Upgrade of Hall probes benches for CPMU based on SAFALI SYSTEM

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Alexis Dutheil, Mathieu Valléau – Synchrotron SOLEIL

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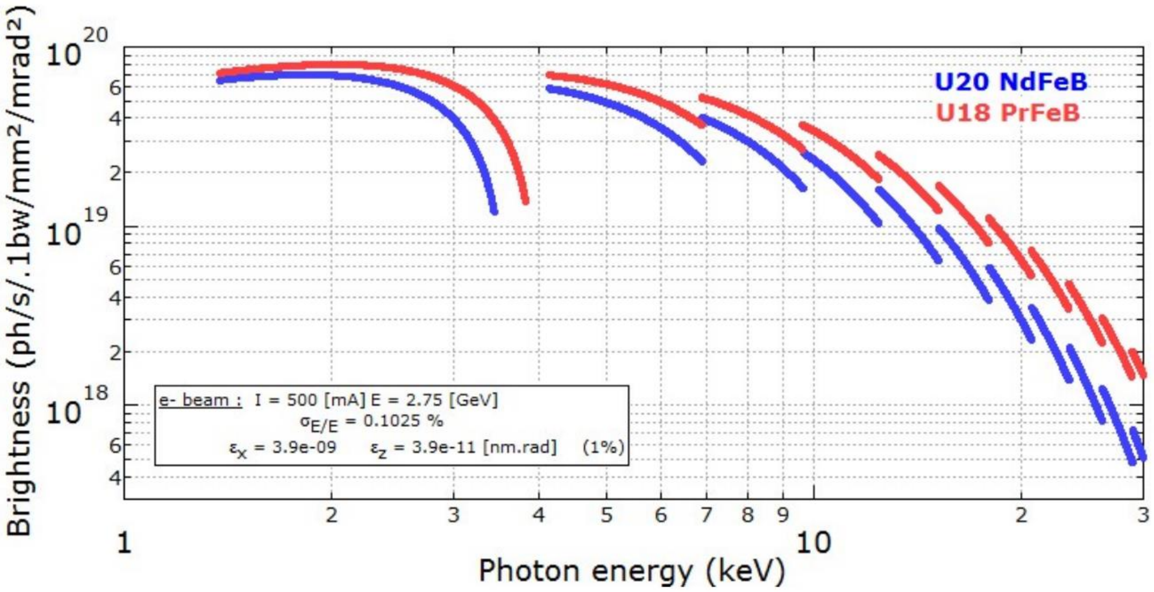
CPMU and the Hall probe bench

Cryogenic Permanent Magnet Undulators (CPMU) enhance magnetic field and coercivity, enabling shorter periods with higher magnetic fields, which results in a brighter synchrotron radiation.

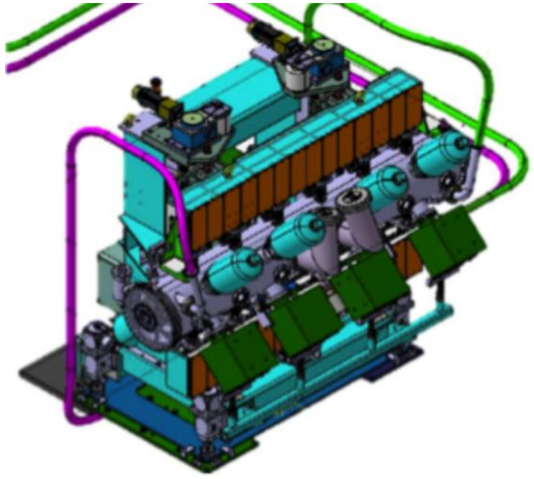


Brightness of a 20 mm period NdFeB undulator compared with an 18 mm period PrFeB cryogenic undulator

- Factor of 3 @ 30 keV on the brightness

CPMU at SOLEIL:

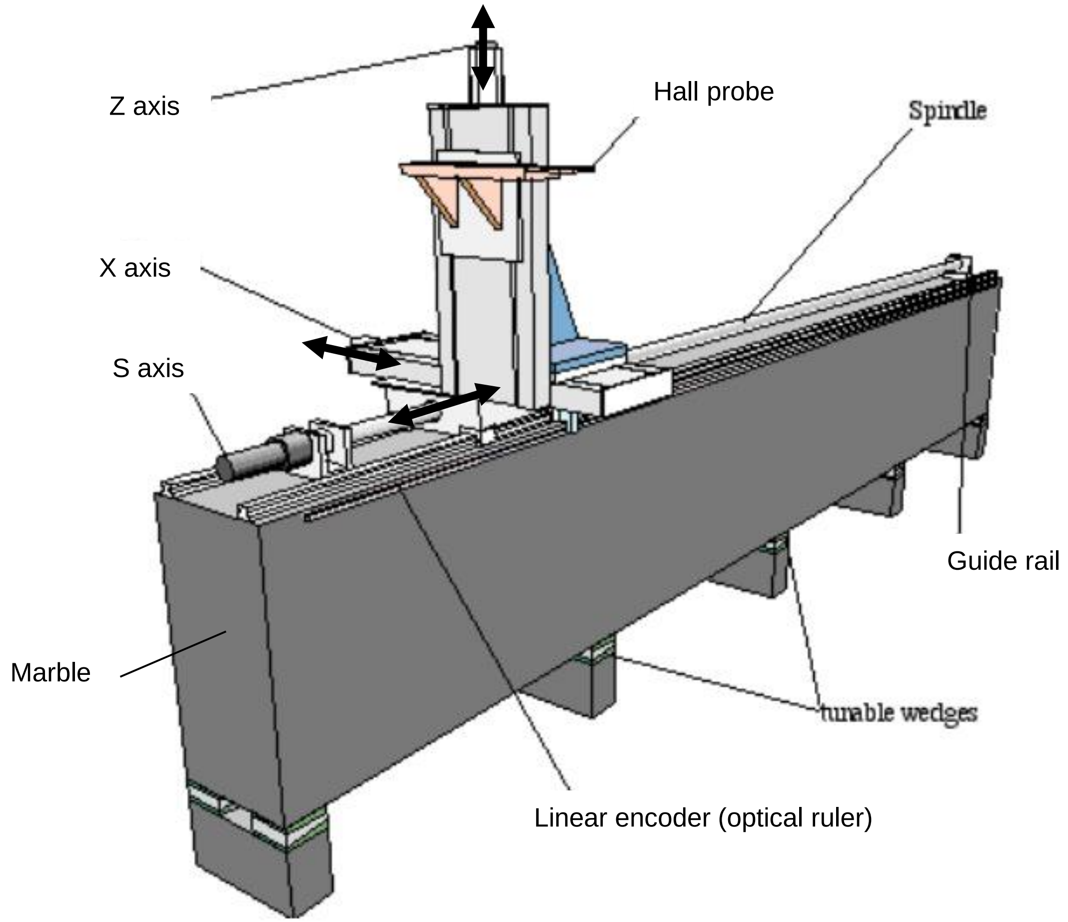
- U18 n°1 : installed for Nanoscopium long beamline in 2011
- U18 n°2 : in use for COXINEL experiments since 2015
- U18 n°3 : installed for Anatomix long beamline in 2017
- U18 n°4 : Soon installed for Cristal beamline
- U15 : under construction and dedicated to LUNEX5 or PX2 beamline
- U12 : Prototype under construction



Drawing of the U18 undulators

CPMU and the Hall probe bench

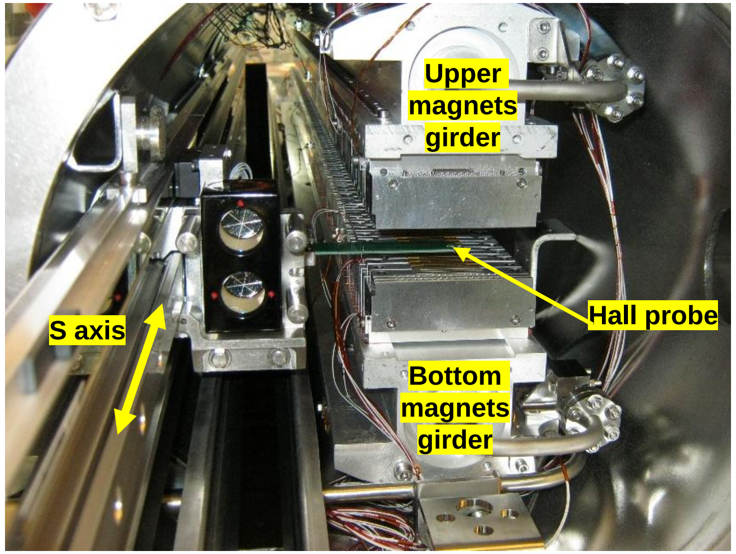
Hall probe bench : Precisely maps magnetic fields from undulator magnets.



Sanning Hall Probe Measuring Bench – P. Ellaume, ESRF, IMMW-X11, Specificity of Magnetic Measurement for Insertion Devices

Adapting the Hall probe bench for CPMU involves:

- Limited access due to the vacuum chamber's small aperture.
- Cryogenic temperatures requiring specialized sensors.
- Thermal stability to prevent measurement errors.
- Precise positioning in a constrained environment.

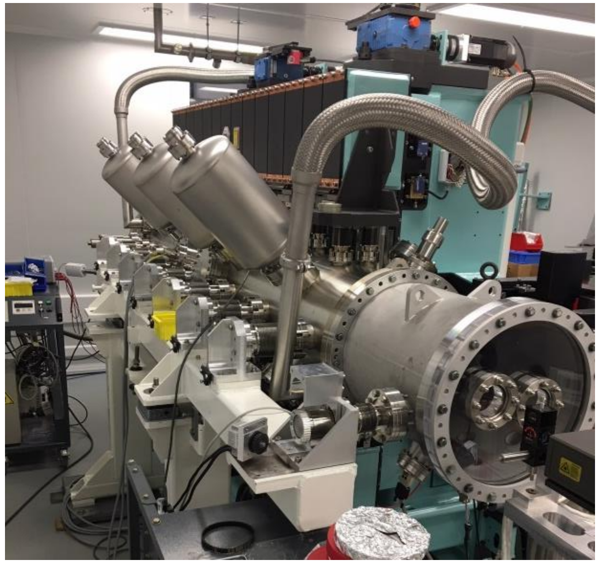


Scanning Hall Probe Measuring Bench inside CPMU18 n°1

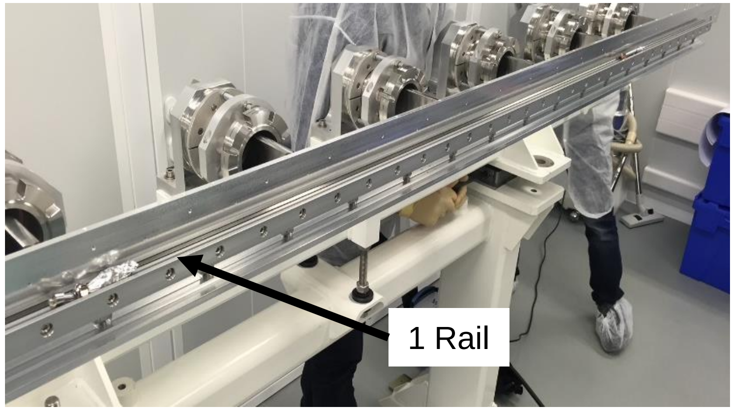
Context of the bench upgrade

1st Bench (CPMU18)

- Built for Nanoscopium's CPMU18 in 2013 and then used for Anatomix's CPMU18 in 2017. Despite good performance in terms of phase error, the trajectories calculated from the measured field were not sufficiently reproducible.
- A stepper motor outside the vacuum chamber drives a shaft inside via a magnetic coupler, moving the Hall probe carriage on a single rail.

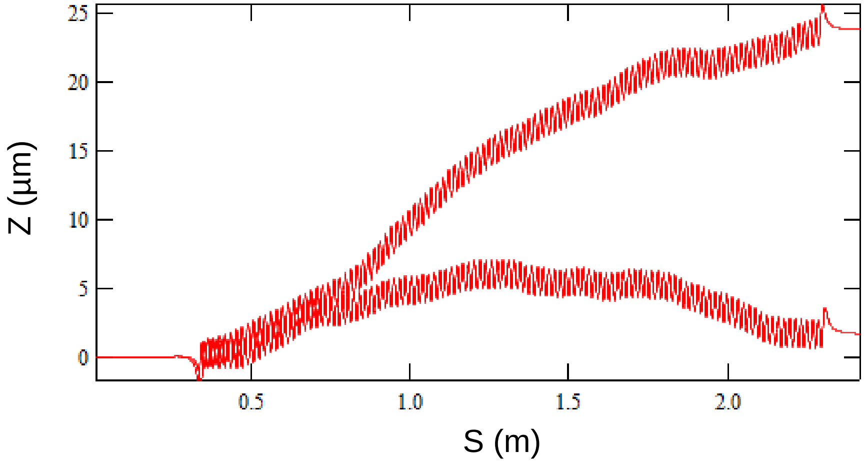


CPMU18 (2017) with the Hall Probe bench inside the vaccum chamber



Hall probe girder for CPMU18 with 1 rail

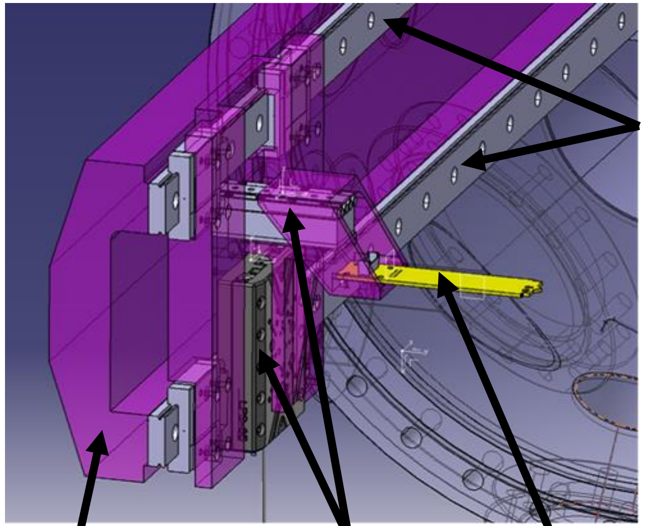
Horizontal trajectories of the electrons inside the undulator for two successive scans.

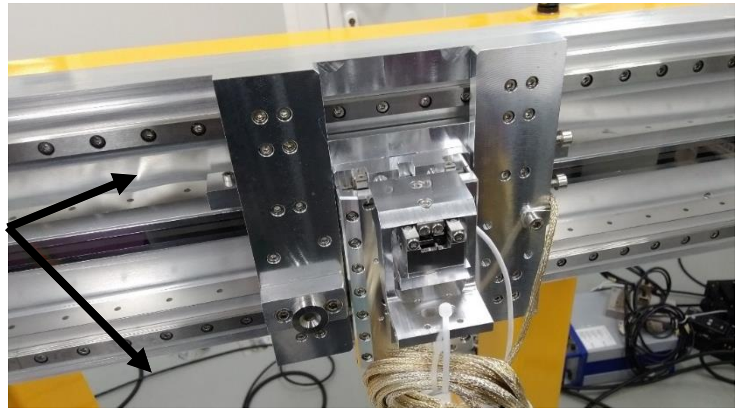


2nd Bench (CPMU15)

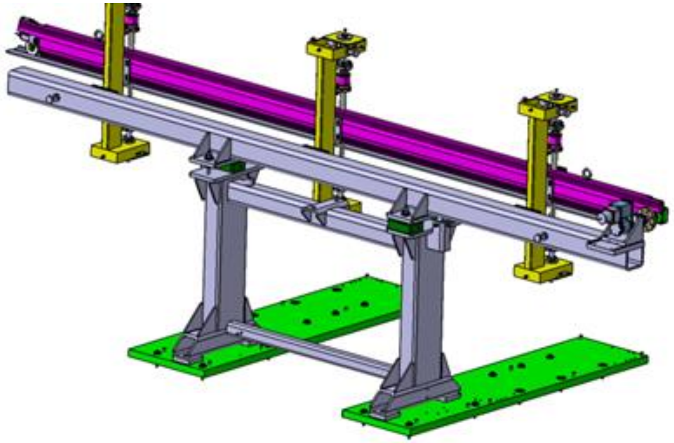
- We switched to the CPMU15 bench with two rails to reduce angular errors around the S-axis and added two piezo motors for the probe holder, as well as a future Safali feedback system. It is not yet operational.

Drawing of the hall probe bench for CPMU15



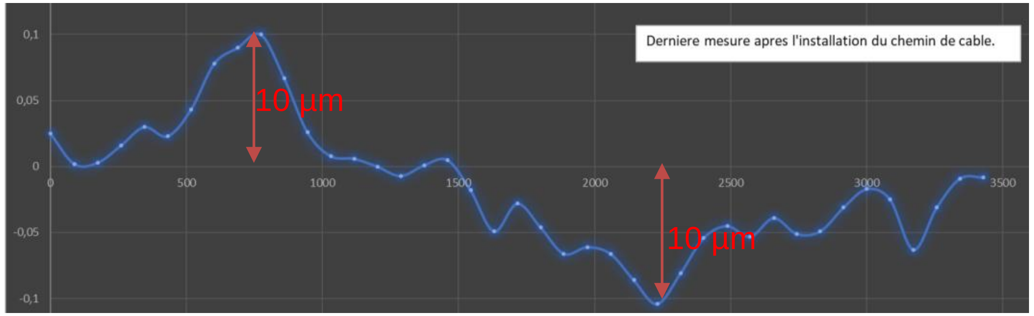


Hall probe carriage on the two rails girder



Drawing of the bench girder support

Z position of the hall probe according to its S position for 3,5 m bench



UPGRADE Bench

- CPMU18 built in 2024 : On the new CPMU18 bench we have adopted a linear motor directly under vacuum for better speed stability with the two rails.

- CPMU12 prototype under construction : including a SAFALI feedback on the bench.
  - Objective : hall probe centered to within **±5 µm**.

Introduction to the Embedded Bench for Hall Probe measurement

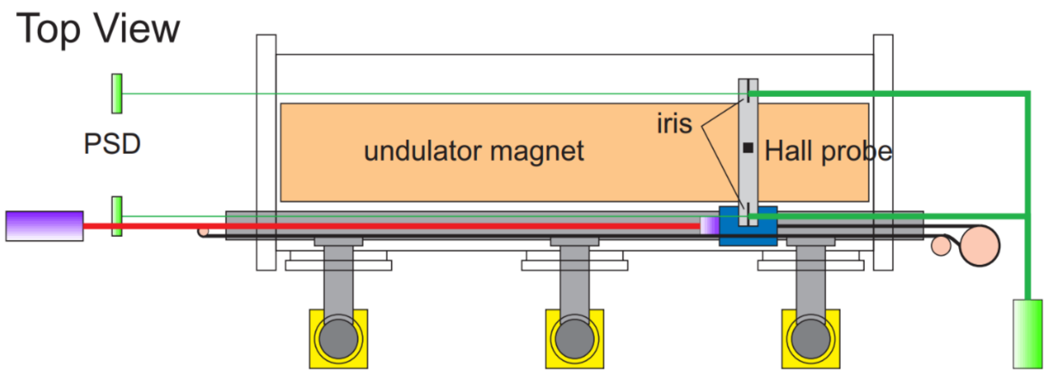
Constraint of the vacuum chamber : No marble → The hall probe moves away from the axis due to errors in alignment, machining of the girder, temperature deformation…

Solution : Dynamic feedback correction of the Hall probe position.

Objective : Standard deviation of the position measurement **< 5 µm** (**≈5,5 mV** on PSD).

Based on :

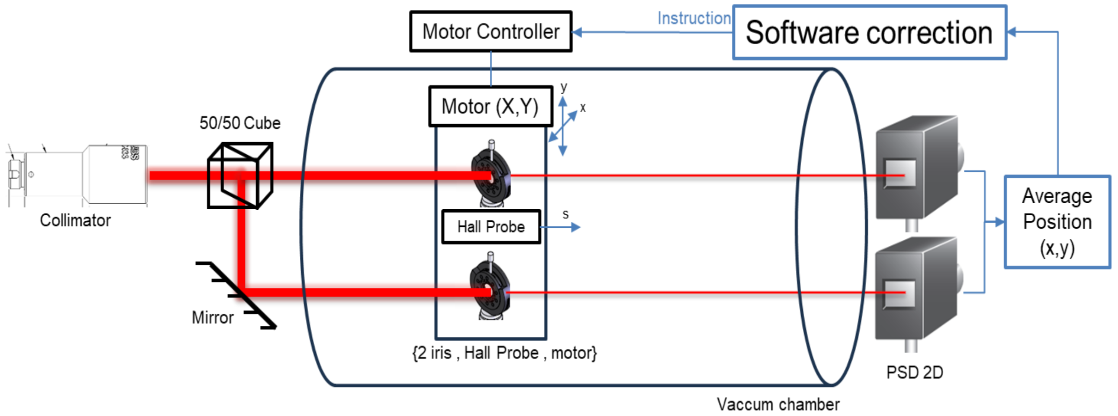
- SAFALI (Self-Aligned Field Analyzer with Laser Instrumentation) System presented at FEL 2007 for IVU24 and CPMU prototype at SPring-8.



Schematic illustration of the SAFALI system for the CPMU prototype at SPring-8

Principle :

- 2 iris attached to the hall probe deviate a laser beam split in 2.
- The deviated beams, image of the transverse Hall Probe position, are spotted by two PSDs.
- The average position is script processed then send as a feedback instruction to the piezo motor controller.

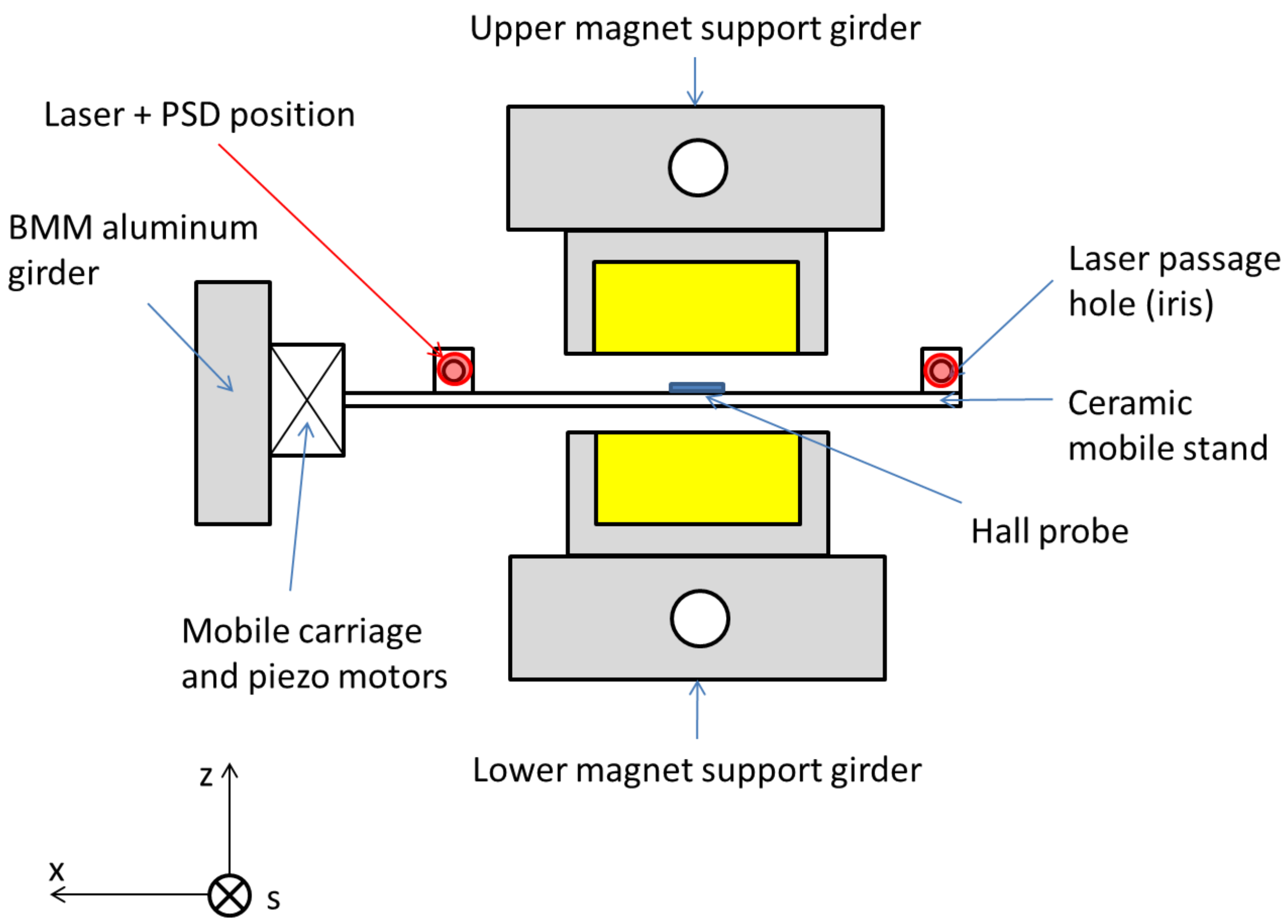


SOLEIL Version of the SAFALI System

T. Tanaka, T. Hara, R. Tsuru, D. Iwaki, X. Marechal, T. Bizen, T. Seike and H. Kitamura SPring-8, Koto 1-1-1, Mikazuki, Sayo, Hyogo 679-5148, Japan, IN-VACUUM UNDULATORS, Proceedings of the 27th International Free Electron Laser Conference (2005)

Introduction to the Embedded Bench for Hall Probe measurement

Front view of the bench with the CPMU



PSD Bench informations

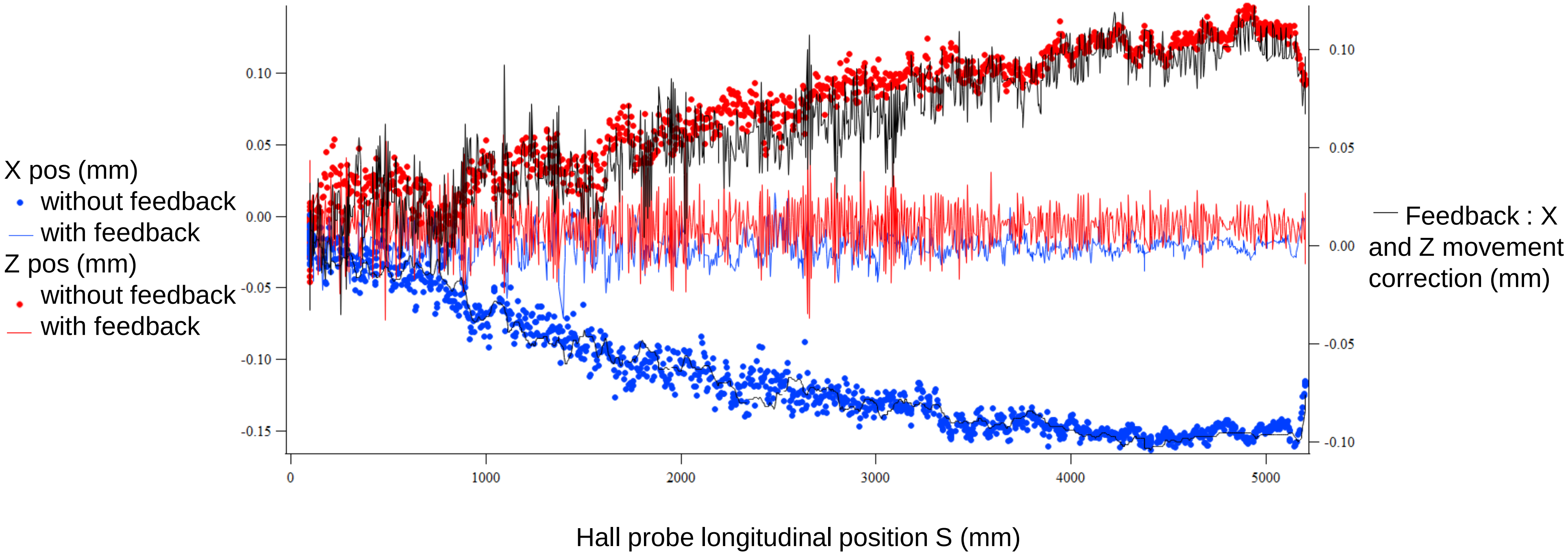
References :

- Laser diode : LP635-SF8 Thorlabs
- Pigtail laser mount : LDM9LP
- Laser diode current and temperature controller : ITC4000 Thorlabs
- Collimator : TC25FC-633 Thorlabs
- Cube : 05BC16NP.4 Newport
- Mirror : 10D20DM.4 Newport
- IRIS : ID5MS/M Thorlabs
- Filter on PSD : 10BPF10-640 Newport
- PSD module : C10443-04 Hamamatsu
- Signal processing unit for PSD module : C10460-01 Hamamatsu
- Piezo motor controller : AMC300 attocube
- Piezo motor : ANPx/ANPz attocube

System characteristics :

- Beam :
  - Diameter = 7 mm
  - λ = 635 nm
- Optical path ≈ 3 m
- Iris :
  - Distance between iris = 7,5 cm → 12 cm
  - Aperture diameter = 2 mm
- Software : Igor Pro 9
- Conversion PSD tension to laser position : ~ **1,1 mV/µm**

Feedback test on a classical hall probe bench of 5 meter long

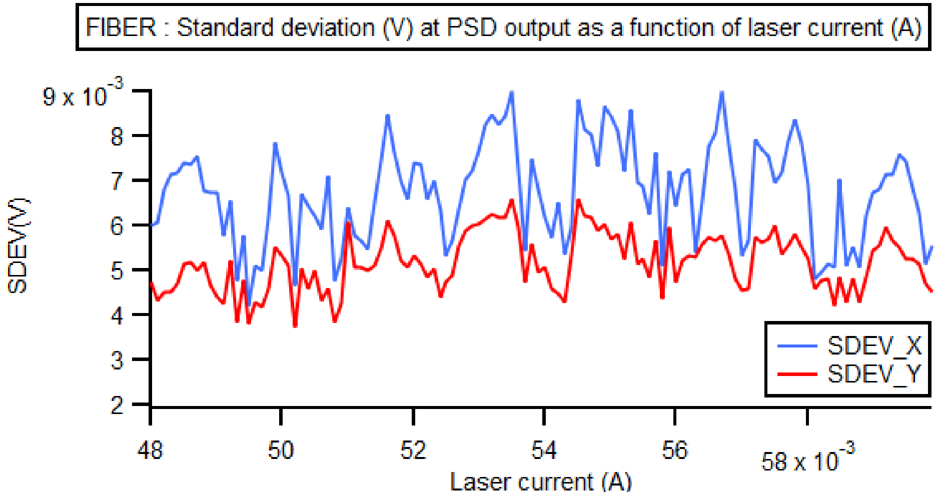


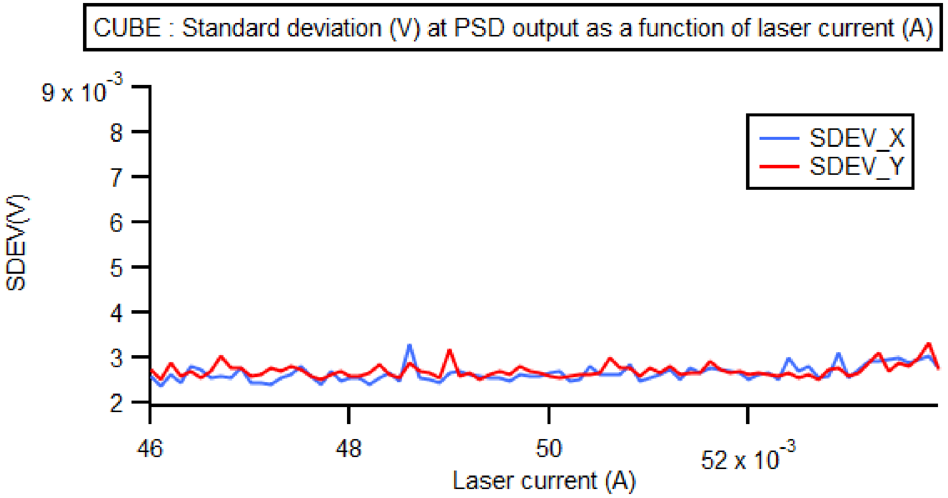
- Without feedback, the Hall probe deviates up to 150 µm in X and Z.
- With feedback, the X and Z positions remain centered with a variation of less than ±50 µm.
- Decrease in variation in the measurement when the iris approaches the PSDs.

Increasing precision of the Embedded Bench for Hall Probe measurement

1) Splitting the beam : Fiber coupling vs 50/50 cube

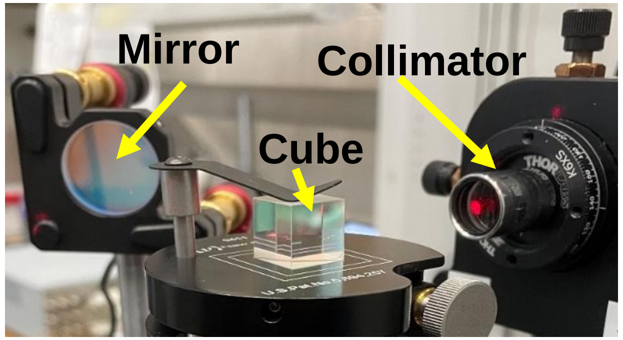
- **Observation :** Using optical fibers to split the beam generate more noise measured by the PSD than using a beamsplitter cube.



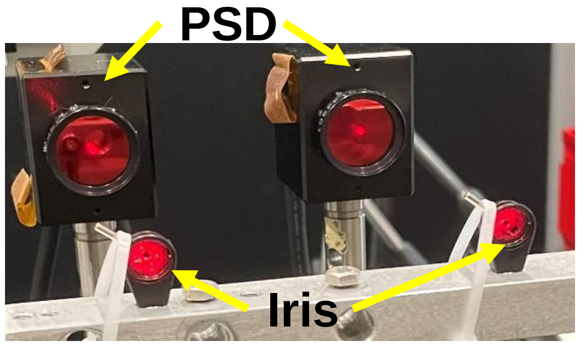


The standard deviation of the X and Y is lower and more stable with the cube :

- Fiber : Sdev ≈ 6mV (+/- 2mV)
- Cube : Sdev ≈ 3mV (+/- 0.5mV)



Laser beam splitted by a 50/50 cube

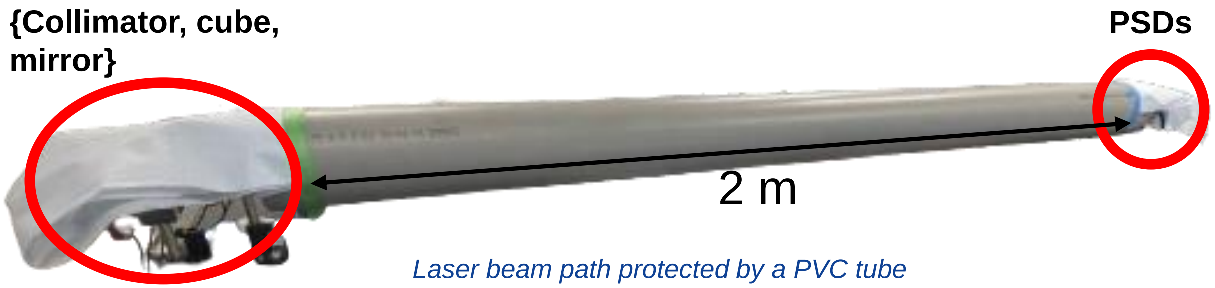


2 beams produced by the iris spotted on PSDs

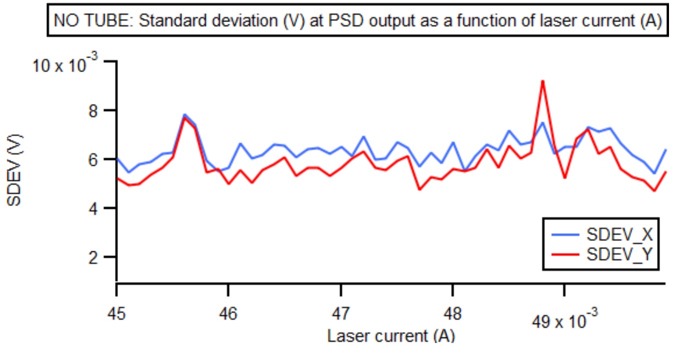
Increasing precision of the Embedded Bench for Hall Probe measurement

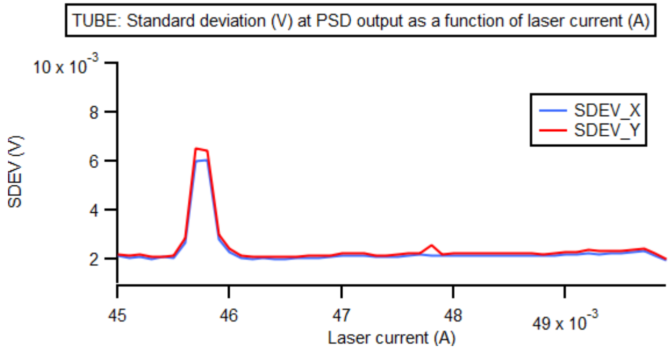
2) Ambiant air deviation

- Optical principle : When a light ray passes through a non-homogeneous medium (refractive index varies spatially) it undergoes a deviation.
- Influence of a protective 2 m PVC tube (without iris).



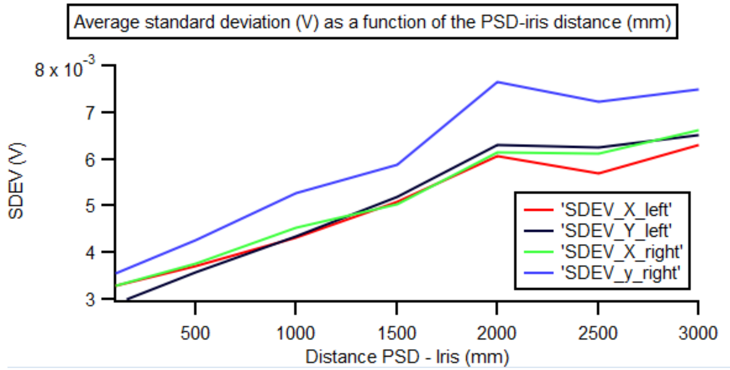
Laser beam path protected by a PVC tube





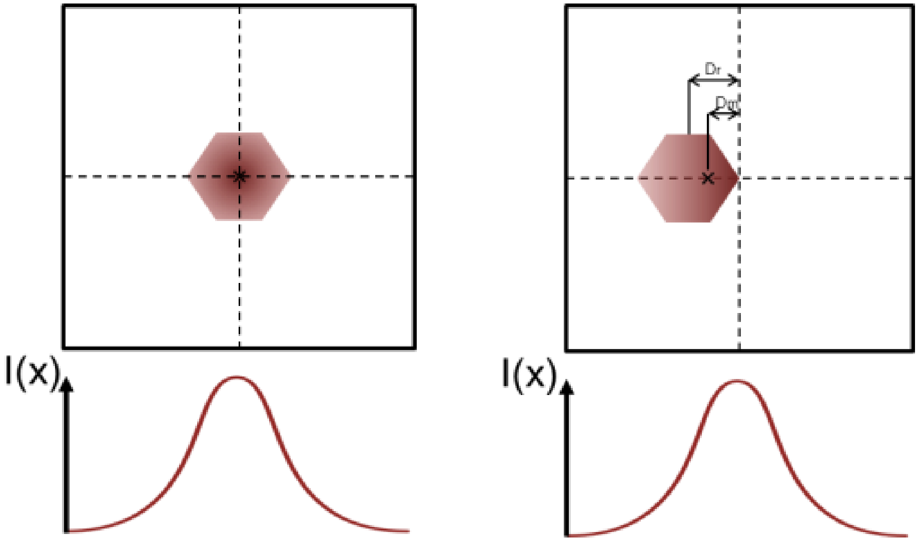
- The standard deviation of the X and Y is lower and more stable with the protective tube :
  - No tube : Sdev ≈ 6 mV (+/- 2 mV)
  - Tube : **Sdev ≈ 2 mV** (+/- 0.5 mV)

- **Verified** with irises (no tube) :
  - ↗ Distance iris PSD => ↗ layer of air crossed => ↗ deviations
  - 0 mm : Sdev ≈ 3 mV
  - 3000 mm : Sdev ≈ 7 mV

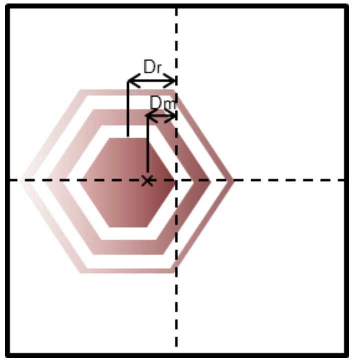


3) Gaussian beam and conversion Voltage - Position

- Optical principle : The laser beam spot is not homogenic, it follows a gaussian curve.
- Observation : The iris (hexagon shaped) does not recreate a gaussian beam.



Laser spot on the PSD after passing through the iris



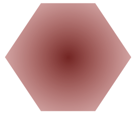
Diffraction figure created by the iris on the PSD

This phenomenon is increased by diffraction (when the iris is far from the PSD).

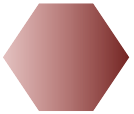
The actual iris displacement (Dr) differs from the displacement measured by the PSD (Dm). This is due to the modification of the barycenter of light intensities (I(x)) when moving the iris.

<u>Voltage measured for a 1 µm displacement :</u>

- Displacement of the irises with collimator (gaussian case) :
  - U = 1,4 mV (0 m)
  - U = 1,4 mV (3 m)



- Displacement of iris (non-gaussian case) :
  - U = 1,2 mV (0 m)
  - **U = 1,1 mV (3 m)** → Diffraction



Increasing precision of the Embedded Bench for Hall Probe measurement

Solutions

- 1) Splitting beam → Use of a cube instead of fibers.
- 2) Ambiant air → Cover the parts which are not under vacuum.
- 3) Gaussian beam and diffraction→ Software calibration to convert voltage to position based on the longitudinal position of the sensor.

In progress with CPMU12

- Measurement of the magnets and installation in modules.

In progress with bench

- Tests and calibrations of the feedback system and piezo motors for hall probe await assembly of the CPMU12 with the vacuum chamber.
- Handling the new interferometer to measure the longitudinal position. Future tests on the CPMU15.
- Automation of bench alignment.

Alignment of the bench with the CPMU

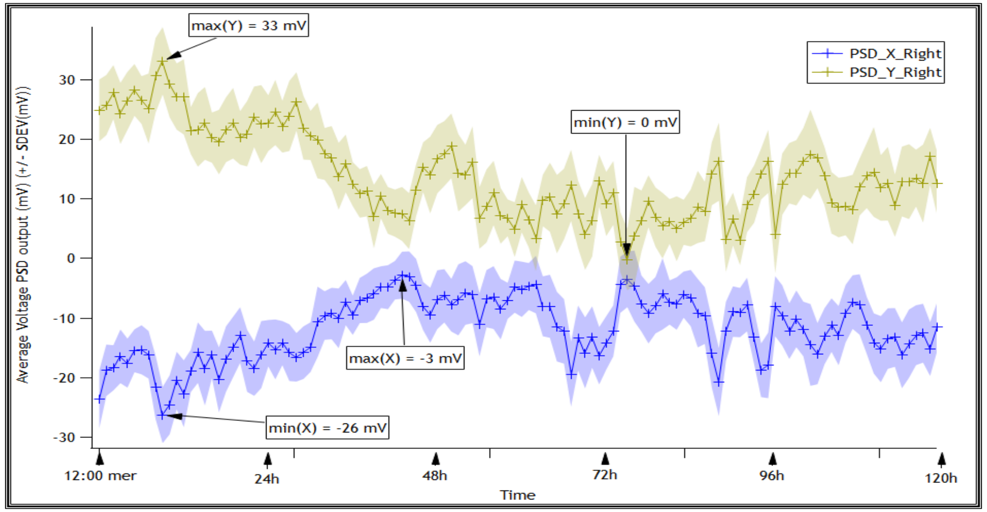
1) Automatic Alignment of the bench itself

Large number of degrees of freedom on optical components :

- Pros : Alignment of the system possible for any position of the probe.
- Cons : Non-rigid system can misalign by around 10 µm over 24 hours (~ 30 µm over 120 h).

Solution : alignment automation with python.

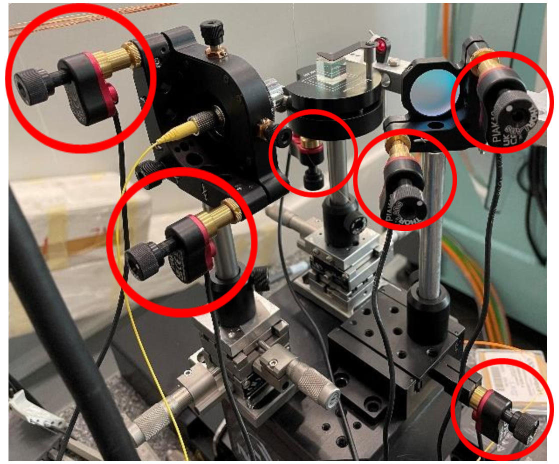
Objective : Reduce alignment time while increasing its precision.



120 hours deviation of the laser beam spotted on the PSD

Automatic movement components :

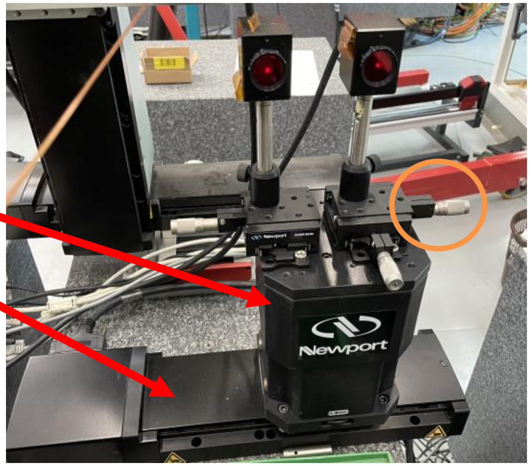
- 6 Thorlabs piezo motors for orientations and translations of : Collimator, cube and mirror (.NET -> **Python**)
- Iris XPS translations (Tango -> **Igor Pro**)
- In progress : PSD and Laser XPS translation (Tango -> **Igor Pro**)



Laser source support

Manual movement components :

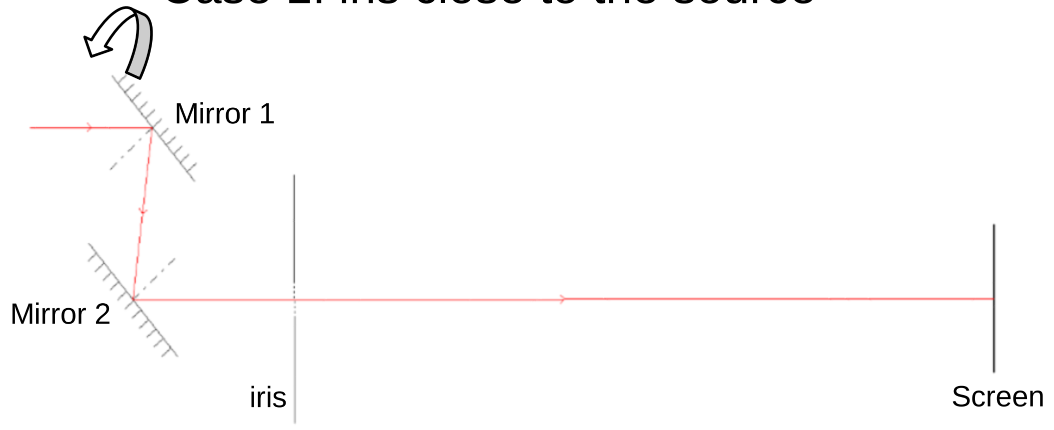
- PSD n°2 translation



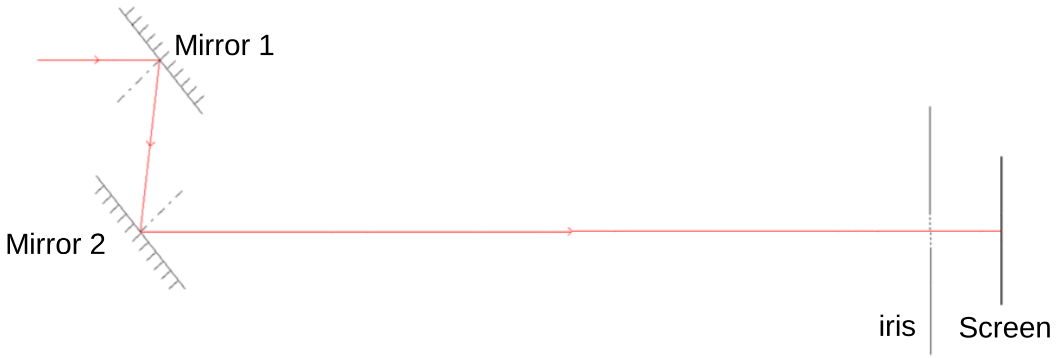
PSDs support

Optical Alignment method - Z LASER system alignment

Case 1: iris close to the source



Case 2: iris close to the screen



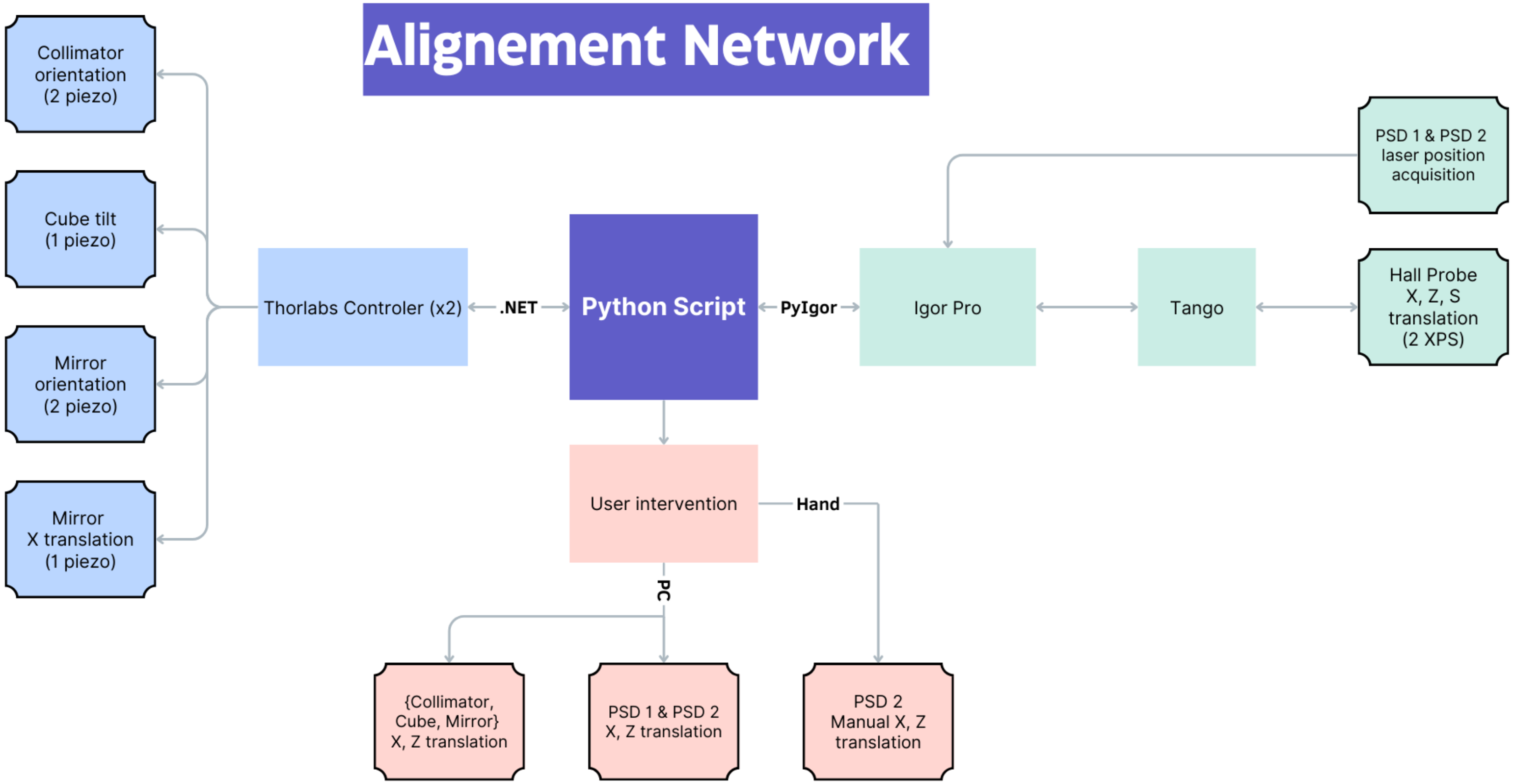
Adjusting the Z Laser system to the center of the screen:

- Case 1: Adjust mirror 1 with the iris close to the source.
- Case 2: Adjust mirror 2 with the iris close to the screen.

Algorithms used in the Python script

- Proportional adjustment method with step reduction – used to center the laser beam on the PSD.
- Hill Climbing – used to optimize the power measured by the PSD.

Alignment of the bench with the CPMU



Scheme : network of the alignment system

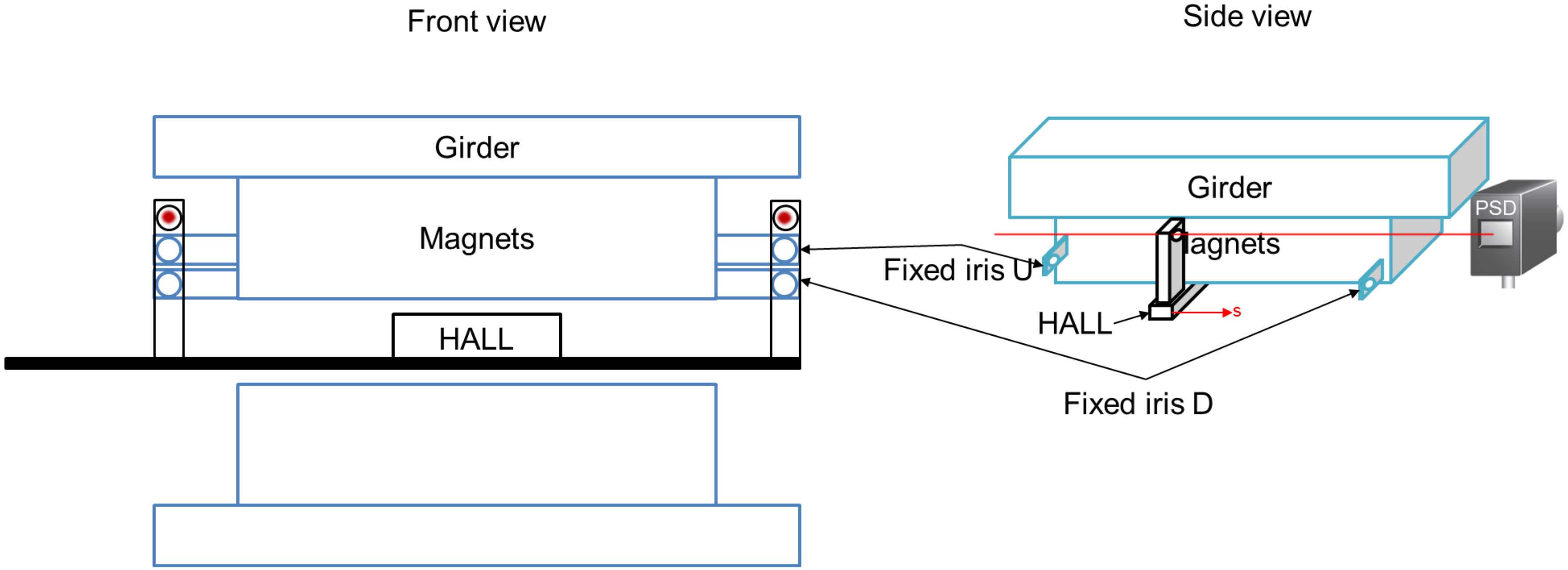
- **Igor Pro** : Graphics software used at Soleil to carry out, with **Tango**, the control of the different Soleil instruments.
- **PyIgor :** Library that allows data to be exchanged and commands to be executed between Python to Igor Pro
- **The Thorlabs piezo motor controller** uses the .NET communication protocol which easily interfaces with Python

Duration of the re-alignment procedure after 24 hours:

- Manual procedure 30 - 45 min
- Automated procedure **<15 min**

2) Alignment with the CPMU

1st solution : Iris fixed as references on the CPMU girder.



Scheme : Fixed iris solution for laser/PSD alignment

Principle :

We use the opening/closing of the gap to alternately insert the U and D irises into the laser beam.

Unsustainable solution :

- High risk of collision between mobile and fixed iris.
- Large gap opening range and probe path not measurable.

2nd solution : Use the start and finish position of the iris as a reference as is done on conventional hall probe benches.

-> Less precise than the 1st solution but much more adaptable without risks.

Conclusion / In progress

Objective : Improve the precision and stability of magnetic measurements for CPMUs by upgrading the Hall probe bench with feedback and automation systems.

Key Improvements :

- Added two rails to reduce angular errors around the S-axis.
- Piezo motors for more precise Hall probe positioning.
- SAFALI system for dynamic feedback, reducing X/Z position variations to less than ±50 µm for classical hall probe benches.

In progress:

- Testing on CPMU12 and CPMU15 : Awaiting the completion of CPMU12 with its vacuum chamber to calibrate and test the SAFALI feedback system.
- Alignment automation : Increasing automation of bench alignment while waiting for the CPMU12, aiming to reduce alignment time and improve precision.

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