Progress with the ALBA-II double-dipole kicker

Gabriele Benedetti
M.Carlà, J.Casanova, R.Muñoz, F.Pérez, M.Pont, O.Traver

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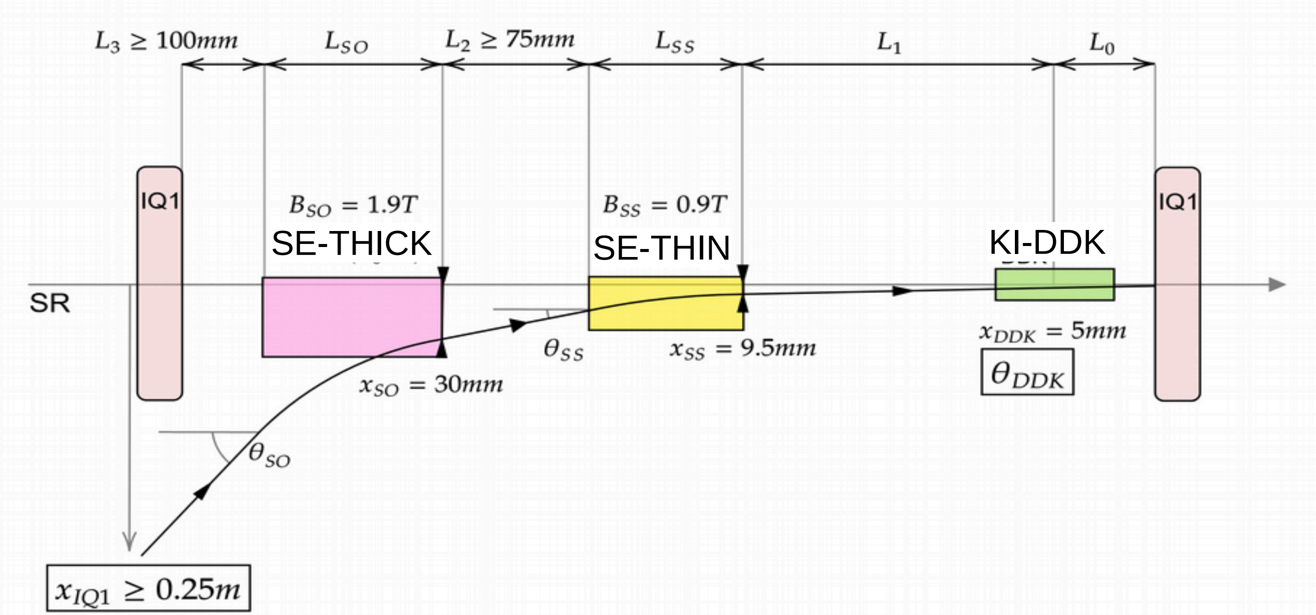
Talk Outline

- Motivation for the double-dipole kicker
- Geometry of the DDK and solutions for transparent injection
- DDK prototype for the existing ALBA SR
- Construction of the DDK prototype
- A vibrating wire setup for the DDK field characterisation

Why a double-dipole kicker

The ALBA-II lattice will be very tight and all the injection elements have to fit in a **4 metres straight section**. Beam injected off-axis and a multipole pulsed kicker reduces its large oscillations within the dynamic aperture.



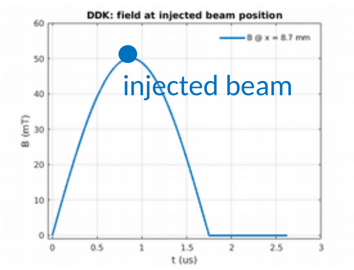
The injected beam trajectory x_{septum}, x'_{septum}, x_{kicker}, the kick etc. will be a trade-off among horizontal dynamic aperture, septa thickness and field, kicker apertures and pulse current/voltage...

Designing the ALBA-II injection scheme

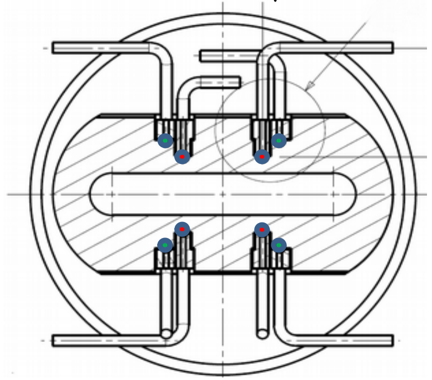
- Injector emittance 10 nm·rad
- All the injection elements in a 4 metres straight section
- Betatron off-axis injection
- Horizontal dynamic aperture as large as possible (> 6 mm)
- **Develop a pulsed multipole kicker**
  - Build and test a prototype matching the existing ALBA ring
  - Define a kicker design fitting the ALBA-II lattice and apertures

Pulsed Non Linear Kicker

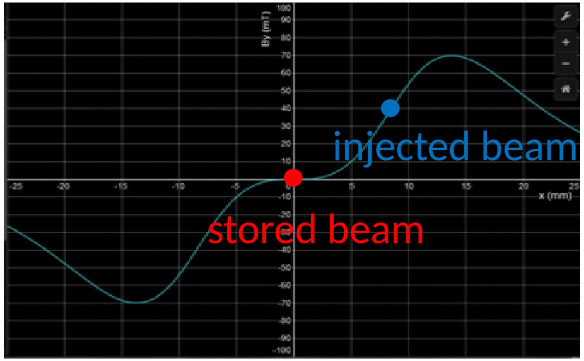
- Conceived at BESSY-2, further developed at MAX-IV, Sirius, Soleil…
- The stored beam is not disturbed
- Only the injected beam is kicked
- Pulse length $T_{pulse} < 2$ turns = 1.75 μs



MIK cross section (MAX-IV/Soleil)



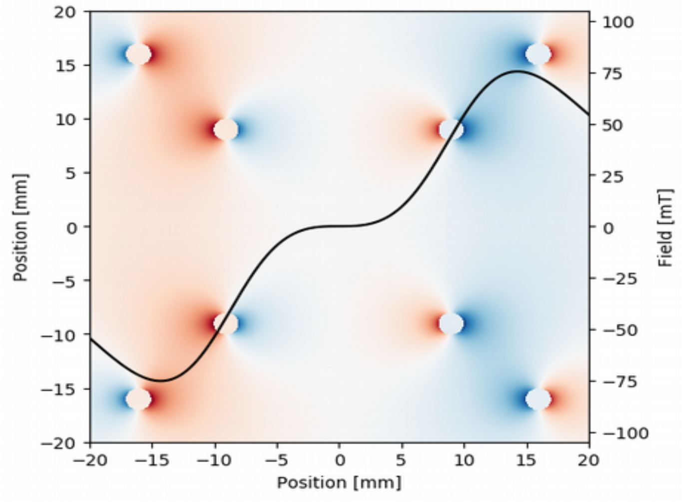
NLK field in the horizontal mid plane



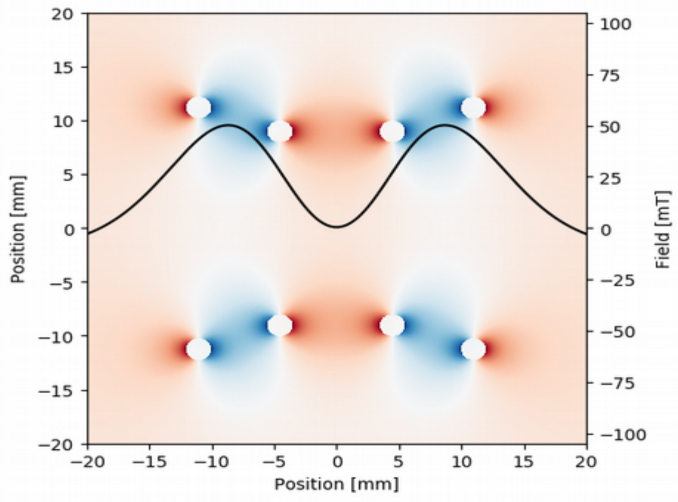
Based on these experiences, **a novel design of multipole kicker** was started in order to install and test a **prototype in the ALBA storage ring** (not yet in ALBA-II)

Different pulsed multipole kicker topologies

octupole-like kicker (NLK, MIK...)



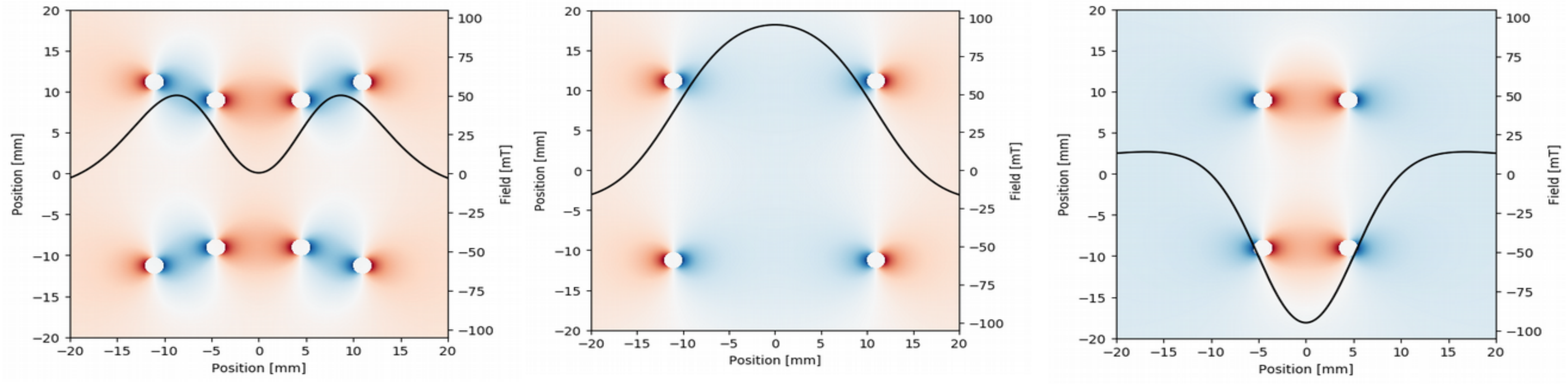
sextupole-like kicker



Both geometries produce a peak of the field, ideal for the injected beam position, and zero field at the centre, for stored beam transparency.
For ALBA-II we are proposing a topology of the coils that produces a sextupole-like field around the stored beam position.
The plateau at the center is not as wide as in the octupole, but there are other advantages that can be valuable for ALBA-II.

Double-dipole Kicker

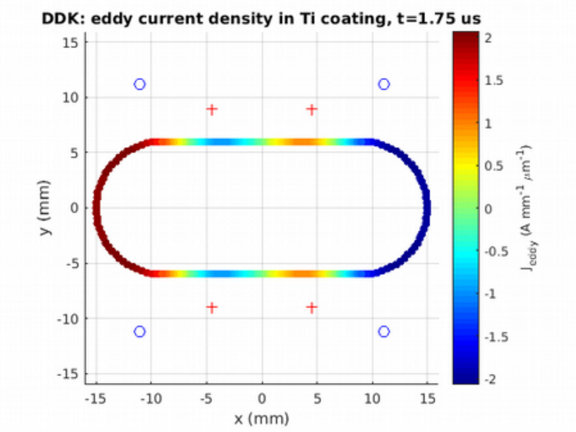
powering 4 inner + 4 outer rods | switching 4 inner rods off | switching 4 outer rods off

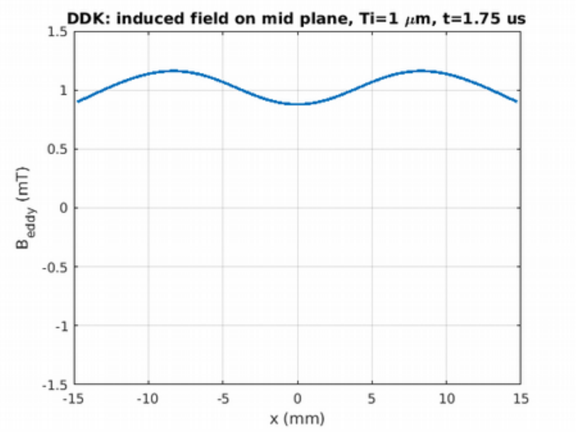


- Switching off either the inner or the outer rods, a dipole field is produced.
- **A dipole is needed for on-axis injection during the ALBA-II commissioning.**
- ALBA-II straight sections have very little room and **combining two kickers in one** will be very useful.

Eddy currents and induced field in the DDK

Eddy currents have been calculated analytically from Maxwell's equations and integrating them by imposing the continuity equation for the density of current:





Ti coating with uniform thickness	Max induced field at stored beam position *(and tolerance for transparent top-up)*
1 μm	**B_y = 0.75 mT** *(0.07 mT)*, **$\partial B_y/\partial x$ = 0** *(0.36 T/m)*

The effect of the eddy currents on the stored beam would be above the tolerances to guarantee transparent top-up.

DDK vs. NLK (ALBA prototype)

	Switch multipole /dipole	Peak at X_{inj}=8.7mm	Field at x_{inj}=8.7mm (mT)	Rod positions x_{in}-y_{in} / x_{out}-y_{out} (mm)	Half apertures HxV (mm)	Length (mm)	Inductance (μH)	Current (A)	Ti coating thickness (um)	Max induced field at stored beam position *(transparent top-up: B < 0.07 mT, B' < 0.35 T/m)*
DDK	**YES**	**YES**	**50**	**4.5-9 / 11-11.2**	**15 x 5.5**	**300**	**0.9**	**2675**	**1**	**B_y = 0.75 mT, B_y'= 0**
NLK	NO	NO	50	8.5-8.5 / 16-16	15 x 5	300	1.7	2825	1	B_y = 0, B_y'= 0.09 T/m

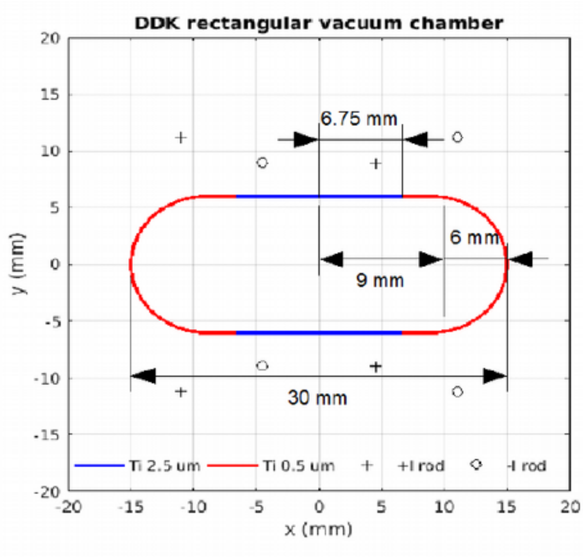
We have to design a solution that guarantees **transparent top-up** despite the mechanical tolerances of the coils positioning and the field induced bt the eddy currents:

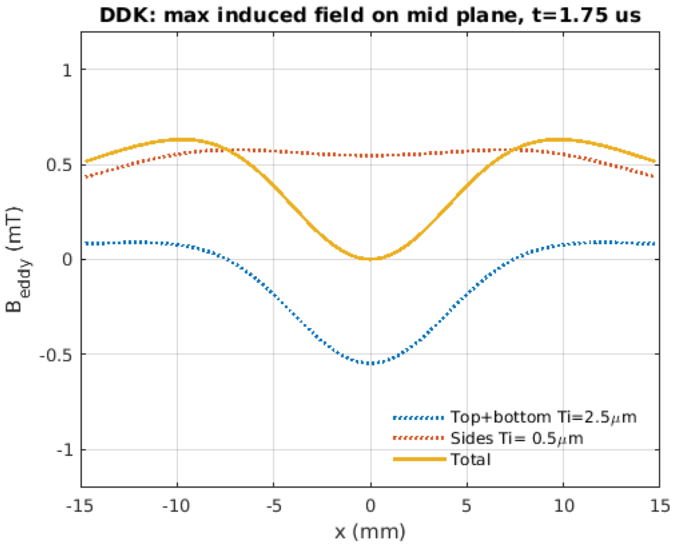
- Realistic **rod positions tolerances are 20-50 um**.
- The defect field due to the positioning errors can be corrected adjusting the current in the inner and outer coils of the DDK with **2 independent power supplies**.
- **The effect of the eddy currents induces a non-negligible dipole of 0.75 mT.**

Different coating thickness on top/bottom and side walls

The dipole induced by the eddy currents on the stored beam can be cancelled by applying **two different coating thickesses** on the inner surface of the chamber.

Coating on the top and bottom surface 5 times thicker than on the side surface **makes the induced dipole zero**.





Ti coating with 2 different thickness	Induced field at stored beam position *(“transparent top-up”)*
2.5 µm top/bottom 0.5 µm sides	B_y = 0 mT *(< 0.07 mT)* $\partial B_y/\partial x$ = 0 *(< 0.36 T/m)*

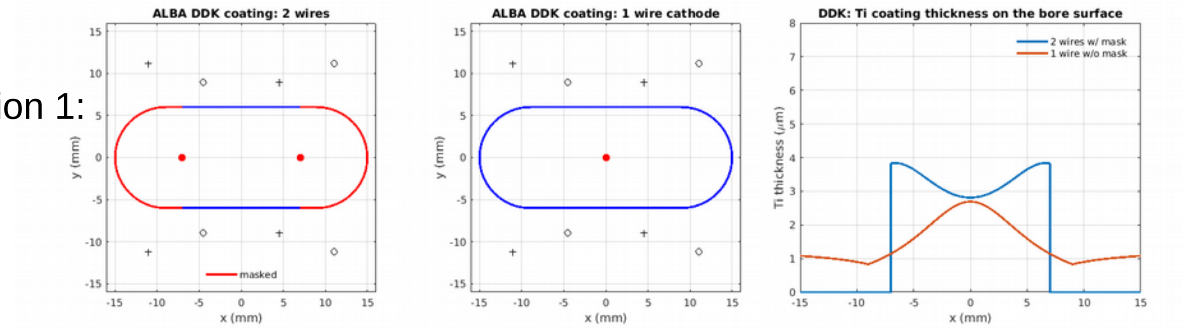
In ALBA, 300 mA/440 bunches and 27.5 ps bunch length, dissipated power 5 W.

Coating deposition process with masking

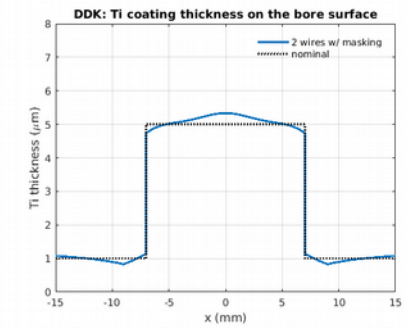
The titanium coating deposition process can be performed in two steps, first masking on the side surface, then removing the masks

Option 1:

2 wires w/ masks | 1 wire w/o masks

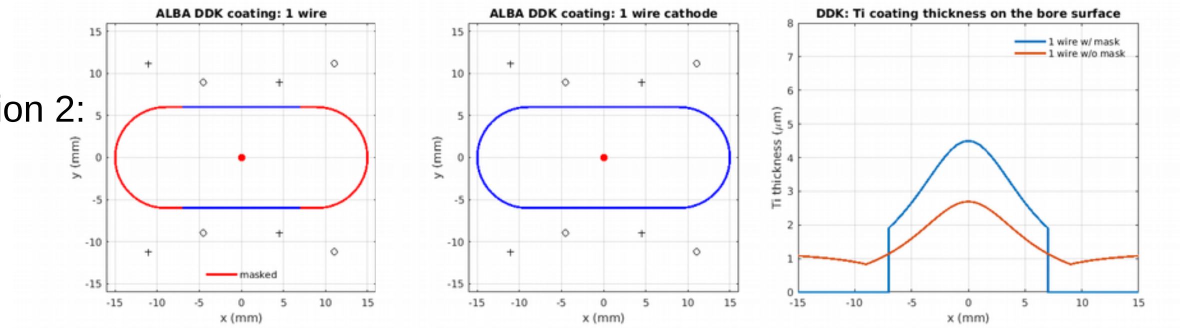


Coating profile

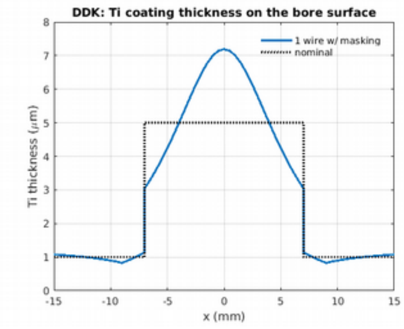


Option 2:

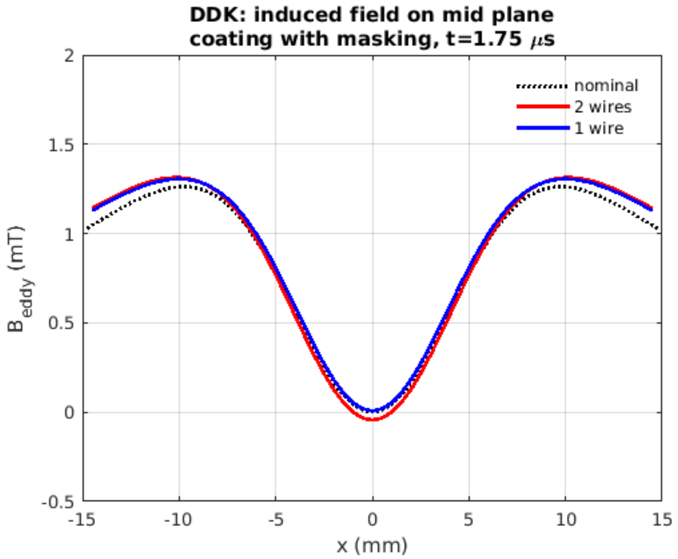
1 wire w/ masks | 1 wire w/o mask



Coating profile



Coating with masking: field induced by eddy currents



Mechanical positioning tolerances for the mask and the wire to guarantee an induced field $\Delta B_y < 0.07$ mT.

Mask positioning	< 1.0 mm
Wire horizontal position	< 0.5 mm
Wire vertical position	< 1.0 mm

A flat profile of the Ti coating thickness is not necessary as long as the ratio between the average thickness in the two regions of the inner surface remains equal to 5

Field error due to finite propagation speed of pulses

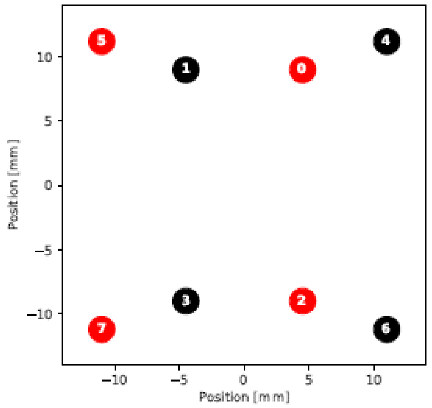
Assuming the current pulse propagates at constant speed through conductors.

- Propagation speed between alumina and vacuum

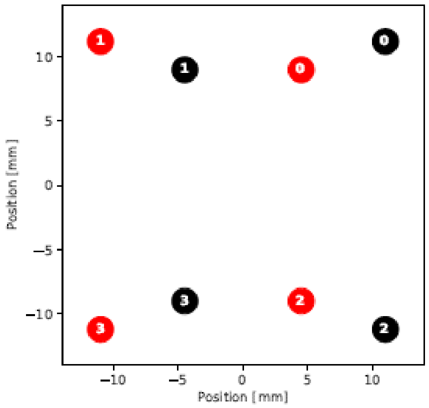
The overall field distortion is affected by the order in which the rods are connected.

- This error can be partially compensated by the use of two independent power supplies.

Overall effect on the stored beam estimation from the mean field error for single and double power supply configurations



1 power supply configuration



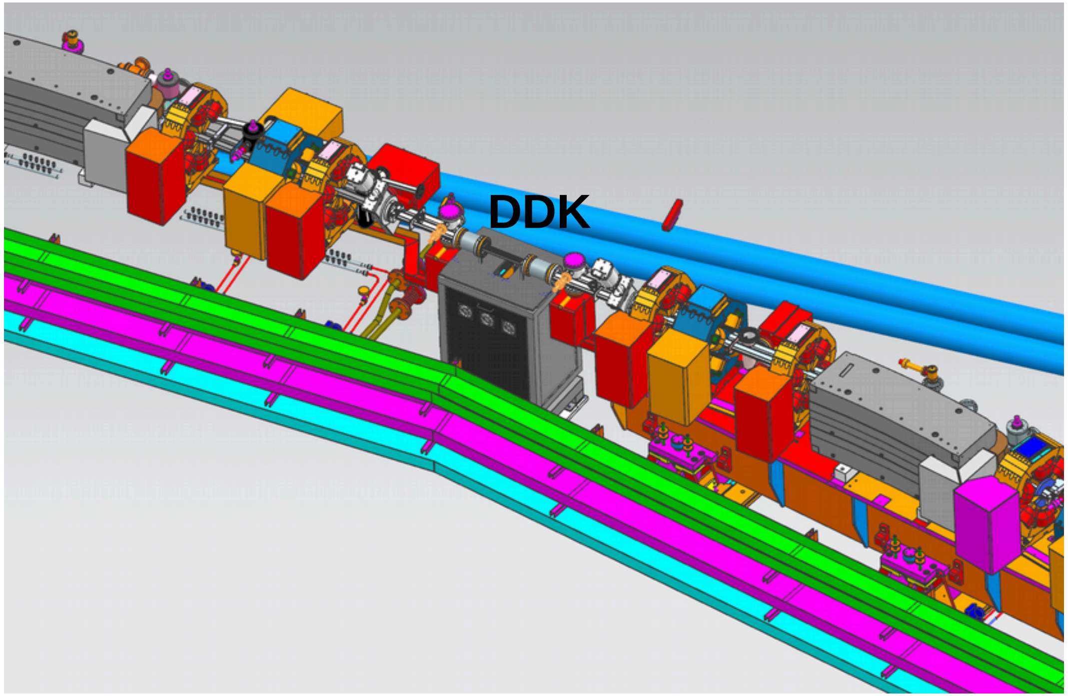
2 power supplies configuration

	Single power supply		Double power supply	
	Vacuum	Alumina	Vacuum	Alumina
ΔB_x	160 µT	475 µT	50 µT	155 µT
ΔB_y	210 µT	630 µT	0	0

DDK prototype in current ALBA storage ring

A DDK prototype matching the ALBA lattice and apertures is already under construction and will be installed in a short straight section of the current storage ring.

From this injection test we expect to confirm and learn how to design the DDK for ALBA-II

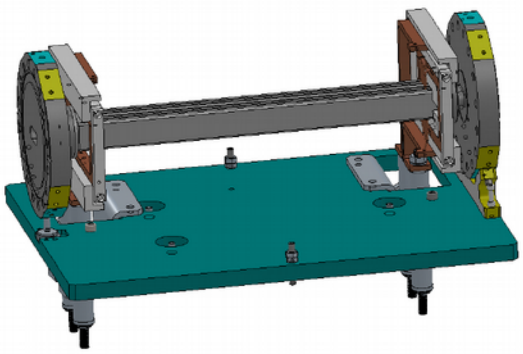


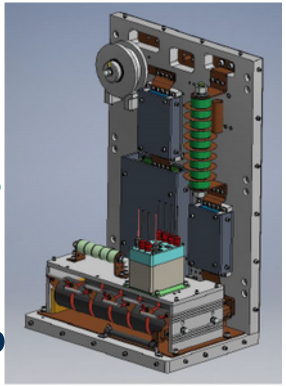
Call for tender for DDK prototype

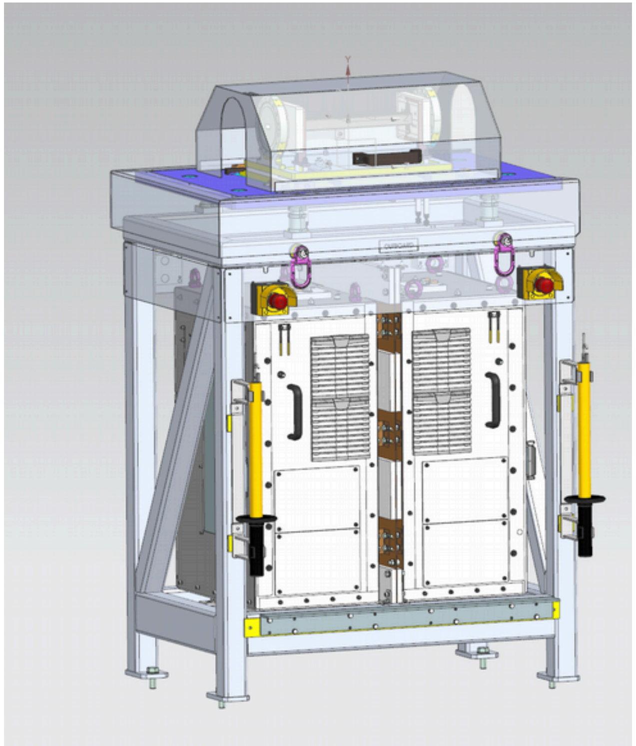
Call for tender awarded in 2023

- **Added Value Solutions (AVS):**
  - DDK:
    - Ceramic vacuum chamber
    - 8 rods (positioning tolerance 50 um)
    - Connection to UHV flanges
  - Support
  - Status:
    - Ceramic chamber under construction
    - Ti coating thickness with 5% uniformity
- **Research Instruments (RI):**
  - 2 pulser units
    - Pulses: 1.75 µs, 3 Hz, jitter 2 ns, 3000 A, ΔI/I<0.1%
  - Status:
    - Items in production, under schedule

Delivery: end 2024. Installation and test in ALBA b

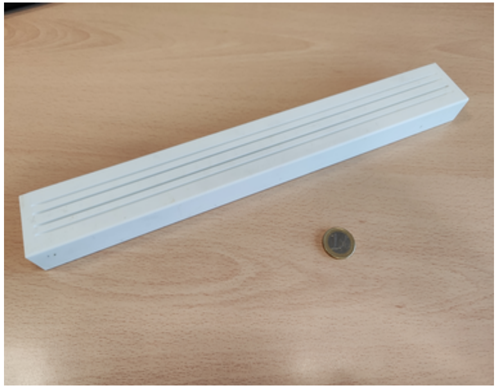


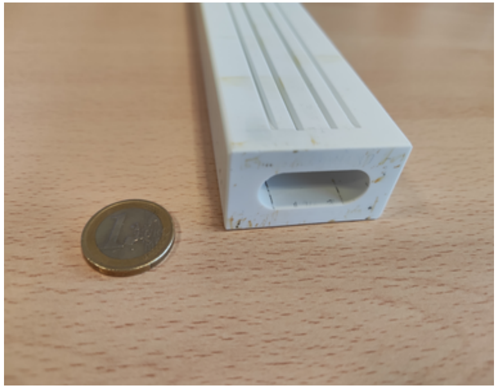




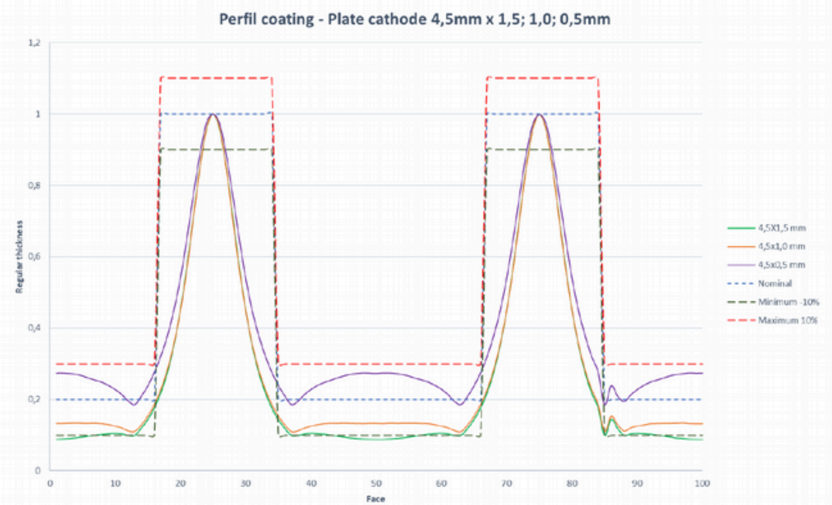
ALBA-Sirius collaboration for NLK-DDK developments

In 2023 started a collaboration that includes:





- Manufacturing of a ceramic vacuum chamber by the Sirius laboratory (CNPEM) with rods positioning tolerance of 50 um and titanium coating with different thickness in the top/bottom and side inner surface



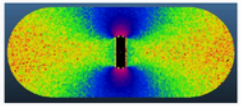


Plate cathode 2,5 x 1,5 mm.

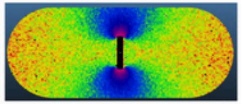


Plate cathode 4,5 x 1,0 mm.

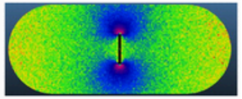


Plate cathode 4,5 x 0,5 mm.

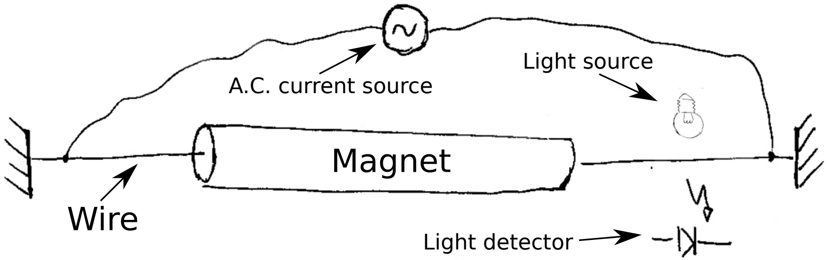
- Metallic coating studies for:
  - Eddy current minimization simulations
  - Heat losses reduction simulations
  - Metallic deposition simulations
  - Metallic coating techinque development

(courtesy of R.Defavari)

A vibrating wire setup for pulsed magnets

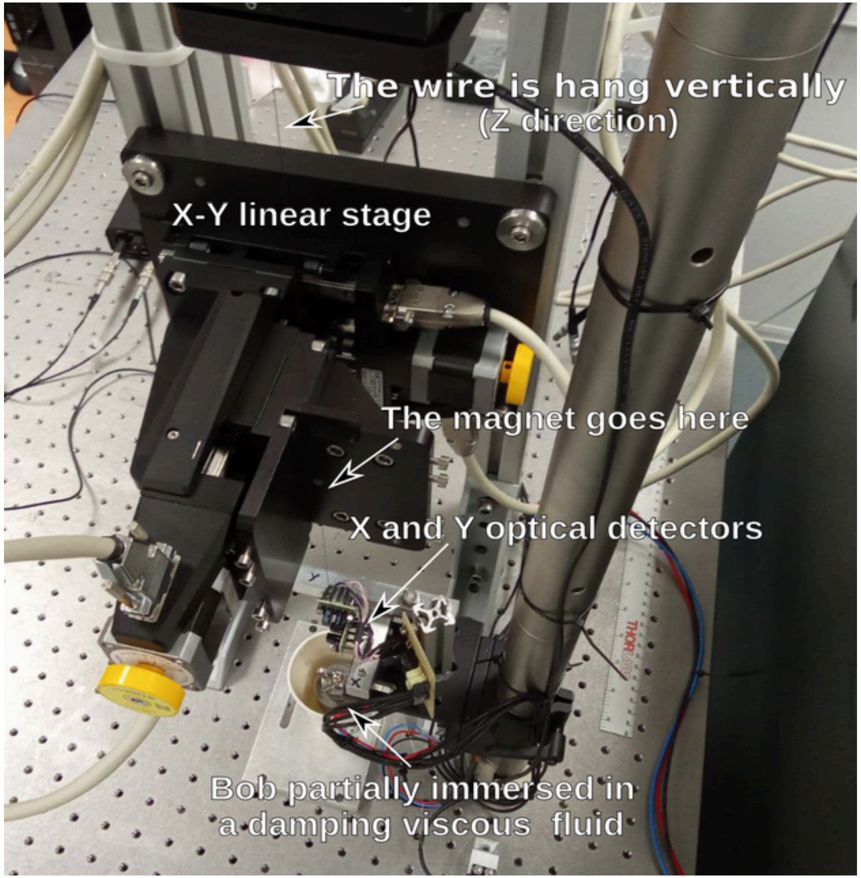
In a traditional vibrating wire setup:

- The wire is stretched horizontally and scanned in the magnet bore
- An alternating current matching the wire’s mechanical resonant frequency is applied to it
- The vibration of the wire is measured with optical sensors

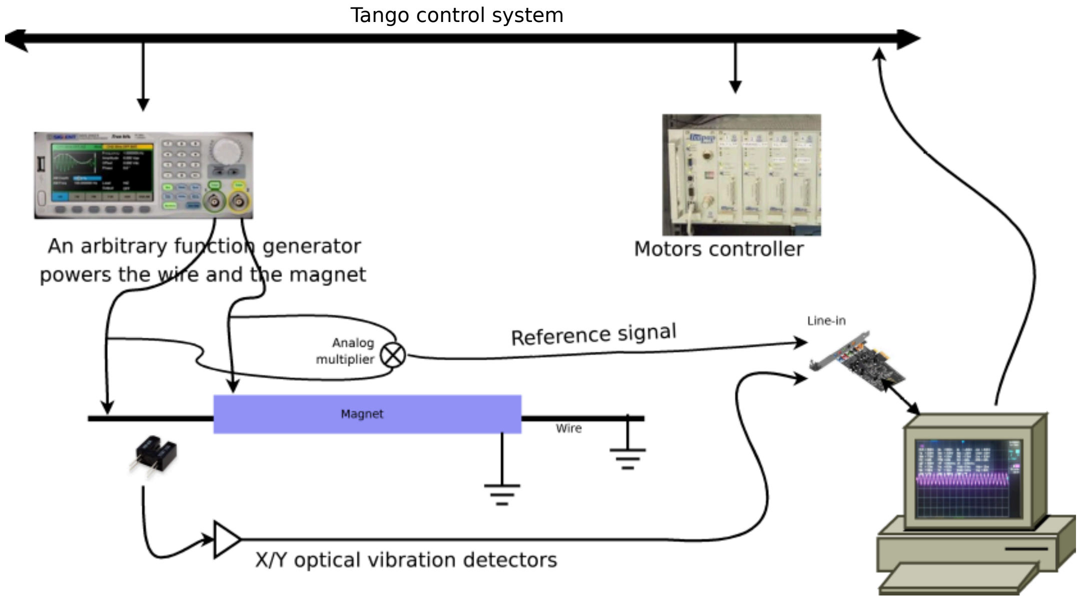


The small size of the kicker allows for some setup optimization:

- The magnet is hold vertically, the wire is hang in a pendulum: the tension of the wire is very constant
- The wire position is kept fixed, the magnet is moved to measure a transverse map of the field
- The wire is short (<1m) allowing for a longitudinal field mapping by measuring different resonant modes of it
- The setup is very compact allowing to use cheap optomechanical components



Measuring time dependent effects (eddy currents)



The ALBA DDK will be pulsed with semi-sinusoidal pulses with 1.75 μs semi-period equivalent to 280 kHz:

- The magnet is powered by a steady sinusoidal ~1 A current at 280 kHz
- 280 kHz is far from the fundamental mode of the wire (~100 Hz): if DC is passed through the wire no vibration would be induced
- Nevertheless <u>a vibration of the wire can be induced by beating the frequency of the magnet with an alternating current in the wire differing in frequency (respect to the magnet field) by the wire resonant frequency</u>
- By increasing the magnet frequency, time dependent effects (such as eddy currents) are stressed!
- Measured signals are always at the wire resonant frequency (audio frequency): electronics is simple

Conclusions and future work

- Betatron off-axis injection in a 4 meters straight section is the first choice for the injection into ALBA-II
- A kicker (named double-dipole kicker “DDK”) performing a dipole kick or a nonlinear kick depending on which combination of conductors are powered has been proposed
- A coating structure to cancel the induced field by eddy currents has been studied and the deposition process simulated
- Constructing a prototype to be installed and tested in the existing ALBA storage ring by end 2025
- A vibrating wire setup to characterise the kicker field is being developed at ALBA

Extra slides

ALBA DDK prototype specs

Kicker magnet design parameters:

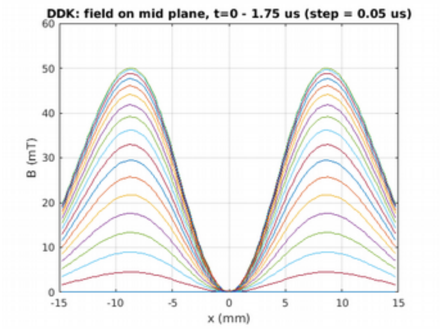
Inner rod position	x_i, y_i	4.50, 9.00	mm
Outer rod position	x_e, y_e	11.00, 11.20	mm
Diameter of the rods		2	mm
Field at x = 8.7 mm	B_y	50	mT
Magnetic length	L	300	mm
Total coils inductance	L_{tot}	0.90	µH
Inner coils inductance	L_{in}	0.83	µH
Outer coils inductance	L_{out}	0.55	µH
Mutual inductance	M_{inout}	-0.24	µH

Half-sinus current pulse parameters:

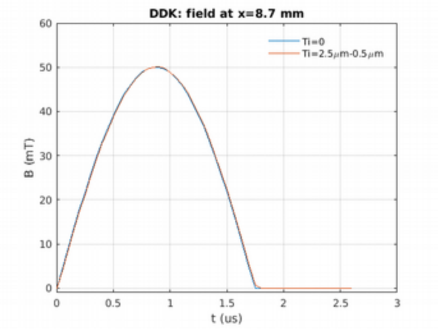
Pulse duration	t_p	1.75	µs
Peak current	I_0	2675	A
Nominal repetition rate	f_{rep}	3.125	Hz

Coating optimisation to cancel eddy current effect

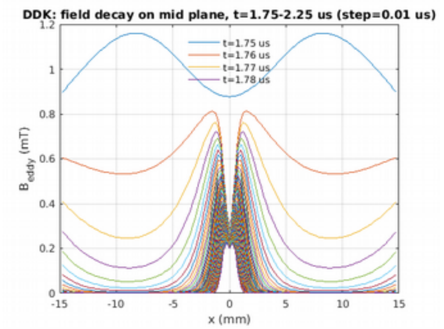
Field pulse on the DDK mid plane



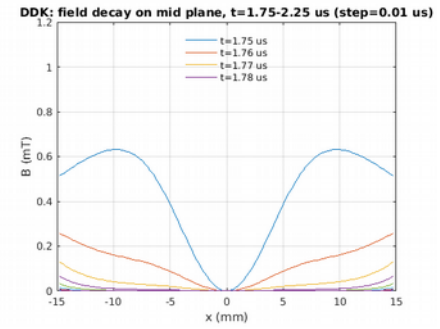
Field pulse at the injected beam position



Field decay with 1 um uniform Ti coating

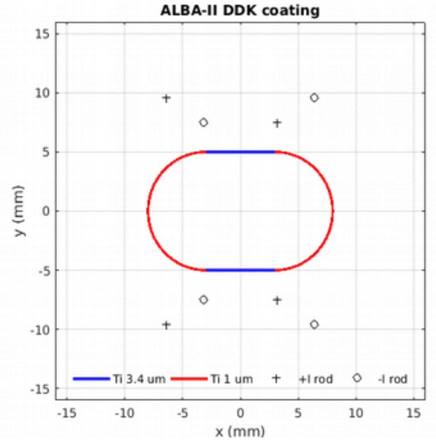


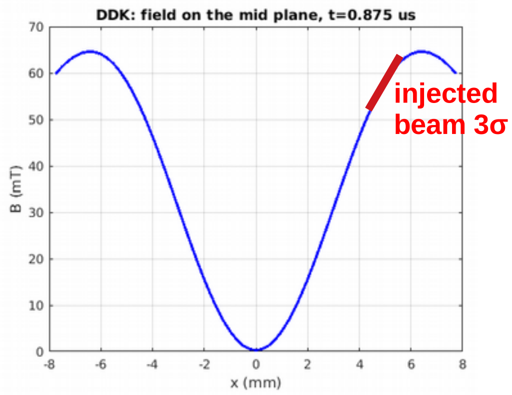
Field decay with 0.5-2.5 um Ti coating



DDK for ALBA-II *(preliminary)*

To perform a first injection simulation for ALBA-II, we have used realistic parameters to design our kicker. Assuming an educated guess for the horizontal DA of 6.5 mm, the beam can be injected at 5 mm. The peak of the field has been positioned as close as possible to the injected beam position:





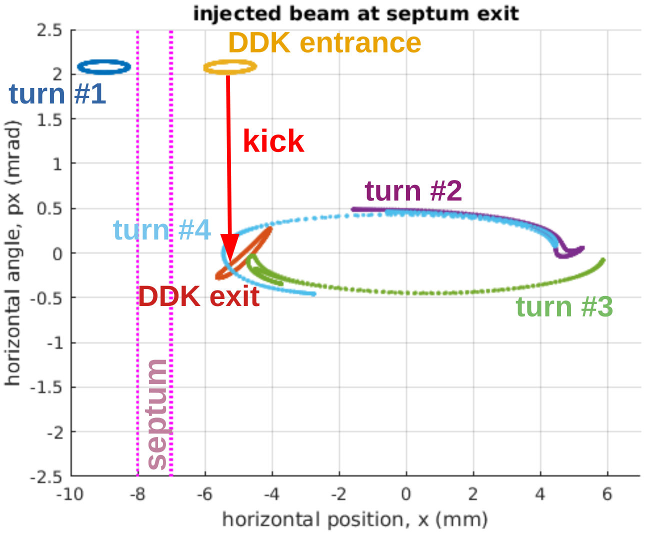
ALBA-II	Peak position (mm)	Field at x_{inj}=5mm (mT)	Rod positions x_{in}-y_{in} / x_{out}-y_{out} (mm)	Half apertures HxV (mm)	Length (mm)	Inductance (μH)	Current (A)	Ti coating thickness (um)	Induced field at stored beam position *("transparent top-up")*
DDK	6.4	60	3.2-7.5 / 6.4-9.6	8 x 5	400	1.1	4400	1.0 (top/bottom) 3.4 (sides)	B_y = 0 *(0.03 mT)*, B_y'= 0

Injection with DDK in ALBA-II *(preliminary)*

Simulation of a 3σ injected beam with realistic parameters (without errors)

Injection parameters (preliminary)

β_x *	25 m
DA*	7 mm
x @ septum	-9.5 mm
x' @ septum	+2.4 mrad
x @ DDK	-5 mm
Kick Δx' DDK	-2.4 mrad
Length DDK	0.4 m
Field DDK at -5 mm	60 mT



- A larger horizontal DA (7.5 mm or more...) would allow taking advantage of the DDK peak at 6.4 mm and relaxing the kicker power supply current/voltage.
- 6-D simulations with optimised parameters, lattice errors and coupling have to performed once the injection cell will be defined.