AI-DIA-PST-I-2168

SOLEIL Timing and synchronization System

2025-12-17

SOLEIL

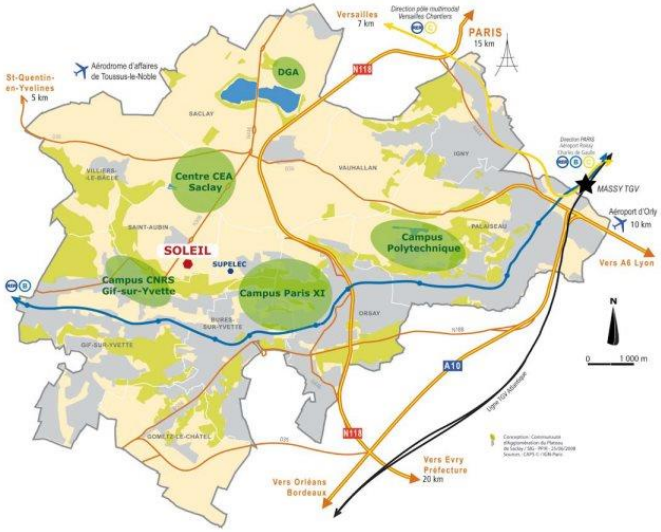
2025-11-07

SOLEIL is a research center that produces and uses synchrotron light.

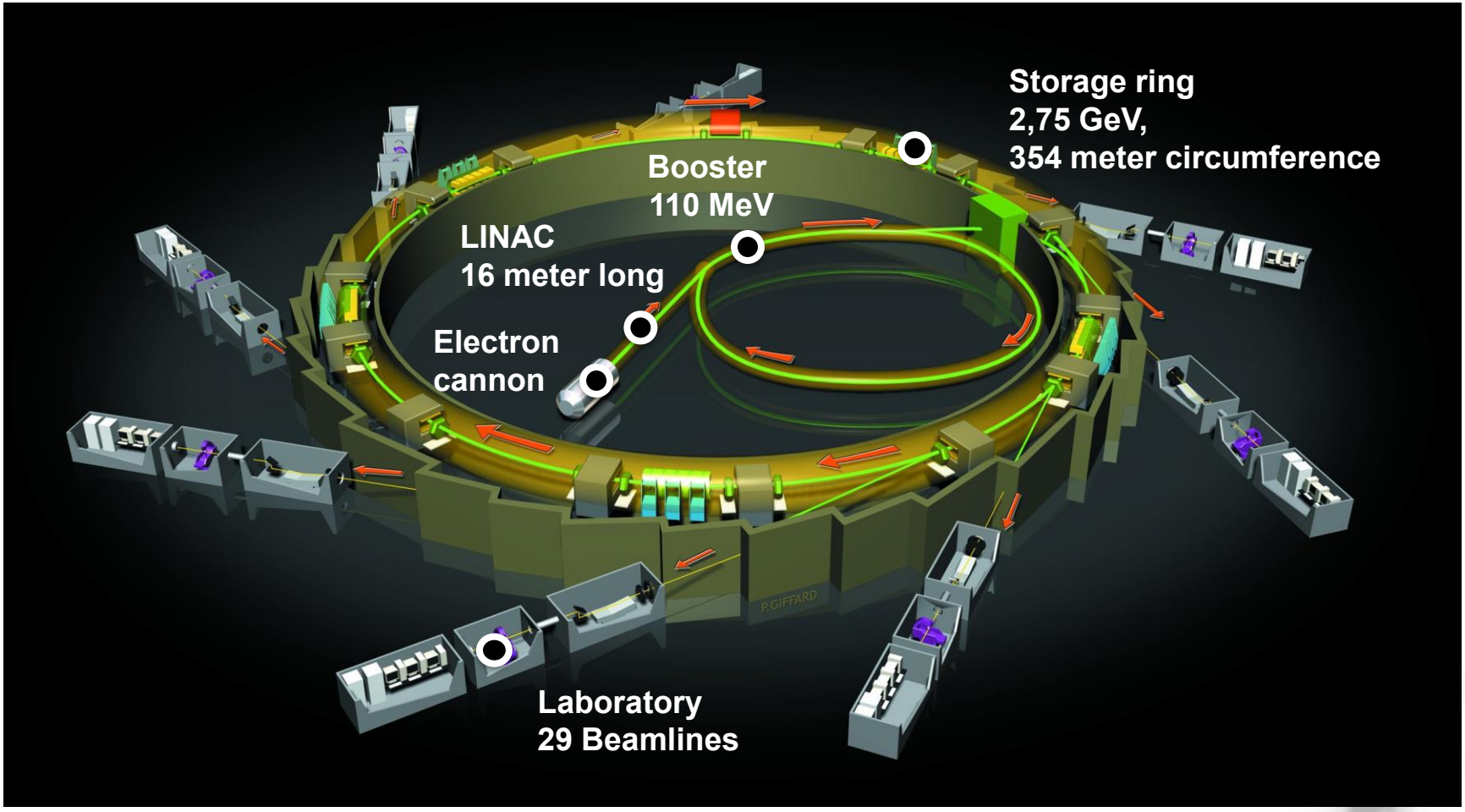
This ultra-bright radiation is 10,000 times brighter than that of the sun.

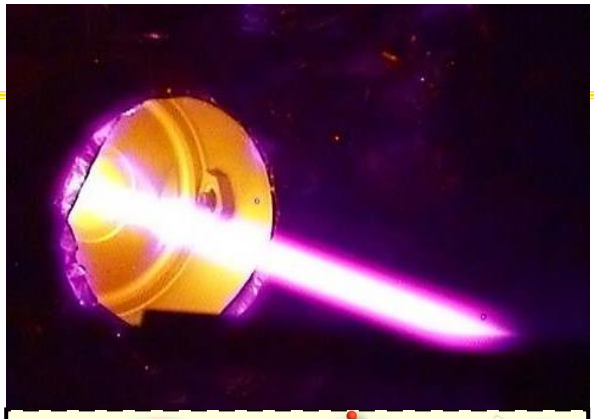
It is used to study samples and materials in order to find out more about their structure and properties. The extreme brightness of SOLEIL will make it possible to make observations on a submicronic scale on materials.

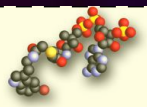
SOLEIL is among 40 major scientific establishments in France.



The staff is about 370 persons + 2500 researchers / year

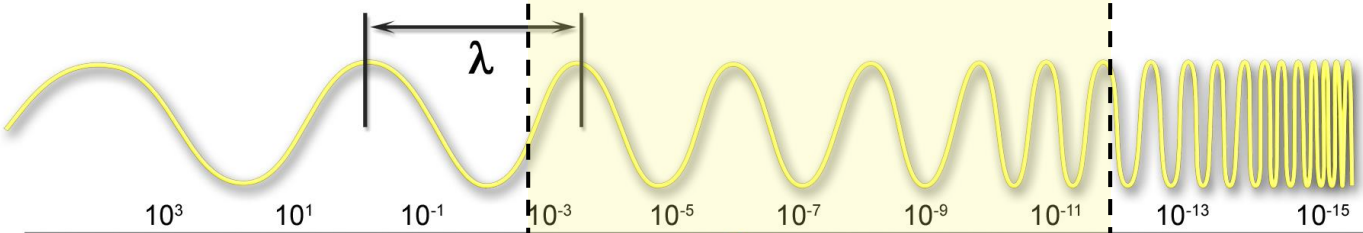

Storage ring
2,75 GeV,
354 meter circumference
Booster
110 MeV
LINAC
16 meter long
Electron
cannon
Laboratory
29 Beamlines
P.GIFFARD

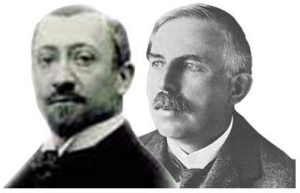




OBJETS DE MÊME TAILLE QUE LA LONGUEUR D'ONDE

Maison | Balle de tennis | Cellule | Protéine | Atome | Noyau | Proton | Quark



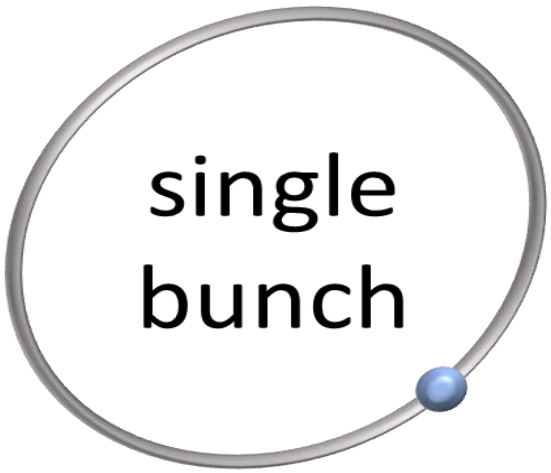


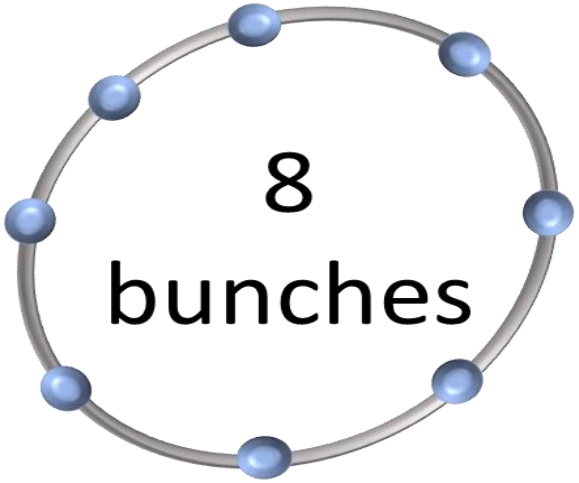
DECOUVERT PAR... EN...

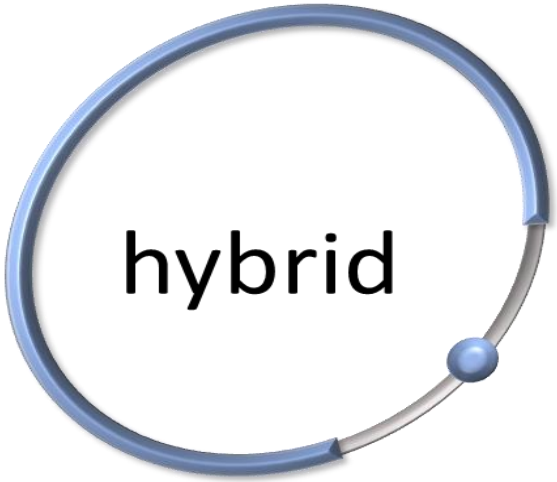
Hertz 1885 | Ponte 1940 | Herschel 1800 | Newton 1666 | Ritter 1801 | Röntgen 1895 | Villard et Rutherford 1900

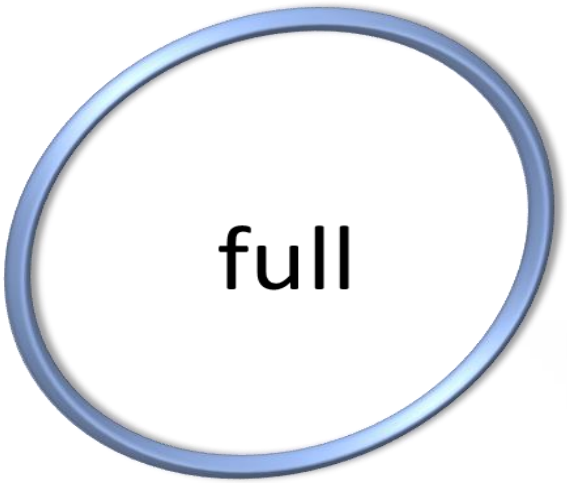
- **Agribusiness**
- **Biology**
  Origin of life - The natural asymmetry of biomolecule
- **Cosmetics**
- **Chemistry**
- **Electronic**
  A major advance in microelectronics: The production of graphene semiconductor nano-ribbon
- **Buildings - Public works**
- **Transport**
- **Materials**
  SOLEIL sheds light on the secret of the Stradivarius varnish
- **Medicine**
  Liver transplants - SOLEIL synchrotron offers a safer method of deciding in a few minutes if a donor liver can be transplanted
  Huntington's disease - The structure of inclusions in patients' brains revealed by IR microspectroscopy
  Diagram of the hepatitis c virus
- **Energy**
- **Environment and eco-industries**
- **Etc.**

Filling modes

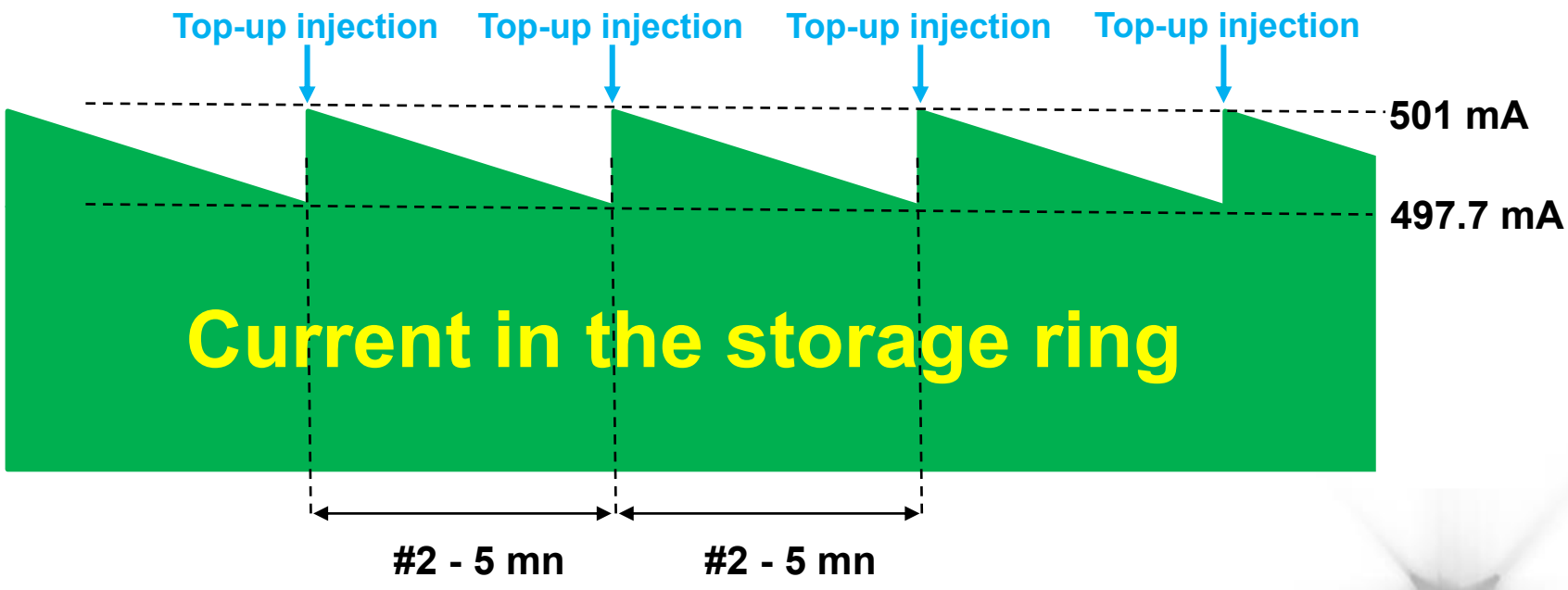


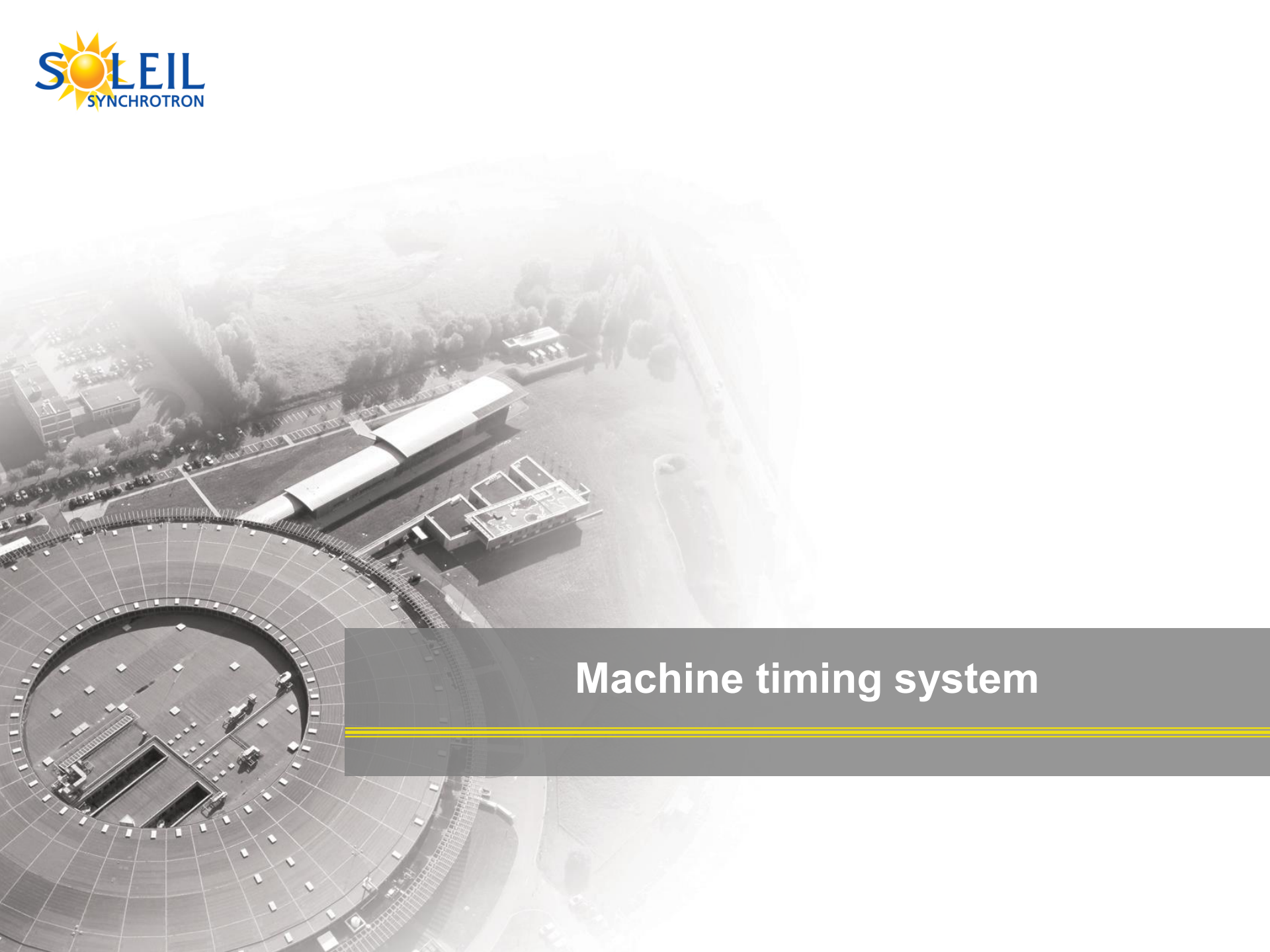






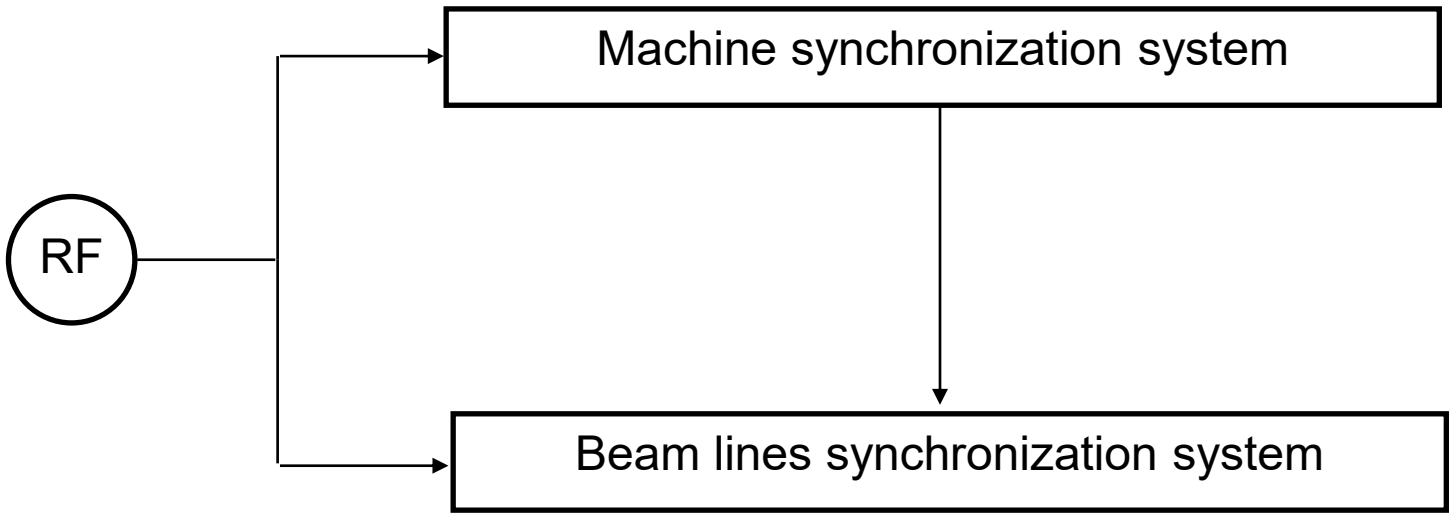
Top-up


Top-up injection
Top-up injection
Top-up injection
Top-up injection
501 mA
497.7 mA
Current in the storage ring
#2 - 5 mn
#2 - 5 mn



Machine timing system

Soleil timing system

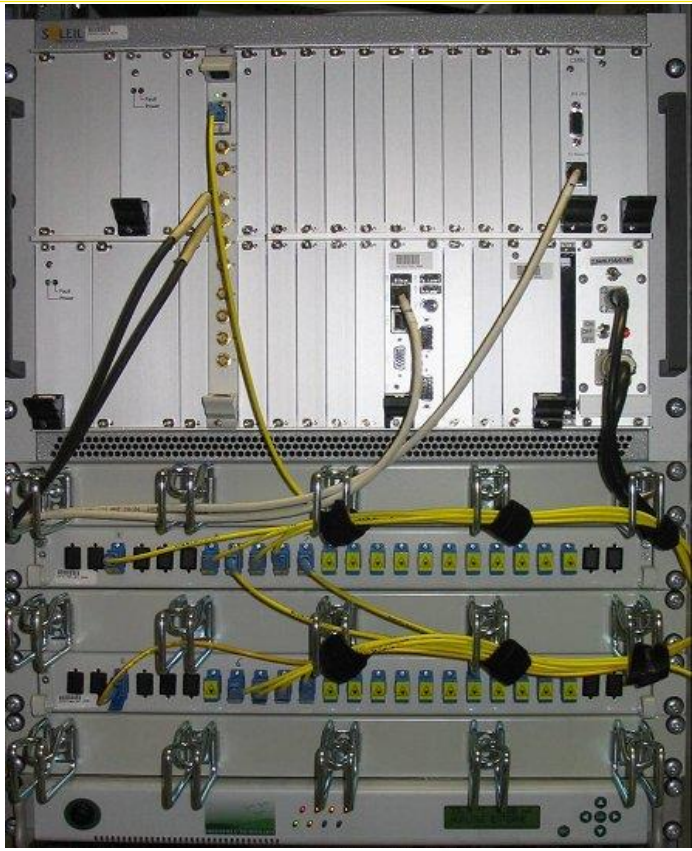


Machine timing system

- Current system

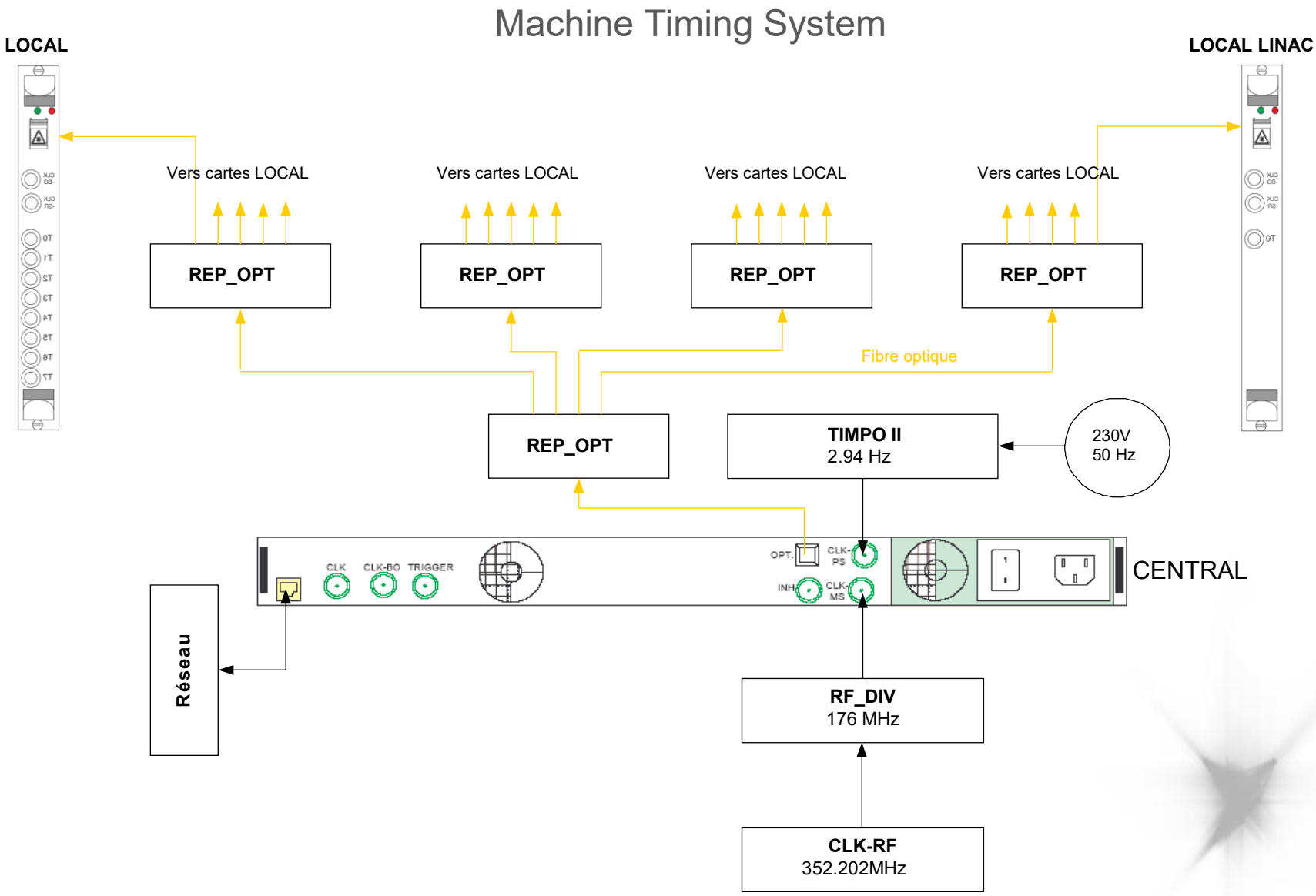
  The current system is based on master/slaves event architecture developed by subcontractor for SOLEIL.

  It has been very reliable since 2006.



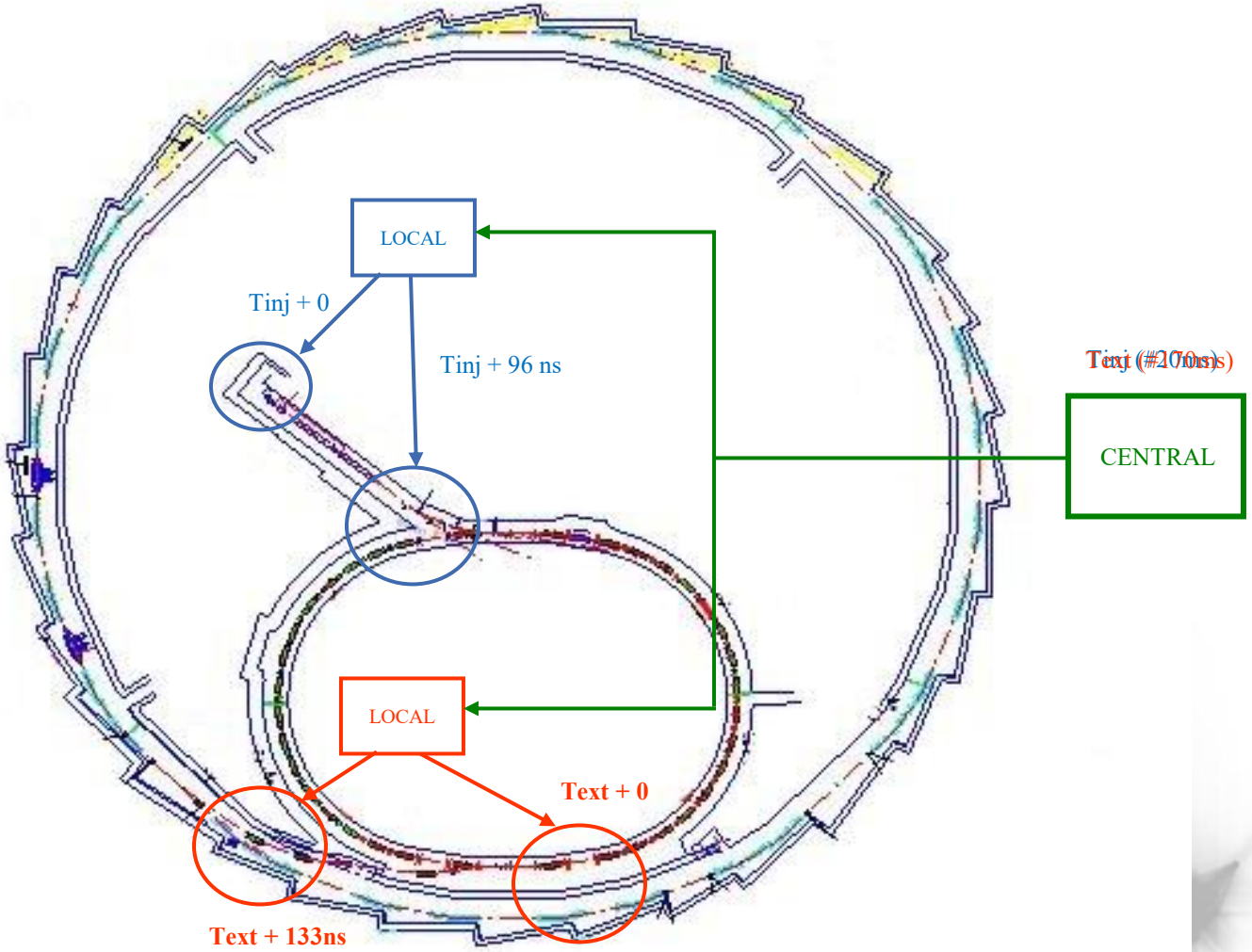
- The aim of the machine's timing system of Soleil:
  - To trigger all devices (LINAC, Kicker, Septum, etc.) needed to bring electrons from the LINAC to the storage ring.
  - To fill the storage ring with a specific pattern defined by users.
  - To manage the top-up mode.

Machine timing system



Machine timing system

Dual delay system:



Machine timing system

CENTRAL system

- Broadcast the events (pre-charge, injection, extraction, continuous trigger, software on demand).
- Broadcast the clocks (booster, storage ring).
- Manage the injection / extraction cycle.
- User configurable delay for events (steps of 1/CLK-BOO #522 ns)
- 256 events

Machine timing system

CENTRAL

Pre charge Delay	BOO injection Delay	SR injection Delay	
00	20	¼ SR	bunch
		50	12
		1027	595
		66	14
		50	32

416

Pre charge event → **Pre charge LOCALs**

Injection event → **Injection LOCALs**

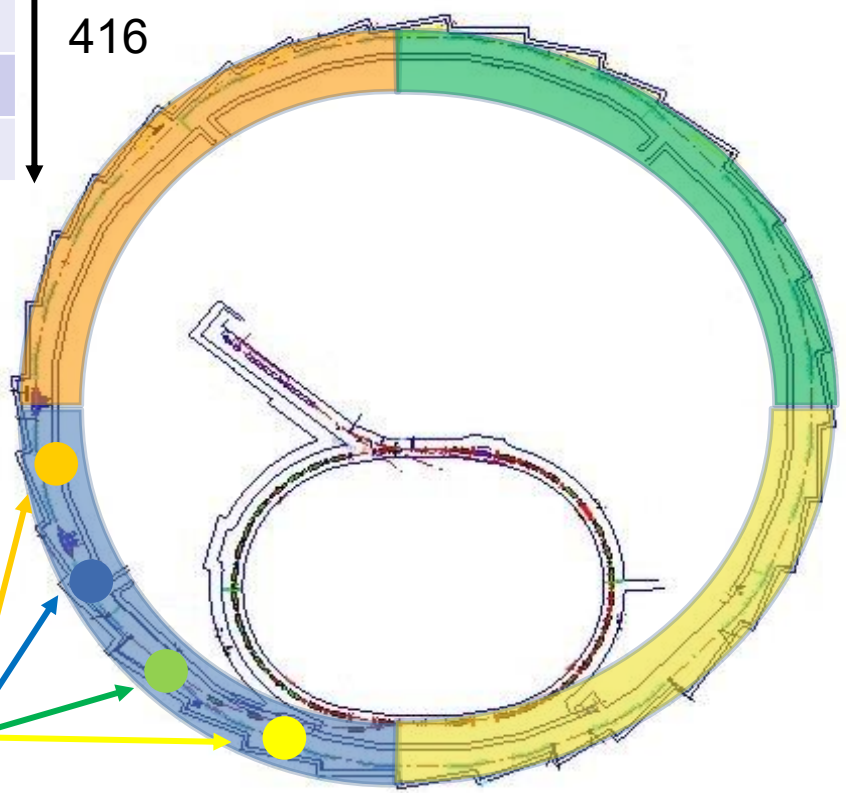
Extraction event → **Storage ring injection LOCALs** → **event 3**

Bunch delay → **LOCAL LINAC**

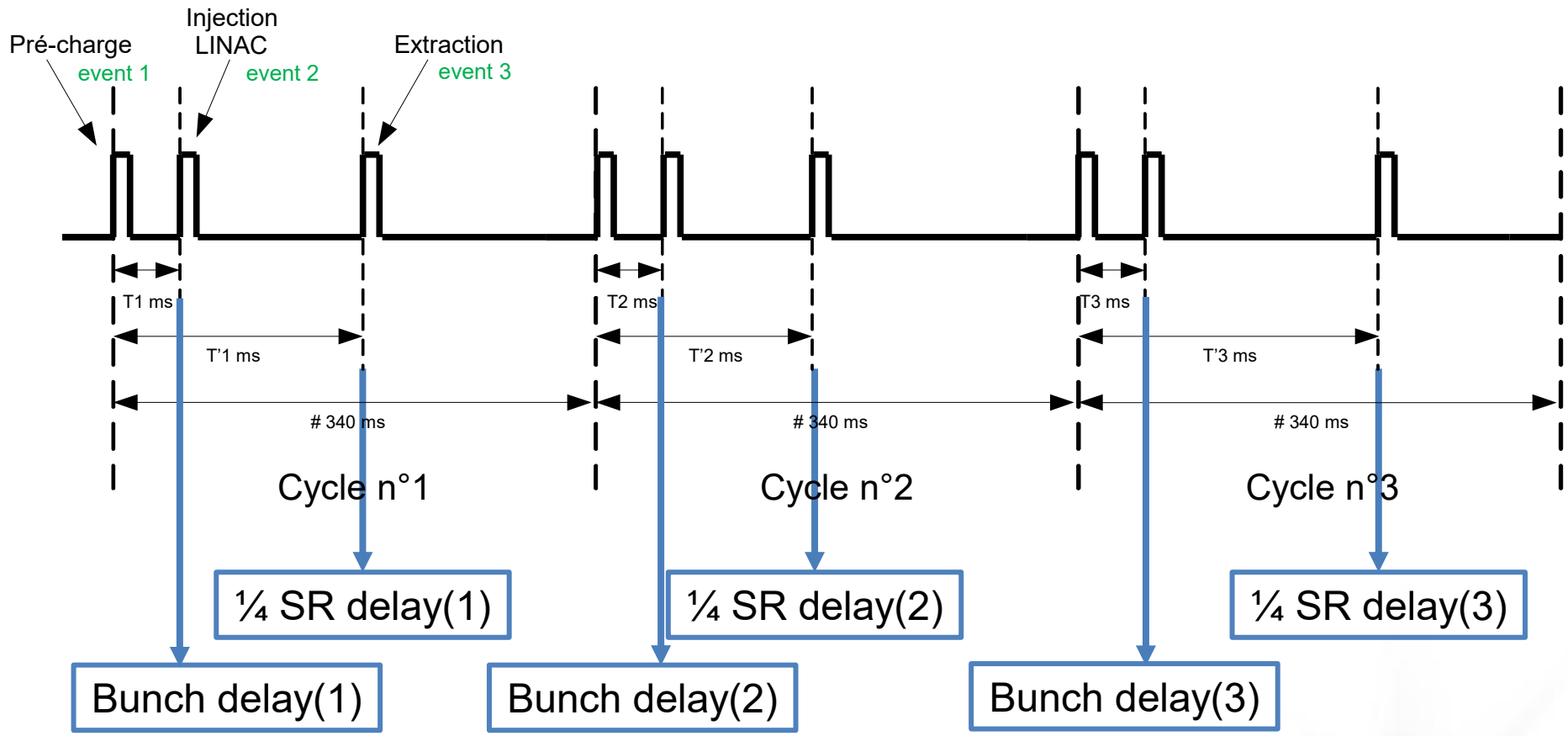
bunch delay
12 ; 595 ; 14 ; …

event 2

Selection of the bunch inside ¼ of the storage ring with the fine delay inside CENTRAL (and the LOCAL LINAC)



Machine timing system

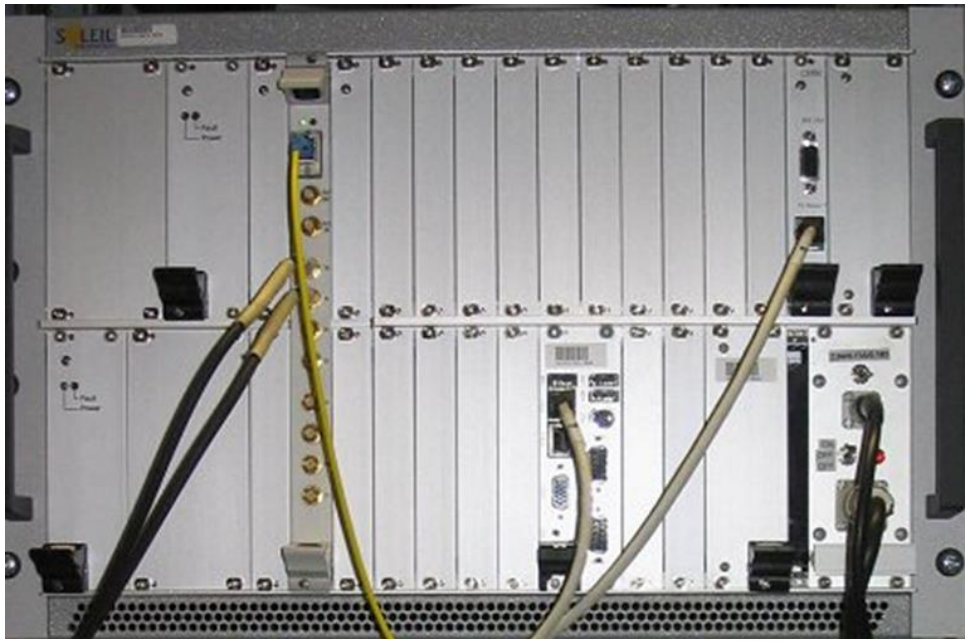


Coherency between ¼ SR delay and bunch delay is warranty by having both of them inside the CENTRAL system

Machine timing system

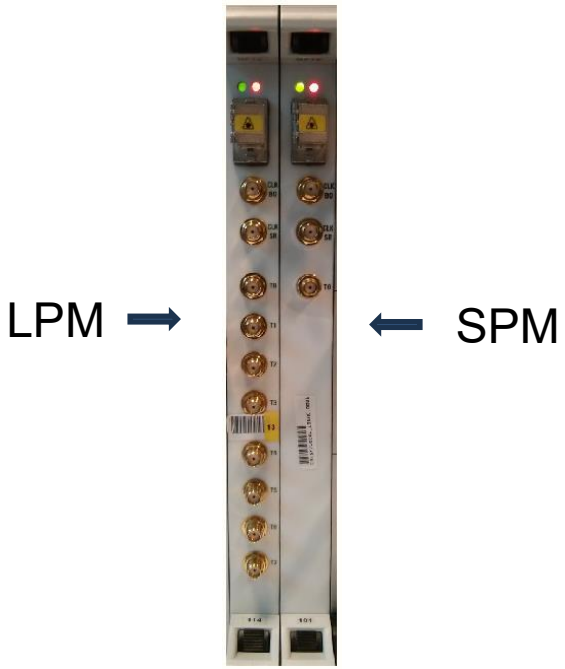
LOCAL boards

- Booster and Storage ring clocks outputs.
- 8 TTL trigger outputs.
- 0 to 340 ms delay adjust by step of 5.64 ns.
- 10 µs pulse width.
- Each output's event and delay can be configured.
- #15 – 25 ps RMS jitter.
- Skew < # ns between boards (fixe).

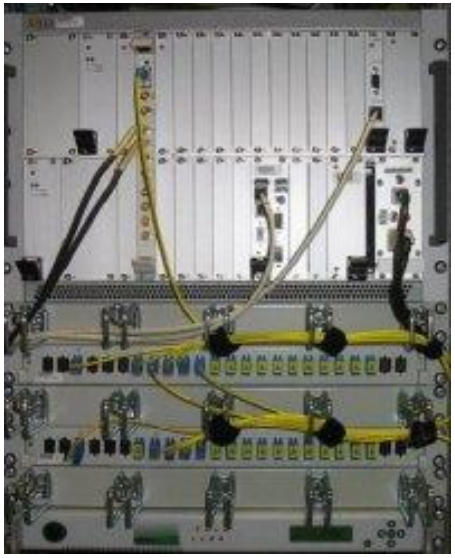


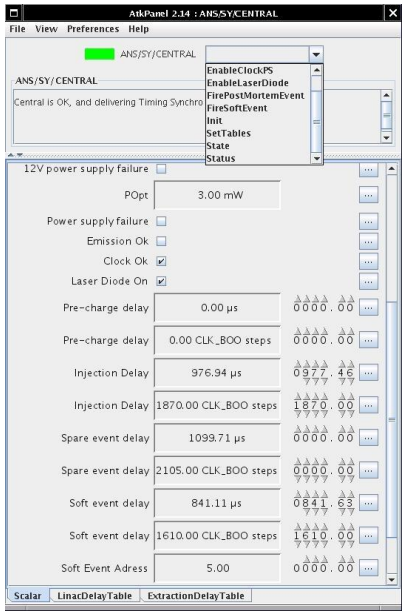
LOCAL LINAC board (SPM)

- Booster and Storage ring clocks outputs.
- 1 TTL trigger output.
- 0 to 340 ms delay adjust by step of 5.64 ns.
- 0 to 357 ns bunch delay adjust by step of # 80 ps.
- 10 ns pulse width.
- #15 – 25 ps RMS jitter.
- 4 modes.



Machine timing system

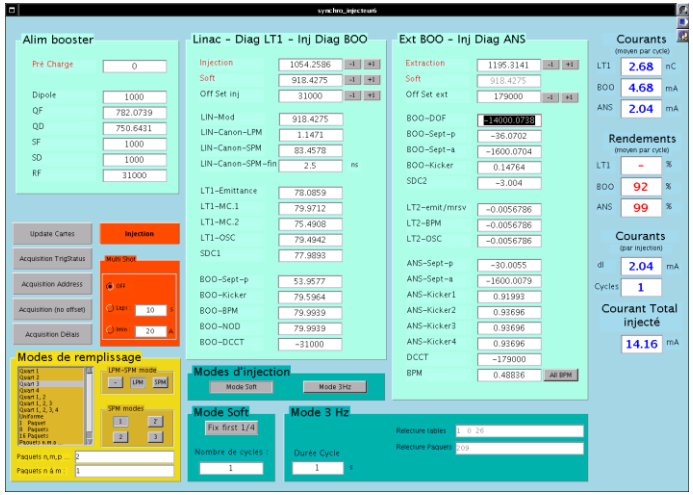


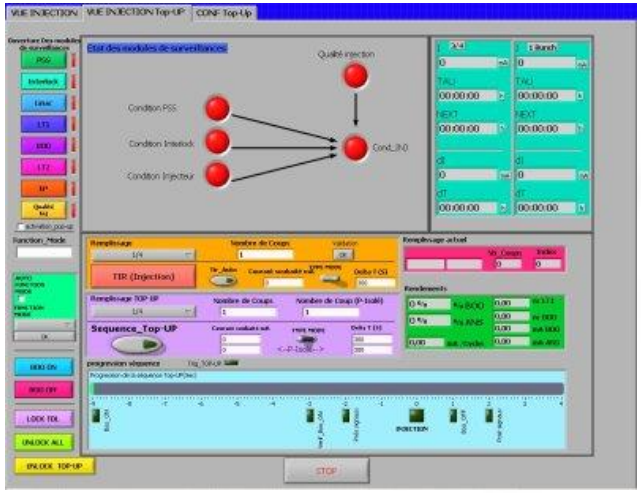


Tango Devices

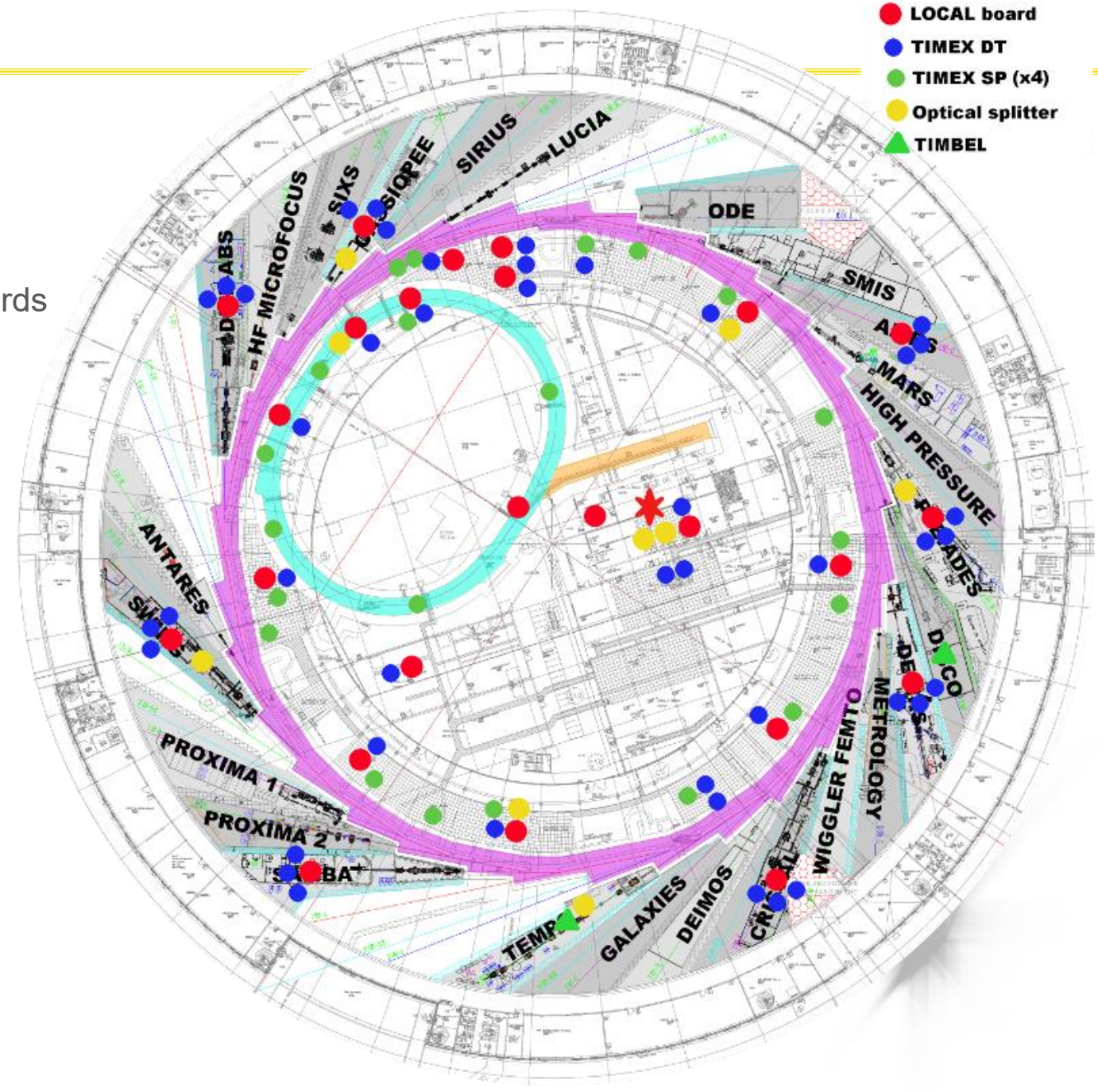
Matlab

LabView





- 1 CENTRAL.
- 25 LOCALs.
- 1 LOCAL LINAC.
- 9 optical splitters
- > #150 duplication boards



Beamlines synchronization system

Beamlines synchronization system

Beamlines needs:

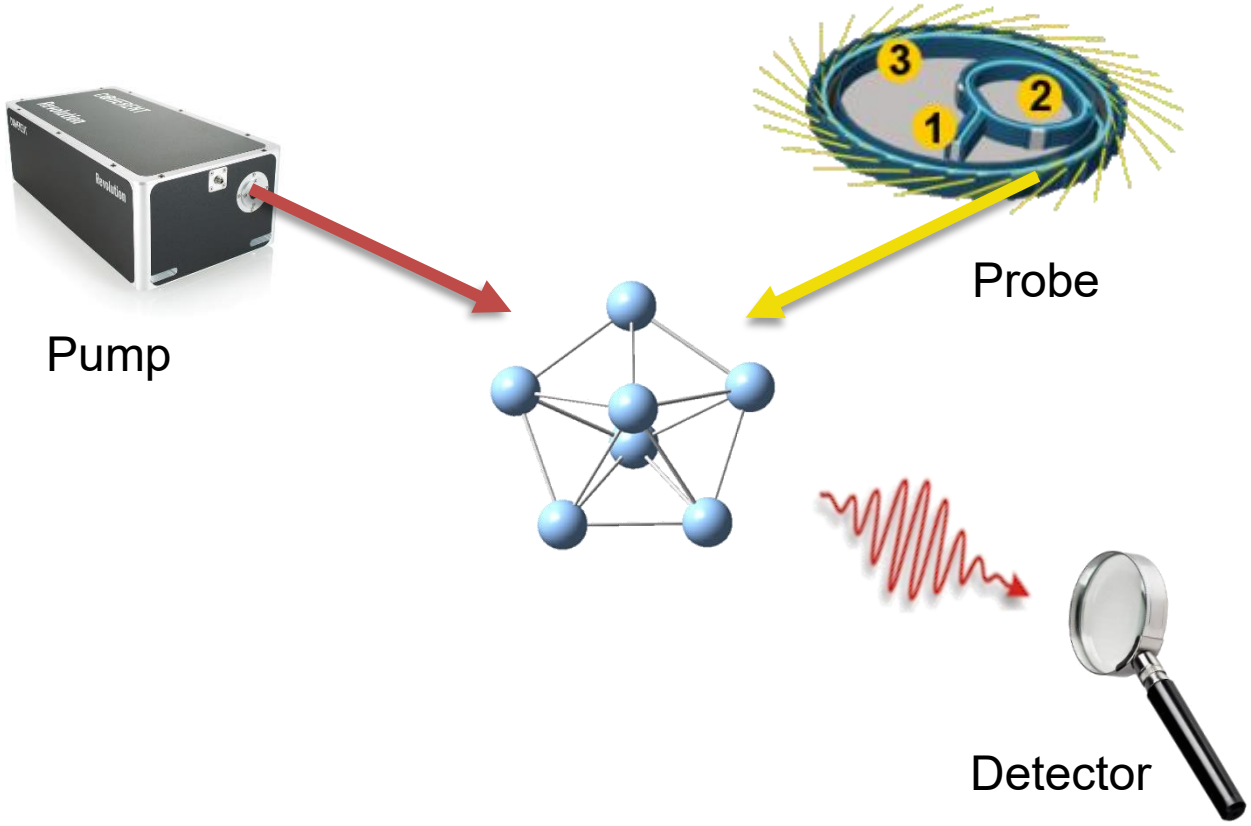
- Trigger XP devices synchronously to the electron bunch.
- *Top-up gating*.
- Laser pomp-probe synchronization.

Machine provides to Beamlines:

- RF signal.
- CLK-SR (Machine clock).
- Pre top-up and beam lost trigger

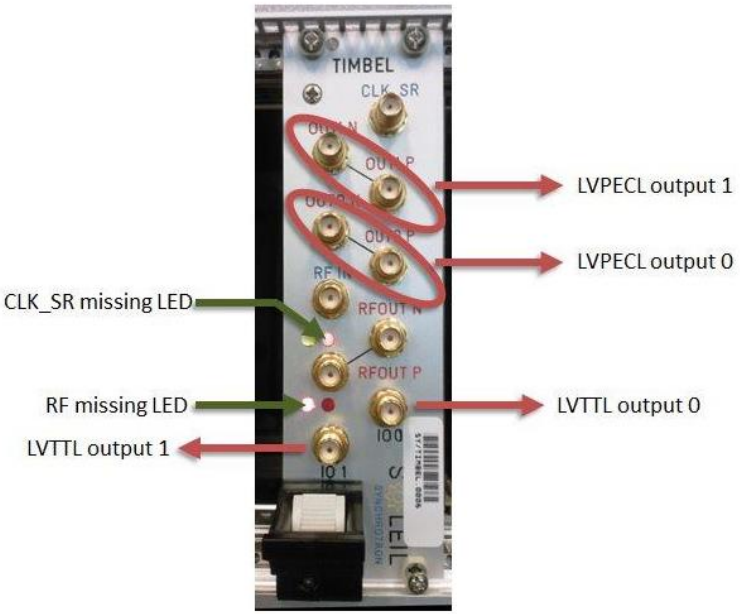
Beamlines synchronization system

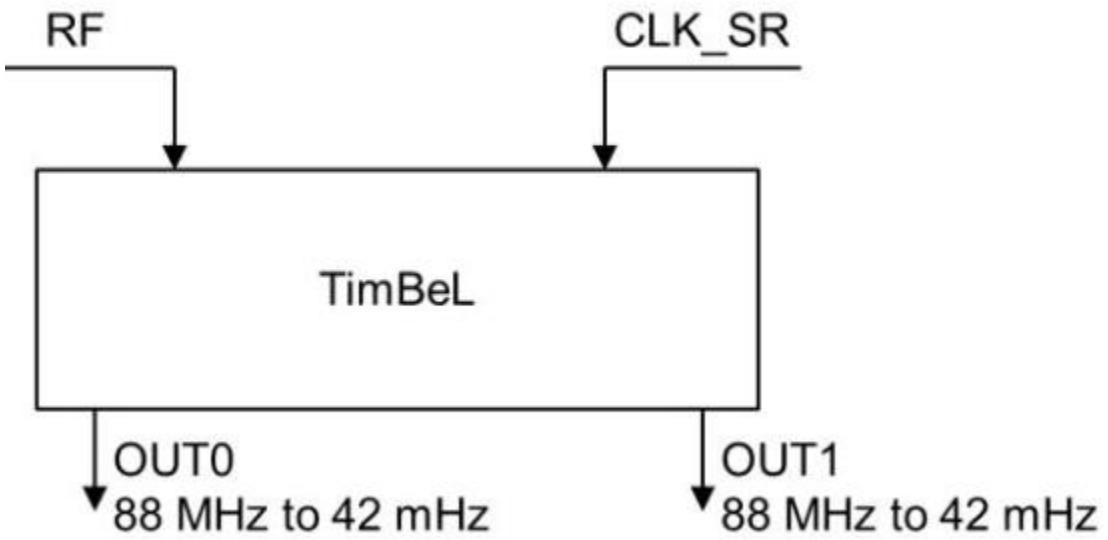
Pump-probe XP



Beamlines synchronization system

TimBeL board





Frequency : f ∈ [88.05 MHz ; 42 mHz] ; f = RF / (2 * n) ; n integer ; n ∈ [2 ; 2^32 - 1] ; user configurable
Duty cycle : r ∈ [5.68 ns ; clock period – 5.68ns] by steps of 5.68 ns ; user configurable
Delay : p ∈ [5.68 ns ; 11.9 ms] by steps of 5.68 ns ; user configurable
Fine delay only on LVPECL outputs : fp ∈ [2.4 ns ; 12.4 ns] by steps of #10 ps ; user configurable

Beamlines synchronization system

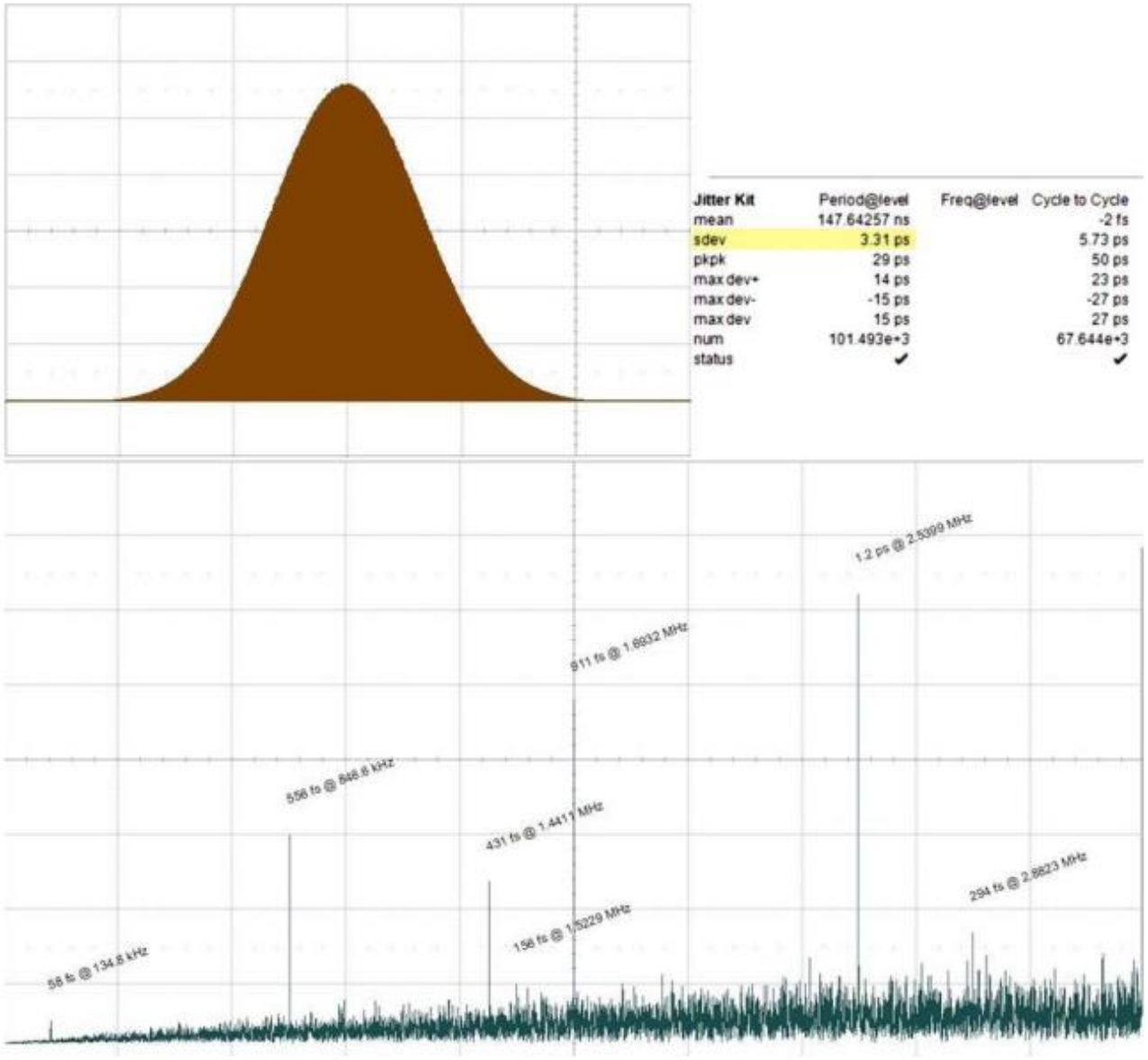
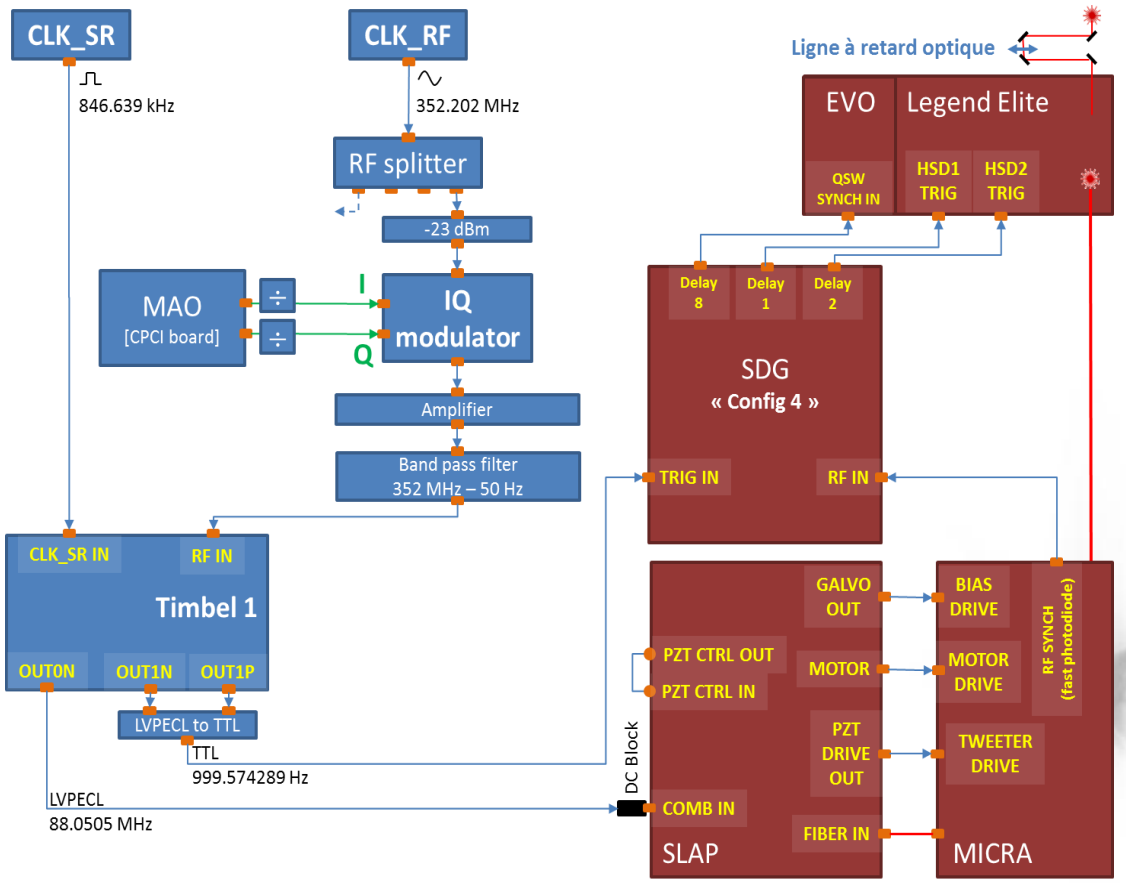


Figure 8. LVPECL outputs jitter.

Beamlines synchronization system

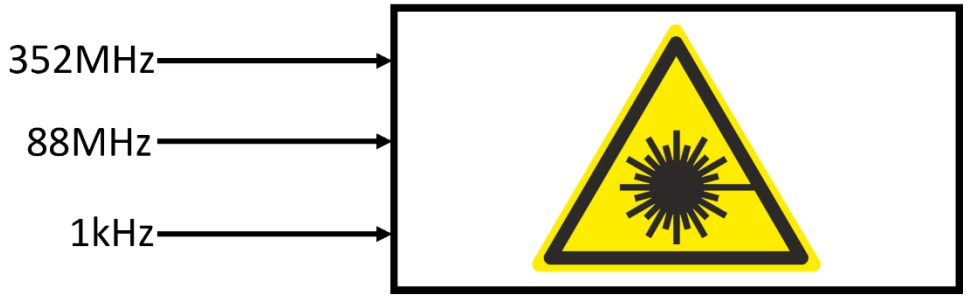
Beamlines lasers



Beamlines synchronization system

Beamlines lasers requirements:

- CLK-RF (CLK-RF harmonic) with phase shift capacity: oscillator.
- CLK-RF / n (88 MHz or 44 MHz) with phase shift capacity: oscillator reference.
- Laser trigger (CLK-RF / 846 = 1 kHz) with configurable delay.



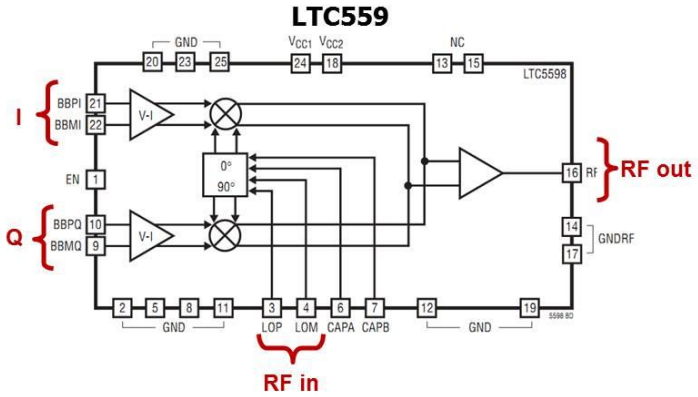
Additional requirements:

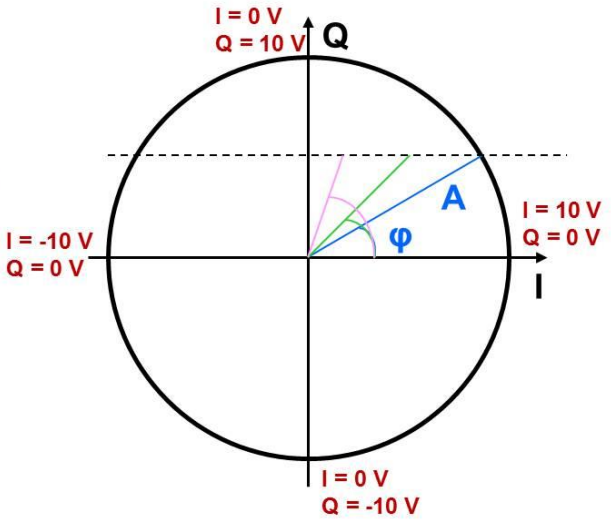
- Oscillator and oscillator reference: continuous shift without jump.
- Laser trigger: no hole in the clock.
- Excellent oscillator clocks phase noise of #10 fs.
- Sub picosecond resolution.

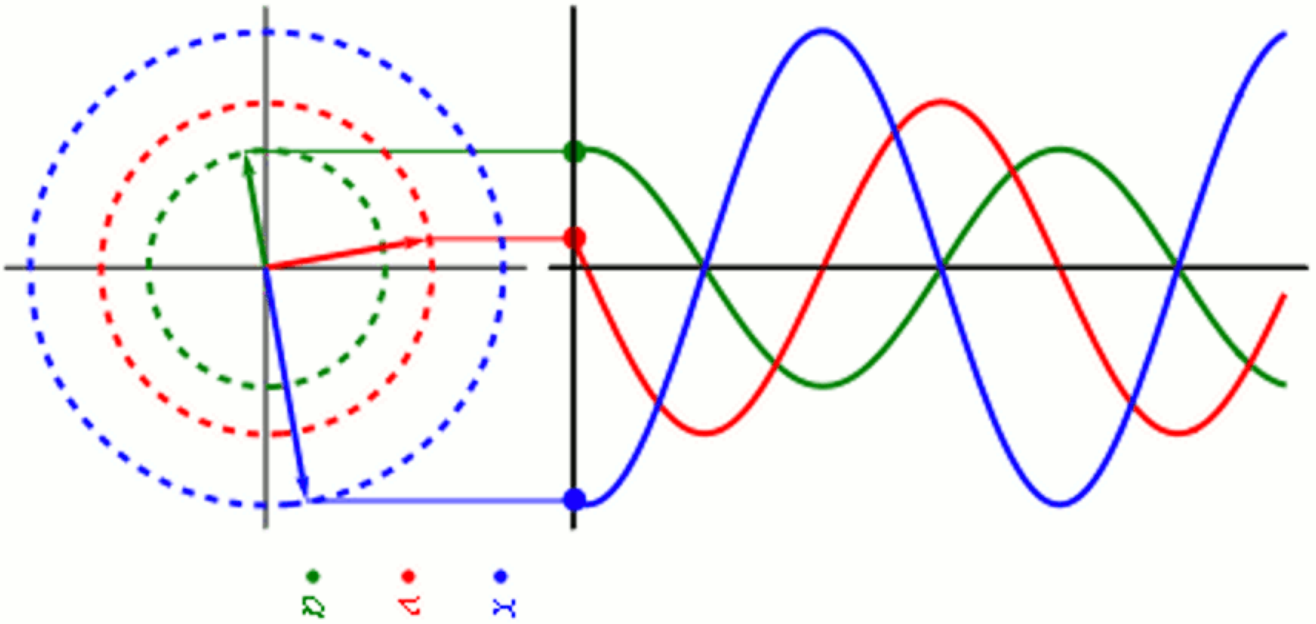
➔ Machine signals and TimBeL are not enough and not good enough

Beamlines synchronization system

IQ modulator





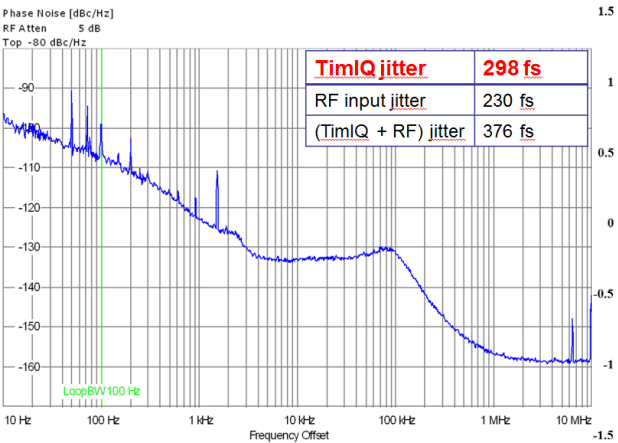


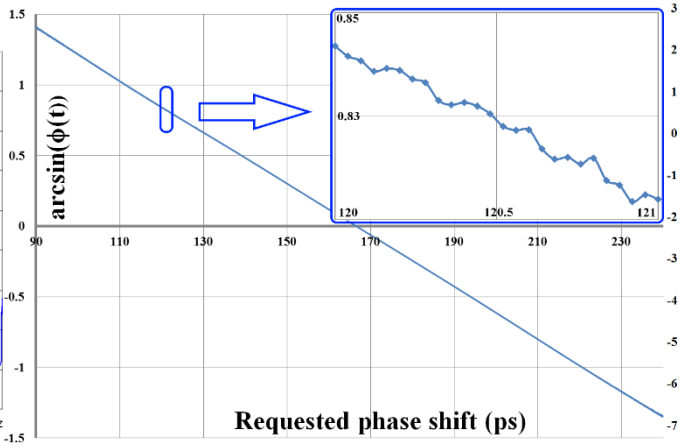
Beamlines synchronization system

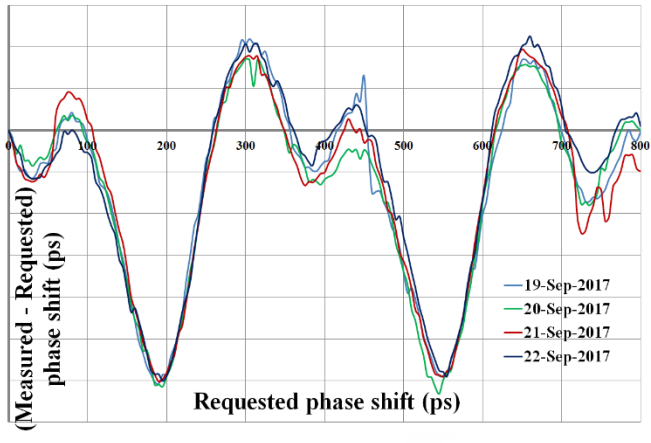
IQ modulator: TimIQ (https://gitlab.com/ohwr/project/timiq)

The TimIQ system is an IQ modulator allowing to phase shift a radio frequency clock with a resolution of 40 fs and an accuracy of 8 ps. It allows to drive with a high precision lasers oscillators.

- 352 MHz or 3GHz input
- 40 fs resolution
- 8.2 ps peak to peak precision and periodic error with a good repeatability
- Less than 300 fs phase noise jitter [10 Hz ; 10MHz] @ 88 MHz
- +/- 0.1°C temperature stabilized
- Readback of the offset
- Real open hardware (KiCAD, FreeCAD, LibreCAD) and open software

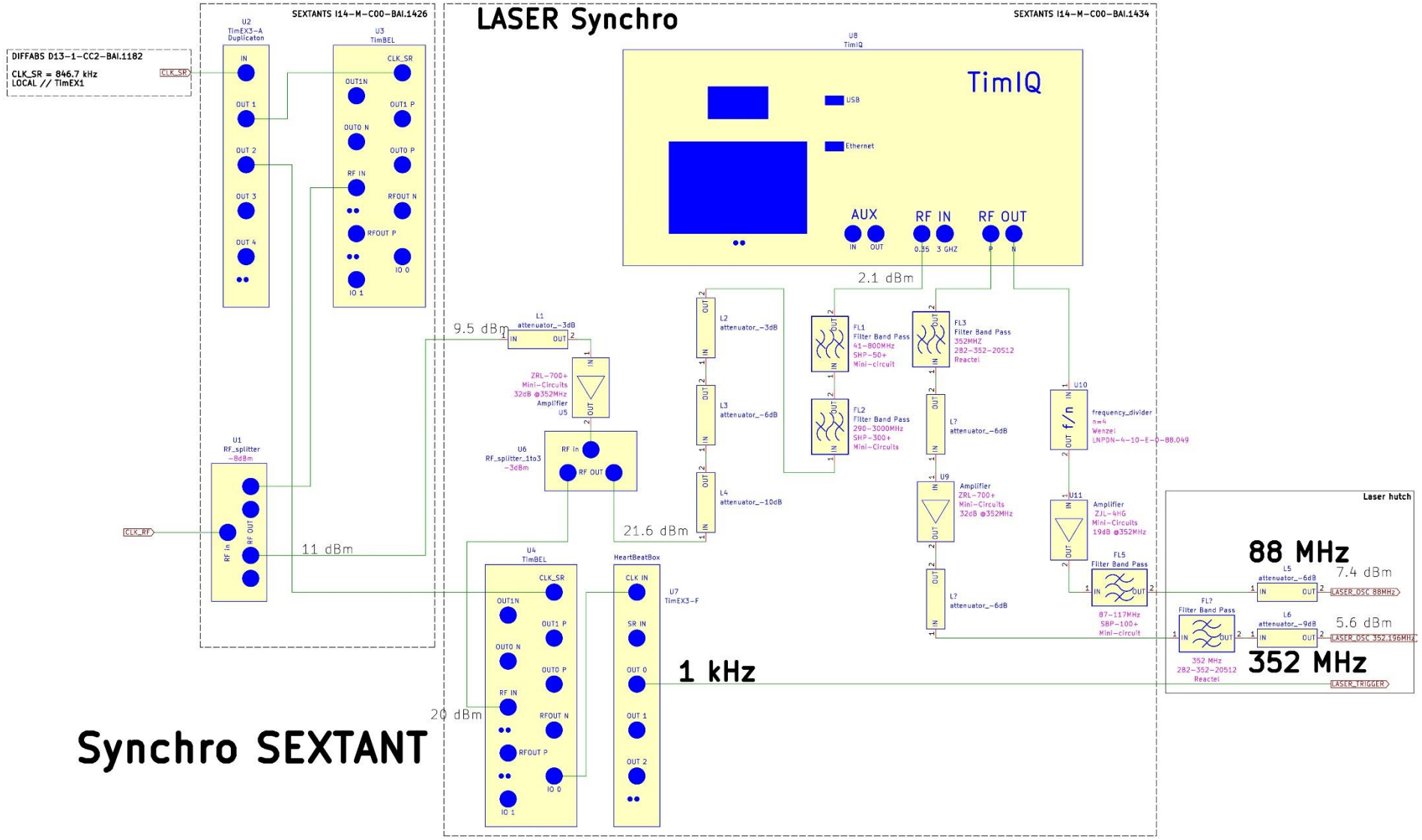






Beamlines synchronization system

Sextant

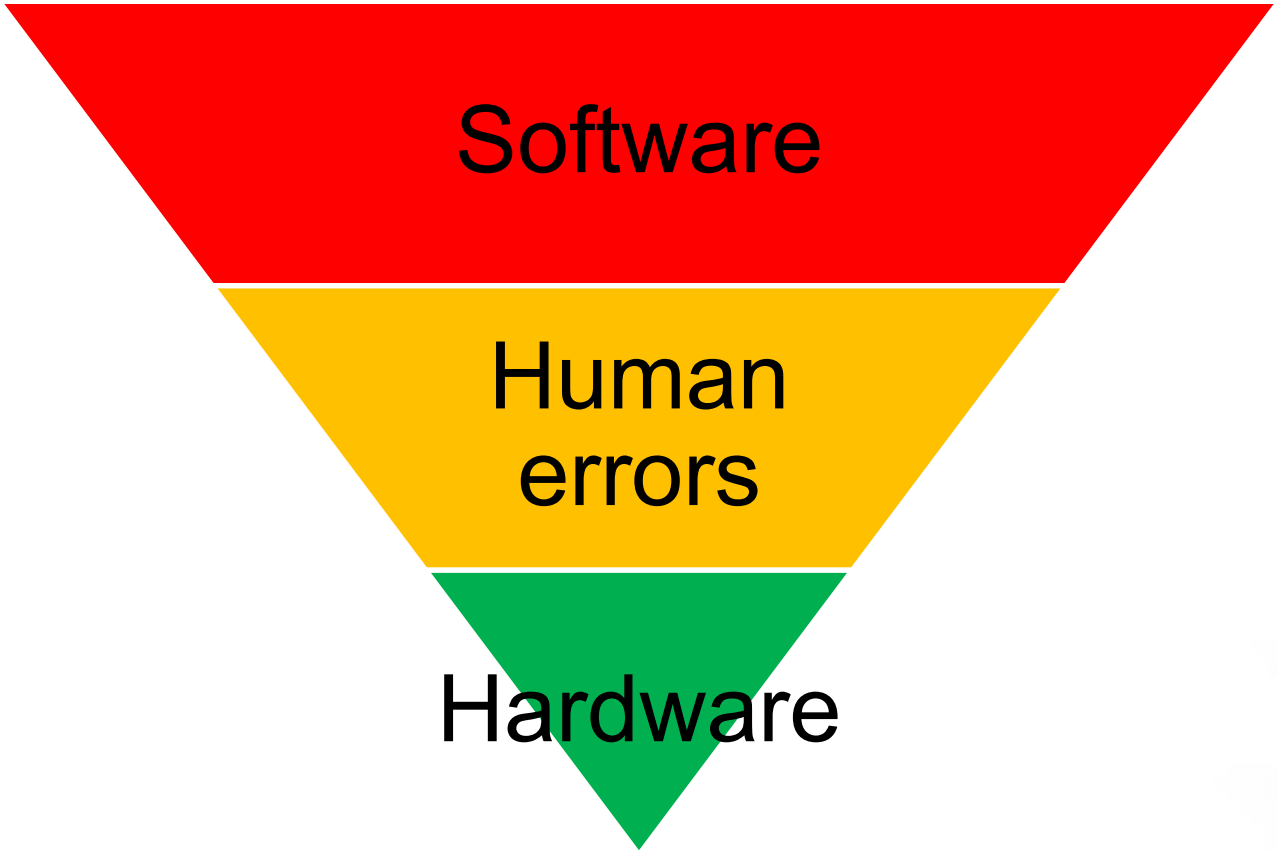


Failures

Failures

Hardware is reliable!

Software system is not!!!



SOLEIL II

SOLEIL II:

- 40 times smaller, circular electron beam
- Better coherency
- Increase of the flux

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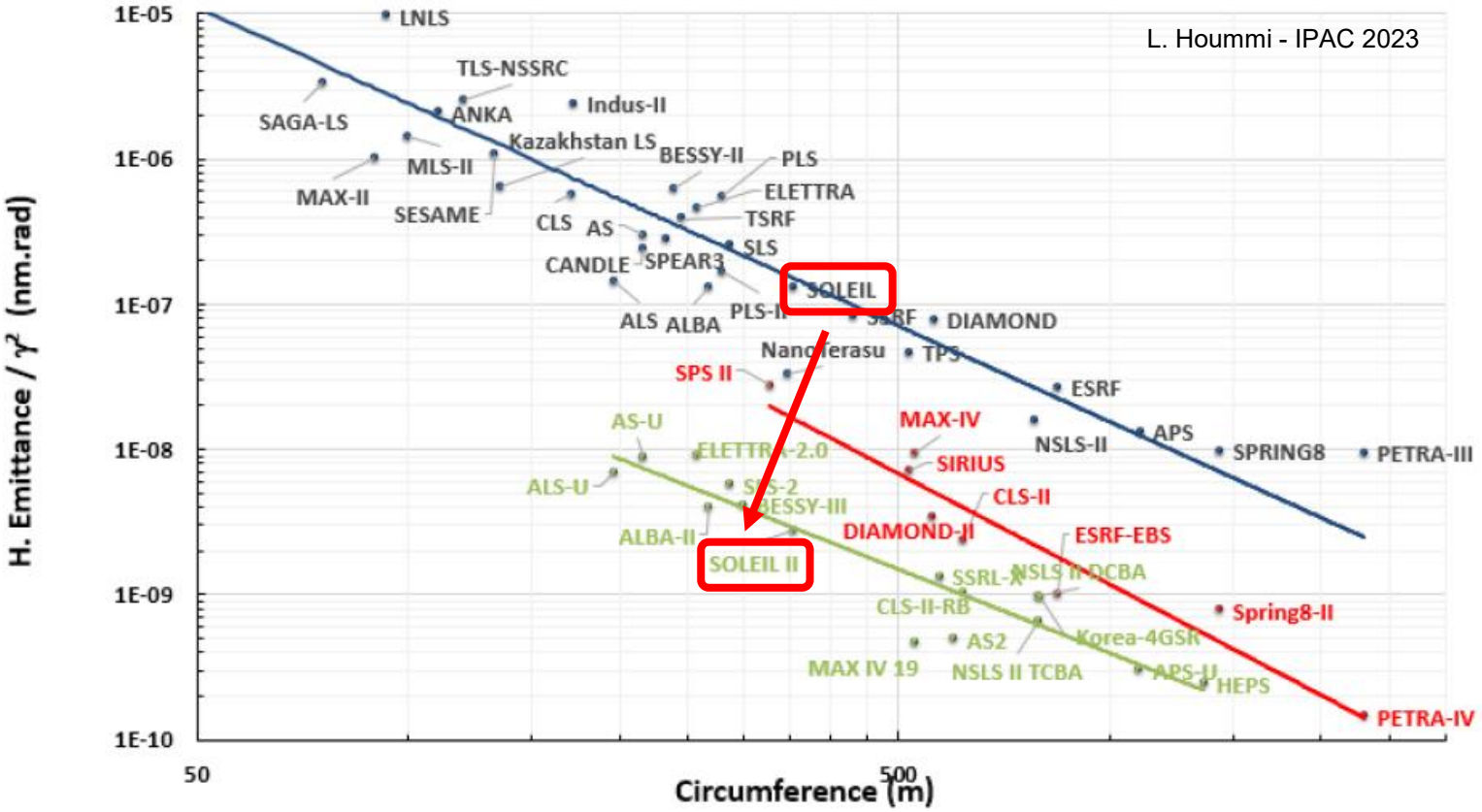
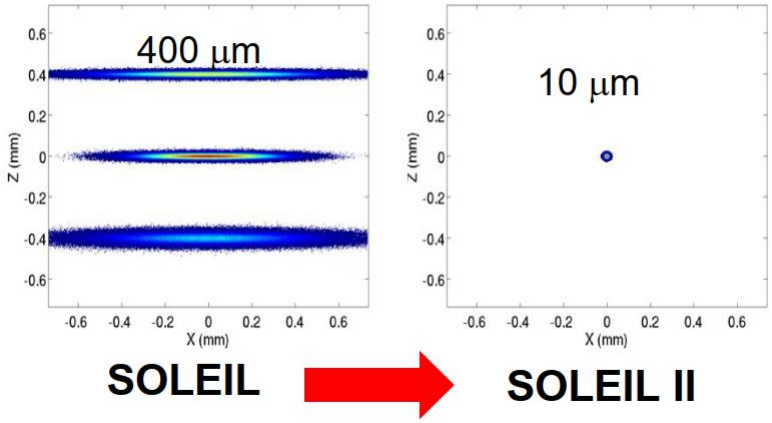
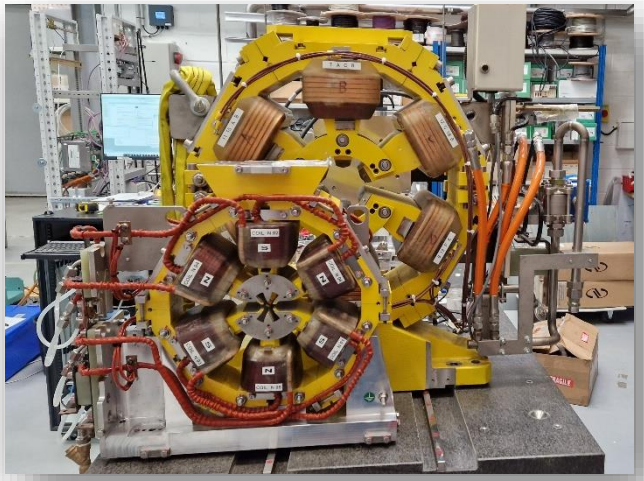
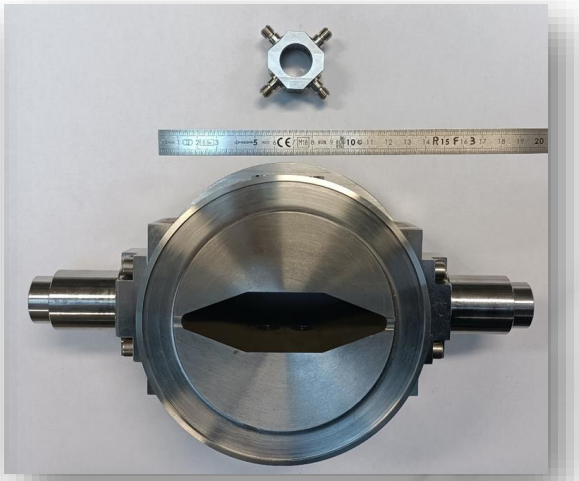


SOLEIL II







Timing system upgrade

GREENFIELD TECHNOLOGY

- ✓ Fully designed for SOLEIL's needs
- ✓ Reliable
- ✓ Integrated with the control room software

- ✗ Fully dependent upon Greenfield Technology
- ✗ Any modification or update must be summited to Greenfield Technology
- ✗ Expensive
- ✗ Paid support

CERN

ESRF
The European Synchrotron

- ✓ Based on WR and adapted by ESRF to be used in synchrotrons
- ✓ Under continues upgrade and development (WHIST, CITY, next CITY)
- ✓ Does not depend on any specific manufacturer
- ✓ Open hardware

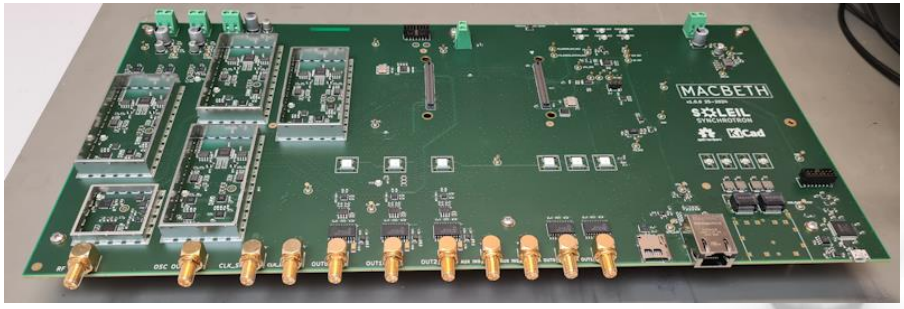
- ✗ Need some additional development to be used at SOLEIL (CITY)
- ✗ Control software need to be rewrite

Beamlines timing system upgrade

Beamlines timing system : MACBETH
(https://gitlab.com/ohwr/project/macbeth)

- Good jitter
- Good resolution
- Multiple outputs
- Flexibility
- Etc.

+




SOLEIL
SYNCHROTRON
Thank you