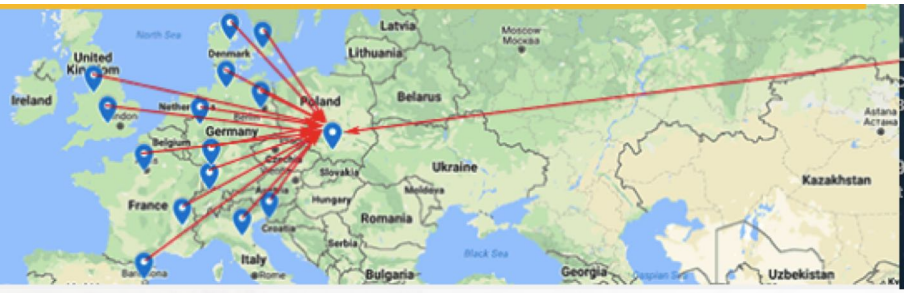
XXVI ESLS WORKSHOP



SOLEIL
Multipole Injector Kicker (Nonlinear Kicker)

Laurent S. Nadolski
Accelerators Coordinator

for Patrick Alexandre
Technical Leader

On behalf of MIK team

SOLEIL SYNCHROTRON

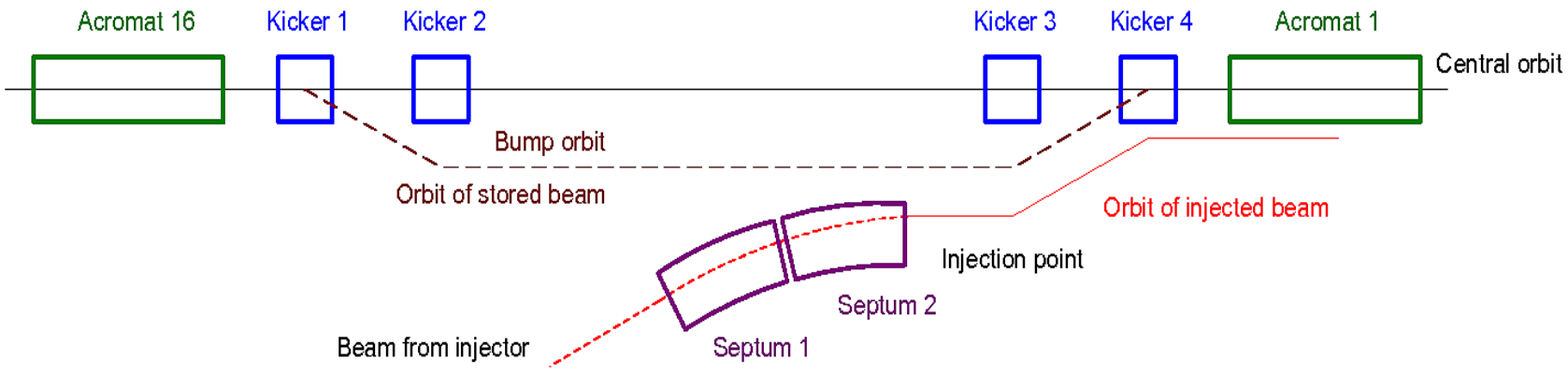
Contents

- **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**
- **Installation at MAX-IV & current status of the project**
- **Conclusions**

MAX-IV & SOLEIL collaboration

- **Collaboration between MAX-IV in Sweden and SOLEIL in France (2012 – 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 Non Linear Kicker (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 (NLK).***

Injection with 4 kickers in a single straight



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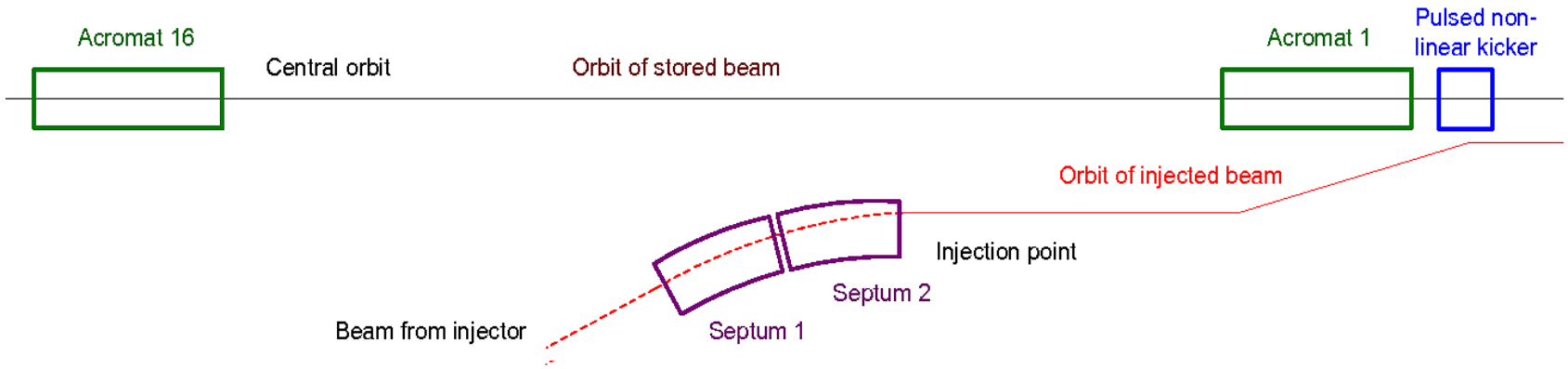
Injection transparency is limited by the non-closure of the bump, ie the identity of the 3 or 4 kickers.

Injection with the MIK



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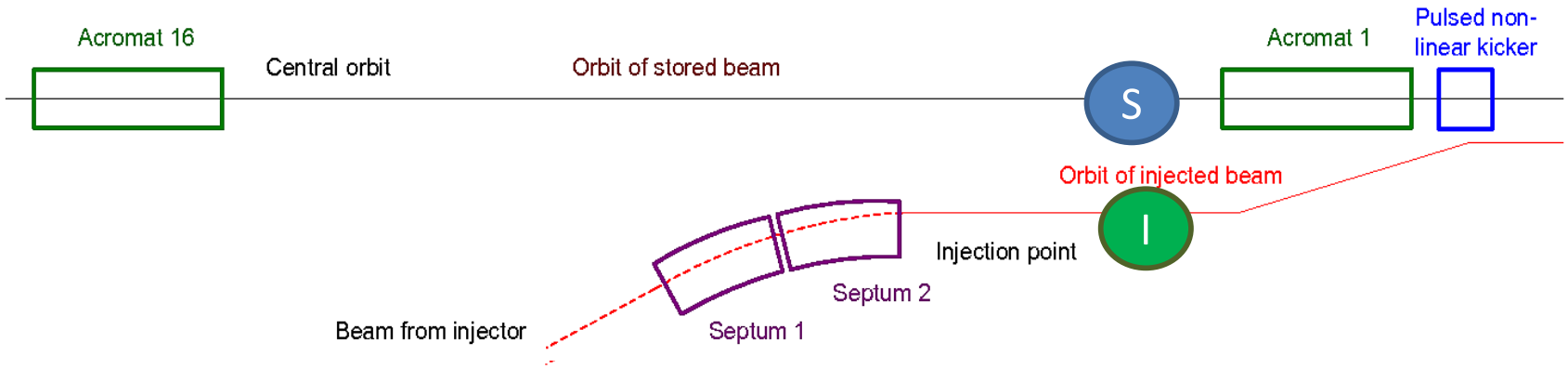
With NLK, the main idea is to avoid kicking the stored beam while kicking the injected beam into the dynamic aperture and let the injected beam damp into the stored beam turn after turn

Easier to get transparent injection

Injection with the MIK: first turn



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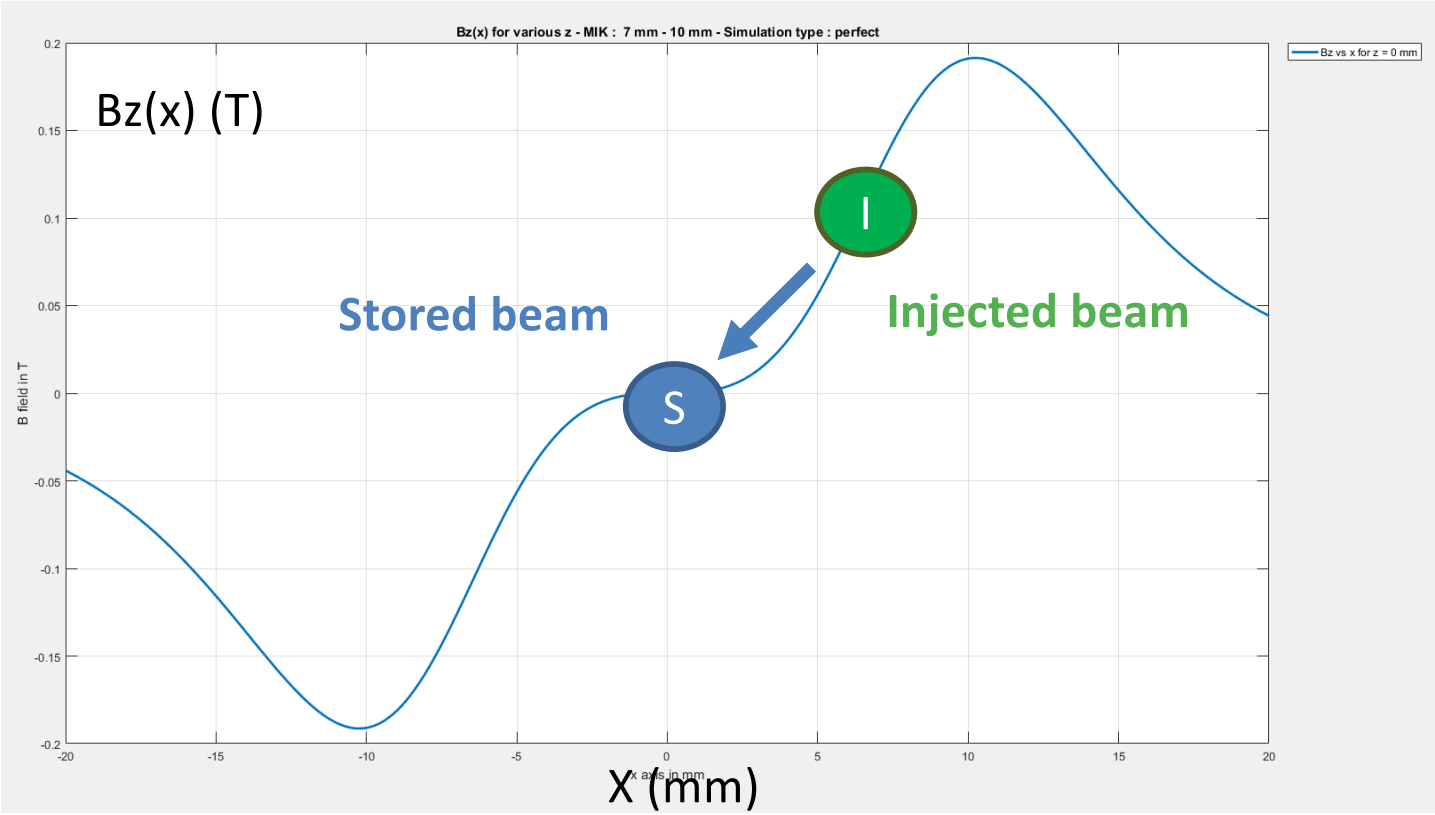
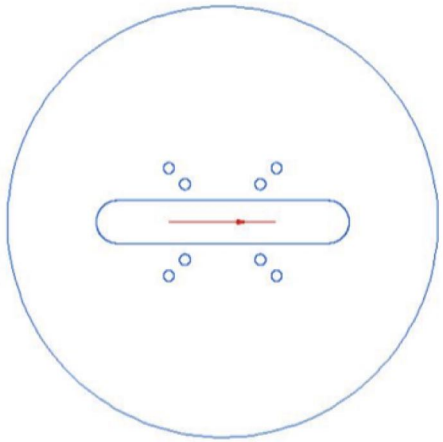
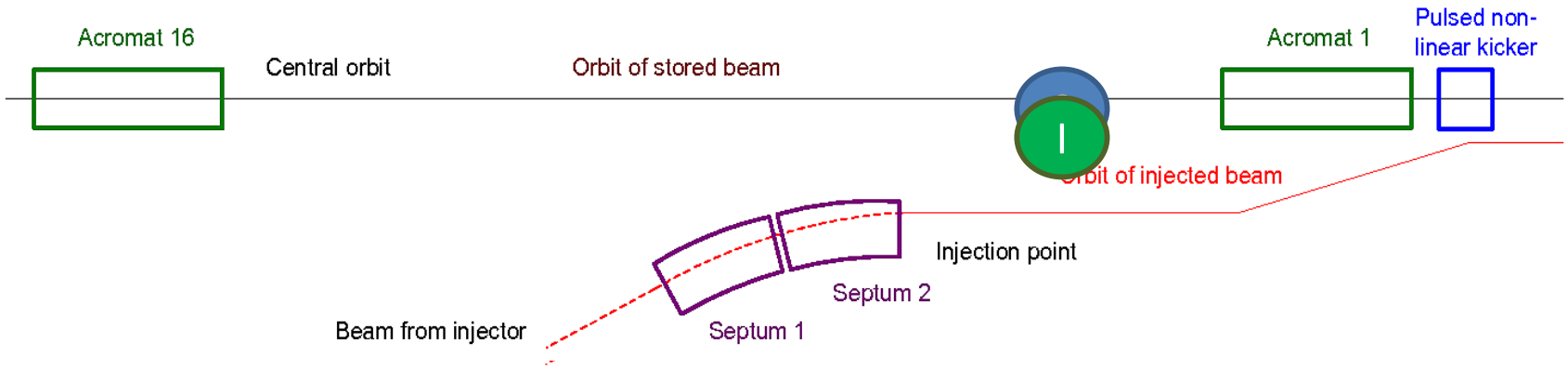




Octupole like B-field

Injection with the MIK: Subsequent turns



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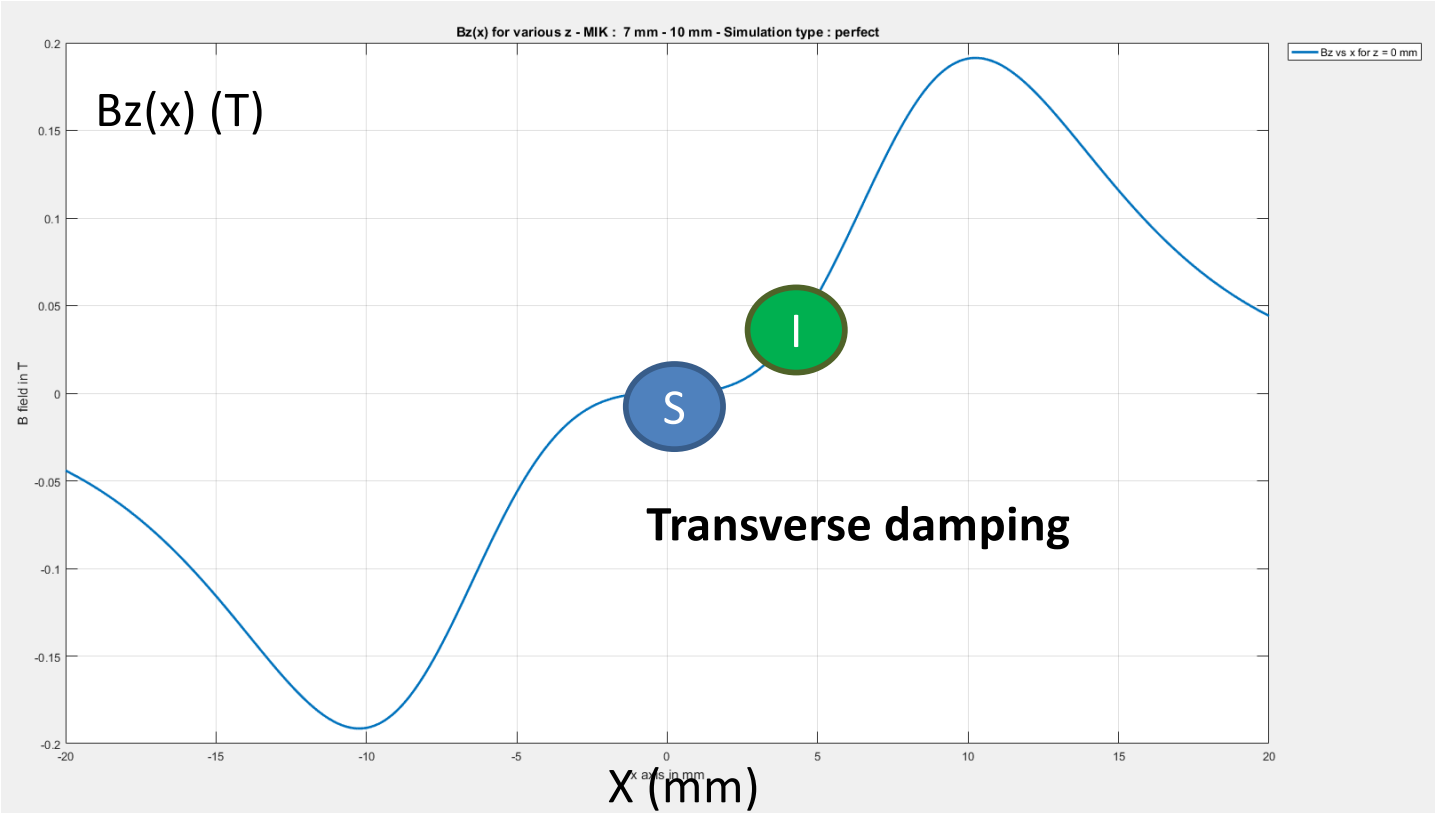
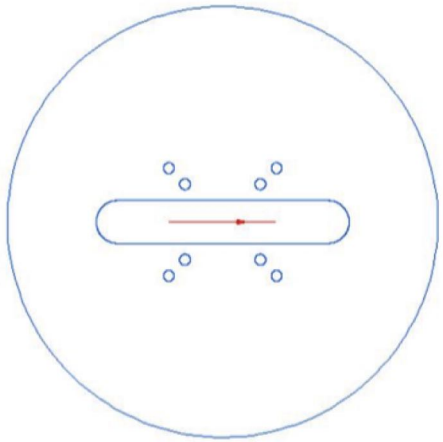
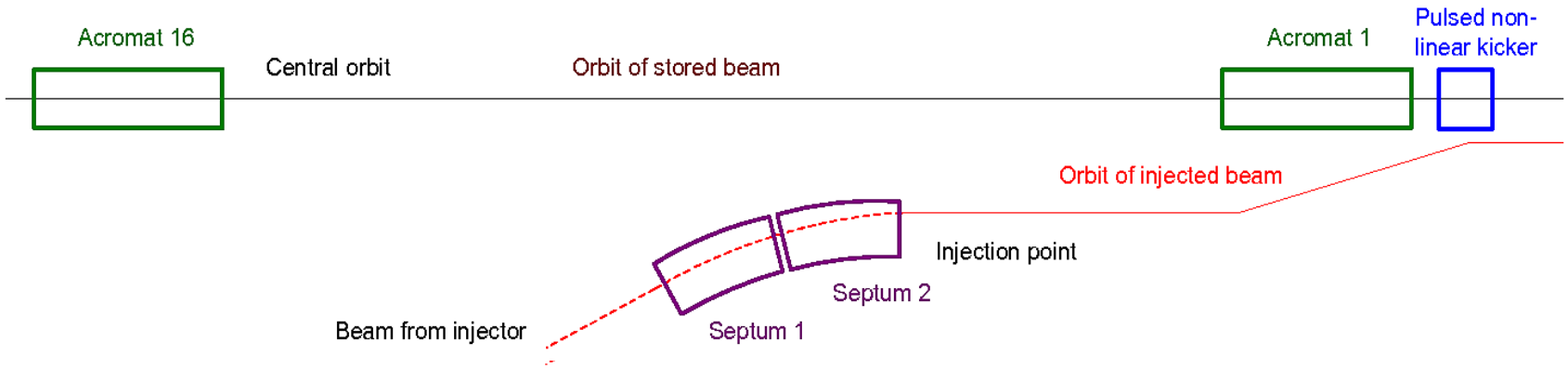




Injection with the MIK



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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 µs	5 µTm	1 µTm	0.3 T/m

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

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

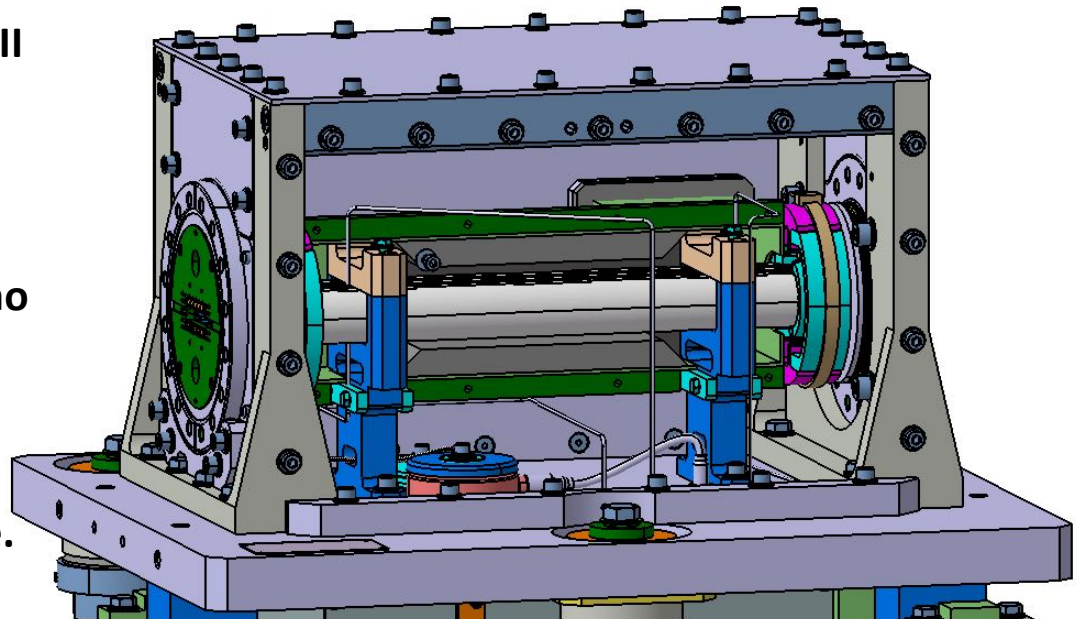
- **Subcontract parts manufacturing:** which parts? control quality?
- **In-house manufacture:** who can do what ? availability, work planning…
- **Prototyping:** how much ? how far do you go ? how many tests ? what parts need prototyping ?
- **Manufacture management:** series/parallel work, test subsystems…
- **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 !**

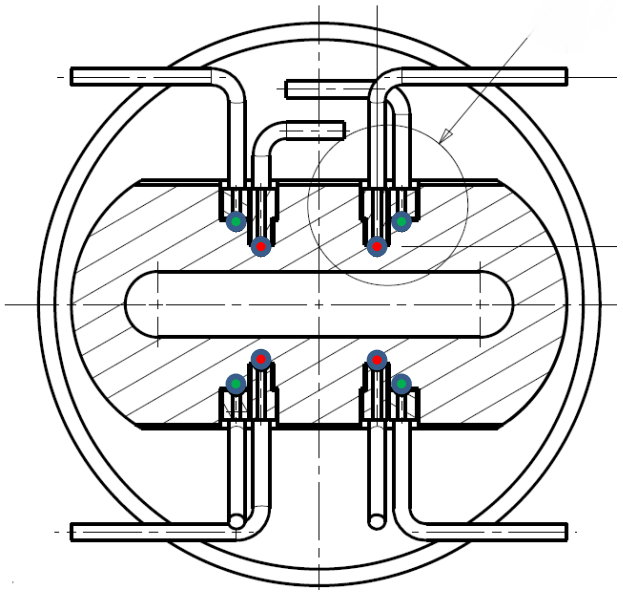
Magnetic Design of the MIK (in-air)

- Design of the MIK is inspired from the Bessy)II in vac. NLK developed in years 2010.
- Specifications for an in-air magnet with reasonable voltage.
- Octupole like magnetic topology to achieve no field at center and sufficient field at injected beam location.
- Solution: 8 current rods along « s » axis to form the octupole with minimum inductance. Thus high peak current is needed (8kA).



4 main challenges:

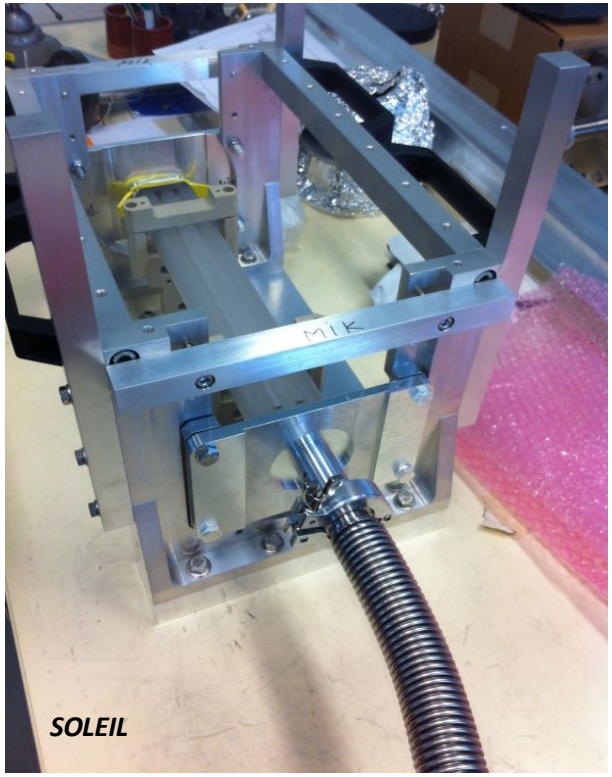
- Achieve very high precision in groove machining on chamber.
- Perform reliable gluing of conductors.
- Design a very compact magnet with high voltage.
- Design a pulser with severe voltage and current constraints.



Summary of Main Characteristics of 3 GeV MIK System

- **7 mm – 10 mm** MIK structure.
- **8 copper rods** accurately positioned. Rods are **2 mm** in diameter.
- Chamber aperture is **8 mm (V) x 46 mm (H).**
- Length: 400 mm (flange to flange).
- Chamber is made of **monocrystalline sapphire**.
- 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 & connections in very confined spaces (range of mm).
- All 8 rods are connected in series : **inductance of 1 µH**
- Titanium coating: **1 to 3.5 µm.**
- Total heat load: **100 W max.** (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 MAX-IV and SOLEIL storage rings.

Design and Construction of the MIK System



Preliminary vacuum tests : verify absence of large leaks. Proper tools & procedures to be developed

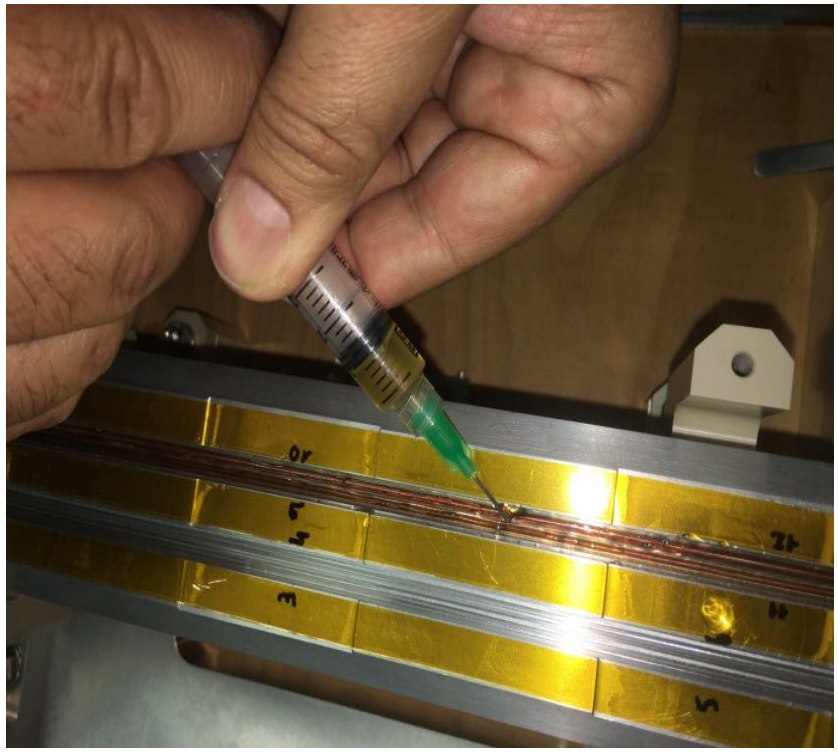
(Vacuum group - SOLEIL – Gif-sur-Yvette)

CF100 flange welding : UHV weld. Proper tools and procedures are developed & training parts made.

(P. Prout - SOLEIL – Gif-sur-Yvette)

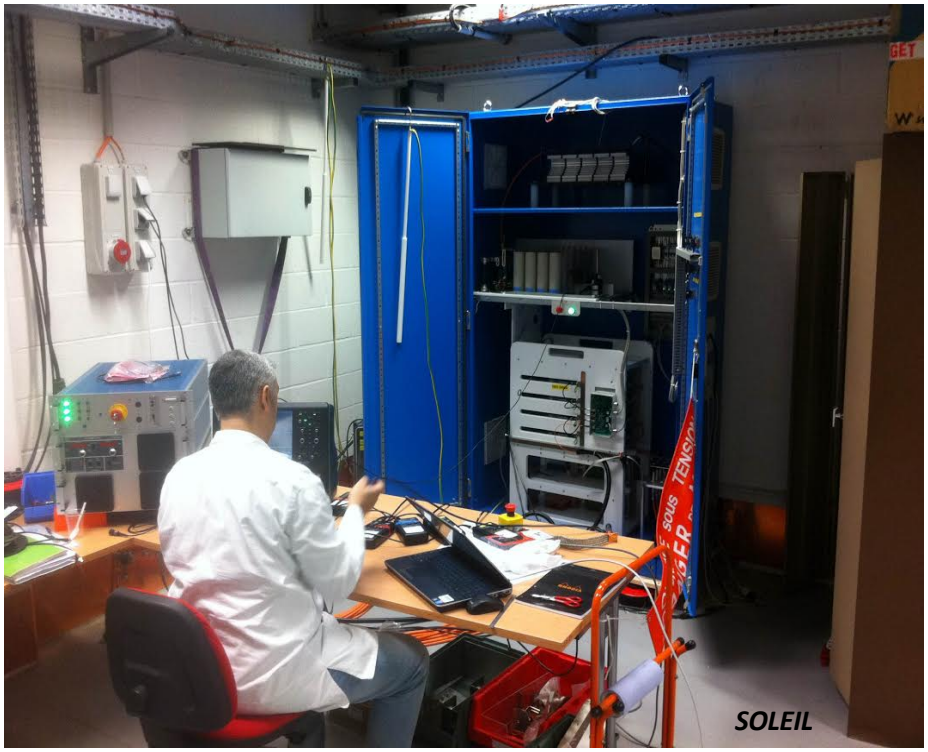
Design and Construction of the MIK System

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



Al test Chamber:
Copper rods preparation and gluing in chamber grooves.
(MIK Team - SOLEIL – Gif-sur-Yvette)

Design and Construction of the MIK System



Pulser manufacture and commissioning.

(PE Team - SOLEIL – Gif-sur-Yvette)

Half sine excitation wave
Capacitive Resonant Discharge

Magnetic measurement.

(PE Team - SOLEIL – Gif-sur-Yvette)

Pick-up coil

Installation at MAX-IV & Current Status of the Project

- **The complete system was installed at MAX-IV on the 3 GeV ring in August 2017.**

Installation @ MAX-IV

Baking-out @ MAX-IV

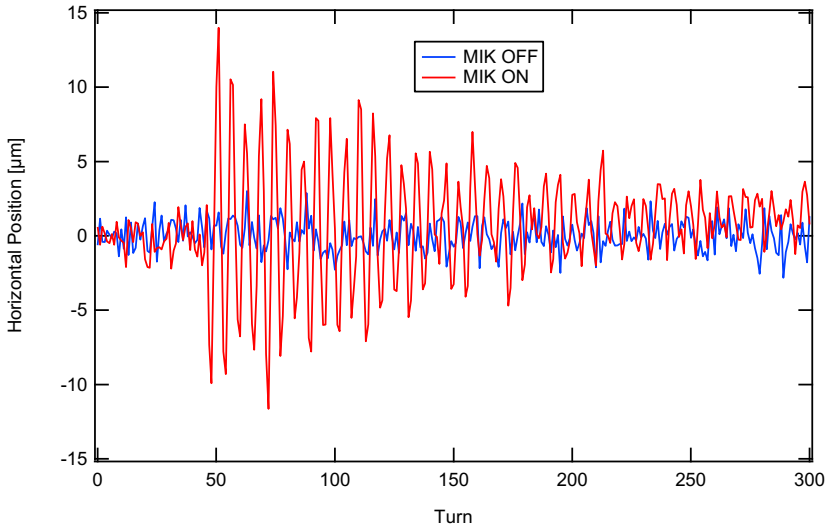
Installation at MAX-IV & Current Status of the Project

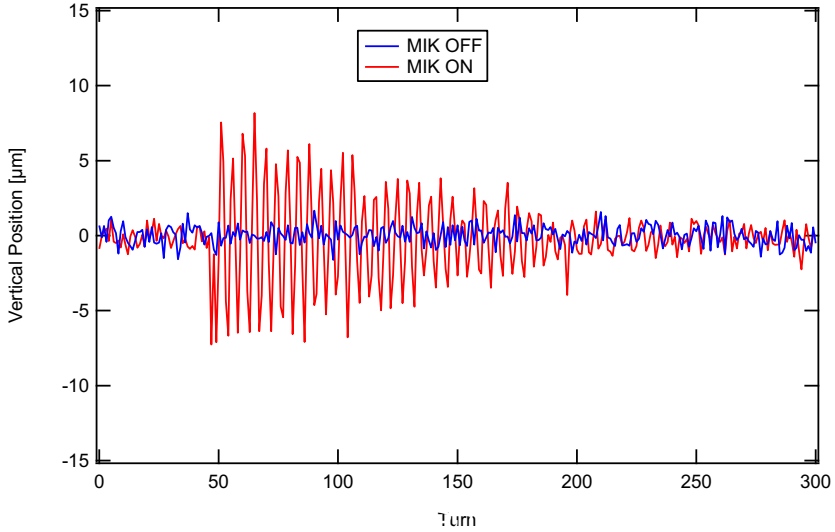
- **The complete system was installed at MAX-IV on the 3 GeV ring in August 2017.**
- **A prototype magnet with an important manufacturing error had to be installed while the definitive magnets were being assembled.**
- **Results with prototype are very encouraging :**
  - ➢ Good injection efficiency : above 85 %
  - ➢ **Low perturbation on stored beam**. (peak value)
    - ○ **Horizontal: ± 13 µm**
    - ○ **Vertical: ± 8 µm**

For reference

4 kickers @ SOLEIL

- ***70 µm H-plane (RMS)***
- ***40 µm V-plane (RMS)***





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 installation of definitive magnet at MAX-IV is planned for summer 2019**
- **Another MIK magnet shall be installed in SOLEIL storage ring in 2020**

The MIK Golden Team

SOLEIL (Gif-sur-Yvette)

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

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

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

ECA - ICA: G. Renaud, P. Monteiro, X. Elattoui, *T. Jablonka*.

Metrology & Alignement: A. Lestrade, C. Bourgoin.

Accelerator Physics: R. Nagaoka, A. Loulergue.

Administration: T. Bucaille, F. Minaeian, E. Monin, N. Guimard.

DAI: A. Nadji, le BCP, et les trois secrétaires de division

EXP : M. Thomasset, N. Jaouen.

and many others!

Project Leader
P. Lebasque (SOLEIL) (*ret*)
P. F. 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.

Pierre Lebasque: In memoriam

Led the design and realization of **Pulsed magnet** for the **injection & extraction** Booster and Storage Ring**.**

Innovative & state of the art design leading to a **remarkable stability and reliability**

Active actor for transfer of know-how to Industry (SIGMAPHI).

Call for tenders: CRYRING (MSL-Stockholm), FAIR installation (Darmstadt), THomX (LAL, Orsay)).

Renown Expert and many **collaborations worldwide**: NSLS-II (Brookhaven-USA), LNLS (Campinas-Brazil), TPS (Taipei-Taïwan), PLS (Pohang-Korea), SESAME (Amman-Jordany).

A Life dedicated to Accelerators

Electronic Engineer in LURE before joining SOLEIL

Pierre Lebasque (1952-2018)

Towards a Brighter Future

SOLEIL SYNCHROTRON

Questions ?

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