

NON LINEAR KICKER R&D AT SOLEIL *A.K.A.* MIK : MULTIPOLE INJECTION KICKER

Patrick ALEXANDRE – SOLEIL
patrick.alexandre@synchrotron-soleil.fr

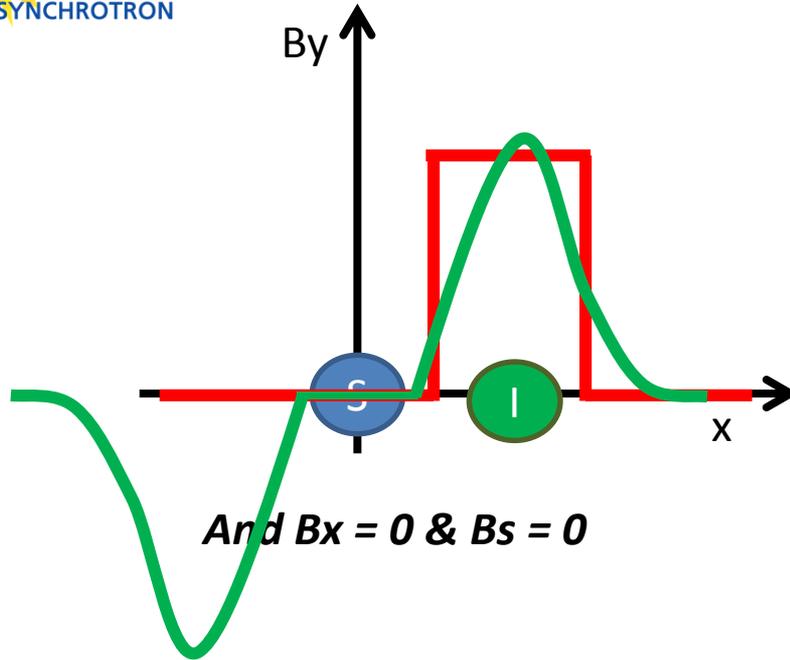
*On behalf of the SOLEIL and MAX-IV teams on the
development, construction and commissioning of the MIKs.*

What we are going to talk about

- MAX-IV & SOLEIL collaboration.
- Injection with a Non Linear Kicker.
- Designing a pulsed magnetic system...
- Magnetic design of the MIK.
- Design and construction of the MIK system.
- Pulsed magnetic measurements.
- Current status of the project.
- Conclusions.

- **Collaboration between MAX-IV in Sweden and SOLEIL in France (2012 – 2016/2017).**
- **Funded by the Swedish Ministry of Research.**
- **Aimed at researching and developing technology for accelerators:**
 - Control systems.
 - Nanobeamlines.
 - Insertion Devices.
 - Sample Environment.
 - Accelerator Devices.
 - Time Resolved Methods.
- **MIK project : 1 complete pulsed NLK for MAX-IV 3 GeV storage ring and 1 complete pulsed NLK for the SOLEIL 2.75 GeV storage ring.**
- ***This presentation (all figures) is about the MAX-IV 3 GeV MIK.***

Injection with NLK : what physics would like...



What magnets could fit in ?

- Quadrupole:

No zero region at center and gradient at injection point.

- Sextupole:

Small zero region at center and gradient at injection point.

- Octupole-like:

Nice zero region and existence of a flat top.

**MAX-IV 3 GeV
Low Emittance
Storage Ring
Transparent
Top-Up
Specifications**

X injection	Integrated Field	Magnetic Length	B field
4.66 mm	11.7 mTm	300 mm	39 mT
Pulse duration	Max. By Integrated Field at X = 0	Max. Bx Integrated Field at X = 0	Max. By Gradient at X = 0
3.5 μ s	5 μ Tm	1 μ Tm	0.3 T/m
<i>On a 96 μm (H) x 21 μm (V) window centered on stored beam.</i>			

Making a pulsed magnet system...

DESIGNING IT

- **Accelerator physics** : injected beam position, integrated field, defect field at center, GFR, chamber apertures...
- **Magnet design** : simulation (DC & Transient : Opera & Matlab), effect of Ti coating on fields, inductance...
- **Thermal study** : image current & current in coils, mechanical stress in magnet/vacuum chamber...
- **Vacuum chamber design** : aperture (H&V), Synchrotron Radiation (SR) ray tracing, static and dynamic pressure simulations, outgassing of materials...
- **Pulser design** : high voltage (HV) pulsed electronics, choice of components, stability & reproducibility of the current pulse, HVPS, coaxial cable, EMC ...
- **Mechanical design** : magnet, pulser & HV insulator design, issues with alignment and metrology, vibration study, handling and installation ...
- **Materials choice** : issues with radiation, high voltage, ultra-high vacuum, availability, mechanical strength & expansion, etc...
- **Alignment and metrology** : measure the magnet to accurately place on the accelerator.
- **Control system design** : triggering, fault monitoring, interlock & safety...
- **Installation and commissioning** : when and how install it, baking, testing...
- **Operation** : ease of use / maintain, reliability..
- **Budget** : money doesn't grow on trees.

BUILDING IT

- **Subcontract parts manufacturing** : which parts? control quality?
- **In-house manufacture** : who can do what ? availability, work planning...
- **Prototyping** : how much ? how far do you go ? how many tests ? what parts need prototyping ?
- **Manufacture management** : series/parallel work, test subsystems...
- **Final testing** : magnetic measurements, electrical tests, long duration tests, debugging...
- **Communicate** : reports on technical design & simulations, procedures for installation-troubleshooting-operation, feedback for/from other groups, forms, various paperwork...

ITERATIVE WORK !

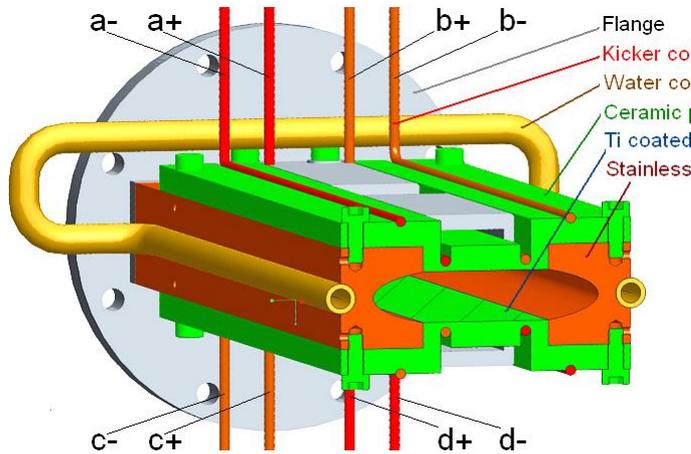
- **Find a solution** that meets some physics specifications -> check all the other aspects...
- **Check tolerance to manufacturing errors** for components, ruggedness of design...
- **New matters will rise !** You don't always foresee all the problems...
- **Until your solution works and meets all the implicit and explicit specifications...**
- **It takes a lot of people !**

MIK for MAX-IV 3 GeV : how it looks like !...

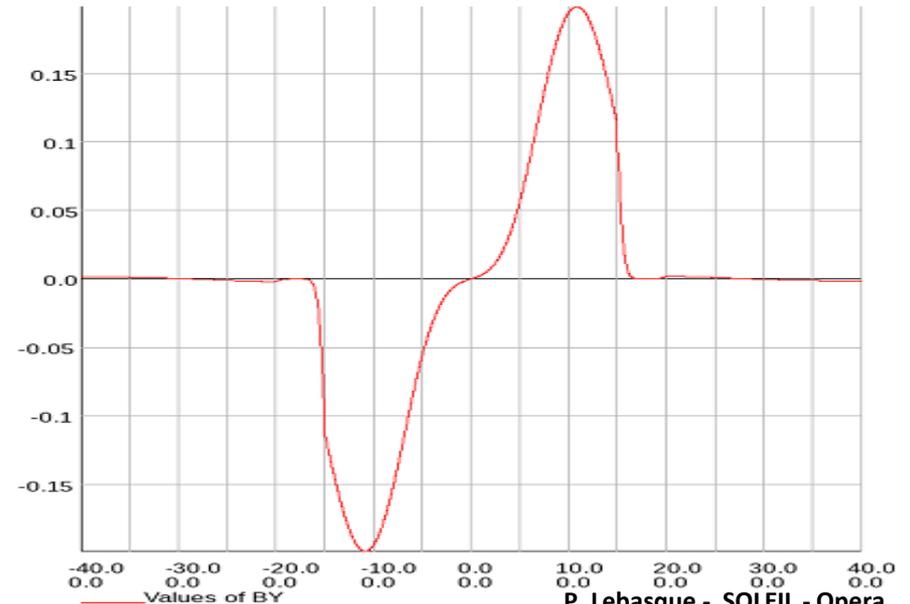


R. Ben El Fekih – SOLEIL – MAX-IV

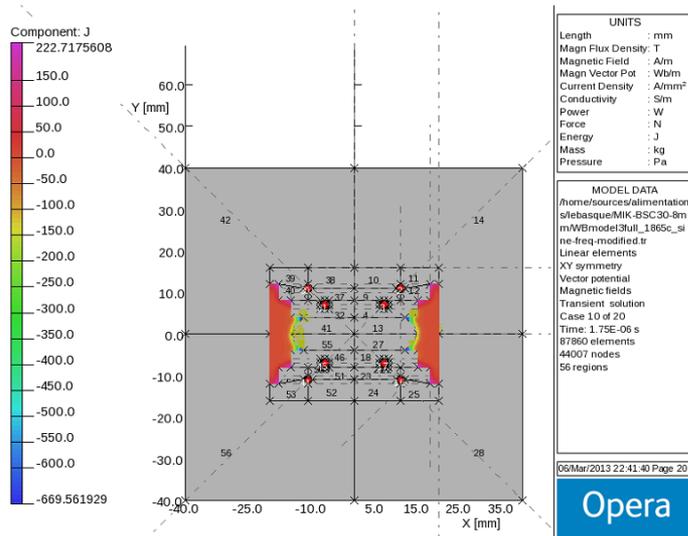
Magnetic design of the MIK : starting from BESSY II NLK



O. Dressler – P. Kuske – BESSY II



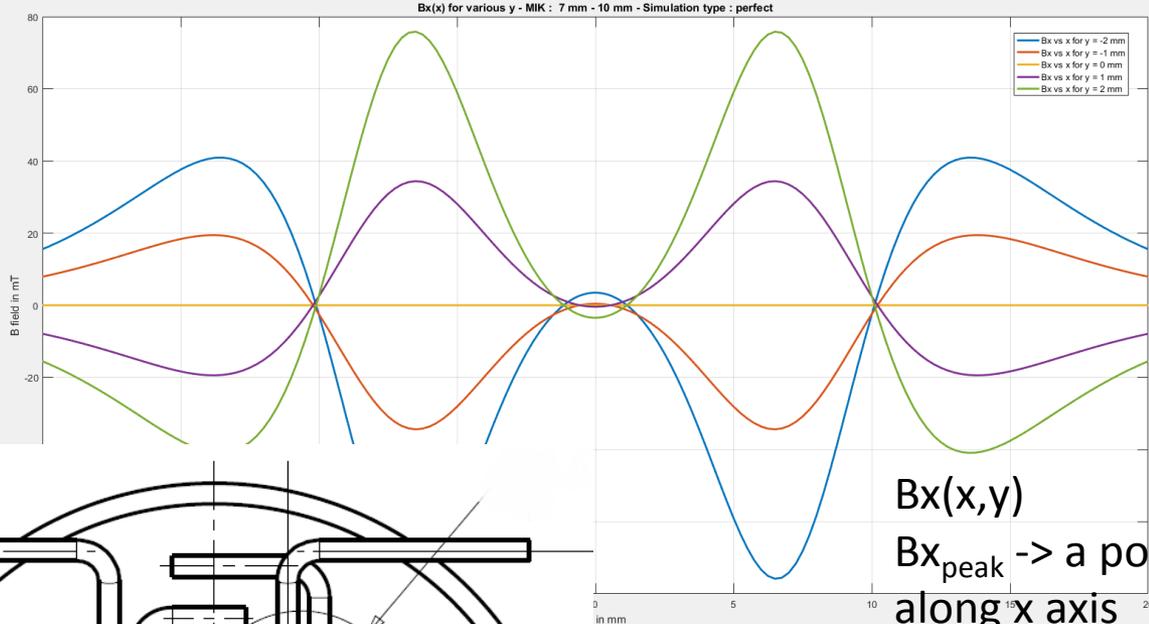
P. Lebasque - SOLEIL - Opera



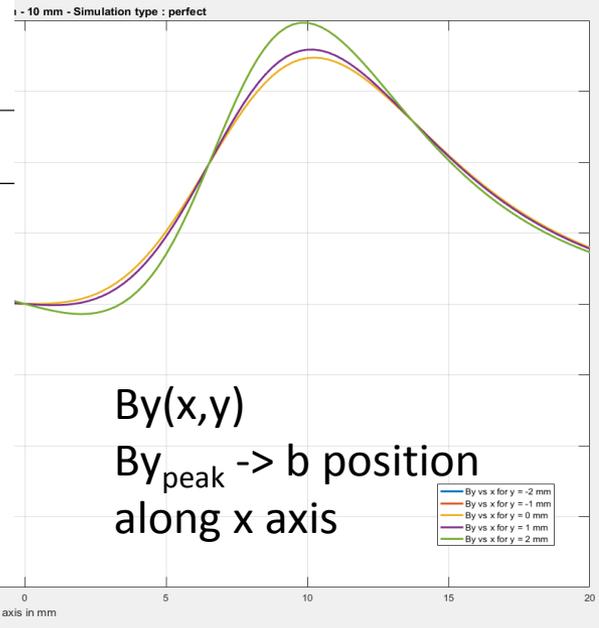
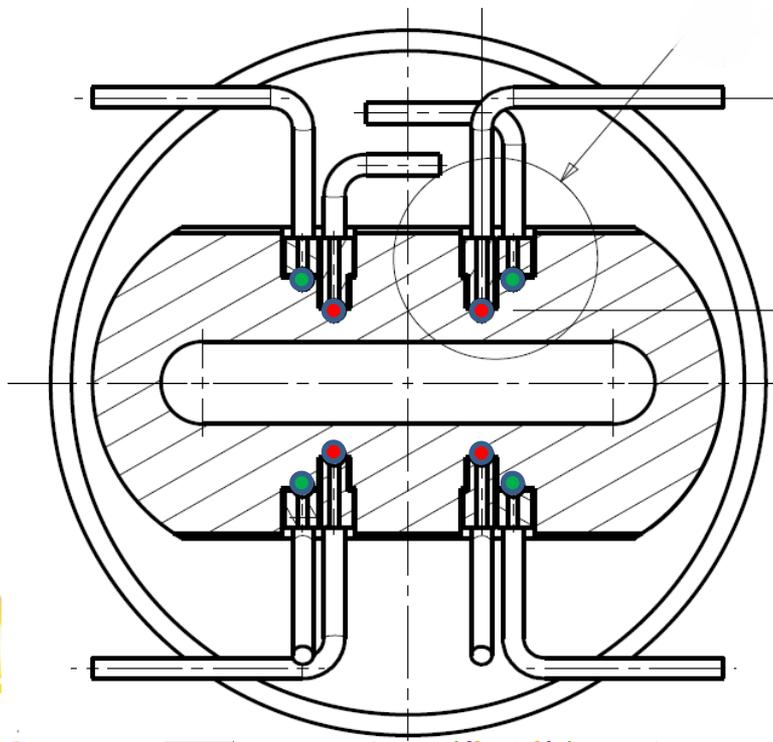
P. Lebasque - SOLEIL - Opera

- Avoid large metallic parts near magnetic fields.
- Coils connected in series.
- Position of 8 coils is critical.
- SR absorption / cooling .
- Titanium coating screening effect.

Magnetic design of the MIK : basic dimensioning



$B_x(x,y)$
 $B_{x,peak} \rightarrow$ a position
 along x axis

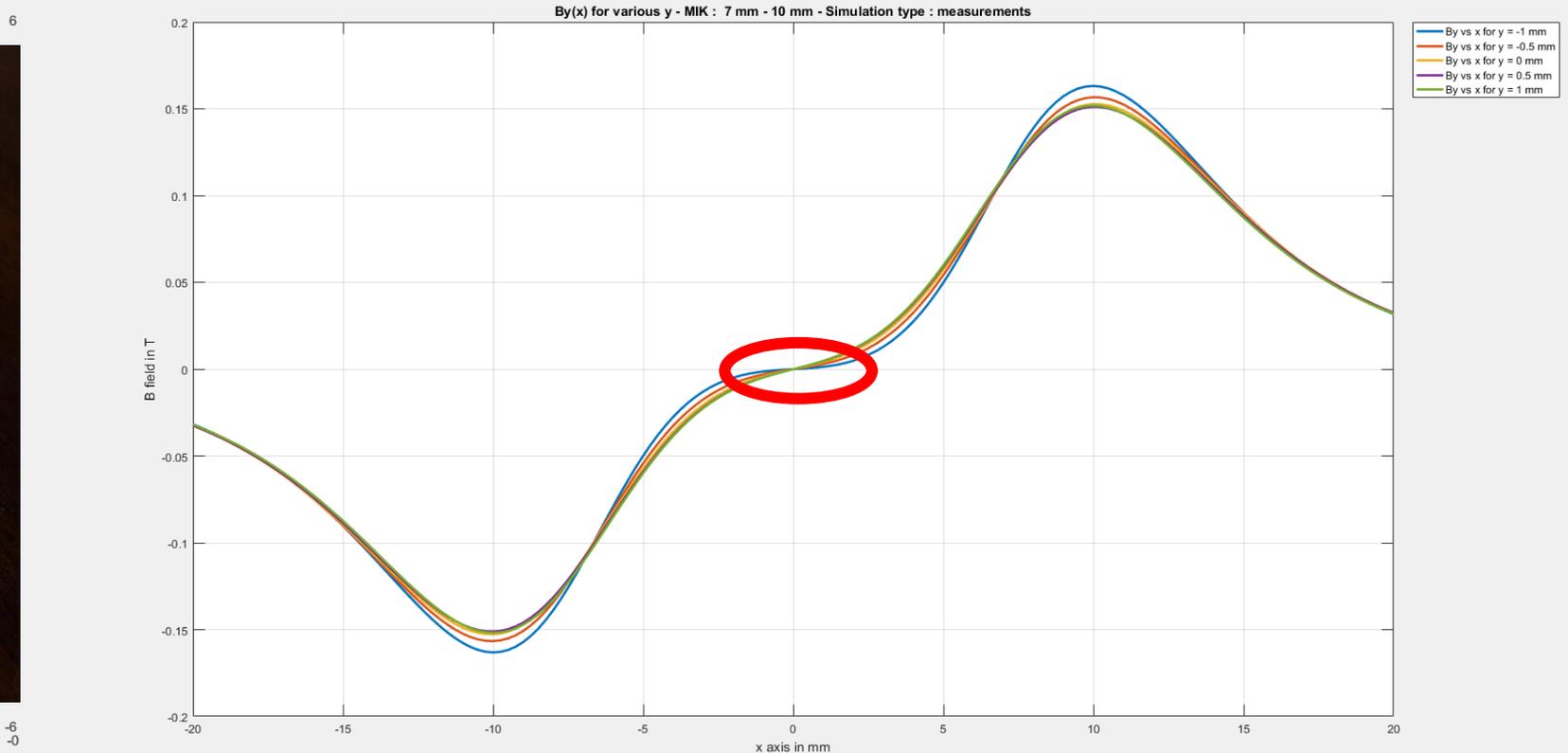
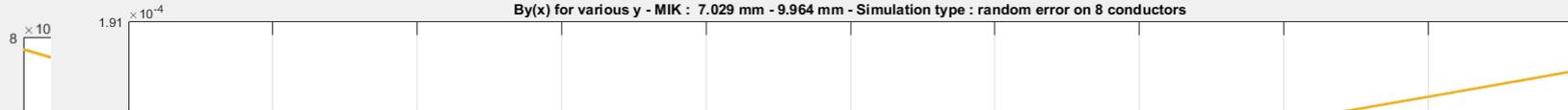


Issue	
Acceptable	
Conductors to close to each other	
Current too high ($\tau_{pulse} = 3.5 \mu s$)	
Inductance too high ($\tau_{pulse} = 3.5 \mu s$)	

$B_{peak}(x=0 \text{ mm} \ \& \ y=0) = 39 \text{ mT}$

(2 mm dia. rods).
 (400 mm total).
 16 mm (H).
 the ceramic

Magnetic design of the MIK : coil position errors & Ti coating effects on zero field



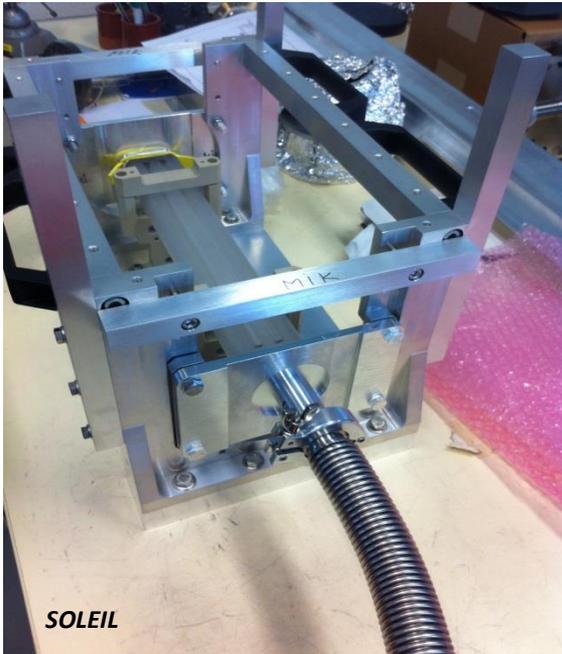
- **7 mm – 10 mm** MIK structure.
- **8 copper rods** accurately positioned (**+/- 10 μm position & straightness**). Rods are **2 mm** in diameter.
- Aperture is **8 mm (V) x 46 mm (H)**.
- Length : 400 mm (flange to flange).
- Chamber is made of **alumina ceramic**.
- No large metallic parts near magnetic fields (except flanges with low permeability stainless steel).
- Current pulse : **7.7 kA @ 14 kV & $\tau_{\text{pulse}} = 3.5 \mu\text{s}$ (half-sine)**
 - Detailed design of HV insulators & connexions in very confined spaces (range of mm).
- All 8 rods are connected in series : **inductance of 1 μH**
- Titanium coating : **1 μm** .
- Total heat load : **100 W** (full stored current & 10 Hz pulsed current repetition rate).
- Magnet is **embedded** in the vacuum chamber.
- Magnet construction split between in house made parts / assembly and subcontracted manufacture.
- Magnets are **identical** for both SOLEIL and MAX-IV storage rings.

Building the magnet.

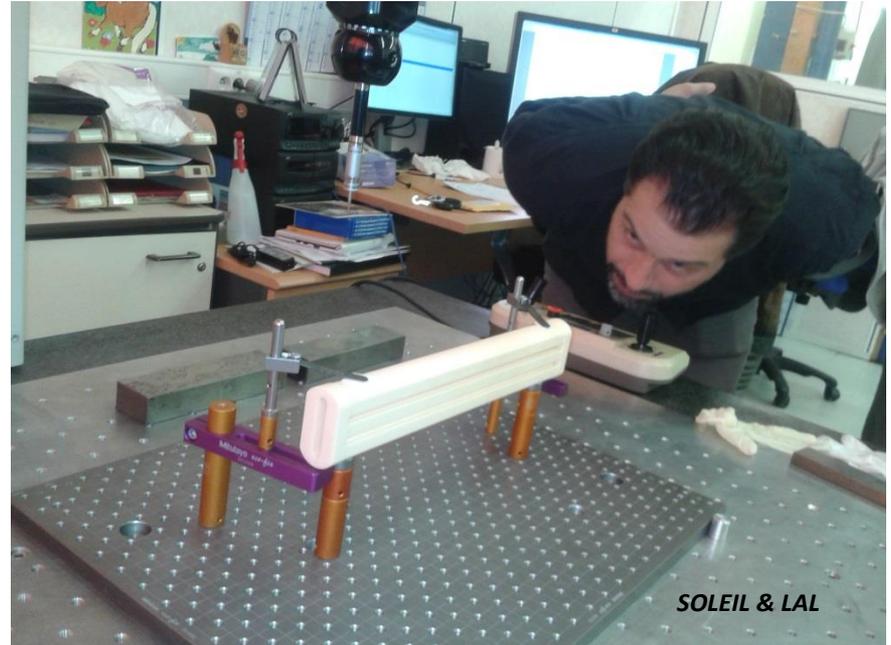
- **KYOCERA (Japan)** won the call for tender and began working on the manufacturing of 4 chambers (2 for MAX-IV & 2 for SOLEIL).
- Main change in matter : **pure crystalline alumina (sapphire)** instead of alumina ceramic.
- First delivered chamber was **largely out of tolerance** : **rejected** with respect to contract but *was kept and used* as prototype for magnet assembly procedure.
- It took **two years** of extended machining tests (KYOCERA & an additional Japanese sub-contractor) **to meet the tolerance requests.**
- Numerous meetings with KYOCERA to discuss **test machining results and improvements on machining technique and procedure.**
- As of Aug. 25th, 2017, we have **received two chambers** (very close to required tolerances : *metrology to be finished*) and are waiting for the two last ones.
- In parallel, we asked another company to **make a test chamber but machining proved to be far from required tolerances.**

Process of assembling the MIK magnet

KYOCERA delivers bare chambers with steel adaptation end-parts



Preliminary vacuum tests :
verify absence of large leaks.
Proper tools & procedures to be
developed
(Vacuum group - SOLEIL – Gif-sur-Yvette)



Metrology of chambers :
using tri-dimensional measurements
verify quality of machining (grooves, aperture,
etc..) with 3 different references.
(B. Leluan – LAL – Orsay)

Process of assembling the MIK magnet

Once chambers are accepted...



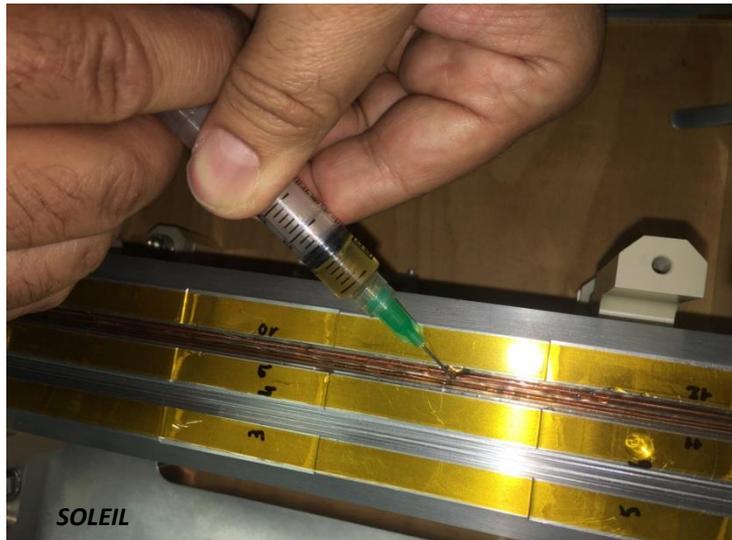
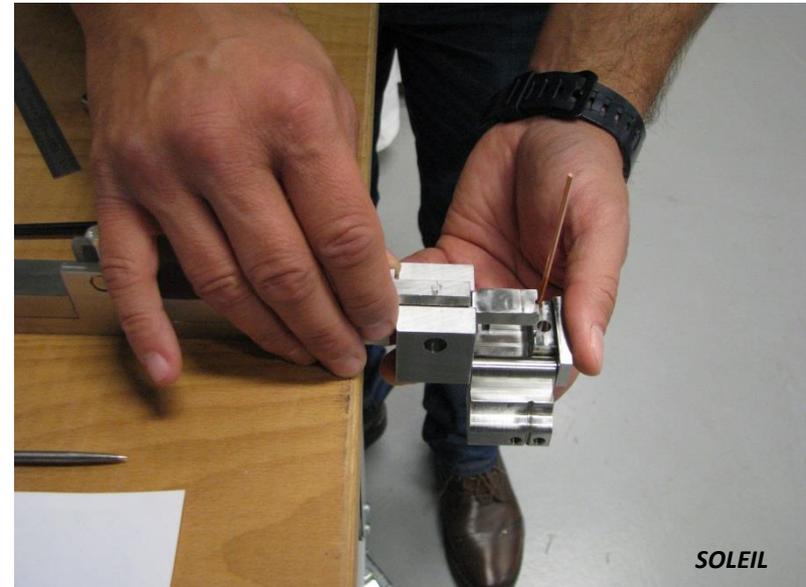
**CF100 flange welding : UHV weld.
Proper tools and procedures are
developed & training parts made.**
(P. Prout - SOLEIL – Gif-sur-Yvette)



**Titanium coating done at ESRF.
Specific tools and procedure developed
for small aperture & non conductive
chambers.**
(M. Dubrulle – H. Marques - ESRF – Grenoble)

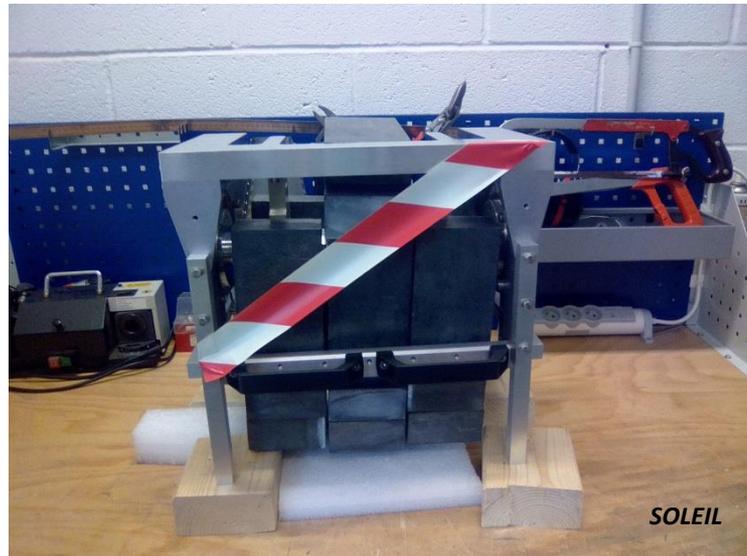
Process of assembling the MIK magnet

- Bending and preparing 8 copper rods.
- Gluing them (4 steps).
- A lot of tools developed for all these steps.
- Procedures tried and tested on an aluminum chamber first, then revised, then put into action on the first real chamber.



Error & mistakes in the assembly processes are not really acceptable.

Careful engineering, planning, testing and highly-skilled staff to make it work !



Static load test : 156 kg of lead bricks uniformly pulling on a single rod assembly of the aluminum test chamber (glue thickness : 100 μm) -> verifying dynamic forces due to current in rods.

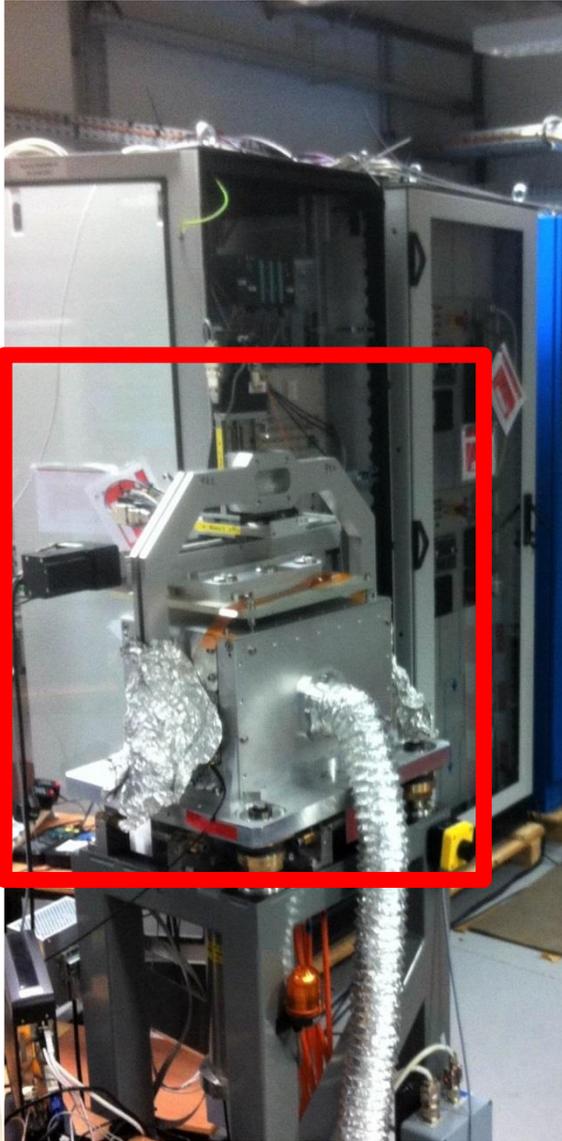
Classic capacitive resonant discharge into the magnet inductance



- 1.2 μF – 20 kV Leclanché capacitor bank.
- 4 HV IGBT Behlke modules (2400 A – 18 kV) in // and 20 kV series fast diodes.
- Resistor and diode cell.
- Resistor and capacitor cell.
- FuG 18kV – 280 mA charging power supply. (10 Hz repetition rate).
- Resistor and capacitor // on magnet inductance.
- 10 coaxial RG-214 cables.
- Pulser is electrically designed in-house.
- Pulser is mechanically designed in-house : high-voltage vs inductance vs maintainability constraints.

Complete system and magnetic measurements

First results...

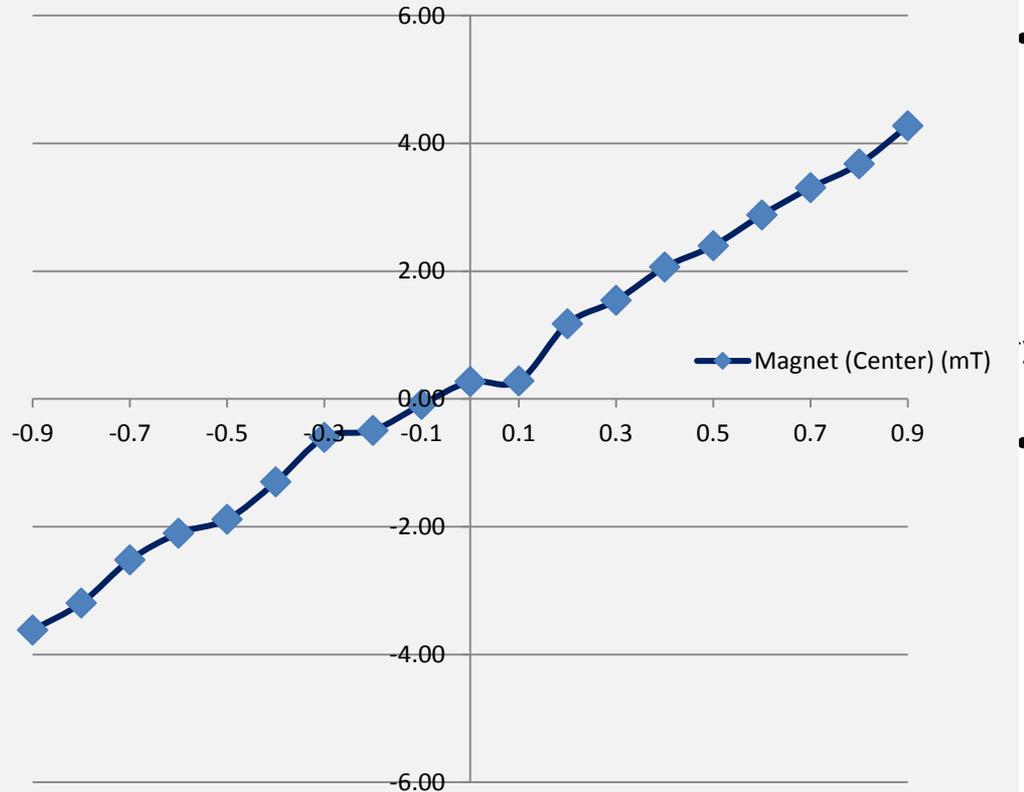


- **Magnetic fields in MIK strongly depend on s , x and y .**
- Magnetic measurements have to be **accurate** : in terms of magnetic component measured (B_s , B_x & B_y) and the location of the measurement.
- **Pulsed magnetic measurement bench redesigned and built :**
 - **Precise positioning in 3 dimensions** of the measurement probes (local & integral) done with stepper motors (50 μm resolution) & precise mechanics.
 - **Straightness of the integral probe** (10 μm) so measurement is done for a known and constant x & y position along s .
 - **Precise (*and long*) alignment** of the bench on the magnet and testing displacements of probes (look-up table).
- After successful high voltage testing of the first magnet (made with rejected KYOCERA chamber), **the magnet was magnetically measured in July 2017.**

Complete system and magnetic measurements

First results...

By (zoom center) : (x = -1 / +1 mm & y=0)

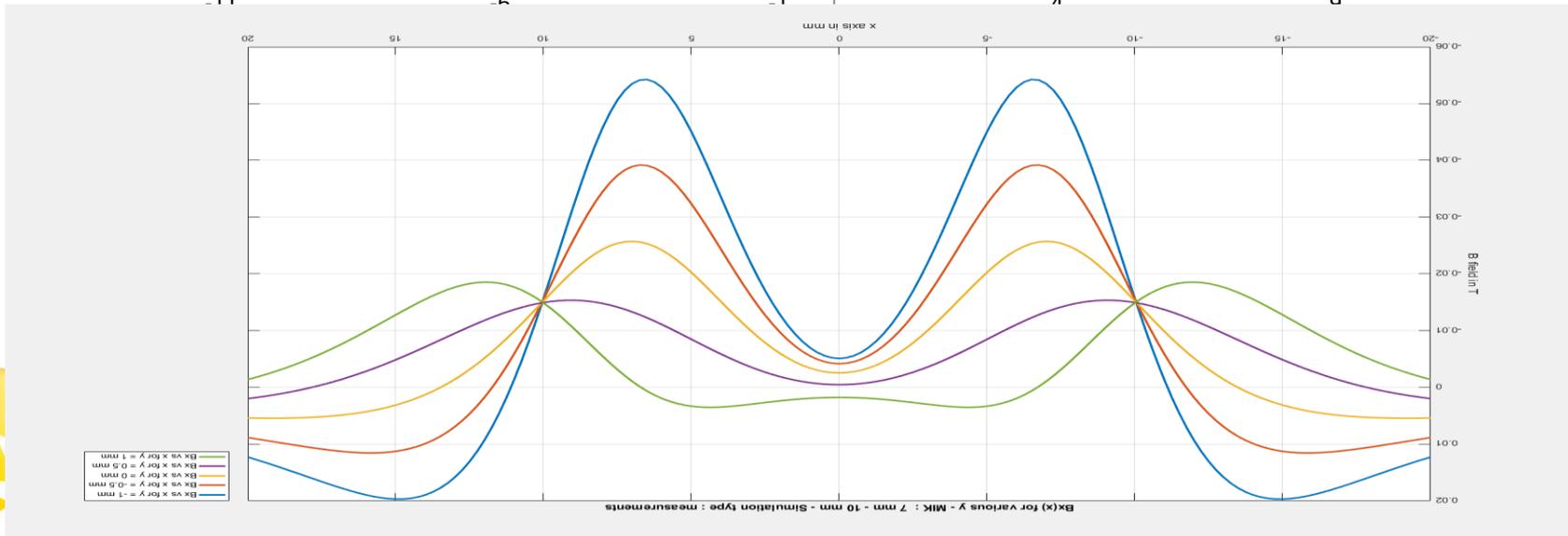
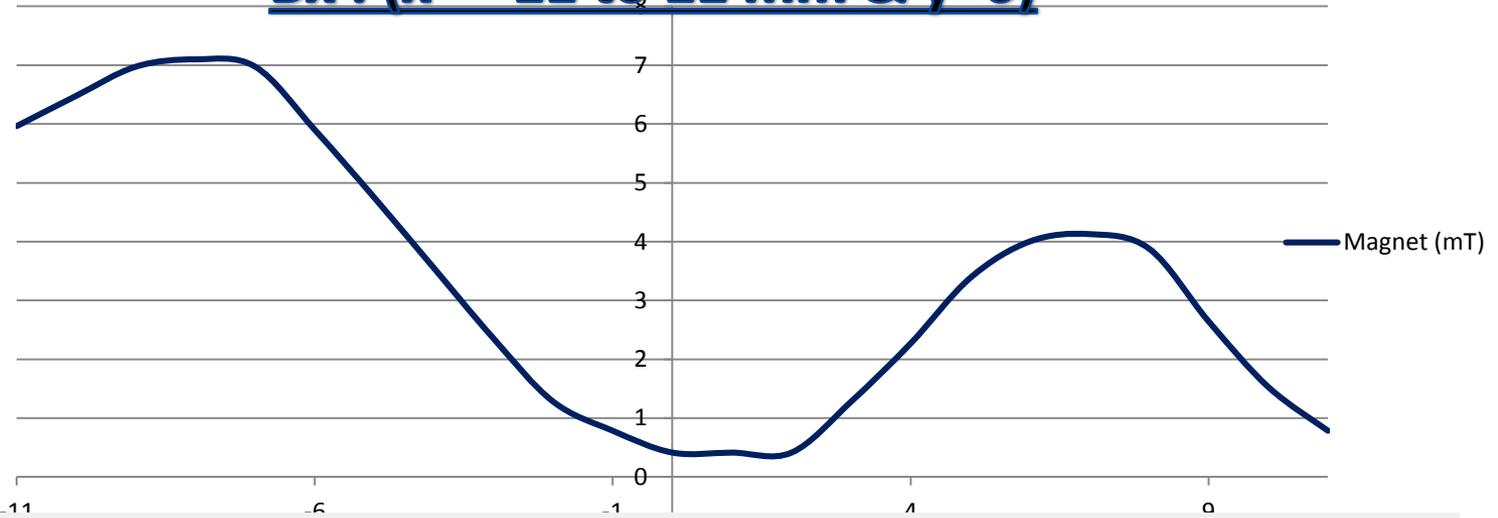


- Shape is as expected :
 - Peaks values at $x \approx 10 \text{ mm} \approx b$ with value close to simulation.
 - **By at injection $\approx 40 \text{ mT}$.**
- Because rods not accurately positioned (rejected chamber), **the zero field region is absent, as simulations predicted it.**

Complete system and magnetic measurements

First results...

Bx : (x = -11 to 11 mm & y=0)



t.

Current status and perspectives

- **One complete MIK system installed on MAX-IV 3 GeV ring, *waiting for the beam...***
- **Two vacuum chambers received** from KYOCERA going through assembly process.
 - *3 month/chamber from reception to magnetic measurements.*
- **Two last vacuum chambers to be received** from KYOCERA (end of 2017).
- Assembly and test of the **SOLEIL MIK pulser & control system** (2018).
- **Commissioning on MAX-IV 3 GeV ring & training of MAX-IV personnel** on operation, maintenance and trouble-shooting (2017-2018) .
- **Installation and commissioning on SOLEIL 2.75 GeV ring (2018-2019).**
- **Publications to come on the MIK project (2018-2019).**
- **Return on experience on the MIK project (2018-2019).**

Conclusion

- A long, **marathon-like**, project that was started in **2012**.
- **Extremely challenging** from the **accelerator physics specifications point of view**.
- Led to detailed engineering on multiple scales :
 - **Macroscopic** : dimensioning of the magnet, high peak current/short pulse/high voltage & insulation in very confined spaces.
 - **Microscopic** : effect of μm of error in positioning of rods on the B fields quality.
- **Sapphire** used for a large vacuum chamber with very small tolerances on machining.
- Outstanding effort on **tool design & procedure** to go from bare chamber to complete magnet with minimum risk of failure with highly-skilled technicians.
- **Accurate pulsed magnetic measurement bench** gave good measurement on test chamber.
- **We are looking forward to measure the « good » chambers once assembled !**

SOLEIL (Gif-sur-Yvette)

Pulsed magnets : P. Alexandre, R. Ben El Fekih, A. Letrésor, A. Hardy (*ret*), D. Muller, M. Bol.

Mechanical Engineering : J.L. Marlats (*ret*), J. Dasilvacastro, S. Thoraud, S. Genix, F. Lepage, P. Prout, C. DeOlivera, C. Basset (*ret*), N. Jobert.

Vacuum : C. Herbeaux, N. Béchu, S. Morand, N. Baron, V. Joyet.

Electronics & Computer Control : G. Renaud, P. Monteiro, X. Elattoui, T. Jablonka.

Metrology and alignment : A. Lestrade, C. Bourgoïn.

Accelerator physics : R. Nagaoka, A. Loulergue.

Purchase & Juridical : T. Bucaille, F. Minaeian, E. Monin.

Collaborations : N. Guimard.

Et al...

General project leadership

P. Lebasque (SOLEIL)

P. Fernandes Tavares (MAX-IV)

MAX-IV (Lund)

E. Al d'Mour, J. Ahlbäck, S. Leeman, M. Johansson, L. Dallin, B. Jenssen, K. Ahnberg, M. Grabski, M. Gunnarsson, V. Hardion, J. Thanel, J. Jamroz.

BESSY II (Berlin)

O. Dressler, P. Kuske.

LAL (Orsay)

B. Leluan.

ESRF (Grenoble)

M. Dubrulle.

H. Marques.

