF**: EBS Storage Ring Technical Report (Sep 2018)
**APS**: Advanced Photon Source Upgrade Project, Final Design Report (May 2019)
**Diamond**: Diamond II Conceptual Design Report (May 2019)
**Elettra:** Elettra 2.0 Technical Design Report (2021)
**SLS**: SLS 2.0 Magnet Specification SLS2-SA81-007-9 (Dec 2020)
**SOLEIL**: Synchrotron SOLEIL upgrade Conceptual Design Report (Jul 2021)
**ALS**: Status of the Advanced Light Source Upgrade Project (Dec 2019)
**BESSY III:** BESSY III & MLS II – Status of the development of the new photon science facility in Berlin (IPAC2021)
**PETRAIV:** Conceptual Design Report (Nov 2019)

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# Magnets group at ALBA

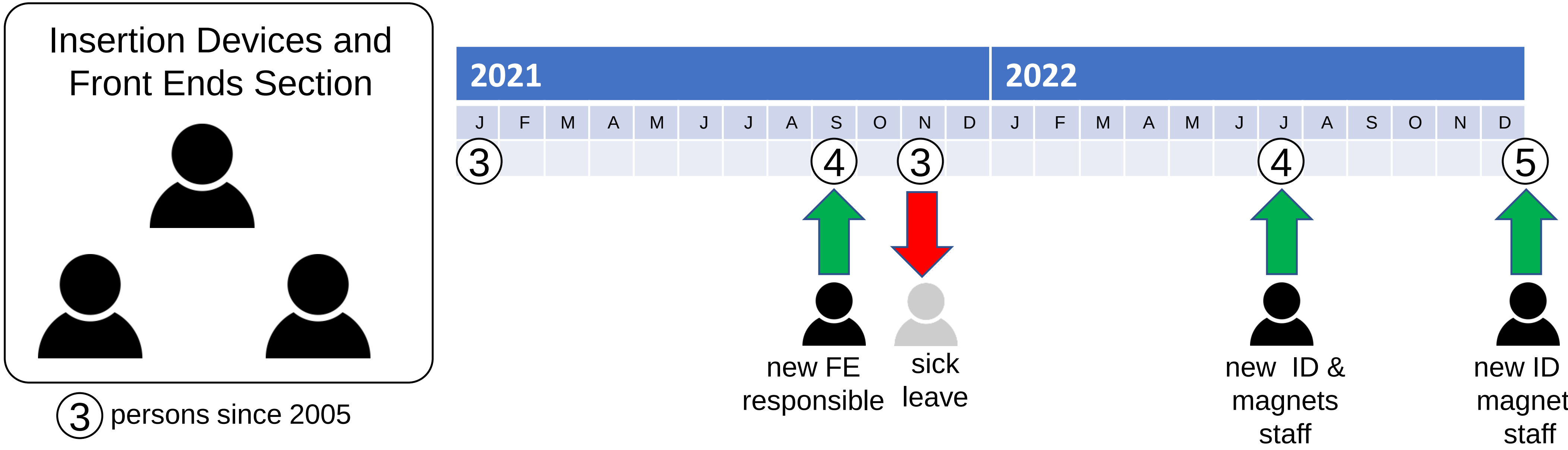
- The team that designed the magnets for original ALBA accelerator (**Magnets and Injector section**) **ceased to exist** after the **start of ALBA operations** on **2012**.

- Since then, the **internal demands on magnetic design** have been covered by Insertion Devices and Front Ends (**IDFE**) section, in charge of ID design and acceptance, and which operates the **Magnetic Measurements laboratory at ALBA**.

- When at the **beginning of 2021** arose the necessity to **design the magnets for ALBA II** Storage Ring, it was assigned to IDFE section, which was renamed as **Insertion Devices, Magnets, and Front Ends** (**IDMAFE**) section.

# Magnets group at ALBA

- During the last 2 years the **IDMAFE Section** has been **rearranged** and **expanded** in order to be ready to deal with the challenge of **designing**, **supervise the manufacturing**, and **test** the magnets for ALBA II



# Magnets group at ALBA

- On top of the section's own personnel, we have the support from people from other sections

**Insertion Devices, Magnets and Front Ends Section**

**Jordi Marcos**

IDs & **Magnets** Group

- **Valentí Massana**
- **Andrea Fontanet** (Jul 2022)
- **Maisui Ning** (Jan 2023)

FEs Group

- Raquel Monge (Aug 2021)

Support operator

- Manuel Rodríguez — *Maintenance and lab activities*

Mechanical engineers

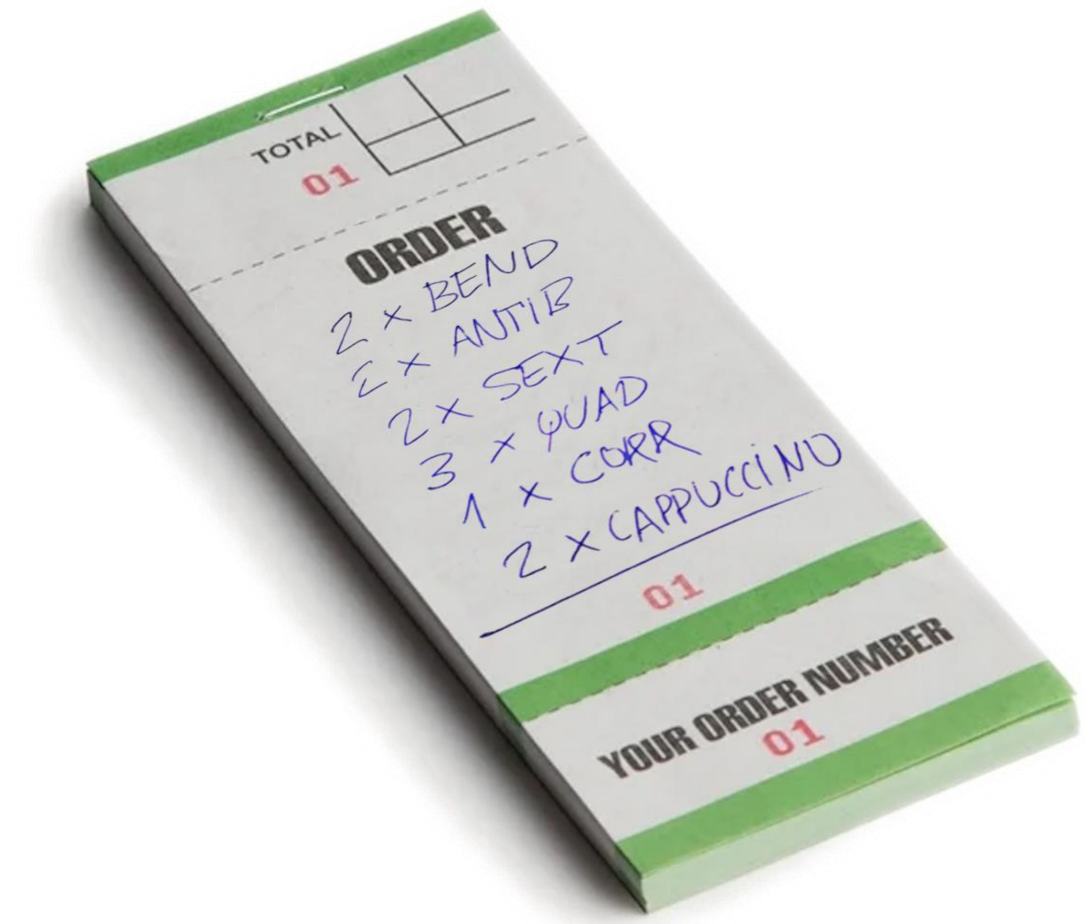
- José Ramón García — *ID maintenance and lab developments*
- **Javier Boyer** (May 2022) — *ALBA II girders & mechanical integration*
- **Pol Salmerón** (Dec 2022) — *ALBA II magnets mechanical design*

# Outline

- Introduction to ALBA
- Motivation for upgrade
- Description of ALBA II project
- ALBA II magnet requirements
- Magnets group at ALBA
- **ALBA II magnets design**
- Conclusions

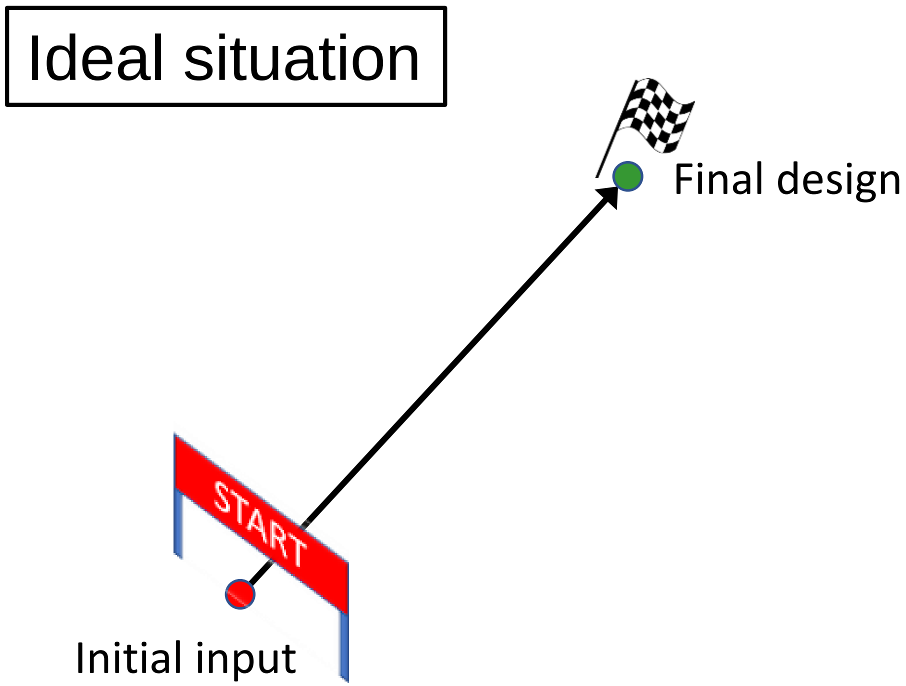
# ALBA II magnets design

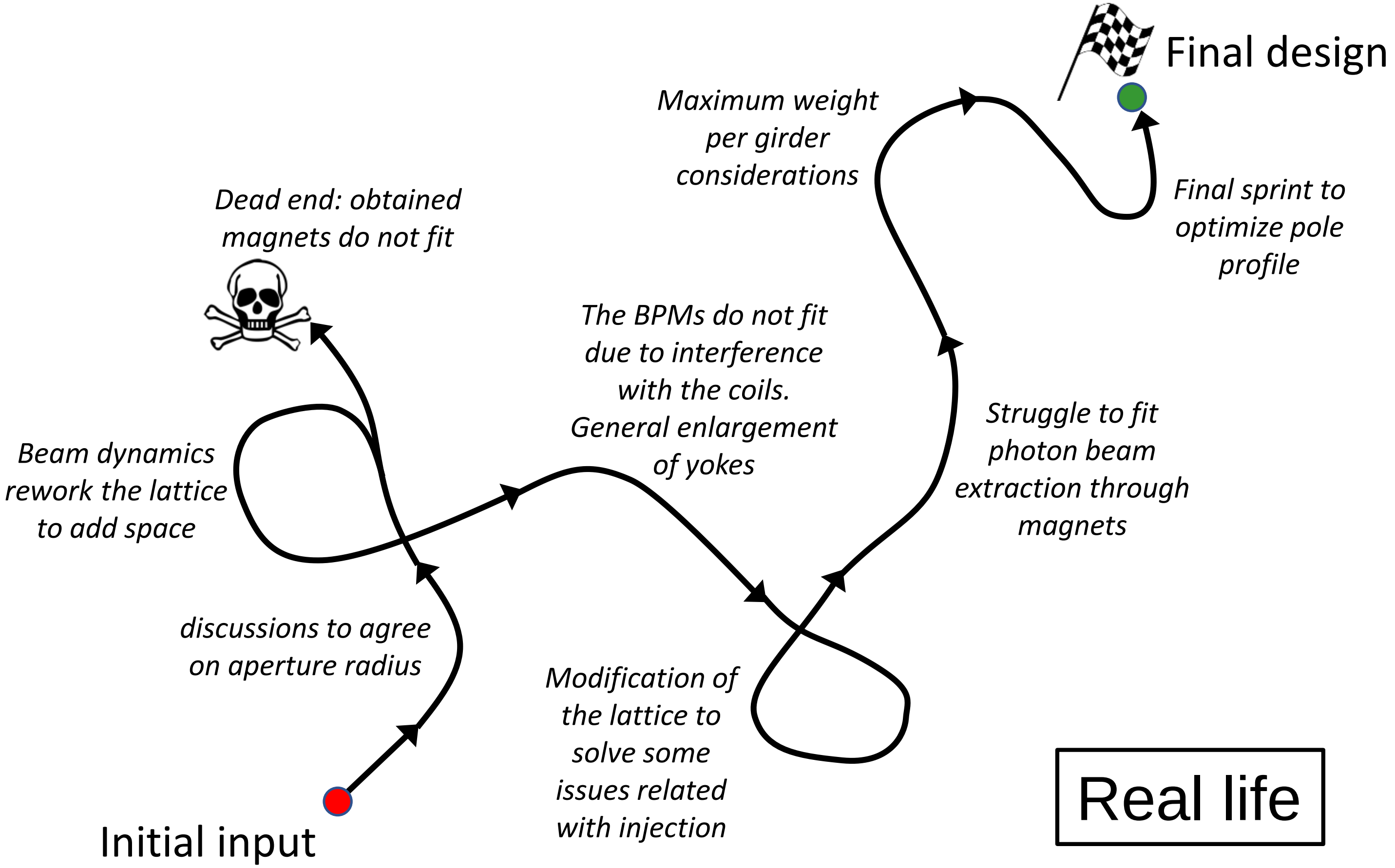
- OK, once that the order has been placed by Beam Dynamics… how shall we proceed?



# ALBA II magnets design

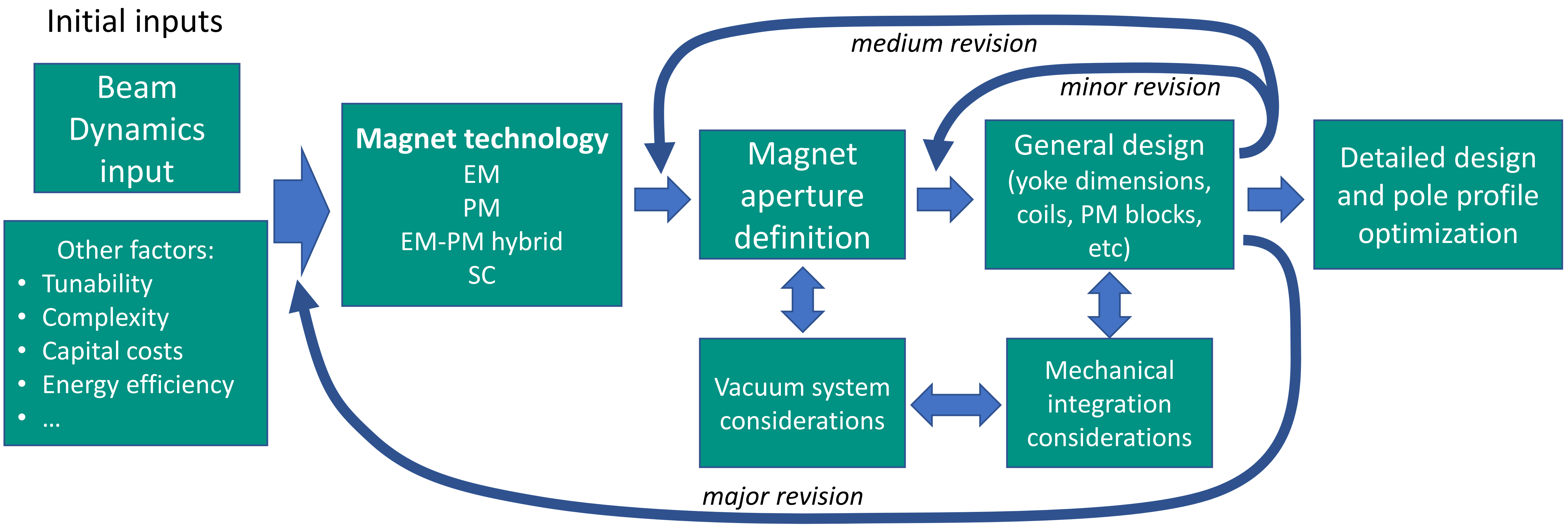
- The design of the magnets within the framework of an **evolving project** is **far from a straightforward journey**



# ALBA II magnets design

- How have we organized the **decision-making process** for the magnet's design?



# ALBA II magnets design

- We are using **several tools** to carry out simulations:
  - **OPERA**: accepted as a benchmark for magnetic simulations among a significant part of accelerator magnets community. License available at ALBA
  - **RADIA**: free access software from ESRF. Originally developed for undulators, it has been successfully used by ESRF and SOLEIL (among others) to simulate electromagnets for their upgrade projects. Particularly well suited to implement optimization procedures
  - **ANSYS**: used by Engineering division at ALBA to carry out thermomechanical simulations. We recently purchased Maxwell package to carry out low frequency EM simulations using the same environment, allowing synergies between the two simulation groups

- The usage of **different simulation tools** will allow us to:
  - Work in **parallel**
  - **Cross-check** of results (if needed)
  - Exploit the **strengths** of each simulation environment

# ALBA II magnets design

- One of the first decisions to be taken is the **technology** to be used for the magnets: **electromagnetic** (**EM**) designs or **permanent magnet** (**PM**)-based ones?
- Several facilities already in operation (**SIRIUS**, **ESRF-EBS**) have used PM technology for some selected magnet types, and some of the on-going projects (**SLS 2.0**, **SOLEIL-U**) foresee an extensive use of pure PM magnets (**>30% of the total**) in their lattices.
- **Which approach shall we use for ALBA II**?

**PM main drivers**

- **Space** → more compact lattice
- **Simplicity & Capital costs** → no need of power supplies, cables, cooling water…
- **Operation costs** → no electrical power
- **Maintenance** → according to ESRF-EBS experience, no action required after 2 years of operation

**PM main challenges**

- **Tunability** → the loss of tunability of the lattice has to be replaced by means of correctors or hybrid designs
- **Thermal stability** → so far, well under control using NiFe shunts
- **Radiation damage** → there are still some doubts on long term stability of these magnets installed in small aperture Storage Rings

# ALBA II magnets design

- At this stage, **we consider unfeasible to adopt a pure PM design for the main magnets at ALBA II (QD and QDS)**, given that it would require a **complete reworking of the lattice** to recover the missing flexibility.

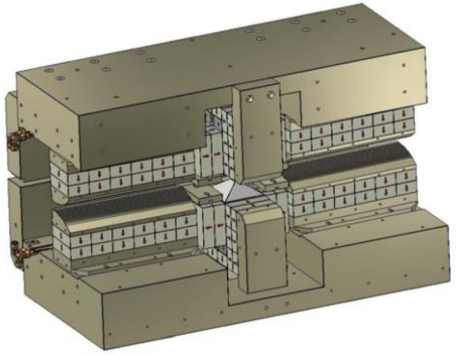
- In particular, it is doubtful that we could find the **space to fit the octupoles** that would be required for **quadrupole correction** (both normal and skew), even taking into account that PM designs are more compact.

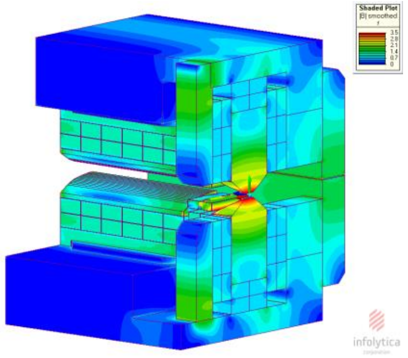
- Another **challenge** for the adoption of PM technology at ALBA is that, as far as we know, no **serial production of a large batch** (>100) of **PM magnets** with the strict tolerances required by a low emittance facility has been **outsourced to industry yet**.

- Facilities using PM technology (**SIRIUS, ESRF-EBS, SLS 2.0, SOLEIL-U**) have relied or will rely on **in-house resources** for magnets **assembly** and **characterization**. **Nowadays this is not a realistic option for ALBA II**.

# ALBA II magnets design

- For all these reasons, we have adopted **conventional EM technology** for the **baseline design** of **ALBA-II SR magnets**, and have given the maximum priority to it.
- However, we want **to explore in parallel more innovative designs** (e.g. **hybrid EM-PM magnets**) for QD and QDS magnets.
- One **clear candidate** to introduce PM are the modified QD dipoles (**superbends**) that will be necessary to feed dipole BLs requiring photon energies **above 4keV**.






SIRIUS 3.2 Tesla BC magnet (superbend) available at wiki-sirius.lnls.br

- In relation with this point, ALBA participates in **PerMaLIC** collaboration, sharing the development of **PM designs** with other facilities.

PerMaLIC

# ALBA II magnets design

- At the initial stage of the design, one of the **most important parameters** of the magnet to be established is the size of its **aperture radius, $r_0$**
- We must find a **compromise** between the **pros** and **cons** of **decreasing $r_0$**

**PROS**

- The required **excitation currents** are smaller
- The magnet will operate **more efficiently** at a **lower saturation level**
- The **power consumption** will be smaller

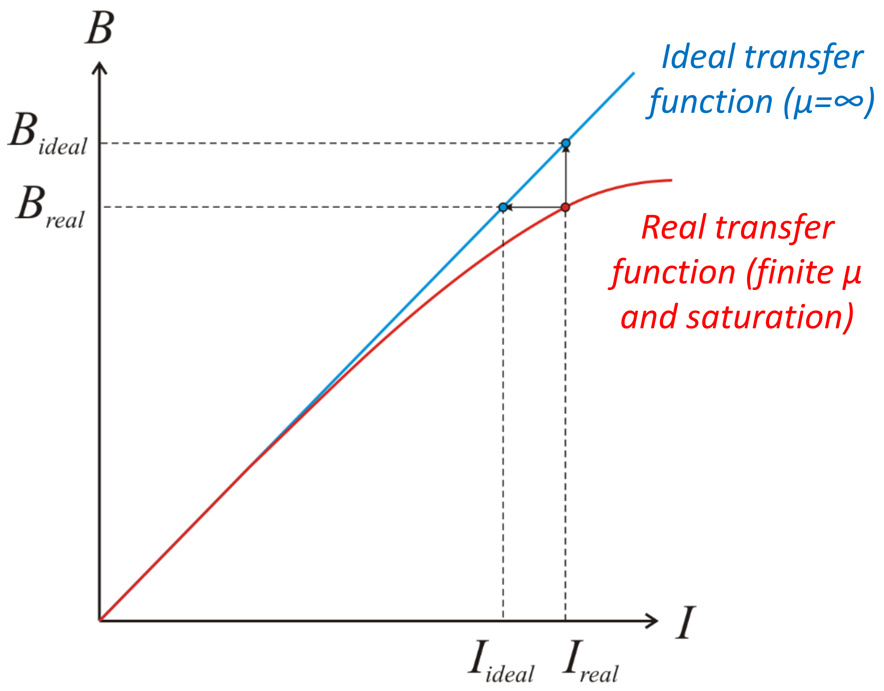
**CONS**

- The impact of the **geometrical errors** (ε) on the multipolar content will be higher (they scale as $\varepsilon/r_0$), making the manufacturing more difficult (and expensive)
- The constraints on the **mechanical design** of the vacuum system will become more stringent
- **Beam impedance** and **vacuum chamber conductance** issues will be more challenging

# ALBA II magnets design

- One of the **main control parameters** to evaluate the overall performance of a given design (defined in terms of **aperture, yoke geometry, material, current density**, etc) is the **magnetic efficiency**, defined as the ratio between the real magnet's current and the ideal one corresponding to an infinite permeability yoke
- **Efficiency** gives a measurement of the **degree of saturation** of the iron yoke

$$\text{Efficiency} \equiv \eta = \frac{I_{ideal}}{I_{real}} = \frac{B_{real}}{B_{ideal}}$$



# ALBA II magnets design

- We have defined as initial target values for the efficiency the ones used at **APS-U** for the different types of magnets:
  - **Single-function magnets** (Quadrupoles, Reverse bends and Transverse Gradient dipoles) were designed to operate at **90%** minimum efficiency.
  - **Multi-function magnets** (Sextupoles with integrated Correctors) were designed to operate above **98%** efficiency in order to **minimize the crosstalk** between the different field configurations.
- Taking into account these efficiency requirements, combined with the results from 2D simulations and vacuum technology feasibility considerations, we have come up to a **minimum opening radius of** $r_0$**=10mm**
- Together with this choice for the magnets opening, we are assuming that the **vacuum chamber** will be **circular** with an **external diameter of 18mm** (feasible to manufacture and to NEG-coat by industry)

$\eta_{single}$>90%

$\eta_{multi}$>98%

**Magnet's aperture**

$r_0$=10mm
∅=20mm

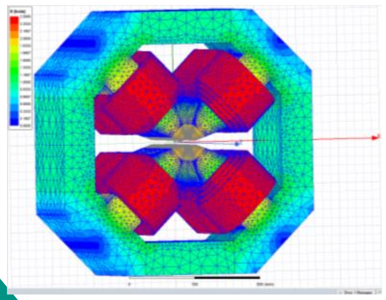
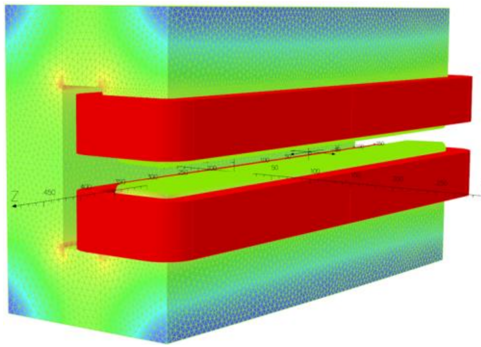
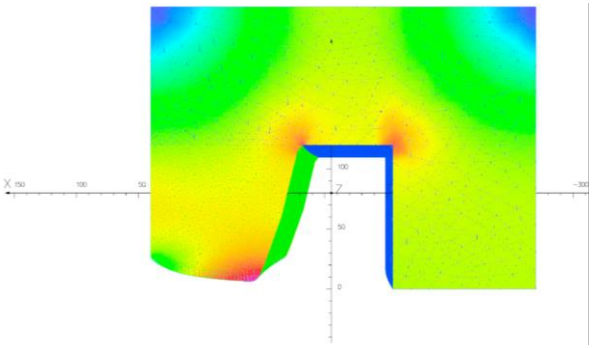
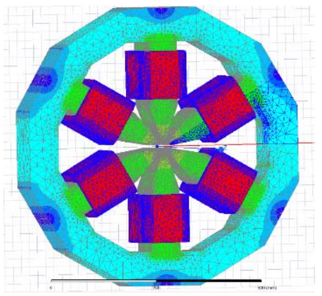
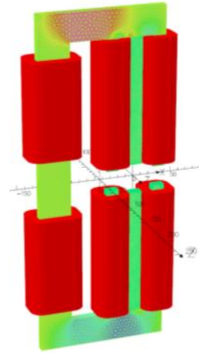
**Vacuum chamber**

$\varnothing_{ext}$=18mm
$\varnothing_{in}$=16mm
thickness=1mm

# ALBA II magnets design

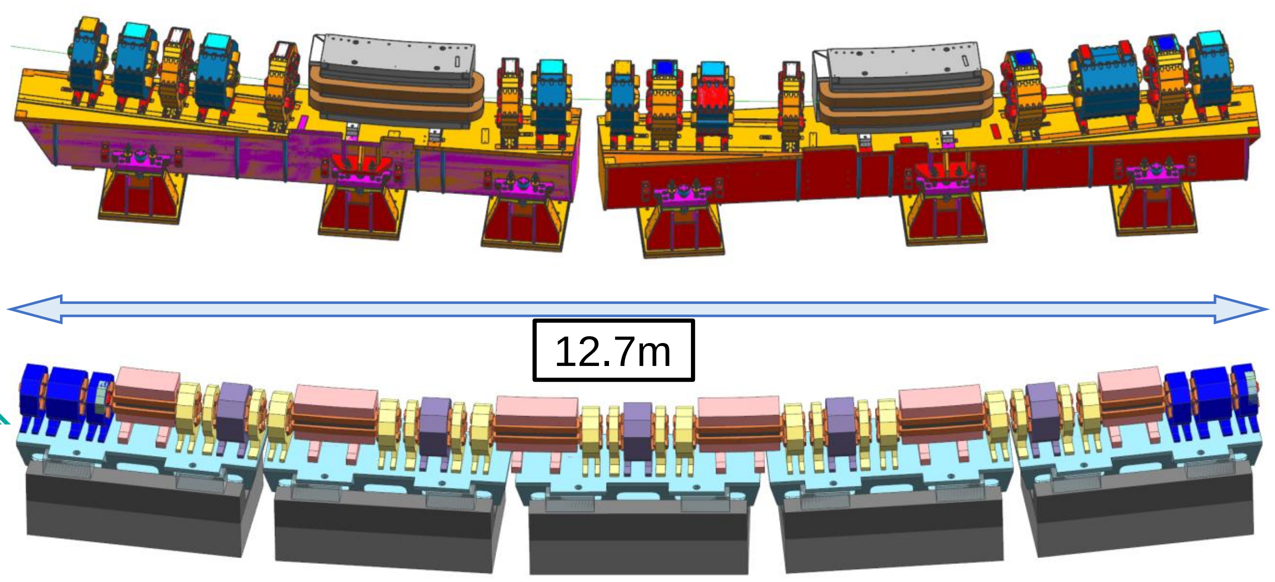
- We have worked out a **preliminary set of 3D models** for **all main magnet types** (overall dimensions without pole profile optimization):

| | Bore diameter [mm] | Min. pole vertical distance [mm] | Effective Length [mm] | Iron Length [mm] | Width [mm] | Height [mm] | Current [Amp·turn] | Efficiency [%] |
|---|---|---|---|---|---|---|---|---|
| QUAD (Q3) | 20 | 10 | 200.0 | 190.6 | 484 | 484 | 5000 | 90 |
| ANTIBEND QF/QFS | 27.8 | 10 | 297.2 | 282.5 | 540 | 540 | 5860 | 91 |
| BEND QD | 20 | 12.2 | 867 | 833.4 | 310 | 470 | 8130 | 99 |
| BEND QDS | 20 | 12.2 | 631 | 602.6 | 227 | 342 | 6573 | 99.8 |
| SEXTUPOLE (SH) | 24 | 7.0 | 104.2 | 96.2 | 514 | 514 | 2450 | 95 |
| SEXTUPOLE (SV) | 26 | 7.6 | 182.0 | 174.0 | 514 | 514 | 2460 | 98 |
| CORRECTOR (COR) | 36 | 25 | 85.0 | 20 | 262 | 430 | 1500/2000 | ---- |

# ALBA II magnets design

- This preliminary set of models has been transferred to engineers to implement them into the accelerator’s layout:




*Info and drawings courtesy of J. Boyer (ALBA Eng. Division)*

**ALBA**

Total magnet equivalent length:
**6.180 mm**

***Compactness:***
6.18/12.7 = **49 %**

**ALBA II**

Total magnet equivalent length:
**10.130 mm**

***Compactness:***
10.13/12.7 = **80 %**

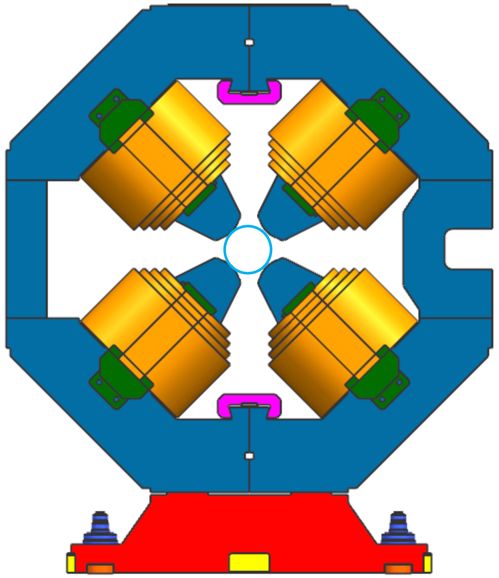
~60% raise in Compactness

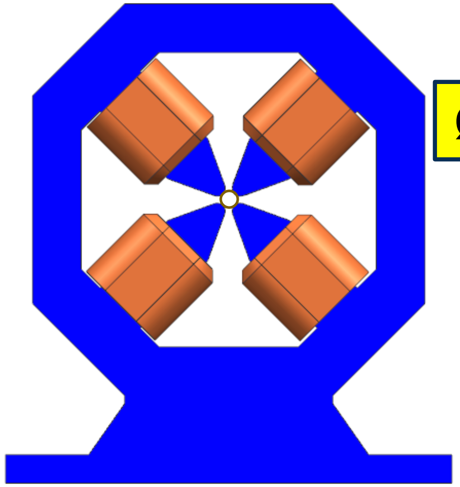
~20 % shrinkage transversal size

# ALBA II magnets design

- Yoke transversal dimensions and vacuum chamber:

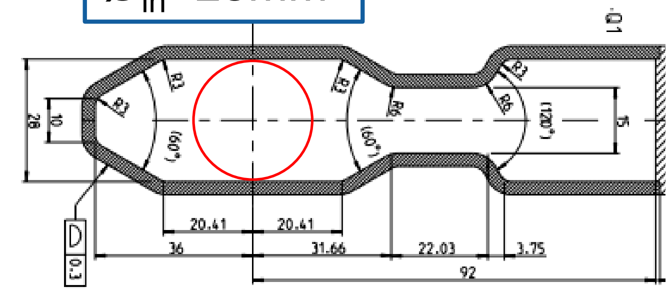
$Ø_{bore}$=61mm

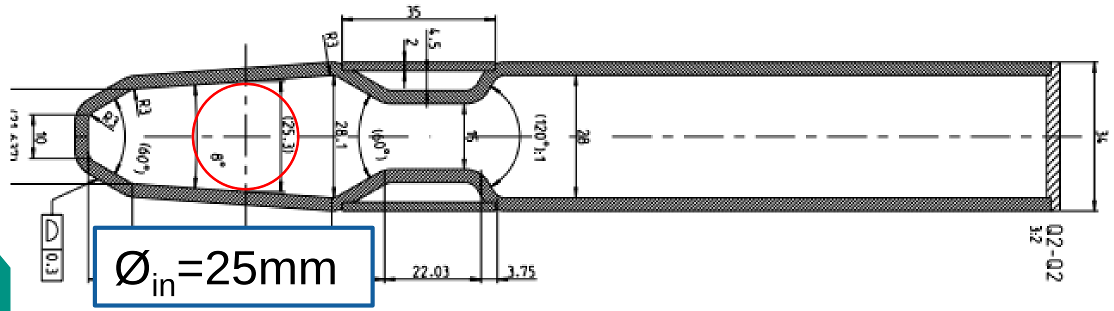




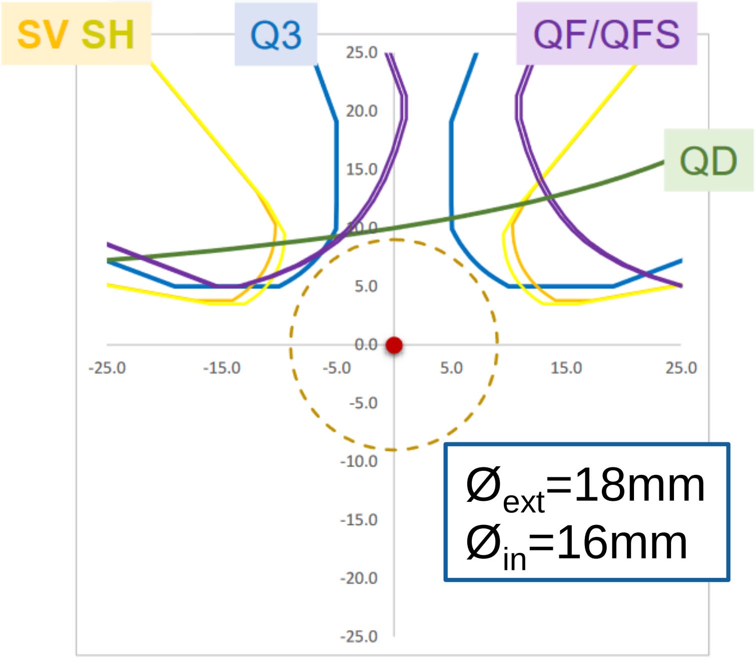
$Ø_{bore}$=20mm

$Ø_{in}$=28mm




$Ø_{in}$=25mm

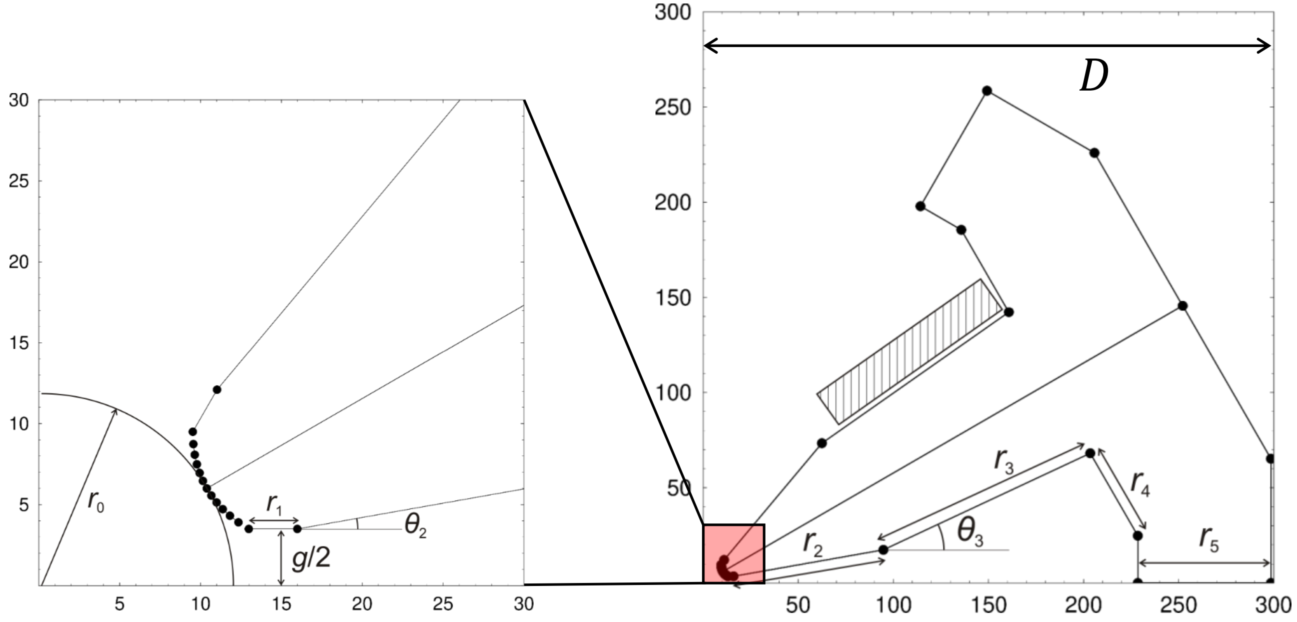



$Ø_{ext}$=18mm
$Ø_{in}$=16mm

*Info and drawings courtesy of J. Boyer and R. Parise (ALBA Eng. Division)*

# ALBA II magnets design

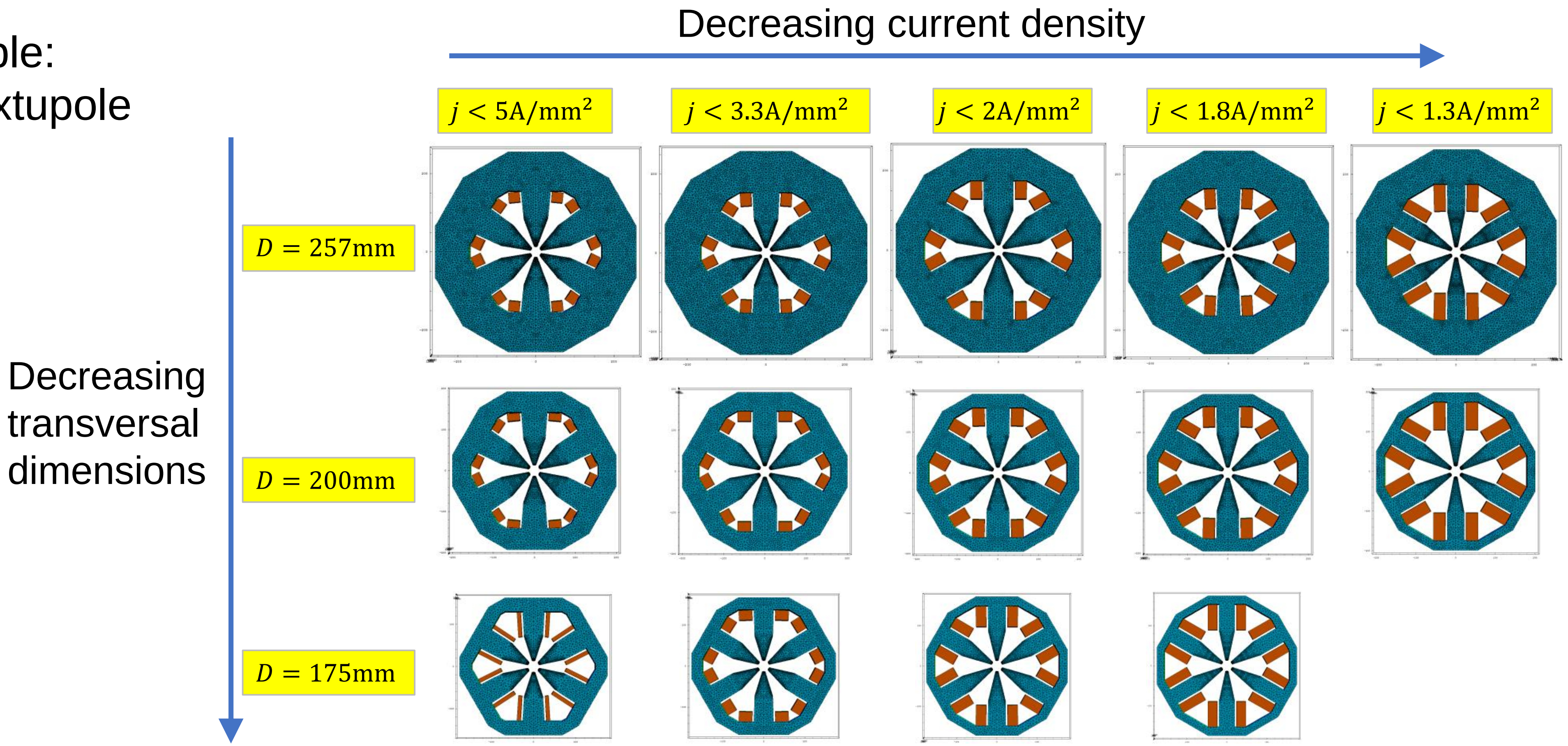
- We have carried out **systematic optimization study** of the **iron yoke dimensions** for different magnets types.
- Optimization has been carried out on **2D parametric models** of the magnets using **RADIA**.
- The aim has been to determine the optimum geometric parameters in order to **maximize the magnet's efficiency**, while keeping the **aperture** $r_0$, the **pole-to-pole vertical distance** $g$, and the **transversal size** $D$ constant.



# ALBA II magnets design

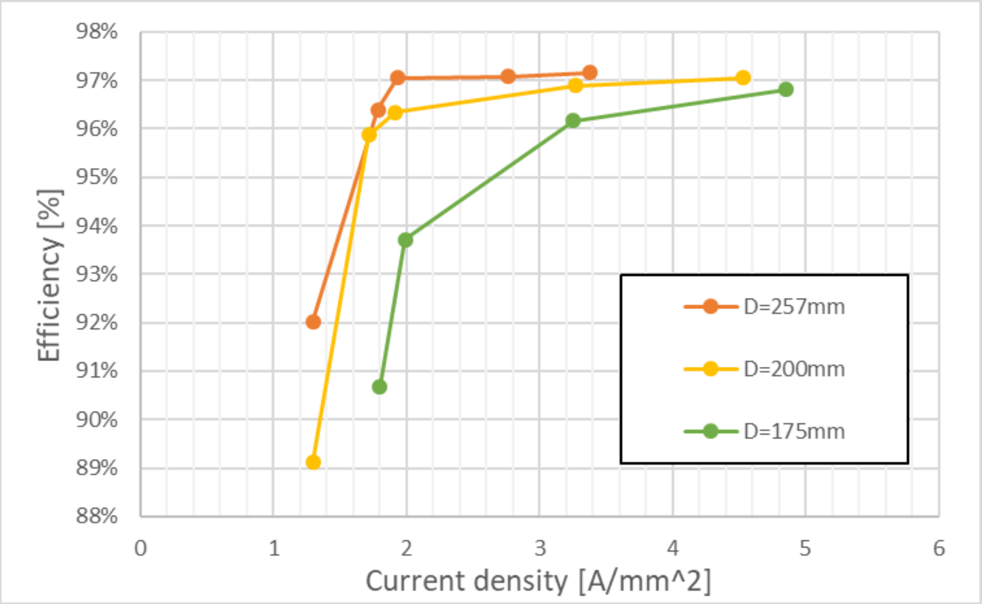
- Simulations have been carried out setting different limits for the current density on the coils.

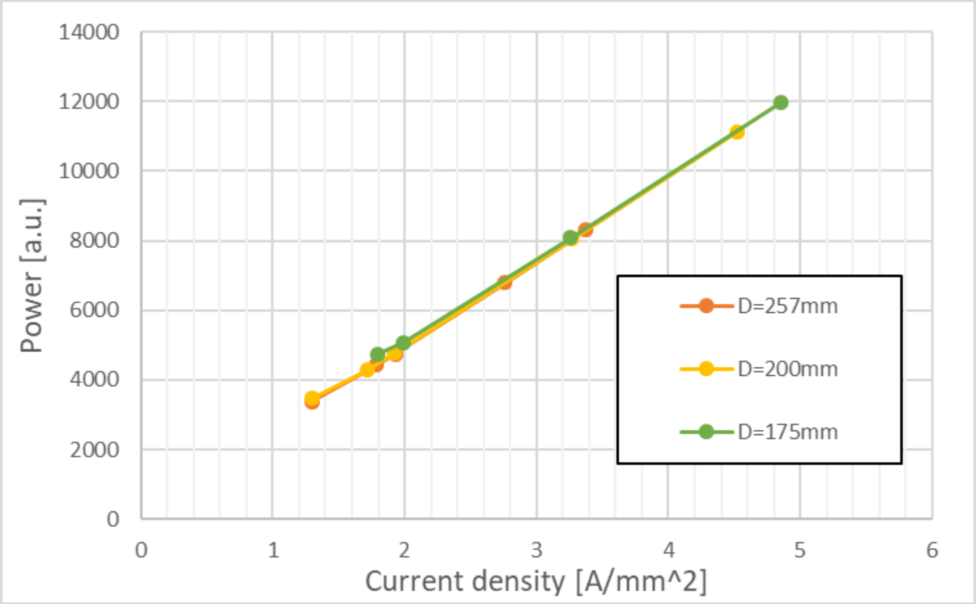
Example:
SV sextupole



# ALBA II magnets design

- Different **current density limits** have a direct implication on the **magnet's power consumption**.
- A **trade-off** between **size**, **efficiency** (linearity) and **power** has to be determined.

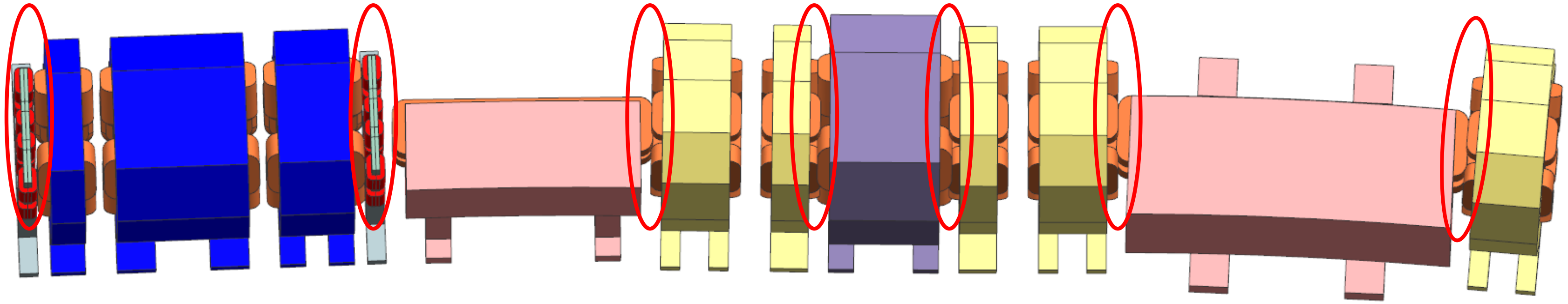


# ALBA II magnets design

**Issues to be addressed:**

- With the current design there are already some problems of **interference between the coils** of adjacent magnets

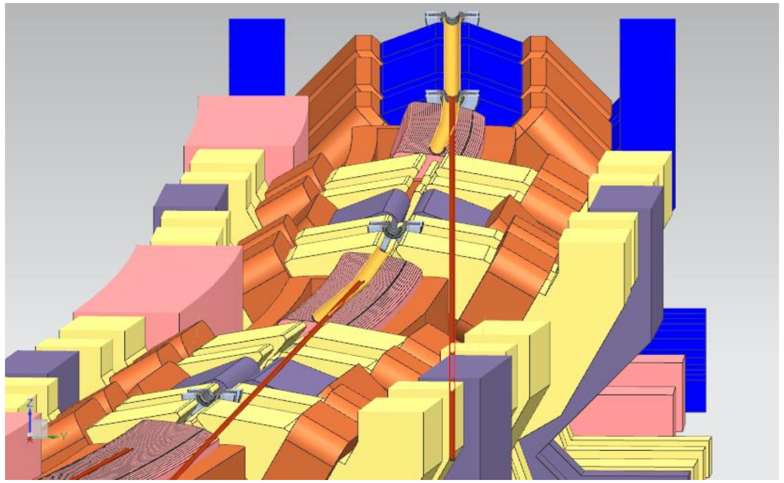


- **Enlarging the gaps between magnets** would be an option, but it would come at the cost of **degrading the emittance** → **last resort solution**
- We are currently working to **optimize the coils' geometry** to **minimize their longitudinal footprint**.
- If necessary, we will explore more aggressive solutions (**coils partially embedded in the yoke**, **coils installed on the return yoke** in the case of dipoles…)

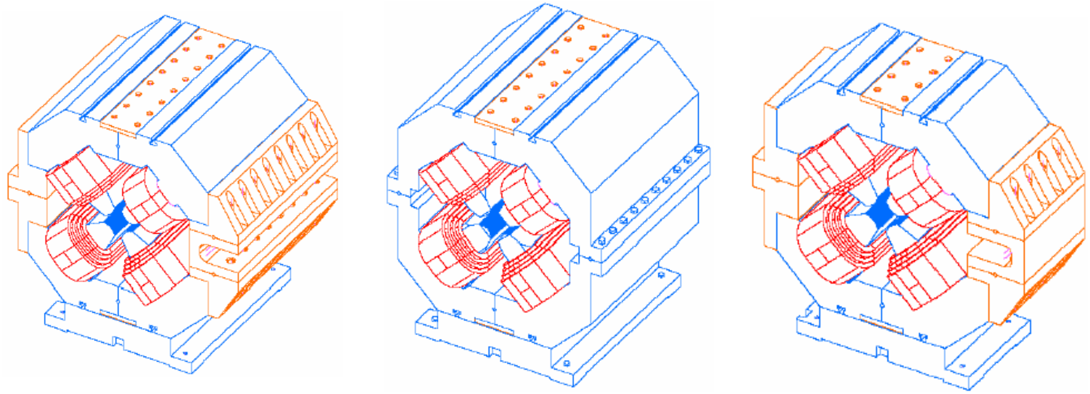
# ALBA II magnets design

**Issues to be addressed:**

- **Modification of iron yokes** to allow for **light extraction**.



*Drawing courtesy of R. Parise (ALBA Eng. Division)*

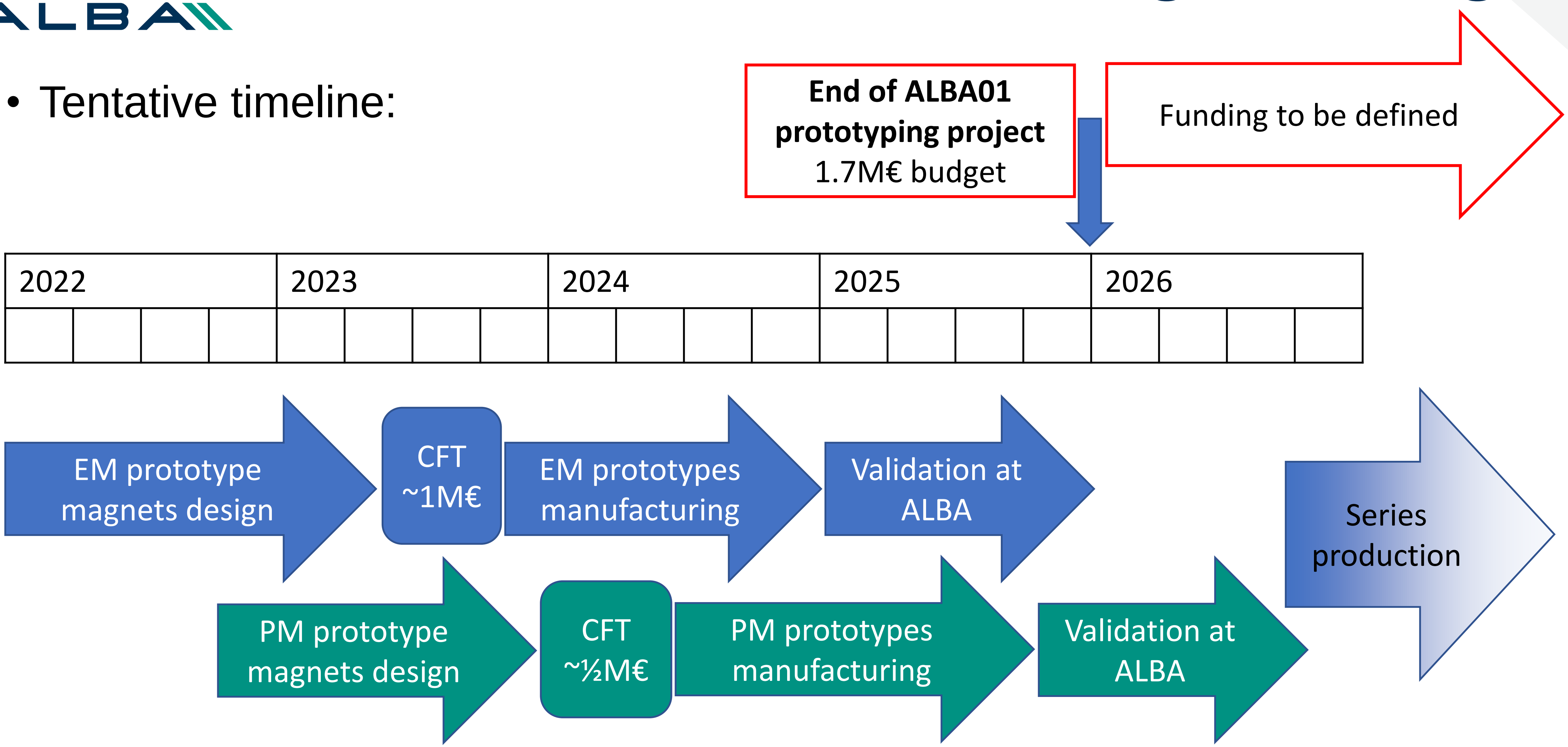


Different yoke types in the case of ALBA

- **Pole profile optimization** to **minimize multipolar component**.
- **Analysis of cross-talk effects** between adjacent magnets.
- …

# ALBA II magnets design

- Tentative timeline:



# ALBA II magnets design

- **Prototyping and procurement strategy:**
  - Given the **tight schedule** for the prototyping program, the CFT will be based on a **set of functional specifications** together with **basic design proposals** → it will be far away from a built-to-print approach.
  - Still to be decided **how many prototypes will be manufactured**.
  - Decision will be prompted by which features do we want to check:
    - **Magnetic performance** of each magnet type (field/gradient levels, linearity, multipolar content, magnetic axis stability with current…).
    - **Mechanical accuracy issues** (pole machining precision, repeatability upon dismounting/remounting, tolerances coil manufacturing…).
    - **Mechanical integration aspects** (mounting mechanism on girders, vacuum chamber assembly…).
    - **Cross-talk effects** between adjacent magnets.

# ALBA II magnets design

- **Prototyping and procurement strategy:**
  - Decision about **number of prototypes** will also be driven by their **unitary cost**.
  - Prototypes **unitary cost** will be largely influenced by **manufacturing process**:
    - **Laminated technology** is **cheaper** for **reasonable volumes of production** (≳20 magnets), and it is convenient to obtain a **good magnet-to-magnet reproducibility** over the whole series.
    - However, for prototypes the **cost of the stamping/stacking tooling** for each magnet type (~50k€) has to be charged to a very limited number of units (just 1 or 2), **increasing the unitary cost by a ~50%**.
    - At the **relatively early stage of the overall design** that we are now, we do not have any guarantee that the magnet designs developed during the prototyping phase will be directly transferred to the series production (for instance, it is not certain that it will be possible to reuse any tooling developed for the prototypes).

# ALBA II magnets design

- **Prototyping and procurement strategy:**
  - **Prototypes** will be tested at **ALBA Magnetic Measurements Lab**.
  - For the **series production**, it is clear that the **manufacturing will be completely outsourced**.
    - The details of the **company validation procedure** are **still to be defined**.
  - The approach to the **validation/characterization of series magnets** has still **to be defined** as well:
    - It is unlikely that we will have the capacity to fully characterize all the magnets in-house.

# Outline

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- ALBA II magnets design
- **Conclusions**

# Conclusions

- After 10 years in operation, ALBA is undertaking the project of upgrading its Storage Ring to achieve ultra-low emittance and hence becoming a 4th generation Synchrotron Light Source (ALBA II).
- The upgrade implies a complete renewal of the Storage Ring, and in particular of all its magnets, that have to be redesigned and manufactured.
- We already have a reference design for the accelerator's lattice, which is based on the MBA concept (6 bendings per cell in our case). However, the lattice is not yet completely frozen.
- With respect to the existing one, the new lattice is a 60% more compact, and requires much higher gradients in quads (×5) and sexts (×10).

# Conclusions

- The baseline design for the magnets makes uses of conventional technology for electromagnets (EM), but we want to explore in parallel some solutions incorporating permanent magnets (PM).
- We have developed some preliminary designs for all the types of magnets, and are using them to check mechanical integration aspects. The feedback from this exercise will be used to further refine the designs (fix mechanical interferences, local modification of geometries for light extraction, etc.).
- Within this year we will prepare the functional specifications to tender the prototypes for the different magnet types.
- Using the experience gained with the prototypes, series production will be prepared and launched starting in 2026.

# Questions?

Comments, criticisms, suggestion and pieces of advice are also most welcome…