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

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

V1 – March 12th

What we are going to talk about ….

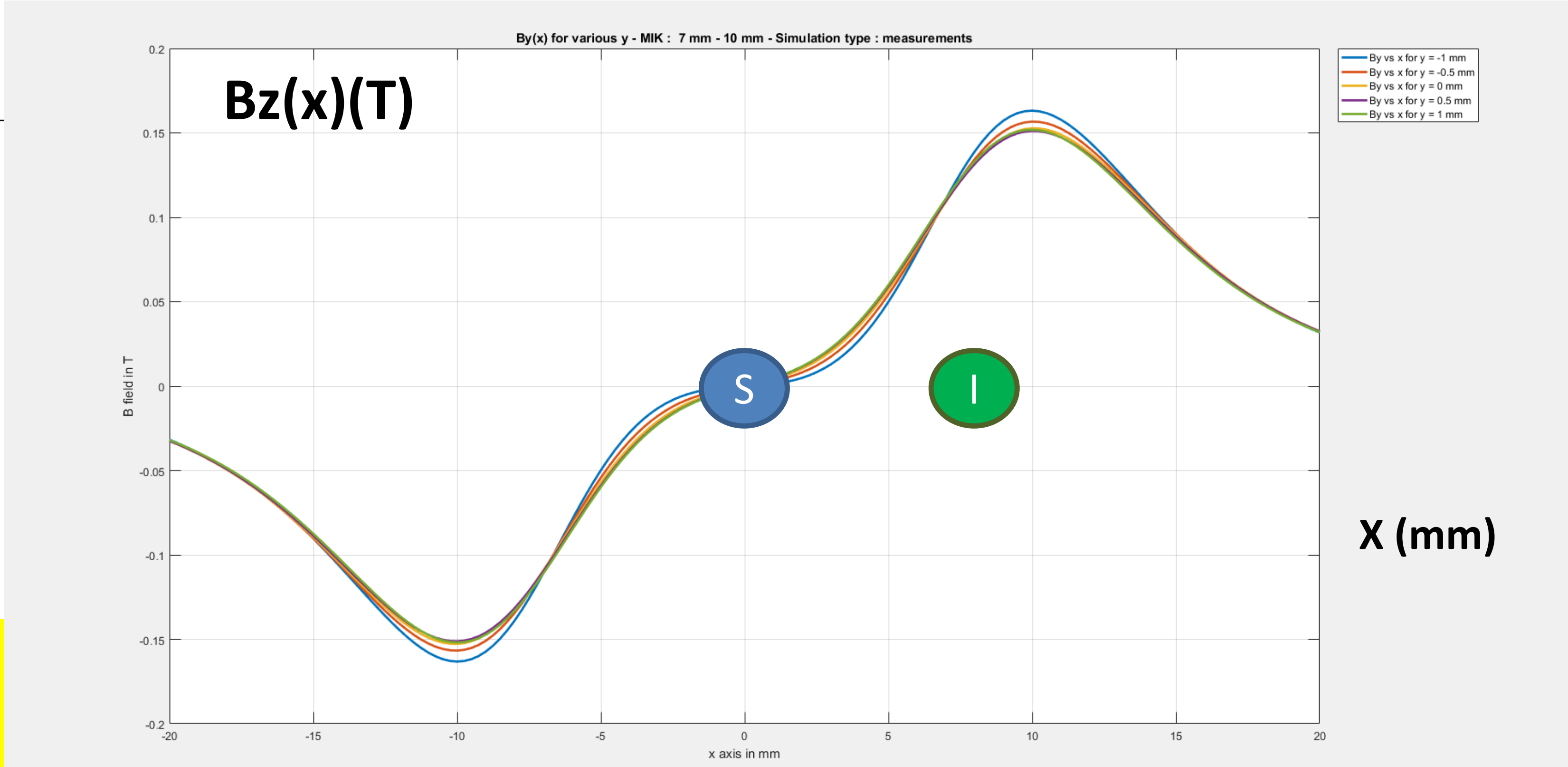
- MAX-IV & SOLEIL collaboration.
- Top-Up injection with a Non Linear Kicker.
- Magnetic design of the MIK.
- Design and construction of the MIK system.
- Pulsed magnetic measurements.
- Conclusions.

MAX-IV & SOLEIL collaboration

- **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.**

- ***<u>This presentation (all figures) is about the MAX-IV 3 GeV MIK.</u>***

Injection with NLK

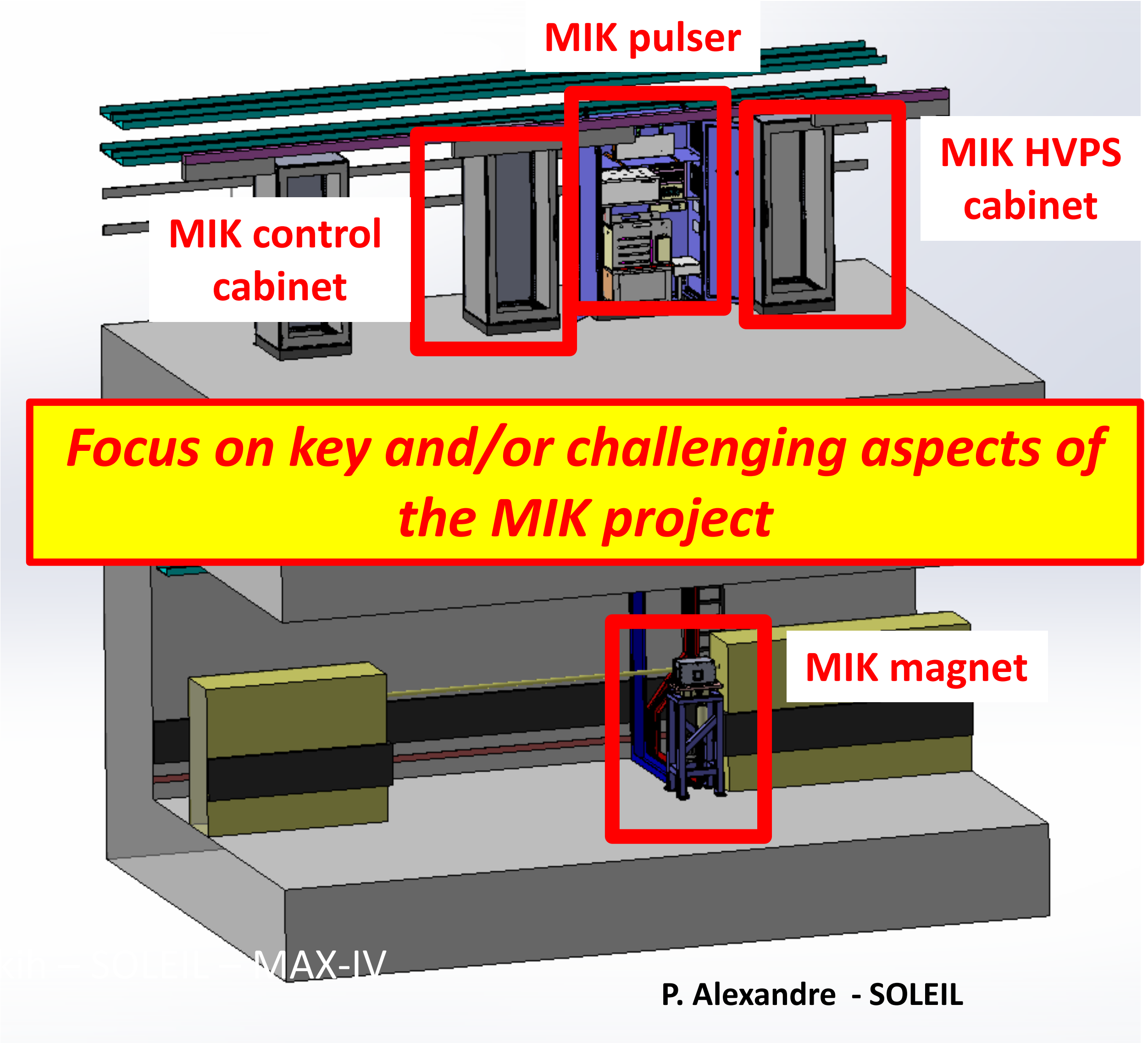


Transparent Top-Up Specifications

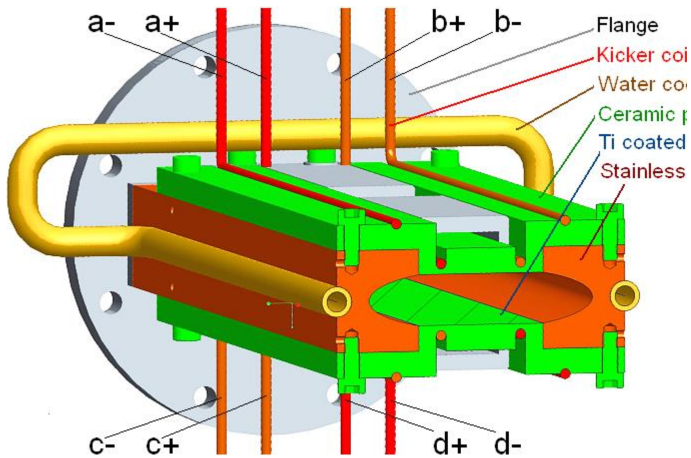
Pulse duration	Max. By Integrated Field at X = 0	Max. Bx Integrated Field at X = 0	Max. By Gradient at X = 0
3.5 µs	5 µTm	1 µTm	0.3 T/m

On a 96 µm (H) x 21 µm (V) window centered on stored beam.

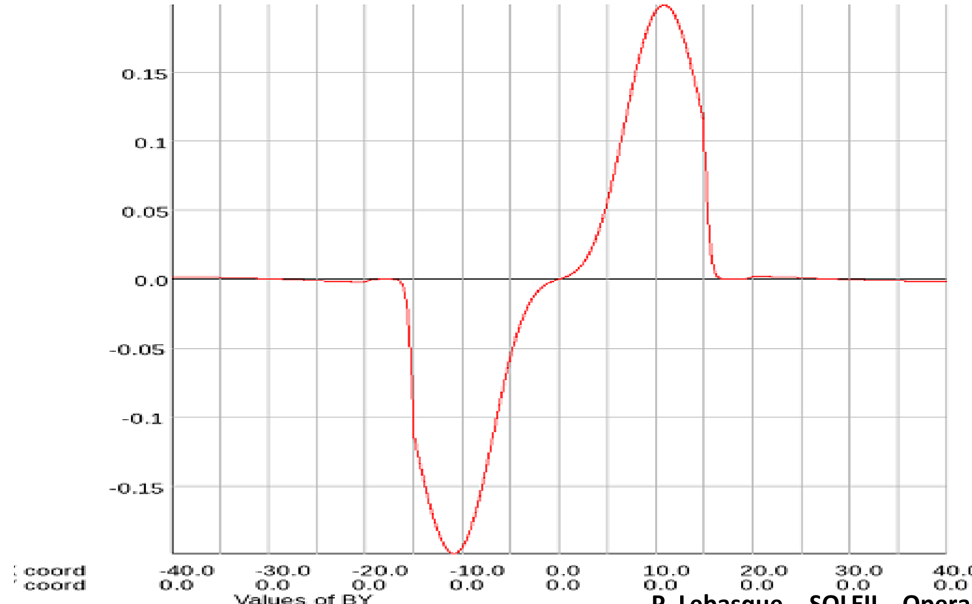
MIK for MAX-IV 3 GeV : how it looks like !...



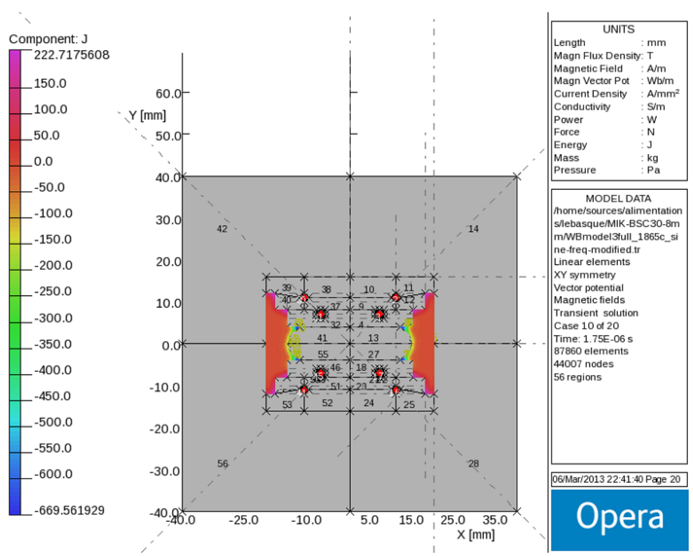
Magnetic design of the MIK : starting from BESSY II NLK



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.**

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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 !

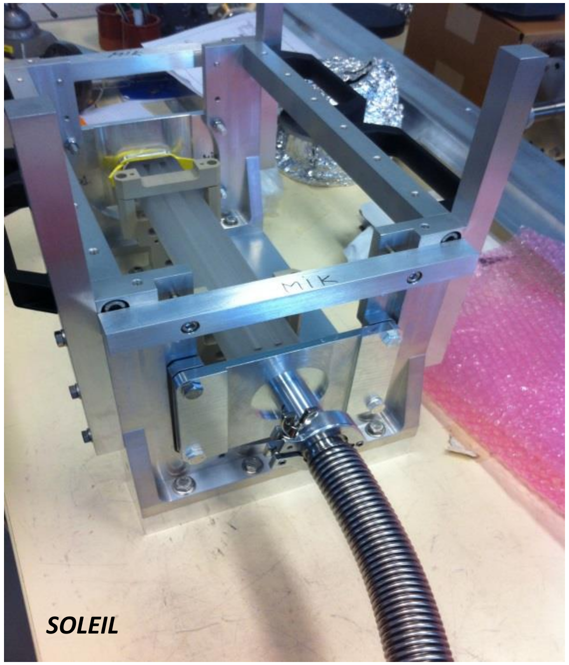
- **Find a solution** that meets some physics specifications -> check all the other aspects…
- **Check tolerance to manufacturing errors** for components, ruggedness of design…
- **New matters will rise !** You don't always foresee all the problems…
- **Until your solution works and meets all the implicit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

Summary of main characteristics (3 GeV MIK)

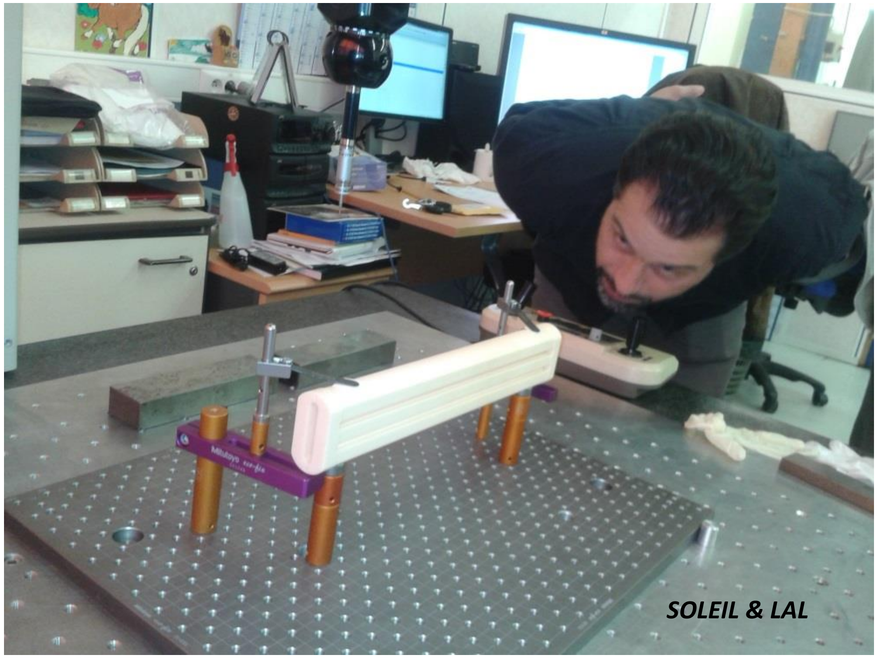
- **7 mm – 10 mm** MIK structure.
- **8 copper rods** accurately positioned. Rods are **2 mm** in diameter.
- Aperture is **8 mm (V) x 46 mm (H).**
- Length : 400 mm (flange to flange).
- Chamber is made of **alumina ceramic**.
- No large metallic parts near magnetic fields (except flanges with low permeability stainless steel).
- Current pulse **: 7.8 kA @ 14 kV on magnet & τ_{pulse} = 3.5 µs**
  - ➢ 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.

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)

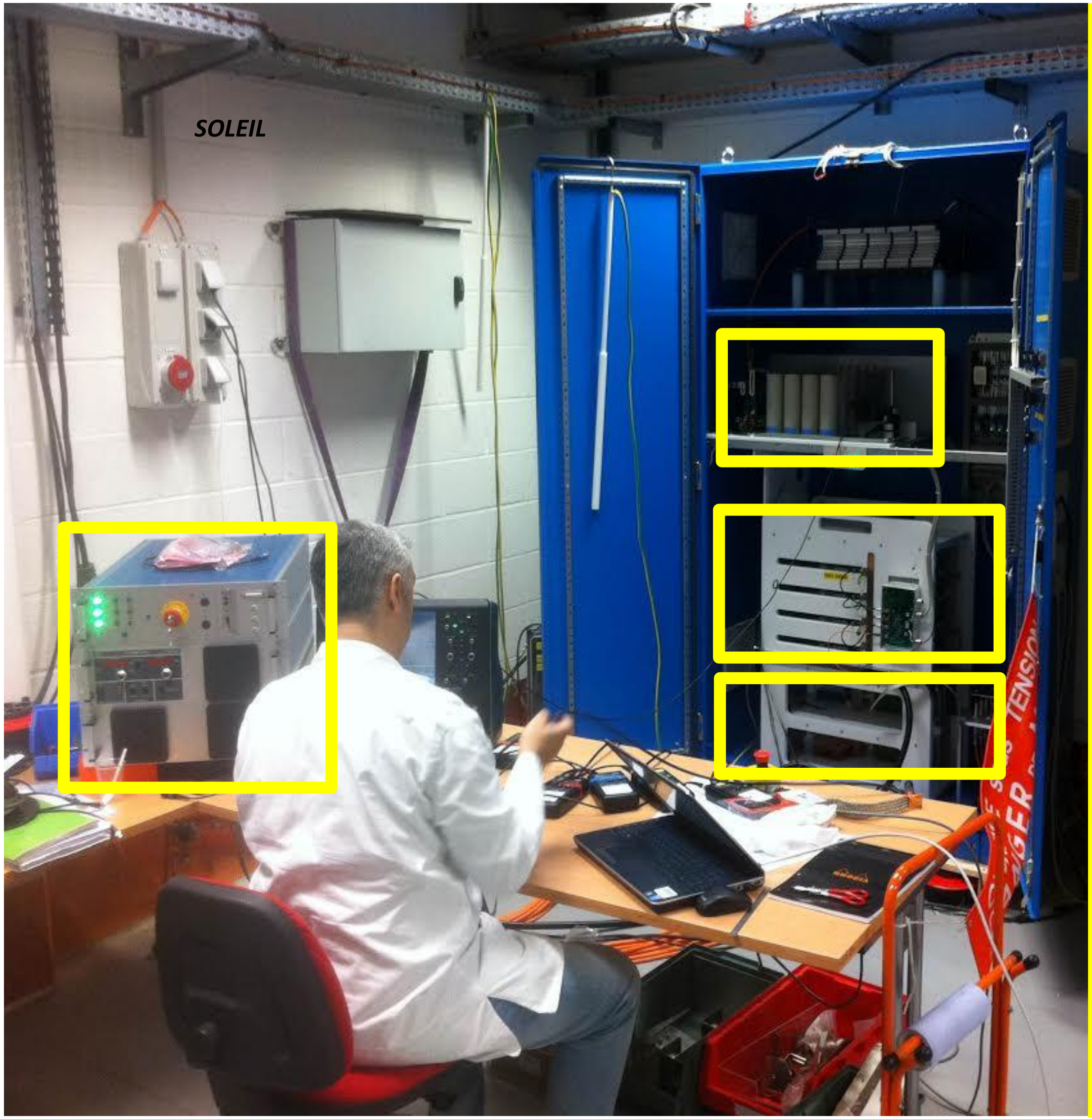
Titanium coating done at ESRF. Specific tools and procedure developed for small aperture & non conductive chambers.
(M. Dubrulle – H. Marques - ESRF – Grenoble)

Process of assembling the MIK magnet

- Bending and preparing 8 copper rods.
- Gluing them !! Not so evident !!
- 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.
- About 3 month procedure to go through until you get one magnet ready for electric and magnetic measurements & testing.

About the pulser …

Classic capacitive resonant discharge into the magnet inductance



- **1.3 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.**

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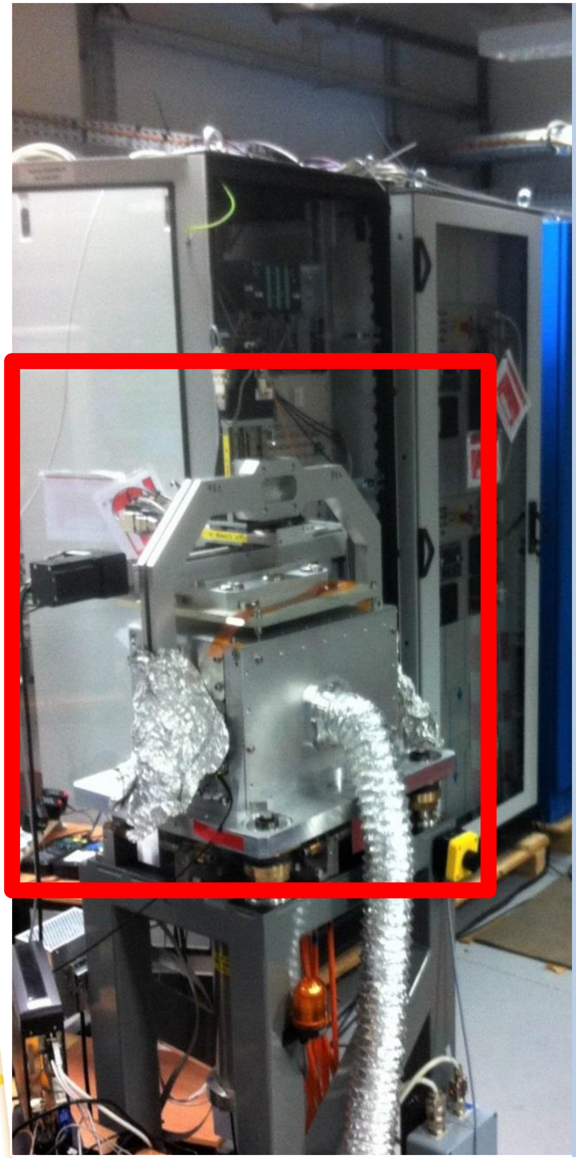
Complete system and magnetic measurements

First results…

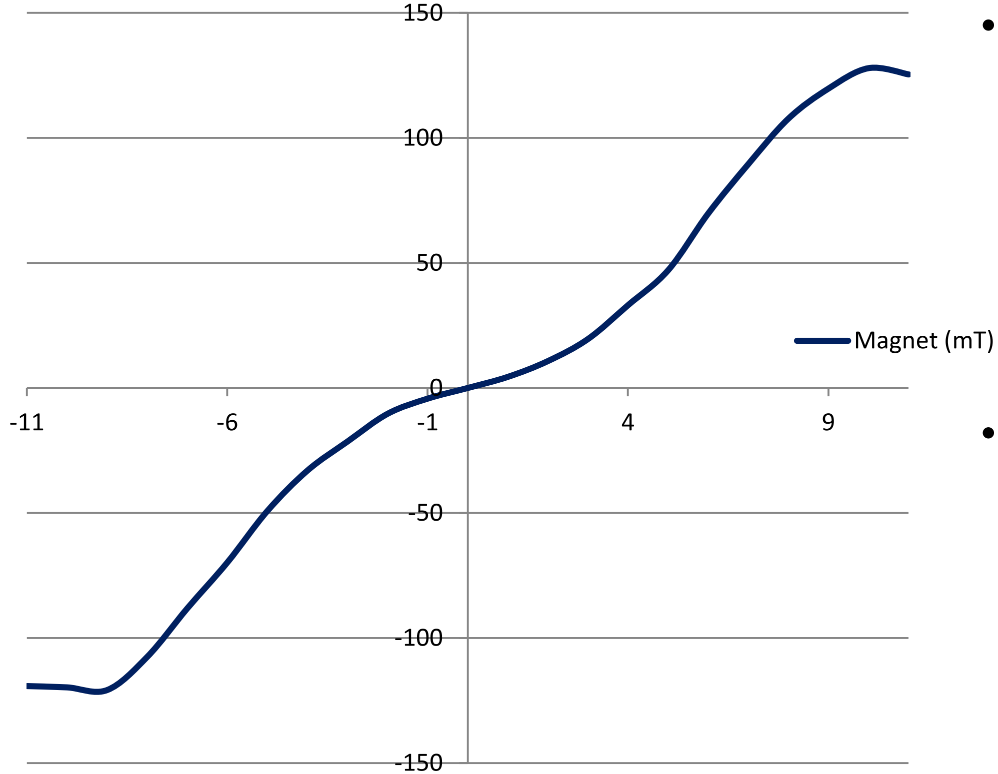


- **No major issues with electrical insulation !**
- **Magnetic fields in MIK strongly depend en s, x and y.**
- Magnetic measurements have to be **accurate** : in terms of magnetic component measured (B_s, B_x & B_y) and the location of the measurement.
- **Pulsed magnetic measurement bench redesigned** and built :
  - **Precise positioning in 3 dimensions** of the measurement probes (local & integral) done with stepper motors & precise mechanics.
  - **Straightness of the integral probe** 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 (x = -11 to + 11 mm & y = 0)



- Shape is as expected :
  - Peaks values at **x ≈ 10 mm ≈ b** with value close to simulation.
  - **By at injection ≈ 40 mT.**
- Because rods not accurately positioned (**rejected chamber due to out of tolerance machining**), **the zero field region is absent, as simulations predicted it.**

Conclusion

- **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 small machining error in positioning of rods on the magnetic 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.
- **First magnetic tests extremely encouraging and we are looking forward to measure the « good » chambers once assembled !**

The people around the MIKs

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. Bourgoin.

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.

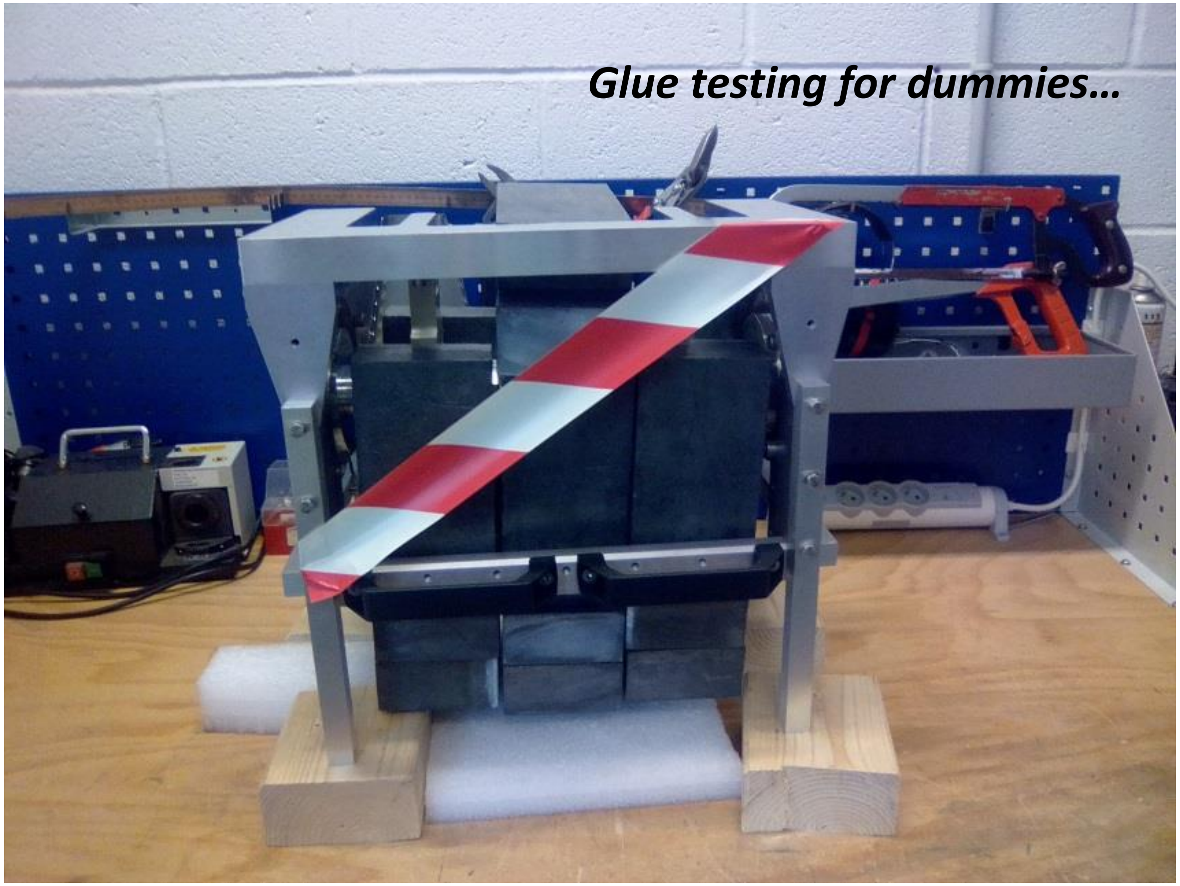
LAL (Orsay)

B. Leluan.

ESRF (Grenoble)

M. Dubrulle.

H. Marques.



Thank you for your attention !

Comments & questions more than welcome !